Altitude Measurement – GPS vs Barometric

With the cross-country season shortly upon us again a number of flight traces are going to be lodged on the OLC, and in many cases these will be logged using devices that only measure GPS altitude. Unfortunately this may lead to the impression that airspace has been breached. The following figure indicates such a trace with an apparent infringement of about 400’ at point A over the 8500’ ceiling.

This indicated infringement is not necessarily so. The reason for this is the fundamental difference in the way that GPS and barometric altitudes are measured. This raises the questions of which is the more accurate, and which should you use?

First briefly some clarification in terms. Altitude is elevation above mean sea-level, as set on an altimeter using QNH (set the altimeter to field elevation prior to launch). Height is elevation above a reference level (usually the airfield) such as by setting the altimeter to QFE (set the altimeter to zero feet before launch). The last scheme in use is flight level, this is elevation above mean sea level in hundreds of feet, but set using a standard reference pressure of 1013.2 millibars (mbar or mb) on the altimeter (QNE). It is only used above the transition level, usually between 10,000 and 11,000 feet (FL110) in Australia, but this level varies between countries.

GPS

The System

So what is GPS, how does it work? The Global Navigation Satellite System (GNSS) relies on a number of satellites set in orbits about 25,000km above the surface of the earth. These satellites contain very accurate atomic clocks. They are continuously transmitting a signal which contains both the satellites position and the current time. The GPS receiver also contains a clock (though a very inaccurate, by comparison, quartz one). Simply put the GPS receiver reads the signal from the satellites it can see, finding the time the signal was sent, and the time it was received, and using the speed of light can calculate how far away it was. By reading the signal from 3 satellites it can fix its position relative to the satellite in two dimensions, 4 satellites and it can fix the position in three dimensions, more satellites and it can be a bit more accurate.
**GPS accuracy**

So how accurate is it? There are a number of potential errors (the following in horizontal location).

- The signal from the satellite can be distorted as it it passes through the ionosphere due to the charged particles present – error about ±5m
- The signal path can be distorted by the troposphere due variations in pressure, humidity, temperature etc – ± 0.5m
- Ephemeris errors (deviation of the satellite from the intended path) – ±2½m
- Satellite clock errors, they are good but not that good – ±2m
- Receiver clock and other errors. Though the receiver clock is pretty poor part of the clever bit of the system is that the error can be corrected for by using the satellites atomic clocks – ±4m
- Uncorrected multipath errors (see below) ± 1m

This gives an error of around ±15m in the horizontal plane. When trilaterating horizontally the receiver can use satellites from any direction. When trilaterating for elevation it can only use satellites above it, this increases the error two to threefold for altimetry, so ±30-45m

If the satellites used for location are well spread then the accuracy will be greater, if they are all in the same area then less accurate. As the receiver knows where the satellites are it can estimate the reliability of the position, this is often presented to the user (the term is GDOP – Geometric Dilution of Precision)

Occasionally a receiver will not receive the satellite signal directly, but reflected off a nearby object or terrain. This can lead to wildly inaccurate reading, but generally obvious by their sporadic nature and improbability, appropriate filtering in the device will take care of these.

There is one last potential source of significant error worth mentioning, though it should not be a problem. As we have seen the GPS measures elevation below the orbit of the satellites, to convert this to altitude it subtracts the distance from the centre of the earth (i.e. centre of the satellites orbits) from mean sea level. Measuring this however introduces some problems. The earth is not a sphere but rather a flattened sphere, an ellipsoid. This can be represented mathematically in a number of ways but the standard used for GPS is usually that defined as WGS84. The GPS may report altitude relative to this.

A further anomaly arises in that the earth’s mass is not evenly distributed, hence the earths gravitational pull, and hence sea level varies across the globe, the so called geoid. In Australia this can result in variations in sea-level of -32m (around Perth) to +78m (Cape York). Around Melbourne the level is +5m. Most GPS units have a table of geoid corrections and report altitude based on this correction.

So taking all this into account does this explain the infringement in the trace above. With a maximum error of around 165’ (Melbourne geoid and the errors above) this falls short in explaining the error of 400’.

---

**Barometric altitude**

**Definition**

Barometric altimetry uses the decrease in pressure with height to calculate altitude. An altimeter is simply a sensitive barometer calibrated in feet. To convert between the two units certain basic assumptions are made. Surface temperature is 15°C, pressure 1013.25mb, and the
temperature lapse rate with height about 2°C/1000', all defined as the standard atmosphere. If these conditions are met then the device is reasonably accurate.

**Potential Errors**

15°C at the surface is not generally associated with wonderful cross-country soaring conditions, at least at Bacchus Marsh. You may remember a few of the gas laws, the relevant ones in this case are Boyle's Law; pressure in inversely proportional to volume and Charle's Law; pressure is proportional to temperature. Combining these we end up with with the ideal gas law PV=kT.

Going back to our opening trace the pressure at 8500' in the standard atmosphere is 738mb, a pressure drop of 275mb from the surface, then this pressure will be calibrated as 8,500' on the altimeter. According to the above If we have a surface temp of 28°C (the predicted for the day) then at our constant pressure drop of 275mbar, the column of air we are in will have to have expanded \((273+28) \div (273+15) \times 8500\) (temperatures are in Kelvin hence add 273) to have the same pressure drop. Working out the maths this indicates 8884'! Remember though the altimeter is only indicating 8,500', the GPS will be indicating nearly 8900'. No wonder the trace on the OLC is indicating an infringement.

If the temperature is higher again then so is the error, over 8% at 40°C. That is why there is a 1000’ high transition layer from QNH at 10,000’. On a hot day your actual altitude may be 10,800’ when you switch to 1013mb on the subscale.

While this is a significant source of apparent errors it is not the only ones. You will remember that the lapse rate on the standard atmosphere is 2°C/1000’. The lapse rate in a thermal is 3°C/1000’, at least if you remain below cloudbase. The standard atmosphere also assumes a linear drop in temperature with height, the soundings issued by the BOM indicate that is never the case.

Another factor is to consider is the error induced by cockpit pressure (if the altimeter is not plumbed) or static errors. Typically these are around 50’ on a typical installation.

**Conclusions**

Going back to our original trace if we actually have a look at the barometric trace we can confirm that the flight did not infringe at the point in question.

This also indicate the general tendency for the GPS to indicate a greater altitude than the barometric altimeter, at least in the atmospheric conditions on the day.

So which is the more accurate. Well GPS certainly seems to be more accurate in determining geometric altitude in varied conditions. This however overlooks the fact that airspace is defined in terms of barometric altitudes, and the errors it introduces are just part of that definition, and allowed for. There are however proposals before the FAI to define badge and record altitude parameters in terms of GPS altitudes, so I guess it is watch this space.

Geelong Training Panel,  
August 12