GNSS

When Charles Kingsford Smith and his crew crossed the Pacific in 1928, they took off from Oakland and had to find Hawaii, 2400 nm away. Then they had to find Fiji, another 3200 nm away. If they flew into cloud and navigator Harry Lyon couldn't use his sextant, they were lost. But these days many pilots are lost even over land unless they can use the navaids in the heavens. Nowadays of course those navaids are not the sun, moon and stars, but a constellation that we've put into space.

Since 2016, all IFR aircraft in Australia have been required to have an approved GNSS. And you're allowed to use any GPS for VFR flight, even your little hand-held one that you stick on your car's dashboard or go prospecting with, as long as it's a supplemental aid and you're looking out the window. Next question: are you allowed to navigate under VFR using GNSS as your primary aid?

Yes you are, and for those of you who wonder where we instructors make this stuff up, here are some of the references:

- A VFR pilot must navigate by visual reference **or** an IFR means (AIP ENR 1.1-4.2.1);
- "IFR means" includes an **approved** area navigation system that meets the performance requirements of the airspace (AIP ENR 1.1-4.1). More on Performance-Based Navigation below;
- An approved GNSS is one that meets the requirements of one of the relevant US FAA Technical Standard Orders (TSO) (CASR Part 91 Manual of Standards – definitions);
- CASR 61.385 says you're allowed to exercise the privileges of your licence as long as you're competent to operate the systems, including the navigation systems, to the standards mentioned in the Part 61 Manual of Standards (MOS);
- In Schedule 2 of the Part 61 MOS, which contains competency standards, Section 3 includes navigation standards. No. 4 in that section includes "underpinning knowledge of basic GNSS principles".

So if it's a TSO-approved (ie. IFR-standard) GNSS, and you're a full bottle on it, you're allowed to use it as your primary means of navigation. Otherwise, your primary navigation instrument is still the one you used in your basic nav training – the front window.

So just in case you were once scared to go outside the training area in case you got lost, but now with GPS you feel invincible, here are some of those underpinning principles.

The constellation

GNSS means Global Navigation Satellite System, and there are a few different ones, including the European Galileo, the Russian GLONASS, and Global Positioning System (GPS), which was developed by the US military. In keeping with the modern need for diversity, equity and inclusion, our regulations refer to GNSS rather than just GPS.

The GPS constellation has about 30 satellites; the number varies as older ones are retired and replaced. It became globally available in 1994, and was initially available for IFR flight as a supplemental enroute aid and a substitute for DME. The satellites are in geosynchronous orbits, meaning they trace constant paths over the earth (as opposed to geostationary satellites, which sit in equatorial orbits over the same point) in six different orbital planes at a height of 20,200 km, and they take just under 12 hours per orbit.

Getting a fix

Each GPS satellite generates a pseudo-random code (a code that looks random but isn't). Your receiver generates the same code as the satellite it's interrogating, it knows what time the satellite generated that code, and because it knows the signal is an electromagnetic wave and therefore travels at the speed of light, it knows how far it is from that satellite. That puts you somewhere on a sphere. With two satellites, you're somewhere on the intersection of two spheres, which is a circle. Three satellites – you're at one of two points on that circle, one of which the system will reject because it's way out in space. But from most places on earth, you're always within range of at least 4 satellites, and that's enough for an accurate position. With five or six satellites in view, the system can identify and potentially eliminate a faulty satellite from the calculation. Also, barometric aiding (input from your altimeter) counts as a satellite.

Some of the errors

Ephemeris errors

This is the difference between the expected and actual position of a satellite. It's typically no more than a few metres.

Clock errors

The satellites' time needs to be extremely accurate, which is why they use atomic clocks. At the speed of light, an error of 1 millisecond in a clock is an error of 150 km. Receivers use quartz crystal clocks, which aren't quite as accurate, but their small errors can be eliminated with enough satellites in view.

Atmospheric errors

The speed of a GPS signal can change as it passes through the atmosphere. The more atmosphere your signal passes through, the greater the error. GPS receivers can generally be set with a masking angle, typically in the order of 10°. A 10° masking angle mean the receiver will ignore any satellites that are lower than 10° above the horizon.

Satellite geometry

If two satellites are too close together, the accuracy of your fix will be degraded. This is the same principle that dictates that a fix from two ground-based navaids must be at least two lines that intersect at no less than 45°. Geometric dilution of precision (GDOP) is a term used to describe this limitation.

Augmentation systems

After GPS became available as a supplementary IFR navigation tool, it was then approved as a primary enroute IFR tool, then it became a tool for non-precision instrument approaches, and eventually it will probably replace ILS as the preferred precision approach, meaning an approach with glidepath information available in the cockpit. All of those enhancements have been based on the required approvals, which in turn have been based on augmentation. Augmentation is any system that improves the accuracy, integrity or availability of GPS without being an inherent part of GPS itself.

- Accuracy – self-explanatory;
- Reliability or availability – ability to get a fix because there are enough satellites in view;
- Integrity – the ability of the system to be honest and tell you its reliability is temporarily in doubt.

A number of different augmentation systems have been developed by both the public and private sectors in different countries.

Some systems provide information about errors, which can then be incorporated into position calculations, but a typical simple view of the process is that is provides corrections to GPS positions. For example, a ground station takes a fix using the satellites in view. It then says, ”Hang on, that’s not right. I haven’t moved since I was installed. I know exactly where I am. I’m 8 metres south of where you’re telling me I am.” It can then send that information to any GPS within range, which will add in the appropriate correction. That’s ground-based augmentation.

Global Differential GPS

GDGPS provides services to users of most GNSS including GPS, GLONASS and Galileo. It was developed by NASA’s Jet Propulsion Laboratory in Pasadena, and employs three operations centres. The system tracks GNSS signals and feeds data to the operations centres, where whizz-bang software takes GNSS orbit and clock data and works out corrections. Accuracy is down to the 10 cm level. This is similar to what I saw in my subsea inspection days. When you identify a fault on a subsea pipeline that may be hundreds of km long, you need to be able to log exactly where it is so someone can find the exact spot later and fix any problems. We could identify the location as, say KP96.552, meaning Kilometre Point 96.552 – a known distance from the starting point. That’s 1 metre accuracy, thanks to Differential GPS.

SouthPAN

The Southern Positioning Augmentation Network (SouthPAN) is a joint initiative of the Australian and NZ governments that provides satellite-based augmentation. It started in 2020 and it includes reference stations, telecommunications infrastructure, and satellites to provide more accurate navigation in Australia, NZ and surrounding maritime areas. SouthPAN provides corrected navigation signals directly from the satellite rather than through a mobile phone, so being in phone range is no longer a limitation, and accuracy is down to 10 cm.

Approaches anywhere

A simple advantage for IFR pilots is how easy it is to design instrument approaches. It’s pretty useful when you’re opening up a new mine up north to be able to get someone to survey the site and design an instrument approach for each runway without having to install a VOR or NDB. This explains the appearance of GNSS approaches at mine sites, as well as at airports in bustling metropolises such as Morawa, Katanning and Manjimup. If a mining company builds an airfield near their camp and gets someone to design a GNSS approach or two, the commute can be a two-hour flight from Perth to site, rather than a two-hour flight to Hedland or Newman and two hours on a bus to site.

And the use of GNSS for enroute navigation explains the disappearance of many aids such as the VOR’s from Ballidu And Jurien, and the NDB’s from Clackline, Pingelly and Narembeen.

Performance Based Navigation

Performance Based Navigation (PBN) is a concept whereby rather than the regulator dictating what equipment you must carry, it dictates performance requirements. Performance in this context is not old-fashioned concepts such as speed and rate of climb and turn radius, but accuracy, integrity and reliability of your navigation system. Part of PBN is airspace and infrastructure-based, and part of it is navigation specifications, which is the bit that pilots care about. A navigation specification is either Area Navigation (RNAV) or Required Navigation Performance (RNP).

RNAV and RNP

Area Navigation (RNAV) is IFR navigation that enables aircraft to fly on routes other than directly between ground-based navaids. It started in the US in the 1960s when aeroplanes were using inertial navigation systems (INS), which only required a ground-based fix every few hours, and it took off with the widespread introduction of GNSS. RNAV specs don't require onboard performance monitoring and alerting to the pilots when the system is not performing accurately enough.

RNP is a set of navigation specifications that requires a higher level of performance, and provided your nav system has that performance, you can navigate, including flying approaches, with a reduced obstacle clearance area. Other than accuracy, the specifications include training and the ability of the system to tell you if it's not performing accurately enough. Old-style ATC was designed to keep you, say, 5 miles away from everyone else, and old-style ground-based navaid approaches were designed to keep you, say, 500 feet above every hill with 3 miles, whereas RNP allows more aircraft in the same airspace, and approaches closer to obstacles without compromising safety. Google some of the videos of approaches to Queenstown in IMC to get an idea of the types of twisting turning approaches that are possible with RNP, that were impossible to publish and fly safely with conventional ground-based aids over that terrain.

Specifications include RNP 2 for enroute, RNP 1 for Standard Instrument Departures (SIDs) and Standard Arrival Routes (STARs), and RNP APCH for non-precision approaches. GNSS approach charts nowadays are titled RNP and not GNSS eg. Katanning RNP Rwy 25.

It's just a navaid

Despite all it can do, GPS is either just a backup aid for a VFR pilot, or an IFR one that you're on top of. So make sure you're a full bottle on it before you get airborne, whether it's entering points, calculating ETI's, or knowing where the CTA and restricted areas are. And of course aviate, navigate, communicate. Don't ever let No. 2 or No. 3 get in the way of No. 1, and don't let your cockpit toys drive you. Keep your head up and eyes outside as much as you can. As stated above, whatever you're flying, and whatever fancy toys you have to help you, the most important instrument is still the front window.