Australian Government
Civil Aviation Safety Authority

CAAP 179A-1(1)

Civil Aviation Advisory Publication

March 2006

Navigation using Global Navigation Satellite Systems (GNSS)

This publication is advisory only but it gives the CASA preferred methods for complying with the Civil Aviation Regulations 1988 (CAR 1988). They are not the only methods, but experience has shown that if you follow these methods you will comply with CAR 1988. Always read this advice in conjunction with the appropriate regulations.

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References

- Regulations 174D, 179A and 232A of CAR 1988
- Sections 20.18, 40.2.1, 40.2.2 and 40.2.3 of the CAOs
- Advisory Circular AC 21-36
- CAAP 178-1 and CAAP 5.13-1
- AIP Australia
- FAA Notice 8110.60
- FAA Technical Standard Orders TSO-C129, 129a, C145a and C146a.
- ICAO Global Navigation Satellite System (GNSS) Manual (Doc 9849)

Who this CAAP applies to

- Pilots and Operators of aircraft using GNSS for navigation.
- Individuals and organisations conducting flight crew training.

Status of this CAAP

This CAAP is revised to reflect new instructions under CAR 179A and to identify revised operational standards. Changes have been indicated by ‘change bars’ on the right hand side of the page.

For further information

Contact the CASA office closest to you on 131757.

Contents

List of GNSS Acronyms

Abbreviations

AAIM	Aircraft Autonomous Integrity Monitor
ABAS	Aircraft Based Augmentation System
ADS-B	Automatic Dependent Surveillance – Broadcast
ADS-C	Automatic Dependent Surveillance – Contract
ATSO	Australian Technical Standard Order
CA	Course Acquisition
CDI	Course Deviation Indicator
DGA	DME or GPS Arrival
EGNOS	European Geostationary Navigation Overlay Service
FD	Fault Detection
FDE	Fault Detection and Exclusion
GBAS	Ground Based Augmentation System
GDOP	Geometric Dilution of Precision
GLONASS	Global Navigation Satellite System (Russian Federation)
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System (US)
GRAS	Ground-based Regional Augmentation System
HMI	Human-Machine Interface
JTSO	Joint Technical Standard Order
LAAS	Local Area Augmentation System
MSAS	MTSAT Satellite-based Augmentation System
MTSAT	Multi-Function Transport Satellite
NANU	Notice Advisory to NavStar Users
NPA	Non-precision Approach
PDOP	Position Dilution of Precision
PPS	Precise Positioning Service
RAIM	Receiver Autonomous Integrity Monitoring
RNAV	Area Navigation
SA	Selective Availability
SARPS	Standards and Recommended Procedures
SBAS	Satellite Based Augmentation System
SPS	Standard Positioning Service
TSO	Technical Standard Order
WAAS	Wide Area Augmentation System
WGS84	World Geodetic System of 1984

1. Introduction

1.1 Why the publication was written

The International Civil Aviation Organization (ICAO) has adopted "Global Navigation Satellite Systems" (GNSS) as a generic term to identify all satellite navigation systems where the user performs onboard position determination from satellite information.

GNSS now provides air navigation services around the world GNSS receivers are common in Australian-registered aircraft and a variety of approvals have been issued for the use of this equipment in both VFR and IFR operations. The purpose of this publication is to compile the relevant requirements, standards and practices for GNSS navigation in one document and provide comprehensive guidance on the use of GNSS for navigation.

More detailed information on the implementation of GNSS can be found in the ICAO *Global Navigation Satellite System Manual* (Doc 9849), ICAO's global and regional plans for CNS/ATM systems and the Australian ATM Strategic Plan.

1.2 The Rules

Civil Aviation Regulations (1988)

Regulation 174D of the Civil Aviation Regulations (1988) states that an aircraft may only be flown under the VFR if it is equipped for navigation and able to obtain positive position fixes in accordance with instructions issued by CASA. Under regulation 179A, an aircraft may only be flown under the IFR if it is equipped for navigation and able to obtain positive position fixes in accordance with instructions issued by CASA. Regulation 232A states that CASA may give directions about operational procedures for navigational computers.

Civil Aviation Orders

CAO 20.18 details directions relating to the use of computers with GPS. CAO 40.2.1 contains the training and qualification requirements for the use of GPS under the IFR by the holder of an Instrument Rating. CAO 40.2.2 specifies the requirements for the use of navigation aids under the VFR at Night by the holder of a Night VFR Rating. CAO 40.2.3 specifies the training and qualification requirements for the use of GPS under the IFR by the holder of a Private IFR Rating.

Aeronautical Information Publication Australia

AIP GEN 1.5 Section 2 of the AIP states the minimum radio navigation system requirements for operations and GEN 1.5 Section 8 lists the operational approvals for area navigation (RNAV) systems, including GNSS. GEN 3.3 Section 3 details the approved methods for determining lowest safe altitude (LSALT). AIP ENR 1.1 details the requirements for navigation and ENR 1.5 contains more detailed information regarding holding, approach and departure procedures. ENR 1.10 relates to flight planning and notification.

Civil Aviation Advisory Publications

CAAP 5.13-1 explains the practical application of the Private IFR Rating to operations.
CAAP 178-1 provides information and guidance on non-precision approaches using GNSS and other navigation equipment. Additionally it provides answers to frequently asked question about DME and GPS arrivals.

Advisory Circulars

AC 21-36 provides information and guidance for authorised persons under CAR 35 and 36 or Supplemental Type Certificate (STC) applicants under CASR Part 21 for the design, development and subsequent airworthiness approval of Global Navigation Satellite System (GNSS) equipment installations and aircraft certificated under the United States Federal Aviation Regulations (FAR) Parts 23, 25, 27 and 29 and CASR Parts 26 and 32. This equipment may be either:

- GNSS standalone equipment; or
- GNSS sensors integrated into a flight management system

AC 21-36 replaced CAAP 35-1 (0) in 2005.

2. Global Navigation Satellite Systems

2.1 GNSS Constellations

The two GNSS constellations currently in operation are the USA's NavStar Global Positioning System (GPS) and the Russian Federation's GLObal NAvigation Satellite System (GLONASS). Both systems comprise a constellation of orbiting satellites supported by ground stations and aircraft receivers. These orbiting constellation systems, while originally designed to a military specification and providing a performance level suitable for some civil applications, may need to be complemented or "augmented" by additional systems to produce the performance required by certain operations.

Developments in satellite technology and its use for aircraft navigation suggest that new satellite navigation systems will evolve in the future, each with its own unique characteristics. A number of augmentation systems are in use or under development, and a third orbiting constellation, known as Galileo, is also under development.

GPS

GPS is a United States Government system operated by the Department of Defense. The two levels of service provided are known as the Standard Positioning Service (SPS) and the Precise Positioning Service (PPS). SPS is available to all users and provides horizontal positioning accuracy of 36 metres or less, with a probability of 95 percent. PPS is more accurate than SPS, but available only to the US military and a limited number of other authorised users.

GPS consists of three distinct functional elements: the space element, the ground-based control element, and the aircraft-based user element. The space element nominally consists of 24 NavStar satellites in six orbital planes (with four in each plane) located approximately 11,000 miles above the earth. The ground-based control element consists of a network of GPS monitoring and control stations that ensure the accuracy of satellite positions and their clocks. The aircraft-based user element consists of the GPS antennae and satellite receiver-processors onboard the aircraft that provide positioning, velocity, and precise timing information to the pilot.

GPS operation is based on the concept of ranging and triangulation from a group of satellites, which act as precise reference points. Each satellite broadcasts a pseudo-random code, called a Course Acquisition (CA) Code, which contains orbit information about the entire constellation (“almanac”), detail of the individual satellite's position (“ephemeris”), the GPS system time, and the health and accuracy of the transmitted data. The GPS receiver matches each satellite's CA code with an identical copy of the code contained in the receiver's database. By shifting its copy of the satellite's code in a matching process, and by comparing this shift with its internal clock, the receiver can calculate how long it took the signal to travel from the satellite to the receiver. The distance derived from this method of computing distance is called a pseudo-range because it is not a direct measurement of distance, but a measurement based on time. Pseudo-range is subject to several error sources, including atmospheric delays and multipath errors.

The GPS receiver mathematically determines its position using the calculated pseudo-range and position information supplied by the satellite. At least four satellites are required to produce a three-dimensional position (latitude, longitude, and altitude) and time solution. The receiver computes navigational values, such as distance and bearing to a waypoint or ground speed, by using the aircraft's known latitude/longitude and referencing these to a database. The system is unaffected by weather and provides a worldwide common grid reference system based on the earth-fixed coordinate system. For its earth model, GPS uses the World Geodetic System of 1984 (WGS84) datum.

The United States declared that GPS had full operational capability in April 1995 and all existing Australian operational approvals for GNSS are based upon GPS with varying levels of augmentation.
Further information on GPS, including the SPS Performance Standard, can be found at http://www.navcen.uscg.gov/gps

GLONASS

GLONASS is operated by the Russian Federation’s Ministry of Defence and managed by the Russian Space Forces. It shares the same principles of data transmission and positioning methods that are used in GPS and is also based on a constellation of orbiting satellites and a ground control segment. Satellites are positioned in three orbital planes and the fully deployed constellation is composed of 24 satellites.
GLONASS was officially declared operational in 1993 although it is currently operating without a full constellation of satellites. Work is underway to modernize the system and launch additional satellites.

Further information on GLONASS can be found at http://www.glonass-center.ru/

Galileo

Galileo is likely to be the third GNSS constellation approved for aviation use and is an initiative of the European Union and the European Space Agency. It is based on a constellation of 30 satellites supported by ground stations and will provide positioning data in a similar way to GPS and GLONASS. Galileo is expected to achieve initial operating capability in 2010.

Further information on Galileo can be found at http://www.esa.int/export/esaSA/navigation.html

2.2 GNSS Performance

GNSS performance may be measured in a number of ways. While accuracy is the most obvious quality of a navigation system, other measures such as data integrity, continuity of service, system availability and vulnerability to interference are also important attributes.

Accuracy

Accuracy is the measure of the precision of the navigation solution.

ICAO SARPS specify the accuracy requirements for various phases of flight. Current technology can use the GNSS constellations to meet the IFR accuracy requirements for oceanic and domestic en-route use as well as terminal area and non-precision approaches. Precision approaches will require some form of GNSS Augmentation to overcome the known limitations of the constellation systems.

The most common causes of reduced accuracy are:

Ephemeris

Although the satellite orbits are extremely stable and predictable, some perturbations do exist. These are caused by gravitational effects of the Earth and Moon, and the pressure of solar radiation.

Clock

Timing errors due to inaccuracies in both the satellite and receiver clocks, as well as relativity effects, can result in position errors of up to 2m.

Receiver

Due to the low signal strength of GNSS transmissions, the receiver's pseudo-random noise codes are at a lower level than the receiver ambient noise. This results in a fuzzy correlation of receiver code to the satellite code, and produces some uncertainty in the relationship of one code to another. The position error that results from this effect is about 1m.

Ionosphere

One of the most significant errors in the pseudo-range measurements results from the passage of the satellite signal through the Earth's ionosphere, which varies depending on the time of day, solar activity and a range of other factors. Ionospheric delays can be predicted and an average correction applied to the GPS position, although there will still be some error introduced by this phenomenon.

Multipath

An error in the pseudo-range measurement results from the reflection and refraction of the satellite signal by objects and ground near the receiver. This is known as multipath error. Ghosting of television pictures is an example of multipath effect.

Because GNSS is a three-dimensional navigation system, the errors do not all lie along a line and therefore should not be added algebraically. Total system range error is calculated by the root-sum-square method, where the total is the square root of the sum of the squares of the individual errors.

Dilution of Precision

Geometric Dilution of Precision (GDOP) is an effect that degrades the accuracy of a position fix, due to the number and relative geometry of satellites in view at the time of calculation. The value given is the factor by which the system range errors are multiplied to give a total system error.

Position Dilution of Precision (PDOP) is a subset of GDOP that affects latitude, longitude and altitude. Many GPS receivers are able to provide an estimate of PDOP.

Integrity

Integrity is the ability of a system to provide timely warnings to the user when the equipment is unreliable for navigation purposes. The concept of integrity includes both a failure to alarm and a false alarm.

In Australia, conventional ground-based navigation aids incorporate monitoring equipment at the ground-site. Should the equipment detect an out-of-tolerance condition, the transmitter is shut down, and the user is alerted by means of a flag or loss of aural identification. GNSS integrity relates to the trust that can be placed in the correctness of the information supplied by the total system. This includes the ability of the system to notify the pilot if a satellite is radiating erroneous signals.

Individual GNSS satellites are not continuously monitored, and several hours can elapse between the onset of a failure and the detection and correction of that failure. Without some additional integrity monitoring, a clock or ephemeris error, for example, can have a significant effect on any navigation system using that satellite. Receiver Autonomous Integrity Monitoring (RAIM) is the most common form of integrity monitoring and is discussed later under the heading of GNSS Augmentation. Many basic GPS receivers do not monitor integrity and will continue to display a navigation solution based on erroneous data.

Availability

Availability may be defined as the percentage of time the services of a navigation system are accessible.

It is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter

facilities. GNSS availability is the system's capacity to provide the number of satellites required for position fixing within the specified coverage area. At least three satellites need to be in view to determine a two-dimensional (2D) position, while four are required to establish an accurate 3D position.

Selective Availability (SA) was a technique used by the US Department of Defense to limit the accuracy of GPS to other than approved users. It was achieved by artificially creating a significant clock or ephemeris error. With growing reliance upon GPS in civil applications, SA was discontinued by Presidential decree in 2000.

Many early GPS receivers were "hard-wired" for SA in the expectation that civil use would always need to assume that SA was active. For receivers that cannot take advantage of SA being discontinued, average RAIM (Fault Detection) availability is 99.7 per cent for non-precision approach operations for a 24-satellite GPS constellation. By contrast, receivers that can take advantage of SA having been discontinued have 99.998% availability of RAIM (FD) for non-precision approach. These percentages will vary locally depending on which satellites are out of service at any given time.

Continuity

Continuity of service is the ability of the total navigation system to continue to perform its function during the intended operation.
Continuity is critical whenever reliance on a particular system is high, such as during an instrument approach procedure. Although the GPS constellation has been declared fully operational, the possibility exists that an unserviceability will occur and reduce the number of 'healthy' satellites in view below the operational requirement.

Vulnerability

Vulnerability is a qualitative measure of the susceptibility of a navigation system to both unintentional and deliberate interference.

All navigation systems have vulnerabilities and the effect of thunderstorms on the ADF receiver is a well known example. The issue of GNSS vulnerability has become prominent because of early proposals to replace multiple terrestrial navigation systems with a single source (GPS). A variety of mitigation strategies are being used to address the vulnerability risks of transitioning to a GNSS-dependent navigation infrastructure. These include advancements in receiver and antenna design, augmentation systems, alternative constellations, multiple frequencies, integrated GNSS/INS receivers retention of a core terrestrial navaid network and careful management of the radiofrequency spectrum.

Required Performance

There will occasions when the geometry of the satellite constellation in view, faults or other factors inhibit GNSS performance to the point where it cannot be used for navigation. Past approvals for GNSS navigation used the terms 'Primary Means' and 'Supplemental Means' to define the required navigation system performance for a particular operation. However, as the variety of GNSS solutions has increased over time, this system of categorisation has proven non-intuitive and sometimes confusing. CASA has now replaced it with descriptions of operational and airworthiness requirements to support each approved application of GNSS.

2.3 GNSS Augmentation

A number of augmentation systems have been proposed to improve the navigational performance provided by the GNSS constellations. There are currently four types of augmentation recognized by ICAO: Aircraft Based Augmentation Systems (ABAS), Satellite Based Augmentation Systems (SBAS), Ground Based Augmentation Systems (GBAS) and Ground-based Regional Augmentation Systems (GRAS).

ABAS

Aircraft-based augmentation is achieved by features of the onboard equipment designed to overcome performance limitations of the GNSS constellations. ABAS equipment to date has been designed to resolve integrity deficiencies, although future systems may address other aspects. The two systems currently in use are Receiver Autonomous Integrity Monitoring (RAIM) and the Aircraft Autonomous Integrity Monitor (AAIM).

RAIM

RAIM provides integrity by detecting the failure of a GNSS satellite. It is a software function incorporated into GPS receivers designed to meet TSO-C129, C129a, C145a, C146a or later versions of these standards. GNSS avionics with RAIM normally provide three modes of operation:

- Navigation solution with RAIM;
- 2D or 3D navigation solution without RAIM; and
- Dead Reckoning (DR), or loss of navigation solution.

RAIM may be either Fault Detection (FD) or Fault Detection & Exclusion (FDE).

RAIM (FD)

FD compares position and time information derived from combinations of four inputs from a set of at least five satellites, or four satellites and a barometric source. In this way, a faulty satellite can be detected and the pilot provided with a warning that the system should no longer be used for navigation. RAIM messages vary between receivers, but there are generally two types. One type indicates that there are not sufficient satellites available to provide RAIM integrity monitoring and another type indicates that the RAIM integrity monitor has detected a potential error that exceeds the limit for the current phase of flight (en-route, terminal or approach). Without RAIM capability, the pilot has no assurance of the accuracy of the GNSS-derived position.

RAIM (FDE)

FDE needs six inputs and, like FD, may use barometric aiding as a data source. With six or more visible satellites FDE will not only detect a faulty satellite but also remove it from the navigational solution and continue to provide FDE or FD with the remaining satellites. FDE is required for Oceanic RNAV approvals and mandated in the 'new generation' TSO-C145a and C146a standards.

RAIM Holes

A RAIM hole occurs for the period of time that there are insufficient GNSS satellites in view to provide an integrity check at a given location. RAIM holes are predictable and those predictions can be used to determine adqueate integrity will exist during the planned operation. The Airservices Australia RAIM Prediction System provides both FD and FDE predictions for non-precision approach operations.

AAIM

The AAIM uses the redundancy of position estimates from multiple sensors, including GNSS, to provide integrity performance that is at least equivalent to RAIM. A common example of AAIM uses inertial navigation solutions as an integrity check of the GPS solution when RAIM is unavailable but GPS positioning information continues to be valid.

SBAS

Satellite-based augmentation seeks to provide comprehensive performance improvements through the provision of ranging, integrity and differential correction signals to aircraft receivers from geostationary satellites. These geostationary satellites are not part of the constellations and are owned and operated by a number of organisations. The SBAS system comprises:

- A network of ground reference stations that monitor satellite signals;
- Master stations that collect and process reference station data and generate SBAS messages;
- Uplink stations that send the messages to geostationary satellites; and
- Transponders on these satellites that broadcast the SBAS messages.

By providing differential corrections, extra ranging signals via geostationary satellites and integrity information for individual constellation satellites, SBAS delivers much higher availability of service that the core satellite constellations with RAIM alone.

The FAA's Wide Area Augmentations System (WAAS) became operational in 2003 and there are three other SBASs planned to commence operations in coming years. It is expected that the four SBAS services will 'seamless' coverage and be compatible with the TSO C145a and C146a receivers.

GBAS

A system meeting the ICAO requirements for GBAS provides two services: the precision approach service and the GBAS positioning service. The precision approach service provides deviation guidance for GNSS Landing System (GLS) approaches, while the GBAS positioning service provides horizontal position, velocity and time information to support RNAV operations in terminal areas. A ground station at an airport broadcasts locally relevant corrections, integrity parameters and approach data to aircraft in the terminal area in the VHF band.

A GBAS installation will typically provide GNSS corrections that support precision approaches to multiple runways at a single airport. In some cases, the corrections may be used for nearby airports and heliports as well. GBAS infrastructure includes electronic equipment, which can be installed in any suitable airport building, and antennas for both the data broadcast and to receive the satellite signals. The cost and flexibility of GBAS will result in more runway-ends having electronic precision approach guidance, resulting in significant safety and efficiency benefits.

GRAS

The Ground-based Regional Augmentation System is a blending of SBAS and GBAS concepts to enhance GNSS performance. One concept uses a distributed network of reference stations for monitoring GPS (or other constellations), and a processing facility(s) for computing integrity and differential correction information. Instead of transmitting this information to users via dedicated geostationary satellites, GRAS delivers data to a network of terrestrial VHF stations. Each site broadcasts a GBAS-like, VHF data signal which can be received by the aircraft to obtain augmentation data for both en route as well as terminal area, approach and departure operations. It is anticipated GLS avionics will be able to accommodate a software change to also accept GRAS messages.

3. Human Factors

GNSS is a prime example of the use of advanced automation at all levels of aviation activity – from integrated glass cockpit Flight Management Systems (FMS), through stand-alone IFR approach-capable panel mounted receivers, to hand-held VFR units. Many of the human factors issues associated with the effects of GNSS design on human performance are common across these groupings, while some issues are only related to specific operations. Human factors considerations include hardware, the operation of the displays and controls; software, the user interface and ability to access the myriad functions; and liveware, the effect of GNSS operation on the human user.

3.1 GNSS Occurrences

The following extracts from reports of occurrences around the world give some insight to the potential for human error in the use of GNSS equipment at all levels. While the occurrences themselves are of concern, perhaps the most important issue is that the chances of them being repeated is minimized. Human factors training and awareness of the issues is central to operations using GNSS.

- "Due to a discrepancy between the flight plan stored in the GPS unit and the submitted flight plan, the aircraft tracked via a waypoint that was not on the flight plan."
- "The pilot contacted ATS and requested clearance to enter the CTR. ATS reported the pilot sounded unsure and further questioning revealed the aircraft was already on a wide left base…. The pilot claimed the aircraft's GPS indicated 54nm away from the destination."
- "ATC queried the pilot regarding navigation aids, to which the pilot reported to have no operable navigation aids on board. The pilot requested a radar heading. However, ATC could not issue a heading as the aircraft was out of radar coverage. Subsequently the pilot reported that the GPS had come back online and indicated a heading of …."
- " …the crew expected to see the selected Initial Approach Fix radial not a changed radial as the IAF… The (Operator's) crew were very familiar with stand alone GPS Approach procedures which they had been using for nearly two years. The reported incident was the first occasion the crew had flown a DME arc procedure and (Location) is the only (Region) GPS instrument approach published using the DME arc as part of the procedure. "
- "A (Procedure Name) STAR was granted and programmed into the GPS. The aircraft then tracked normally as required to (Waypoint). From (Waypoint) the aircraft then turned in towards (Destination) instead of tracking via the 10DME arc onto Final. The error was picked up by the crew and the autopilot was disconnected and at the same time ATC also took corrective action by assigning a radar vector."
- "The crew of an outbound aircraft had climbed through the altitude specified by ATC. Their aircraft was only 500 ft vertically distant and 1.25 nm 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. "
- "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. "
- "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. "

- "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…."

3.2 A New Navigation System

GNSS is an Area Navigation (RNAV) system substantially different in design philosophy to the conventional azimuthal systems like NDB, VOR and Localizer. GNSS measures distance differently to DME or TACAN and is also quite different to inertial RNAV systems in terms of initialisation, updating and accuracy. As such, GNSS introduces new variables to the navigation problem. The potential for human error is real and the complexity of aviation operations provides the potential for even small errors to cause serious occurrences. For pilots transitioning from IFR flying using conventional ground-based navigation aids to an RNAV environment the display of distance to the next waypoint, crosstrack error measured in distance rather than degrees and absence of slant range, scalloping and other errors means that some rules of thumb and situational awareness techniques cannot be applied.

The keys to the safe use of GNSS in aviation operations are:

- Sound theoretical knowledge;
- Operational proficiency with the equipment;
- Awareness of vulnerabilities of the system and human operator; and
- Standardisation of systems and procedures wherever possible.

Be Aware of the Issues

Human factors issues for the appropriate use of GNSS involve the user having an awareness of the equipment limitations of design, controls, displays, and software logic in order to avoid making errors that could lead to undesired aircraft states or accidents. These errors include entry of information into the machine, interpretation of information from the machine, inadequate cross-checking from alternative sources, and inappropriate decision-making based on the GNSS information output.

The importance of GNSS training and system familiarity cannot be overemphasised, not only for flight crew, but air traffic controllers, engineers and all individuals involved with flight operations. GNSS is a complex piece of advanced technology, needing training and practice to operate effectively. Even the most basic GPS receivers have many functions and pages of data demanding more head-down attention from the pilot to interpret displays and operate controls.

The power and accuracy of GNSS encourages behaviours such as complacency, over-confidence, and over-reliance. It is easy to assume that the machine is always right and lose situational awareness, which in turn increases workload and decreases decision-making ability. This may also lead to the pilot becoming "de-skilled" in the use of alternative navigation techniques.

Automation Induced Complacency

The highly automated nature of navigational calculations using GNSS provides significant benefits including increased reliability, accuracy, proficiency and system monitoring ability. However, it can be difficult to stay alert and detect gross errors when monitoring automatic equipment. The operators’ continuing experience of highly accurate positioning information from GNSS can lead to the assumption of infallibility promoting a complacent attitude resulting in decreased crosschecking of the system.

The use of GPS for primary navigation reference on VFR flights may result in the degradation of flight planning and map reading skills, especially when the “Direct-to” function is habitually used instead of planning via a programmed series of route waypoints.

3.3 The Human-Machine Interface

The majority of GNSS receivers currently available on the market are essentially non-standardised add-on navigation systems and GNSS itself is still in the early stages of implementation. Like many new automated systems, the design characteristics implemented to overcome limitations of earlier systems can themselves present problems to the human operators.

Most stand-alone GNSS receivers have relatively small displays and controls, which can encourage small data entry errors with the potential for gross error results. The speed of GNSS development has also encouraged a proliferation of different approaches to hardware and software design. Standards for terminology, displays, controls, and operating logic are still in development and marketing imperatives encourage manufacturers to differentiate their designs from other products on the market.

Non-standard Interfaces

TSO-C129 specifies minimum performance standards for GPS equipment but do not specify a standard set of controls, features, displays or operating modes. The later TSO-C146a receiver design standard goes some way to improving this situation, but there will continue to be variation between manufacturers and even between different models and software editions by the same manufacturer.

Generally all receivers provide similar displays, and require similar pilot entered data in the primary operating modes. However, there is considerable variation in how these modes are accessed and how data is entered. A greater variation can occur in the auxiliary operating modes with similar information or features being available through different receiver modes.

Pilots need to demonstrate proficiency with one type of approved GPS receiver to qualify for a certification permitting the use of GPS as a Night VFR or IFR navigation aid. This should ensure the pilot understands the generic functions required in flight using the en-route approvals. When using a different model, it is important to study the operating instructions and become familiar with the equipment and the required functions before going flying. Operational experience with a new receiver should be gained without the additional workload of Pilot in Command duties or in the less demanding VMC environment.

Human Information Processing and Situational Awareness

The amount of information humans can deal with at any one time is limited and at times, particularly in the IFR environment during high workload phases of flight, it is possible to exceed individual processing capacity. When this happens, pilots tend to shed tasks, concentrating on what is perceived as important at the expense of the seemingly more trivial tasks.

GNSS technology has the potential to significantly ease pilot workload, but before the pilot is proficient in its use it can require a very high level of pilot attention. Situational awareness can be lost when a person focuses on a complex or unusual task, such as learning to operate avionics in flight.

Before using GNSS for any flight operation, it is important to become completely familiar with the equipment and to plan well ahead. For example, it is far better to enter the waypoints that may be required for an alternate during the pre-flight stage than following a missed approach. The pilot’s task is to Aviate, Navigate and Communicate in that order and the operation of the technology should not be allowed to interfere with the primary task of flying the aircraft.

Mode Errors

Mode errors occur when devices have different modes of operation and the action appropriate for one mode has different meanings in the other modes. These are likely to occur whenever controls perform more than one function, or control more than one display.

Mode errors are especially likely when equipment does not make the mode visible, so that the user is expected to remember what mode has been established, sometimes for many hours. An example is selecting the IAS hold mode instead of the Vertical Speed (VS) hold mode on an autopilot, and only being able to verify the selection on a display not visible to the other crew.
Some of the operating modes available from GNSS equipment include Nav, Flight Plan, Waypoint and Dead Reckoning. Some of the displayed information is similar in different operating modes and it is possible to lose track of which mode is currently selected. Unfortunately, the functions grouped under the various modes differ from one equipment type to another and do not always appear logical.

The development and use of standard operating procedures to ensure that the intended mode is the one actually selected is encouraged.

Data Entry

The sheer compactness of GNSS technology carries some human factors penalties. Data entry keypads are small, and most keys have multiple functions. This means the operator has to be especially accurate with respect to data entry, and must remain mentally aware of the mode in which the receiver is operating. Data entry while flying in turbulence is a special case and it is important that pilots recognise the increased potential for error in this situation.

When data is entered manually, data entries must be cross-checked by at least two crew members for accuracy and reasonableness. If possible, have one crewmember enter the data, with the second crew member making an independent cross-check, by retrieving the entered data and reviewing against appropriate documents. For single pilot operations, an independent check against current chart data must be made. Comparing GPS derived distance and bearing information against the flight plan can be done on the ground, where there is less likelihood of distraction.

Both manually entered and database derived information should be checked for reasonableness with a confidence check in the following cases:

- Prior to each compulsory reporting point;
- At or prior to arrival at each en route waypoint;
- At hourly intervals during area type operations when operating off established routes; and
- After insertion of new data - eg, creation or amendment of a flight plan.

Many similar or identical waypoint names exist in a database and it is possible for pilots or software producers to inadvertently load the wrong waypoint into a sequence. Confidence checks should compare tracks and distances against charted information rather than simply scroll through a list of waypoints. Pilots should refer to their company operations manual and to CAO 20.18 for additional information regarding data entry.

Cockpit Ergonomics

Many aircraft have been fitted with GPS receivers some years after the aircraft was designed and built. As a result, displays are not necessarily in the ideal location in the cockpit, although IFR installations do require the displays to be in the pilot's field of view. Reflected sunlight can cause problems with both screen displays and annunciator lights and pilots should ensure familiarity with the illumination of the particular receiver installation before night flight.

A large number of GPS receivers are coupled to the Horizontal Situation Indicator (HSI) or the primary navigation display. Mode awareness is critical with these installations as different switching and logic arrangements are used to display data from GNSS, VOR, ILS and other sources. Pilots should also be aware of the attentional dominance of the HSI when navigating by a system not displayed on the HSI, and avoid this configuration where possible.

4. Aircraft Equipment

Where significant aberrations in GNSS information are observed, and in addition to any mandatory occurrence reporting to the ATSB, pilots should advise Air Traffic Services of interference or errors.

4.1 Receiver Standards

Aircraft equipment certified for different operations is measured against a technical standard. These standards are promulgated by the US Federal Aviation Administration as a Technical Standard Order (TSO), by the European Joint Aviation Authority as a Joint Technical Standard Order (JTSO) and by CASA as an Australian Technical Standard Order (ATSO). CASA has not issued any ATSOs for GNSS equipment to date but has accepted the TSO-C129, TSO-C129a, TSO-C145a and TSO-C146a standards for GPS receivers.

Pilots can identify the TSO status of GPS equipment by referring to the compliance stamp on the receiver or by referring to the operating handbook in the aircraft. Reference to a manufacturer's model number is not a guarantee of TSO certification.

Non-TSO

Pilots should be aware that non-TSO GPS receivers are not required to meet any regulatory standards for power supply, installation, lighting, database, integrity monitoring or performance. Many hand-held units not identified as suitable for aviation purposes are unable to operate when the aircraft groundspeed exceeds 99 knots.

Navigation information from non-TSO equipment should be treated with extra care until verified by another means. While rare, position fixing errors in excess of 500 nm have occurred using non-TSO receivers. Rudimentary GPS integrity checking can be achieved by comparing the navigational information provided with monitored traditional navigation aids such as VOR, NDB or DME. In selecting and using a GPS to aid VFR navigation, operators should take note of both the human factors and operational issues described elsewhere in this CAAP.

Day VFR

CASA does not prescribe any required equipment standards and both "panel-mount" and "hand-held" equipment may be used for Day VFR operations. Non-TSO equipment can be used to supplement visual navigation under the VFR.

Night VFR

For Night VFR operations a non-TSO receiver may also be used to supplement visual navigation, but no credit may be claimed against alternate aerodrome, mandatory aircraft equipment or flight crew qualification requirements.

IFR

A non-TSO receiver does not meet any of the requirements for IFR navigation.

TSO-C129

TSO-C129 and the later C129a version specify minimum performance standards for approved GPS equipment and include integrity monitoring. Australian IFR operations with GNSS require the installation of a receiver meeting at least the "RAIM-capable" TSO-C129 standard, or equivalent. The receiver should be installed in accordance with AC21-36, which includes barometric aiding.

Some GPS receivers integrated with a FMS may not be individually certified to a TSO standard and may use systems other than RAIM, such as AAIM, to monitor integrity. Where reference to RAIM or TSO-C129 is used in this CAAP, it may include systems determined to be at least equivalent to these basic IFR standards.

Operators should be aware that not all TSO-C129 receivers will meet the requirements for non-precision approaches and that TSO-C129 receivers are not be able to take advantage of enhanced GNSS capabilities enabled by SBAS, GBAS or GRAS.

There are three main classes of TSO-C129 GPS equipment, which are further divided to form 10 sub-classes. Class A relates to stand-alone GPS equipment, while Classes B and C relate to GPS equipment installed as part of a multi-sensor navigation system. For GA operators the most widely available equipment is Class A1 and Class A2. Although both of these classes are suitable for the IFR RNAV approval, only Class A1 receivers satisfy the requirements for RNAV(GNSS) approaches. Both A1 and A2 receivers incorporate RAIM.

Course Deviation Indicator (CDI) sensitivity and RAIM Horizontal Integrity Limit (HIL) values for TSO-C129 receivers are shown in the table below.

	CDI Scaling	**RAIM HIL**
En-Route Mode	± 5.0nm	2.0nm
Terminal Mode	± 1.0nm	1.0nm
Approach Mode		0.3nm

Day VFR

TSO-C129 equipment may be used to supplement visual navigation under the VFR.

Night VFR

For Night VFR operations, TSO-C129 receivers may also be used to supplement visual navigation, and suitably qualified pilots may be able to use these units to satisfy alternate aerodrome and mandatory aircraft equipment requirements.
Refer to Section 5 of this CAAP for further details.

IFR

TSO-C129 receivers are the minimum standard approved for IFR operations in Australia. Technical limitations of TSO-C129 receivers mean that they are often required to be backed up by conventional navaid alternatives. The actual approvals available to a pilot with TSO-C129 equipment depends upon a number of airworthiness and operational requirements specified in AIP.
Refer to Section 6 of this CAAP for further details.

TSO-C145a and TSO-C146a

The FAA first released the "GPS/WAAS" standards in 1998, although delays to the WAAS program have meant that these products have only become widely available in recent years.

TSO-C145a is a standard for airborne GPS sensors providing data to a flight management system, while TSO-C146a is for stand-alone GPS receivers. The principal improvements over the TSO-C129 standard are that RAIM (FDE), the capability to use SBAS augmentation, and a greater standardisation of displays and controls are required. Additionally, they do not suffer the constraints of many early receivers that were built to operate on the assumption that SA was operational.

Day VFR

TSO-C145a and 146a equipment may be used to supplement visual navigation under the VFR.

Night VFR

For Night VFR operations, TSO-C145a and C146a receivers may also be used to supplement visual navigation, and suitably qualified pilots may be able to use these units to satisfy alternate aerodrome and mandatory aircraft equipment requirements.
Refer to Section 5 of this CAAP for further details.

IFR

TSO-C145a and C146a receivers are approved for the same IFR applications as the TSO-C129 generation, but not subject to the same contingency requirements when supported by a suitable prediction of FDE.
Refer to Section 6 of this CAAP for further details.

4.2 Use of the Avionics

Satellite navigation offers a great opportunity to improve aviation safety and efficiency. Many pilots are already benefiting from the advantages of GPS as a navigation tool and it is important to use the right tool the right way. Further details about VFR and IFR operations may be found in Sections 5 and 6 of this CAAP.

Safety First

To ensure safety, pilots must use GNSS properly. Here are some safety tips:

- Use only the appropriate standard of avionics equipment for the operation. Hand-held and panel-mount VFR equipment does not ensure the integrity and reliability needed for IFR and some Night VFR applications.
- Use a database valid for the operation. Anecdotal evidence suggests that many non-aviation databases lack accuracy, and currency is critical for operations relying on GNSS for navigation clear of terrain, obstacles and airspace boundaries.
- Check that all procedures that could be required are present in the database. Data storage limitations have resulted in some manufacturers omitting certain data, such as small aerodromes, from the receiver database.
- Do not be tempted to design your own approach. Approach designers receive special training and use specific tools. There are many levels of validation before an approach is commissioned.
- Never fly below published minimum altitudes while in instrument conditions. Accidents have resulted from pilots placing too much reliance on the accuracy and integrity of GNSS.
- VFR receivers can be used to supplement map reading in visual conditions. Always carry and use current VFR charts, as they are the primary reference for navigation. Some VFR units show airspace boundaries and terrain, but there is no standard for this data and no guarantee that the depiction is correct.
- Portable receivers and related cables should be positioned carefully in the cockpit to avoid the potential for electromagnetic interference (EMI), and to avoid interfering with aircraft controls. Don’t rest the GPS on the glareshield near the magnetic compass and be aware of the potential for EMI from mobile phones and other personal electronic devices.

- Don’t rely on a backup battery to give a navigation solution following an electrical failure. Pilots should continue to use and practice navigation skills by running a basic plot at all times.
- Resist the urge to fly into marginal weather when navigating VFR. The risk of becoming lost is small when using GPS, but the risk of controlled flight into terrain or obstacles increases in low visibility.

CASA Directions for GPS Computers

CASA gives some directions for computers fitted in an aircraft for use with GPS. Pilots and operators should refer to CAO 20.18 for full details, but the following summary provides a useful addition to the safety tips listed above:

- If a GPS database contains details of waypoints and navigation aids that are published in maps and charts required to be carried in the aircraft, then those details must not be capable of modification by the aircraft operator or flight crew. (This does not prevent the storage of “user-defined data” within the equipment).
- The database must also be current and provided by an approved supplier.
- The manufacturer’s operating instructions for the GPS receiver must be carried in the aircraft, in a place easily accessible to the crew.
- If the aircraft is engaged in commercial operations, the operating instructions must be incorporated in the aircraft’s operations manual.
- GPS equipment must be operated in accordance with its operating instructions.
- Additional requirements relating to the operation of GPS equipment may be incorporated in an aircraft’s flight manual, if they are consistent with the operating instructions.
- Manually entered data must be cross-checked by not less than two flight crew members for accuracy.
- In the case of a single pilot operation, manually entered data must be checked against other aeronautical information, such as current maps and charts.

4.3 Navigational Data

Data Integrity

As discussed in Section 3, a significant number of data errors in general applications occur as a result of human error during manual data entry. Whenever possible, navaid and waypoint positions should be derived from a commercially prepared aviation database which cannot be modified by the operator or crew.

- In some situations it may be necessary to create "user" waypoints by manual entry. In this situation, pilots are responsible for the integrity of the data and must follow CASA's directions for cross-checking. Manually entered data must not be used for navigation below the Lowest Safe Altitude (LSALT) or Minimum Sector Altitude (MSA), unless specifically authorised by CASA.

Stored user waypoints and stored flight plans are considered manually entered data and must be checked prior to use.

Database Currency

Many VFR databases do not have an expiry date as the VFR equipment is only intended to supplement visual navigation with current charts and documents. All IFR databases have an expiry date as data currency (integrity) is critical to safe navigation without visual reference.

The principal requirements relating to GNSS navigation data are:

- GNSS navigation requires a current database appropriate to the operation.
- Only data from a current validated database may be used for navigation below the LSALT or MSA.

GPS navigation database maintenance

Quality control of the navigation database extends to the maintenance activity associated with updating the database. For some equipment types procedures are relatively straightforward, however others may involve maintenance that may only be undertaken by pilots with a maintenance authority issued by CASA. CASA can provide more information on the requirements applicable to particular avionics on request.

WGS84 Co-ordinate System

Waypoint co-ordinates, particularly those used for approach and landing, must be based on the same geodetic reference system used by satellite positioning systems. In support of GNSS, ICAO and Australia adopted the co-ordinate system known as the World Geodetic System of 1984 (WGS84) as the common geodetic reference datum for civil aviation.

Pilots and operators should ensure that WGS84 is selected as the default geodetic reference in their GPS receivers.

5. VFR operations

GPS may be used under the VFR in the following applications:

- Visual Navigation
- Night VFR RNAV

In the event of GNSS performance degrading to the point where an alert is raised, or other cause to doubt the integrity of GNSS information exists, the pilot in command must discontinue its use and carry out appropriate navaid failure procedures.

The following table summarises the airworthiness and operational requirements for GNSS applications under the VFR.

GNSS Applications - VFR		
Application	Operational Requirement	Airworthiness Requirement
Visual Navigation	Limited to supplementing visual navigation techniques.	Any GPS receiver may be used, but installed receivers must be fitted in accordance with AC21-36.
Night VFR RNAV	1. GPS receiver operated in accordance with the manufacturer's operating instructions, and any additional instructions specified by the operator. 2. Flight crew hold appropriate GPS qualifications.	1. GPS receiver certified to TSO-C129, C129a, C145a, C146a or equivalent standard approved by CASA. 2. GPS receiver fitted in accordance with AC21-36 and automatic barometric aiding options functional. 3. Manufacturer's operating instructions, and any additional instructions specified by the operator carried on board the aircraft.

5.1 Visual Navigation

Pilots operating under the VFR may use GPS to supplement map reading and other visual navigation techniques. It must be stressed that this is not an approval to replace visual navigation techniques with GNSS. "Blind" faith in GPS is often 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 earlier in this CAAP.

Pilot Qualifications

There are no mandatory qualifications required to use GPS by day under the VFR. However, pilots are strongly encouraged to become familiar with their equipment before flight and keep appropriate operating instructions within easy reach.

VFR Parallel Offsets

Overseas studies and initial work carried out within Australia indicate there is some increased risk of head–to–head collision due to the increased navigation accuracy provided to aircraft using GNSS equipment. The following provides guidance to pilots using GNSS for VFR navigation in Class E and Class G airspace.

- Pilots should use known waypoints to determine tracks and, when broadcasting, give position information in relation to those waypoints to provide meaningful alerted 'see and avoid' positions to any possibly conflicting traffic.
- When operating clear of Class C, Class D and GAAP airspace, pilots flying VFR using a GNSS navigation source should offset 1.0 nm RIGHT of track. The offsets must not be used in proximity to controlled or restricted airspace because their use could infringe aircraft segregation from that airspace.
- Prior to entering Class C, Class D or GAAP airspace or when changing to the IFR, this offset must be cancelled. Offsets should not be included in default receiver settings and pilots should ensure that that they are removed from the CDI settings after use.
- Pilots using the offset procedure while operating under the VFR at Night must ensure that LSALT calculations are based on the offset track.
- This guidance does not apply to IFR operations.

Refer to Section 6 of this CAAP for information about offsets under the IFR.

5.2 Night VFR

In addition to the use of GPS to supplement visual navigation, pilots may undertake training and become qualified to use GNSS equipment as a Night VFR navigation aid in Australian domestic airspace.

The following descriptions provide a general summary for educational purposes. Refer to AIP for full details of the approvals.

Pilot Qualifications

Pilot qualifications for the use of GPS in Night VFR operations are detailed in Section 7 of this CAAP.

RNAV Approval

GPS may be used under the VFR at Night as a navigation aid and RNAV system for the following purposes:

- Position fixing in accordance with AIP ENR 1.1;
- Operations on designated RNAV routes and application of RNAV-based LSALT;
- Deriving distance information for en-route navigation, traffic information and ATC separation; and
- Meeting the Night VFR requirements for carriage of radio navigation systems and alternate aerodromes.

Lowest Safe Altitude

AIP GEN 3.3 permits Night VFR LSALT to be determined by a number of different methods, including on the basis of GNSS RNAV capability. Refer to AIP for full detail.

Mandatory Navigation Equipment

GNSS systems used by appropriately qualified pilots may satisfy the Night VFR requirements for serviceable radio navigation systems as specified in AIP GEN 1.5 Section 2.

Alternate Aerodromes

GNSS equipment may be used to satisfy the navigation aid aspects of Night VFR alternate aerodrome requirements as detailed in AIP ENR 1.1.

6. IFR Operations

GNSS must not be used as navigation reference for flight below the LSALT/MSA, except as specified in the IFR applications detailed in this section, or as otherwise authorised by CASA.

Parallel offset tracking is only approved for oceanic operations. The current separation standards, safety height calculations, and tracking requirements for IFR aircraft are based on the requirement that the pilot will attempt to maintain track as closely as possible. Offsets are not approved for non-oceanic IFR aircraft.

GPS may be used under the IFR in the following applications:

- DR Substitute
- IFR RNAV
- RNAV(GNSS) Non-precision Approach
- Oceanic RNAV
- GNSS Landing System (GLS)

In the event of GNSS performance degrading to the point where an alert is raised, or other cause to doubt the integrity of GNSS information exists, the pilot in command must discontinue its use and carry out appropriate navaid failure procedures.

Pilots and operators should note that DR Substitute and IFR RNAV operations are limited to Australian Domestic Airspace. Beyond the boundary of Australian Domestic Airspace, GNSS operations must be conducted in accordance with an Oceanic RNAV approval issued by CASA. The definition of Australian Domestic Airspace for these approvals is the airspace overlying the Australian mainland and surrounding areas, with lateral limits defined by the common boundary of domestic controlled airspace and oceanic controlled airspace (OCA).

The following table summarises the airworthiness and operational requirements for GNSS applications under IFR.

GNSS Applications - IFR		
Application	Operational Requirement	Airworthiness Requirement
DR Substitute	1. GPS receiver operated in accordance with the manufacturer's operating instructions, and any additional instructions specified by the operator.	1. GPS receiver certified to TSO-C129, C129a, C145a, C146a or equivalent standard approved by CASA. 2. GPS receiver fitted in accordance with AC21-36 or applicable equivalent standard. Automatic barometric aiding is not required. 3. Manufacturer's operating instructions, and any additional instructions specified by the operator carried on board the aircraft.
IFR RNAV	1. GPS receiver operated in accordance with the manufacturer's operating instructions, and any additional instructions specified by the operator. 2. Flight crew meet appropriate GNSS qualification and recency requirements. 3. For SID, STAR and approach procedures, other than those titled RNAV procedures, primary track guidance must be provided by the navaid (NDB, VOR, LLZ or ILS) nominated on the IAL chart.	1. GPS receiver certified to TSO-C129, C129a, C145a, C146a or equivalent standard approved by CASA. 2. GPS receiver fitted in accordance with AC21-36 or applicable equivalent standard at the time of fitment and automatic barometric aiding options functional. 3. Manufacturer's operating instructions, and any additional instructions specified by the operator carried on board the aircraft.

RNAV(GNSS) Non-precision Approach	1. GPS receiver operated in accordance with the manufacturer's operating instructions, and any additional instructions specified by the operator. 2. Flight crew meet appropriate RNAV(GNSS) qualification and recency requirements. 3. Unless using a TSO-C145a or C146a receiver and a valid prediction of approach FDE availability, at both the destination and alternate if required, provision for an alternate aerodrome may not be based on RNAV (GNSS) approach capability. 4. If a TSO-C129 or C129a receiver is used at any time, or a C145a or C146 receiver is used during a period when FDE is not predicted to be available, an alternate visual approach or instrument approach based on NDB or VOR must be planned.	1. GPS receiver certified to TSO-C129, C129a, C145a, C146a or equivalent standard approved by CASA. 2. GPS receiver fitted in accordance with AC21-36 and automatic barometric aiding options functional. 3. Manufacturer's operating instructions, and any additional instructions specified by the operator carried on board the aircraft.
Oceanic RNAV	Requires an approval issued by CASA. *Refer Para 6.4 of this CAAP*	As detailed in an approval issued by CASA. *Refer Para 6.4 of this CAAP*
GLS	Requires an approval issued by CASA. *Refer Para 6.5 of this CAAP*	As detailed in an approval issued by CASA. *Refer Para 6.5 of this CAAP*

6.1 DR Substitute.

Pilots operating under the IFR may use GPS in lieu of Dead Reckoning (DR) navigation techniques for that part of the flight that is outside the rated coverage of terrestrial navigation aids.

Note: This is not an RNAV approval.

6.2 IFR RNAV.

Pilots operating in Australian Domestic Airspace under the IFR may use GPS for position fixing and long range navigation in accordance with ENR 1.1 Section 19, operations on designated RNAV routes, application of RNAV based LSALT, deriving distance information of enroute navigation, traffic information and ATC separation. ATC may apply RNAV based separation standards to aircraft meeting the requirement for IFR RNAV.

GPS may also be used as a navigation aid to determine distanceinformation for SID, STAR and Instrument Approach procedures where the use of GPS is specified on the IAL Chart. GPS may be used to meet the IFR requirements for radio navigation systems specified in GEN 1.5 section 2.

GPS Arrivals

Although technically instrument approach procedures, “GPS Arrivals” and “DME or GPS Arrivals” (DGA) are included in the IFR RNAV application and approval. Operators and pilots should note that additional competency and recency qualifications apply to the conduct of DGA. Refer to CAO 40.2.1, CAO 40.2.3 and CAAP 5.13-1 for further detail.

For these procedures, the destination navaid (VOR or NDB) nominated on the approach chart must be used to provide primary track guidance during the arrival procedure and the distance information must be based on the 'reference waypoint' navaid nominated on the chart.

Lowest Safe Altitude

AIP GEN 3.3 permits IFR LSALT to be determined on the basis of GPS RNAV capability. For routes and route segments not shown on AIP aeronautical charts, the obstacle clearance to be considered must be within an area of 5nm surrounding and including an area defined by lines drawn from the departure point not less than 10.3° each side of the nominal track to a maximum of 7nm, thence parallelling track to abeam the destination and converging by a semicircle of 7nm centred on the destination. Refer to AIP for full detail.

6.3 RNAV(GNSS) Non-precision Approach.

Pilots operating und the IFR may use GPS as an approach navigation aid to determine distance and track information for RNAV(GNSS) non-precision approach procedures. As with other IFR applications, TSO-C129 is the minimum standard of receiver approved for these operations.

Operators and pilots should be aware that there are no published “overlay” approaches in Australian domestic airspace, as the TSO-C129 receiver is unable to accurately fly the base turn reversal procedure of the “teardrop” design commonly used in Australia.

“Overlay” and “T-pattern” GNSS approaches are used in some other countries and pilots should familiarize themselves with the design, procedures and naming conventions used prior to conducting these approaches under the IFR.

Australian Approach Design

The Australian-developed "Y-pattern" runway aligned design has been adopted by ICAO and is published in PANS-OPS. The approaches are essentially "straight-in" to the runway and can usually be joined at any of three Initial Approach waypoints without the need for a reversal or base turn manoeuvre.

Naming Conventions

The approach name is based on aerodrome identification and the runway used for alignment, or in some cases the direction of the approach in relation to the aerodrome.

In general, waypoint names use the first three letters to identify the aerodrome, the next letter to identify the compass quadrant from which the approach is flown, and the final letter for the approach waypoint. As an example, the Runway 24 GPS approach for Paraburdoo, WA (YPBO) uses "PBO" as the first three letters, and "E" as the fourth letter, of all waypoints. The various waypoints are identified as follows:

- The initial approach waypoints (usually a selection of three) allow flying of the approach without use of a sector entry procedure. The initial points mark the start of the approach and are usually designated with "A", "B" and "C" as the fifth letter of the waypoint name.
- The intermediate waypoint achieves alignment with the final approach course and has "I" as its fifth letter.
- The final approach waypoint marks the point where the receiver has completed transition to the approach mode (CDI scale and RAIM tolerance goes to 0.3nm) and has the "F" designator.
- The missed approach waypoint is normally at the runway threshold and is designated with the letter "M". The missed approach mode must be manually selected for the receiver to give missed approach tracking information. On selection, the receiver CDI scale and RAIM tolerance reverts to 1.0nm.
- A missed approach turning waypoint, if required, is designated with the letter "T".
- The missed approach holding waypoint is designated with the letter "H" and used to provide tracking for the missed approach.

The exception to this rule is that initial approach fixes may be given a pronounceable five letter name when they are located at the terminating waypoint of a STAR.

Vertical Navigation

The GPS does not provide accurate altitude guidance and all altitudes must be obtained from the aircraft altimeter. At runways where visual approach slope indicators are not provided, pilots should ensure that the correct aircraft approach angle is maintained.

A distance altitude scale is usually provided on the approach plate to give a 3° approach profile, and a corresponding altitude may be included on the profile view at selected points. A maximum descent gradient of 3.77 degrees may be shown for Category A and B aircraft, and a maximum of 3.5 degrees for Category C and D aircraft.
See CAAP 178-1 for more information on instrument approaches.

RAIM Planning and Operational Issues

As described in Paragraph 2.3 of this CAAP, RAIM FD uses multiple satellites and barometric input to mathematically verify the positional data supplied by each satellite. However, FD alone will not provide the pilot with an alternative navigation solution. With conventional navaids like NDB or VOR the pilot can simply tune the receiver to another aid, but with a basic C129 receiver the faulty data continues to degrade the integrity until the satellite is taken off-line or moves below the horizon. This may take some hours, so until recently the rules for GNSS approaches have required the use of conventional navaids or visual conditions to provide a contingency solution for this situation.

However, FDE provides an improvement over FD in that it will identify the faulty satellite and exclude it from the navigation solution, meaning that the pilot can continue to use GNSS for navigation. FDE needs one more satellite input than FD to allow for exclusion of a satellite in the event of a fault. With the contingency capability provided by an FDE capable TSO-C146a receiver and a prediction that FDE will be available during the approach, it is possible to treat GNSS much as you would the ADF or VOR,

While this is a significant step forward, the time has not yet come to throw out the ADF. The number of satellites required to be in view means that FDE is not always possible due to a RAIM hole at the destination, so there will be times when planning needs to be based on the FD rules or a conventional navaid. *See paragraph 8.2 of this CAAP for a GNSS alternate planning flowchart.*

RAIM Loss or Warning during approach

After the approach mode has been armed and the aircraft approaches the Final Approach Fix, the receiver will automatically perform a RAIM(FD) prediction for the approach. The receiver will not enter approach mode unless RAIM(FD) is predicted to be available for the approach.

In the event that RAIM is lost after passing the Final Approach Fix, the equipment will continue to provide navigation, where possible, for five minutes before providing a RAIM loss indication. This should be sufficient time to complete the approach. Should RAIM detect an out-of-tolerance situation, an immediate warning will be provided, and a missed approach must be initiated.

Flying the Approaches

GNSS receivers are essentially navigation management computers and require more pilot attention than traditional ILS, VOR and ADF receivers, particularly during approach. Pilots are cautioned about the level of complexity of equipment and should take advantage of receiver simulation modes and ground training prior to undertaking airborne training.

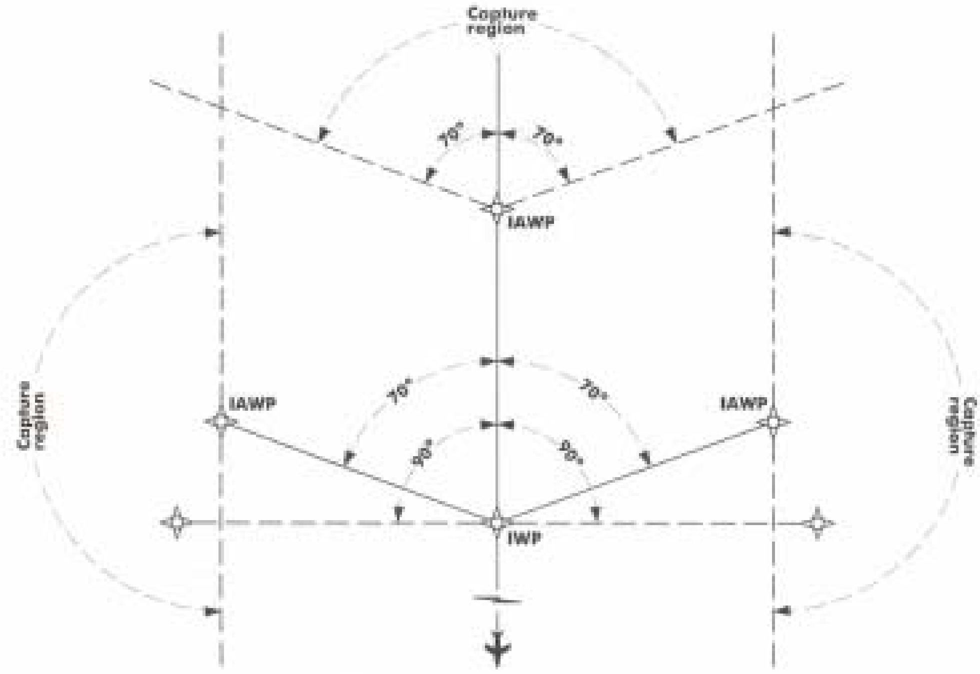
Prior to flight, pilots should ensure that the receiver is set to the required aviation parameters; ie, nautical miles, knots, altitude in feet, pressure in hectopascals and WGS84 reference system. The recommended en-route CDI scaling is 5nm full-scale deflection.

To fly the approach, the database must be current and contain the relevant approach. The approach should first be retrieved from the database and then selected along with the desired initial approach waypoint. The intermediate, final and missed approach segments must only be flown in that sequence. Select the desired approach and the initial approach waypoint and add this to the flight plan. Check waypoint sequence, tracks and distances against the approach chart.

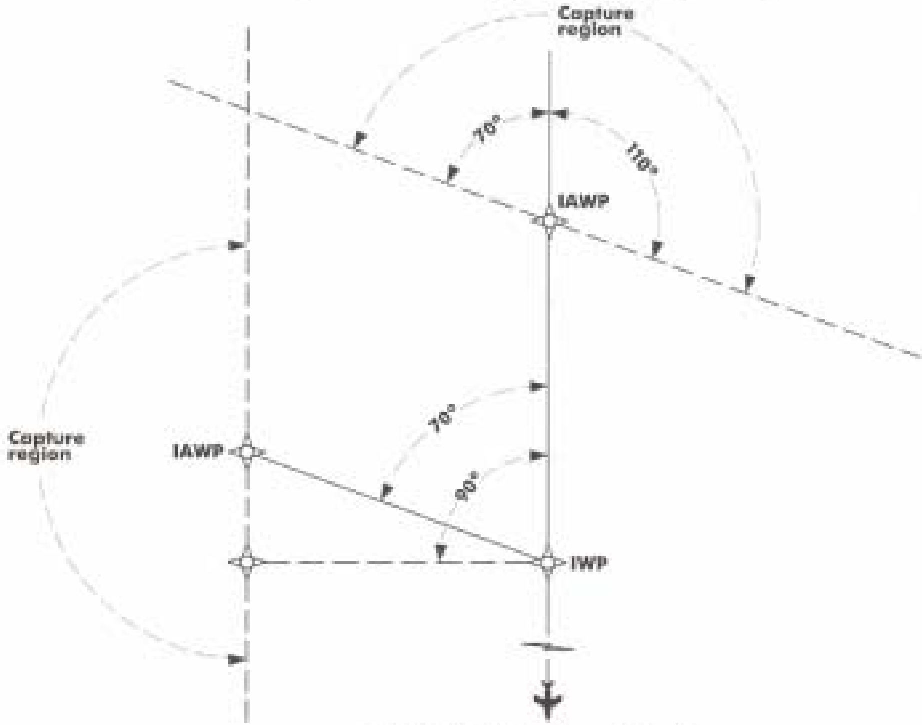
Pilot identification of each waypoint is essential for situation awareness during the approach, and to ensure compliance with limiting altitudes. The distance provided by the receiver is to the next approach waypoint (not to the airport) and the receiver will adjust the CDI scaling through the approach. The tracking tolerance is half of full-scale deflection regardless of the CDI scale.

An aircraft that is not required to hold or to lose height in a holding pattern may commence the approach without entering the holding pattern for procedures using GPS, if the aircraft is tracking to an initial approach waypoint from within the capture region for that waypoint (see diagram below). Capture regions ensure that the radius of turn will permit interception of the approach segment prior to the next waypoint.

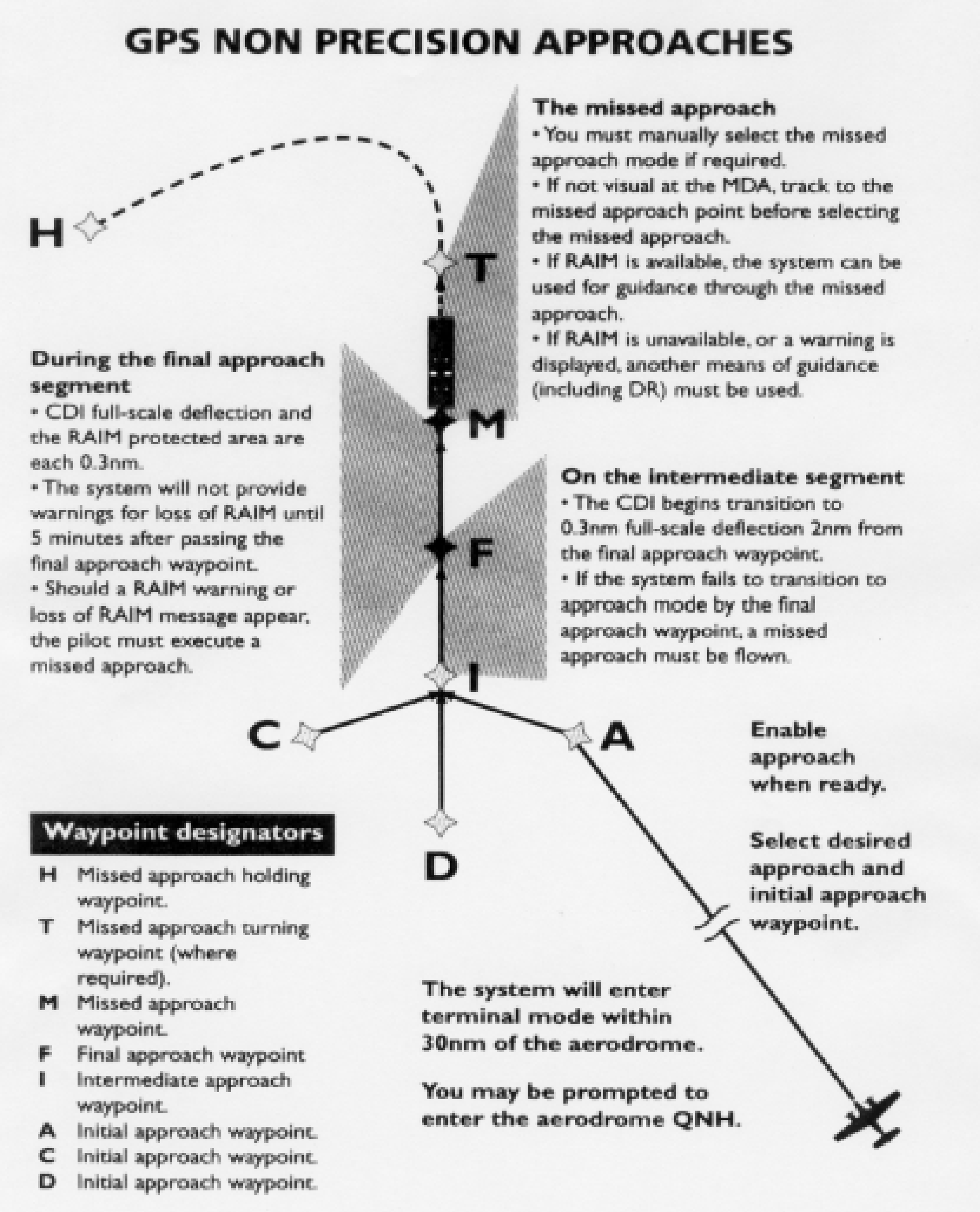
Should a missed approach be required, the missed approach mode (and hence tracking) must be manually selected. This expands the CDI scale to the terminal mode of 1.0nm.



GPS NPA Approach Capture Regions
(Three Initial Approach Way-points)



GPS NPA Capture Regions
(Two Initial Approach Way-points)



Airmanship Points

- Ensure you are familiar with the operating procedures before using the avionics in IMC.
- Check receiver, database, approach plate and setup.
- Include GPS displays in your instrument scan, maintain situational awareness and be aware of LSALT/MSA.
- Don't become fixated on the GNSS receiver and avoid complacency by cross-checking with all available navigation sources.

6.4 Oceanic RNAV.

CASA may issue an approval for an operator to use GNSS an enroute navigation aid to in oceanic and remote areas outside the boundaries of Australian Domestic Airspace. The following description provides a general summary for educational purposes. Contact your local CASA field Office to apply for an Oceanic approval.

The Oceanic RNAV approval is based on FAA Notice 8110.60 and designed for operations over the high seas and in remote areas such as Antarctica. The definition of remote areas for this approval is not related to the designated remote areas requiring the carriage of emergency equipment.

Pilot Qualifications

Pilot must have completed the en-route training for IFR operations detailed in Section 7 of this CAAP.

Equipment Requirements

The GPS equipment requirements include dual installations of FDE capable receivers to ensure adequate redundancy and navigation performance. Installations in Australian registered aircraft must be approved, and equipment capable of carrying out an appropriate Enroute RAIM prediction analysis for the route to be flown, using software provided by the avionics manufacturer, must be available.

Operational Requirements

GPS navigation equipment must be operated in accordance with the operating instructions and any additional requirements specified in the approved aircraft flight manual or flight manual supplement. Those operating instructions must be carried on board the aircraft.

In addition to GPS, aircraft must be equipped with serviceable radio navigation systems as specified at GEN 1.5 Section 2, or the operator’s minimum equipment list;

An appropriate en route GPS prediction analysis, using the software provided by the GPS manufacturer, must be conducted prior to each flight. For this analysis, the following parameters, or equivalents, must be used:

- the route or airspace RNP, where published, or
- a centreline space of 20NM for flight in Classes A, C, D & E airspace or 50NM for flight in OCA; and

For Australian operators, a record of the GPS prediction analysis must be retained as required by the instrument of approval.

Oceanic Lateral Offsets

ICAO has conducted a technical analysis of airspace safety issues associated with the use of lateral offsets when operating in oceanic areas.

Authorisation

AIP ENR 2.2 states that aircraft operating in Oceanic Controlled Airspace in the Australian FIR are authorised to use lateral offsets in accordance with certain requirements. This approval is no longer specific to operations with GNSS and full details of the requirements are listed in AIP.

6.5 GNSS Landing System (GLS)

CASA may issue an approval for an operator to use GNSS as a precision approach navigation aid. At this stage GLS is still a developmental system and approvals have significant operational limitations.

7. Flight Crew Qualifications

This Section details the different pilot training and certifications required to use the various GNSS approvals. Pilots unsure about the required training and qualifications should contact CASA, a flight training organisation or their company training and checking organisation. Flying Instructors, Training Pilots, Check Pilots and Testing Officers will find additional guidance material in CASA's Flight Crew Licensing Industry Delegates Handbook.

7.1 VFR Pilots

Day VFR Operations

There are no GNSS qualifications issued for the use of GPS as a supplement to visual navigation. Pilots should review the competency requirements of the Day VFR syllabus in regard to the use of navigation aids.

Night VFR Operations

Appendix I to CAO 40.2.2 permits the holder of a Night VFR Rating to use only those navigation aids for which his or her rating is endorsed. There are no recency requirements associated with the use of GPS under the VFR at Night.

In order to qualify for the endorsement of GPS to a Night VFR rating, pilots must complete ground training and demonstrate competency to CASA or an Approved Testing Officer (ATO).

Applicants seeking the GPS endorsement as part of the issue of a Night VFR rating must complete a syllabus of ground training as detailed in Appendix 2 of this CAAP and demonstrate competency in the use of GPS during the Night VFR flight test.

Applicants seeking to add the GPS endorsement to an existing Night VFR Rating must also complete a syllabus of ground training and demonstrate competency in the use of GPS either in flight or on the ground using the "ground training simulator" function of a TSO-C129 or C146a receiver. Holders of a current Instrument Rating or Private IFR Rating are exempted from these prerequisites if they hold the qualifications required to use GPS for en-route navigation under the IFR.

At the discretion of the ATO, a computer based "software-only" simulator produced by a receiver manufacturer may be used to demonstrate competency. In this case the software must be designed for the purpose of training pilots to use a specific type of receiver, and include an appropriate navigational database. The ATO must be satisfied that the software is capable of simulating all the functions required to assess the candidate's competency in the use of the receiver.

7.2 IFR Pilots

The various competency and recency requirements for use of GPS by instrumented-rated pilots are summarized in this section. Refer to AIP GEN 1.5 Section 8, CAO 40.2.1, CAO 40.2.3 and CAAP 5.13-1 for further detail.

Night VFR Operations

Pilots wishing to use the privileges of a Command Instrument Rating to conduct flight by night under Night VFR procedures must not use GPS for navigation unless they also have the appropriate en-route IFR qualifications.

IFR Operations

Prior to using GPS in IFR operations pilots must have completed a course of ground training, based on the syllabus contained in Appendix IV of CAO 40.2.1. The course may be conducted by:

- CASA; or
- An approved training and checking organisation; or
- An instrument school.

The course must cover general information and procedures applicable to all types of GPS equipment, as well as the essential operating procedures for a specific type of aircraft equipment. The practical component of the course should be based on a particular type of TSO-C129 or C145 or C146 equipment. A recommended training syllabus based on the syllabus contained in CAO 40.2.1 is detailed in Appendix 2 of this CAAP.

Log Book Certification

Satisfactory completion of the course and demonstration of competence in operation must be certified in the body of the pilot's logbook in the following format:

> **__________________ has satisfactorily completed a course of ground** instruction in **GPS principles and operation in accordance with the syllabus contained in CAO 40.2.1 Appendix IV and I consider him or her competent in the operation of __________________ type of GPS equipment for the purposes specified in CAO 40.2.1 paragraph 13.6.**
>
> ________________________
>
> ***(Name & ARN)*** **Date:**

Pilots may subsequently use a different type of GPS aircraft equipment to that specified in the certification, but must ensure that they are familiar with and competent in the operating procedures required for that type of equipment, before using it in flight for any of the purposes approved in AIP.

Command Instrument Rating and Co-pilot Instrument Rating Holders

No other competency or recency requirements are specified for:

- En-route GPS Navigation
- Use of GPS in lieu of DME

Rating Endorsements are required, and recency specified for:

- DME or GPS Arrival (DGA)
- RNAV (GNSS) Non-precision Approach

Although an endorsement may not be required in some cases as described CAO 40.2.1 subsection 13A.

Private IFR Rating Holders

A GPS Flight Procedure Authorisation (FPA) is required for:

- En-route GNSS Navigation
- Use of GPS in lieu of DME

Additional FPAs are required, and recency recommended for:

- DME or GPS Arrival (DGA)
- RNAV (GNSS) Non-precision Approach

8. Flight Planning and ATS

8.1 RAIM Prediction and NOTAM

There are generally three sources of RAIM prediction available to civil aviation users.

- TSO Receivers;
- Flight Planning Software;
- NOTAM.

Receiver

All TSO-C129 and some TSO-C146a receivers have a built-in Approach RAIM prediction function available to the pilot. These are useful tools for in-flight use. However, these systems are usually not capable of FDE prediction and use the last issue of the constellation almanac to predict RAIM. The resulting prediction is therefore less accurate with the increasing length of time between prediction and approach, and unsuitable for flight planning purposes

Software

The GPS oceanic and remote area approval requires an appropriate En-route RAIM prediction, using the software provided by the receiver manufacturer, to be conducted prior to flight. This analysis takes into account the required navigation performance for the route or centreline spacing. Australian operators are required to retain a record of the GPS prediction analysis by the instrument of approval.

NOTAM

GPS Status Reports

Airservices Australia makes GPS Status Reports available via the AVFAX system. These reports are issued by the US Coast Guard and contain details of the satellites in orbit, Notice Advisory to NavStar Users (NANU) and other general remarks.

RAIM Prediction Service

The Airservices Australia RAIM Prediction Service (RPS) uses NANU and the current almanac to provide GPS NOTAMs for flight planning purposes.

Approach RAIM outages are given for 72 hours from the UTC prediction time shown in the first line of the prediction message. RPS has recently been upgraded to facilitate the differences between TSO C129 and TSO C146 equipment.

Sample text of the RAIM prediction output is attached below.

```
BUTLER (YBUT)
GPS RAIM PREDICTION 071401
YBUT

 TSO-C129 (AND EQUIVALENT)
FAULT DETECTION
03080610 TIL 03080615
03090606 TIL 03090611
03100602 TIL 03100607
GPS RAIM FD UNAVBL FOR NPA

 TSO-C146A (AND EQUIVALENT)
FAULT DETECTION ONLY
NO GPS RAIM FD OUTAGES

FAULT DETECTION AND EXCLUSION
03080610 TIL 03080613
GPS RAIM FDE UNAVBL FOR NPA
```

8.2 Alternate Aerodromes

AIP ENR 1.1 details requirements for the provision of Alternate Aerodromes. When supported by RAIM FDE prediction, TSO-C145a or C146a equipment may be used to meet the Navigation Aid requirements for alternate Aerodromes. However, the limitations of TSO-C129 GPS performance have restricted the application of GPS to satisfy those requirements. The following is a summary of the Navigation Aid requirements relating to GNSS, refer to AIP for more detail.

Night VFR

When both pilot and aircraft meet the requirements of AIP GEN 1.5 Section 8, a pilot may not need to provide for an alternate aerodrome to a “no-aid” destination under the VFR at Night.

AIP requires that the pilot provide for an alternate within one hour’s flight time of the destination unless:

- The destination is served by a radio navigation aid (NDB or VOR) and the aircraft is fitted with the appropriate radio navigation system capable of using the aid; or
- The aircraft is fitted with an approved GPS receiver, and pilot and aircraft meet the requirements of AIP GEN 1.5 Section 8.

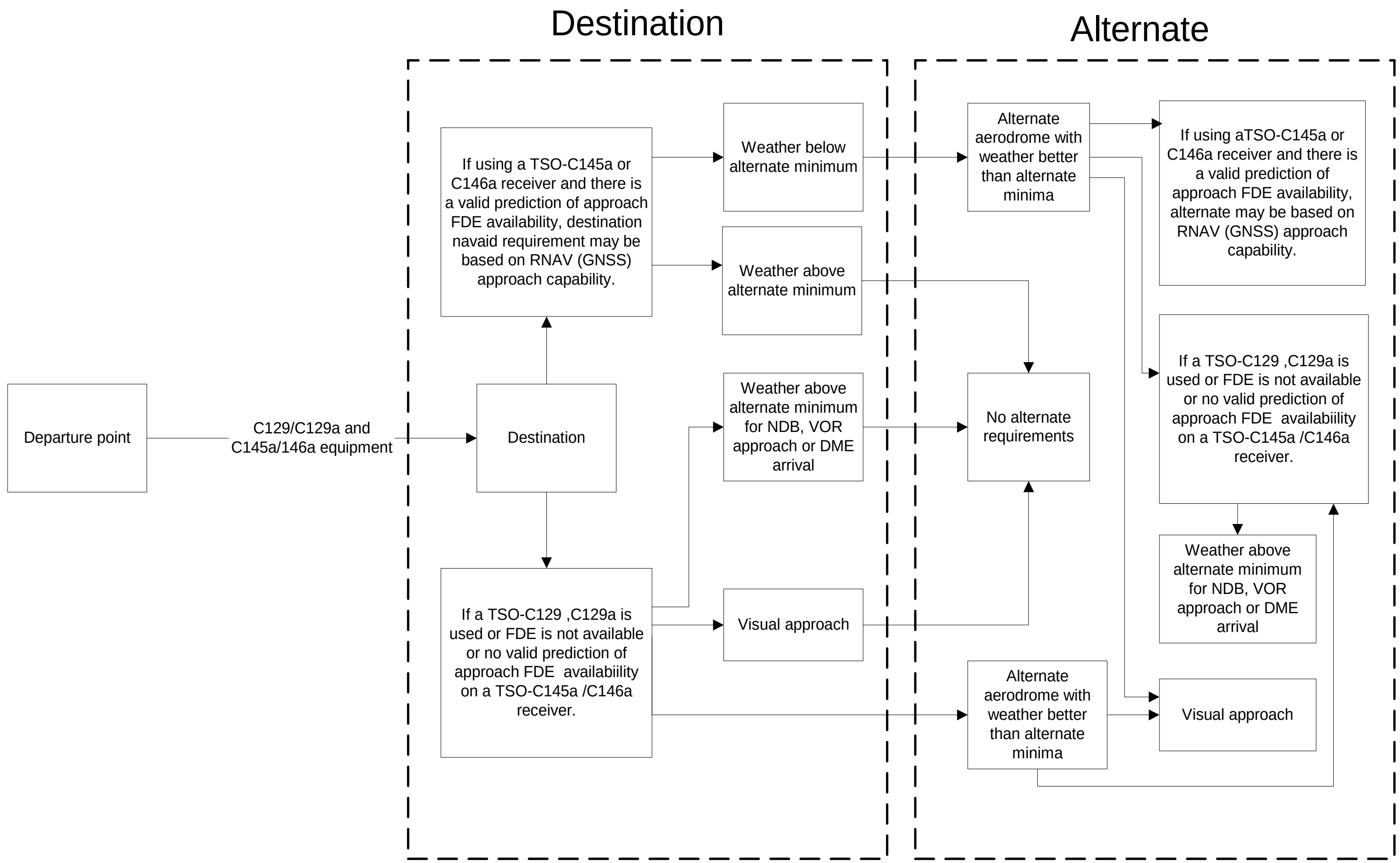
The alternate aerodrome must be served by a NDB or VOR that the aircraft is equipped to use.

IFR

The approvals for use of GPS under the IFR in AIP GEN 1.5 Section 8 specify that GPS may be used to satisfy any of the IFR requirements for provision of an alternate aerodrome provided that it is certified to TSO-C145a or C146a and a valid prediction of approach FDE availability is used. This applies to the requirements for navaids at both the destination and the alternate aerodrome.

When using a TSO-C129 receiver, or a C146a receiver with a prediction that FDE will not be available, and the forecast weather is below the alternate weather minima, the alternate must be suitable for visual approach or an instrument approach using ground-based navigation aids.

The following flow chart shows the alternate considerations for both TSO-C129a and TSO-C145a/C146a equipment under various weather conditions. It does not attempt to show the interaction of aerodrome lighting requirements or operational requirements for multiple navigation aids


Destination
Alternate
Departure point
C129/C129a and C145a/146a equipment
Destination
If using a TSO-C145a or C146a receiver and there is a valid prediction of approach FDE availability, destination navaid requirement may be based on RNAV (GNSS) approach capability.
Weather below alternate minimum
Weather above alternate minimum
Weather above alternate minimum for NDB, VOR approach or DME arrival
If a TSO-C129 ,C129a is used or FDE is not available or no valid prediction of approach FDE availabiility on a TSO-C145a /C146a receiver.
Visual approach
Alternate aerodrome with weather better than alternate minima
If using aTSO-C145a or C146a receiver and there is a valid prediction of approach FDE availability, alternate may be based on RNAV (GNSS) approach capability.
If a TSO-C129 ,C129a is used or FDE is not available or no valid prediction of approach FDE availabiility on a TSO-C145a /C146a receiver.
No alternate requirements
Weather above alternate minimum for NDB, VOR approach or DME arrival
Alternate aerodrome with weather better than alternate minima
Visual approach

8.3 Flight Notification

Flight notifications submitted to ATS include provision for the aircraft's navigation capability. This notification includes the assumption of the system being fully operational and that the crew is able to use the system. While flights notifying only GNSS capability can be accommodated, pilots should ensure that ATS is notified of all navigation capability to maximise flexibility and avoid delays in the issue of airways clearances.

Don't use "G" for GPS

The field 10 designator "G" is reserved for the notification of GNSS navigation capability. It is expected that Australia will use this designator in the future, but at present the notification has not been defined for any particular level of capability. The Australian flight plan processing system does not recognise "G".

GPS RNAV

Insert "Z" in field 10 and "NAV/GPSRNAV" in field 18 of the flight notification form for:

- Night VFR RNAV;
- IFR RNAV; or
- RNAV(GNSS) Non-precision Approach.

GPS OCEANIC

Insert "Z" in field 10 and "NAV/GPSOCEANIC" in field 18 of the flight notification form.

GLS

Insert "Z" in field 10 and "NAV/GLS" in field 18 of the flight notification form.

No Notification

No notification should be given for any of:

- Non-TSO systems supplementing visual navigation;
- DR Substitute; or
- Unqualified flight crew.

8.4 Air Traffic Services

Separation based on GPS

GPS systems meeting the requirements of NVFR RNAV, IFR RNAV or RNAV (GNSS) Non-precision approach may be used to provide distance information to ATS units.

ATC may apply some DME-based separation standards to approved aircraft providing GPS distance information. Separation standards involving the use of RNAV systems will only be applied by ATC between aircraft with approved RNAV, or between an aircraft with approved RNAV equipment and an aircraft with DME.

Pilots must be familiar with and comply with GPS reporting requirements and procedures. When a DME distance is not specifically requested, or when the provision of a DME distance is not possible, distance information based on GPS-derived information may be provided. When responding to ATS requests for distance information, pilots should:

- Provide either a DME distance or a GPS distance unless RAIM is currently not available, and has been unavailable for the previous 10 minutes; and
- Include the source and point of reference (eg: 115 GPS Melbourne, 79 DME Newman, 257 GPS BEEZA, etc).

If a GPS distance is provided to an ATC unit, and RAIM is not currently available, but has been available in the preceding 10 minutes, the distance report should be suffixed "NEGATIVE RAIM" (eg: 26 GPS LT VOR, NEGATIVE RAIM).

Databases sometimes contain waypoint information that is not shown on published AIP charts and maps. Distance information must only be provided in relation to published waypoints unless specifically requested by an ATS unit. Where GPS distance is requested or provided from an NDB, VOR, DME, or published waypoint, the latitude and longitude of the navigation aid or way-point must be derived from a validated database which cannot be modified by the operator or crew.

ATC may request GNSS-equipped aircraft to establish on, and track with reference to, a particular VOR radial or NDB track to assist in the provision of separation.

Advising ATS of GPS Status

ATS services, in particular aircraft separation, are predicated on accurate aircraft navigation and position fixing. If data integrity is lost, the accuracy of the GNSS system is assumed not to meet the required standard for navigation and, consequently, for the application of RNAV separation standards by ATC. Accordingly, when data integrity or RAIM is lost, the following procedures must be adopted:

- Aircraft tracking must be closely monitored against other available navigation systems.
- In controlled airspace, ATC must be advised if:
  - RAIM is lost for periods greater than 10 minutes, even if GPS is still providing position information; or
  - RAIM is not available when ATC requests GPS distance, or if an ATC clearance or requirement based on GPS distance is imposed; or
  - The GNSS receiver is in DR mode, or experiences loss of navigation function, for more than one minute; or
  - Indicated displacement from track centreline exceeds 2.0nm.
- If valid position information is lost (2D or DR Mode), or non-RAIM operation exceeds 10 minutes, the GPS information is to be considered unreliable and another means of navigation should be used until RAIM is restored and the aircraft is re-established on track.
- Following re-establishment of RAIM, the appropriate ATS unit should be notified of RAIM restoration prior to using GPS information. This will allow ATC to reassess the appropriate separation standards.
- When advising ATS of the status of GPS, the phrases “RAIM FAILURE” or “RAIM RESTORED” must be used.

On receipt of advice, ATC may adjust separation.

Appendix A

A Recommended GNSS Training Syllabus

This appendix provides a suggested syllabus for GNSS ground training. It is intended to cover the mandatory syllabus for IFR training as well as additional Night VFR aspects applicable to the en-route navigation approvals. Part A comprises modules common to both IFR and VFR pilots; Part B applies only to IFR operations. It is recommended that the Night VFR ground training cover at least the material in Part A and the IFR ground training cover the entire syllabus.

The training must cover general information and procedures applicable to all types of GNSS equipment, as well as the essential operating procedures for a specific type of aircraft equipment. Pilots who have completed the training and who wish to use a different type of GPS aircraft equipment must ensure that they are familiar with and competent in the operating procedures required for that type of equipment, before using it in operations. Pilots are reminded of the need to have suitable type-specific recency for GPS approach operations.

Where any discrepancies between this syllabus and Appendix IV of CAO 40.2.1 occur, the Order takes precedence in all matters relating to training for the use of GPS under the IFR.

Part A En-route Navigation using GNSS

System Components and Principles of Operation

Demonstrate an understanding of the GPS system and its principles of operation:

- GPS system components, space, control and user
- Aircraft equipment requirements
- GPS satellite signal and pseudo random code
- Principle of position fixing
- Geocentric altitude
- Method of minimizing receiver clock error
- Minimum satellites required for navigation functions
- Masking function
- Performance limitations of various equipment types
- GNSS use of the WGS84 coordinate system.

Navigation System Performance Requirements

Define the following terms in relation to a navigational system and recall to what extent the GPS system meets the associated requirements:

- Accuracy
- Integrity:
  - Means of providing GNSS integrity
  - RAIM, procedural, systems integration
- Availability
- Continuity

Authorisation and Documentation

- Recall the requirements applicable to pilots and equipment for operations using GNSS.
- Pilot training requirements
- Logbook certification
- Ratings and Endorsements
- Aircraft equipment requirements.
- GNSS NOTAMs.

Errors and Limitations

Recall the cause and magnitude of typical errors:

- Ephemeris
- Clock
- Receiver
- Atmospheric / Ionospheric
- Multipath
- SA
- Typical Total error
- Effect of PDOP/GDOP on position accuracy
- Susceptibility to interference
- Comparison of vertical and horizontal errors
- Tracking accuracy and collision avoidance.

Human Factors and GNSS

Be aware of the human factors limitations associated with the use of GNSS equipment. Apply GNSS operating procedures which provide safeguards against navigational errors and loss of situational awareness because of the following:

- Mode errors
- Data entry errors
- Data validation and checking including independent cross checking procedures
- Automation induced complacency
- Non-standardisation of the human-machine interface
- Human information processing and situational awareness.

Equipment-specific Navigation Procedures

Recall and apply knowledge of appropriate operating procedures to typical navigational tasks using a specific type of GNSS aircraft equipment, including:

- Select appropriate operational modes
- Recall categories of information contained in the navigational database
- Predict RAIM availability
- Enter and check user defined waypoints
- Enter/retrieve and check flight plan data

- Interpret typical GNSS navigational displays Lat/Long, distance and bearing to waypoint, CDI, HSI, ND
- Intercept and maintain GNSS defined tracks
- Determine TMG, GS, ETA, time and distance to WPT, WV in flight
- Indications of waypoint passage
- Use of direct to function
- Use of nearest airport function

GNSS Equipment Checks
For the specific type of aircraft equipment, carry out the following GNSS operational and serviceability checks at appropriate times:

- TSO Status
- Satellites acquired
- RAIM status

PDOP/G6. IFR Operations

- DOP status
- Database currency
- Receiver serviceability
- CDI sensitivity.
- Position indication.

GNSS Warnings and Messages
For the specific type of aircraft GNSS equipment recognize and take appropriate action for warnings and messages, including the following:

- Loss of RAIM
- 2D navigation
- In Dead Reckoning mode
- Database out of date
- Database missing
- GPS fail
- Barometric input fail
- Power /battery fail
- Parallel offset on
- Satellite fail.

Night VFR Operational Requirements
Know the operational requirements that apply to planning a flight on the basis of GPS RNAV capability and, in a given operational situation, correctly state the requirements for:

- Provision of alternate aerodromes
- Determination of lowest safe altitude
- Mandatory carriage of navigation systems

Part B GNSS Approach and Arrival Procedures

Human Factors in GPS Arrival and GPS NPA Operations

Syllabus requirements

Criteria to be met by applicant:

- Be able to describe how the following factors may adversely affect the conduct of a GPS approach and describe suitable pilot procedures to minimise such effects:
  - data input
  - functions selection logic
  - automation effects
  - fixation
  - mode awareness
  - alert modes
  - the control loop
  - situational awareness

Competence to be shown

Applicant to demonstrate:

- That he or she knows operating procedures for GPS equipment which eliminate, as far as possible, errors due to any of the factors specified.
- Methods of RAIM Prediction

Syllabus requirements

Criteria to be satisfied by applicant:

- Know the parameters applicable to RAIM warnings in the en-route, terminal and approach modes.
- Know the effect of availability or otherwise of baro-aiding on RAIM availability and prediction
- Be able to predict RAIM availability at destination and ETA using:
- aircraft GPS receiver; and
- if available, an external RAIM prediction service
- Know the effect of satellite unserviceability on the reliability of each type of prediction
- Know the effect of each type of RAIM prediction on operational requirements.

Competence to be shown

Applicant to demonstrate:

- That he or she can accurately predict, within a period of 1 hour before departure, the availability of approach RAIM at the destination or alternate aerodrome within ± 15 minutes of ETA
- That he or she knows any limitations which apply to the prediction.

GPS Arrival Operational Requirements

Syllabus requirements

Criteria to be met by applicant:

- Know the appropriate alternate requirements and operational procedures that apply to the conduct of a GPS Arrival.
- State the indications requiring a missed approach to be initiated.

Competence to be shown

Applicant to demonstrate:

- That he or she can, in a given operational situation and using a specific type of GNSS aircraft equipment, correctly apply the operational requirements which apply to alternate aerodrome provision, GPS reference points, azimuthal tracking and RAIM availability for GPS Arrival procedures.
- GPS NPA Operational Modes

Syllabus requirements

Criteria to be met by applicant:

- Know the conditions and actions that allow the GPS receiver to function in the appropriate mode for the successful conduct of a GPS NPA. Know the parameters applicable to tracking tolerances, automatic waypoint sequencing, CDI sensitivity and RAIM availability in each of the following segments:
    - entry
    - RAIM availability
    - initial approach
    - intermediate approach
    - final approach
    - missed approach
    - State the indications requiring a missed approach to be initiated.

Competence to be shown

Applicant to demonstrate:

- that he or she can correctly state the mode of operation required during each segment of a GPS NPA, the conditions required to transition to and operate in that mode, and the associated CDI sensitivity and RAIM protection provided.GPS NPA Operational Requirements

Syllabus requirements

Criteria to be met by applicant:

- Know the operational requirements which apply to planning a flight on the basis of conducting a GPS NPA at destination.

Competence to be shown

Applicant to demonstrate:

- That he or she can, in a given operational situation, correctly state the alternate and/or holding requirements which apply at a destination served by a GPS NPA procedure.

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