Appendix – Air Traffic Surveillance Primer

Originally part of my COSC3000 Project submission, I separated it to a reference as is primarily background information.

For Enroute Aircraft, aircraft surveillance is typically from two sources :

Nomenclature

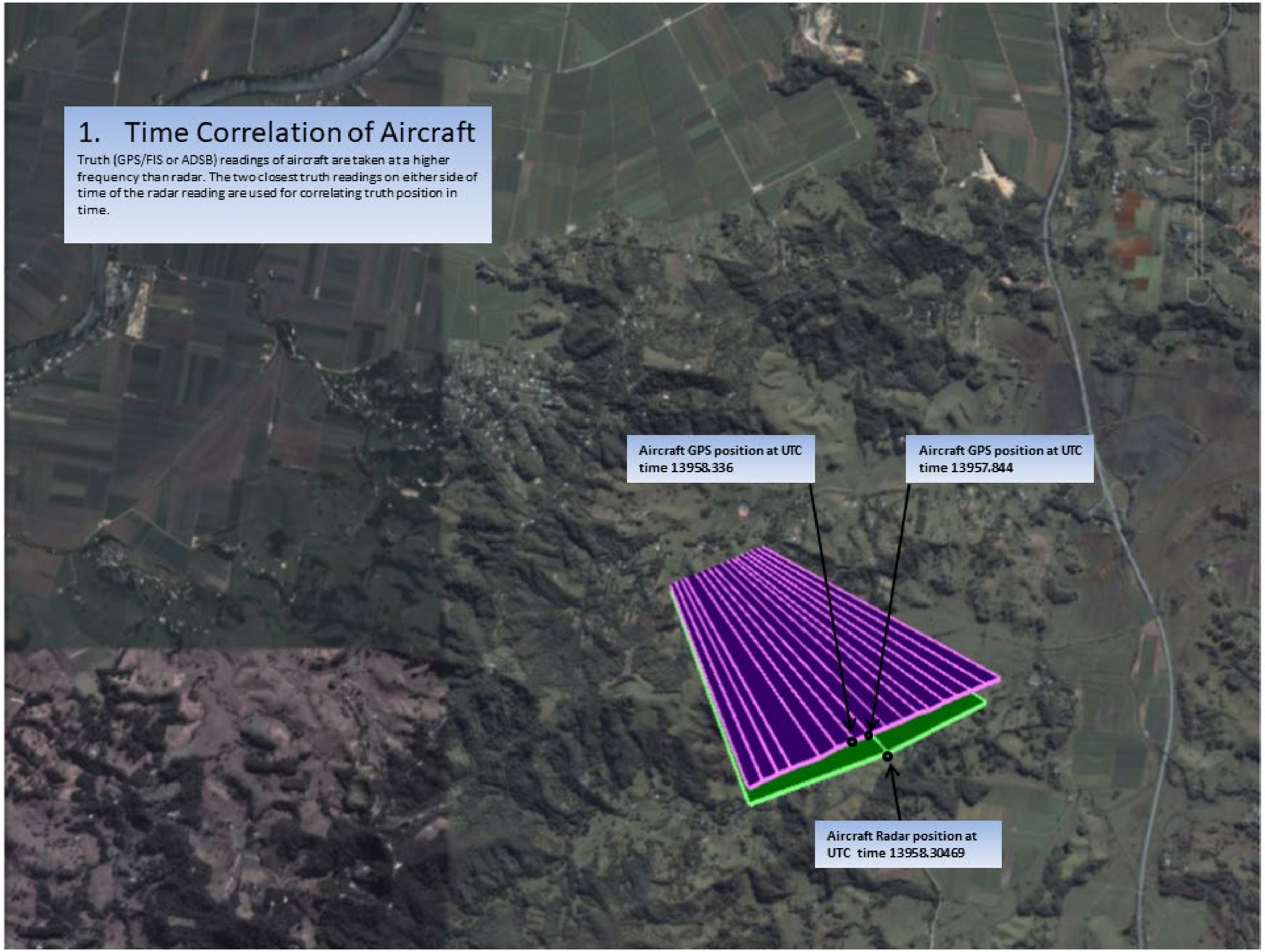
Aircraft use several different identifications in flight, such as

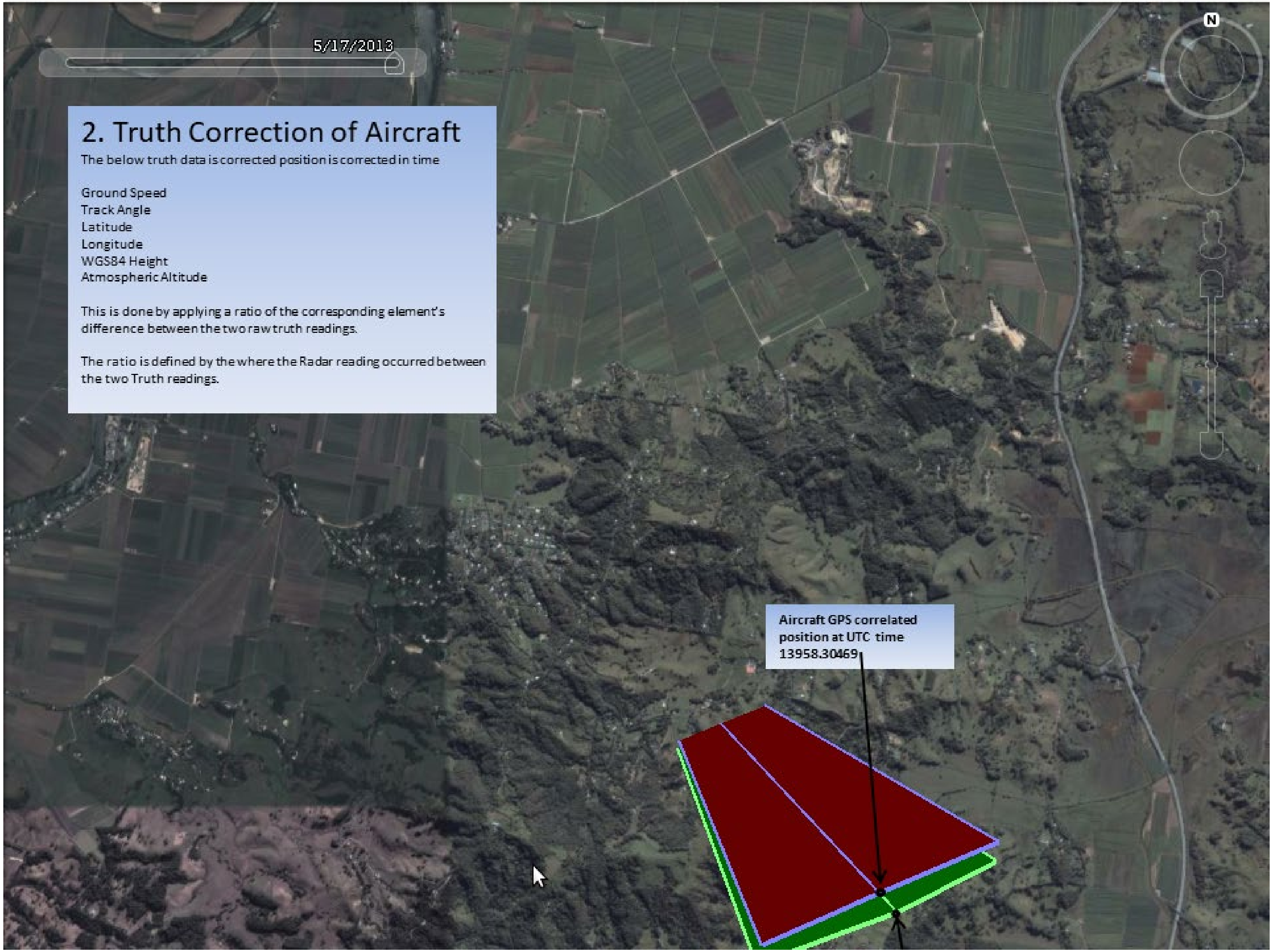
- **Mode S Address** – this is a 6 digit Hexademical code, this is hard wired to the airframe and unique for every aircraft
- **Mode A Address** – this is a 4 digit octal code, used by the older transponders, still valid, but can change during flight, and not necessarily unique (some codes are shared codes, used by multiple aircraft simultaneously – hard to programmatically separate reports)
- **Callsign** – This is a 8 alphanumeric code, usually designated for the route it is flying – but not always – typically changes between flights.
- **Registration** – This is more used in general aviation for Tail Identification on ground, it is used for logistics, regulation and business activities. Not usually used in flight operations.

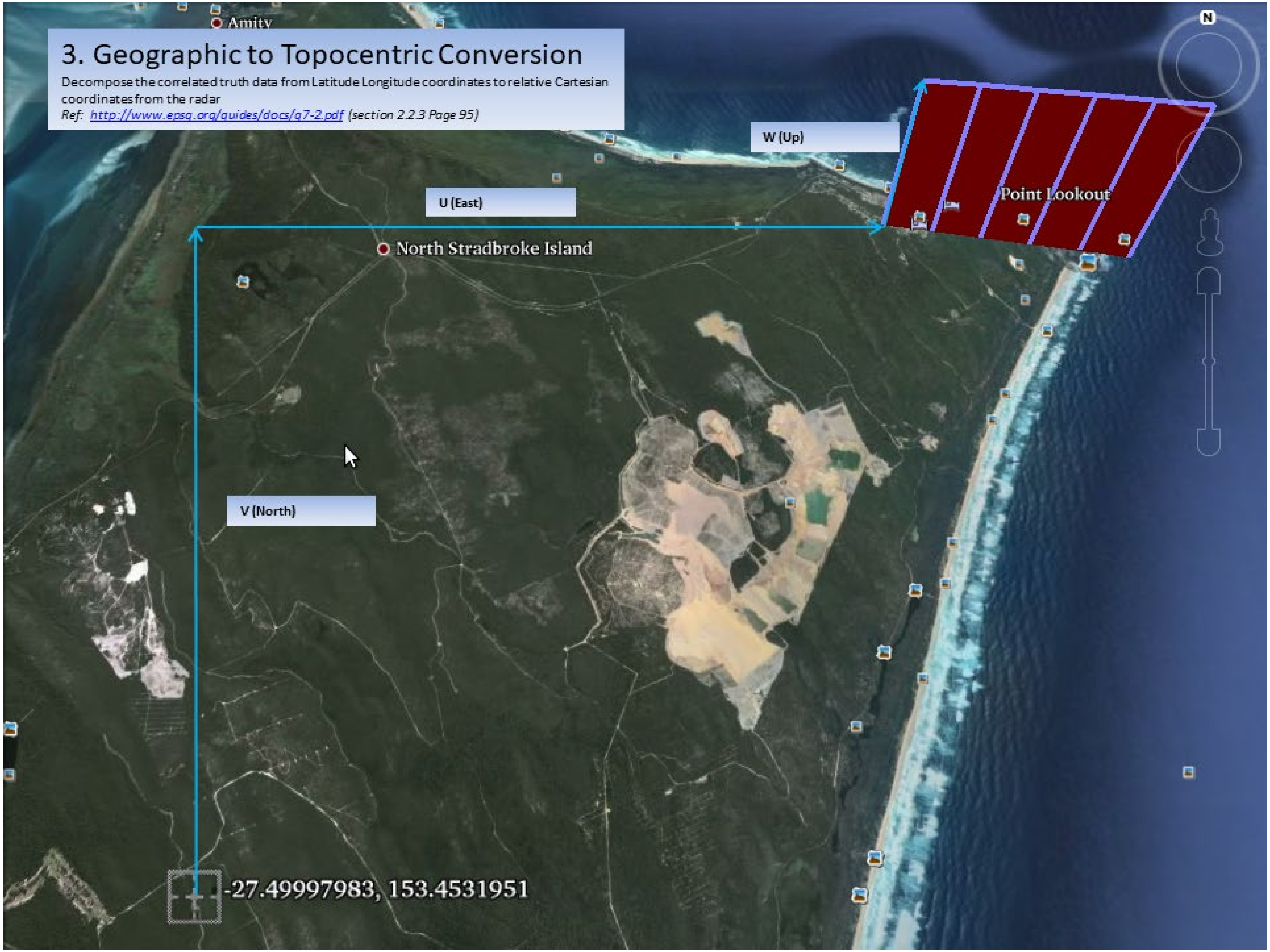
- Automatic Dependent Surveillance – Broadcast (or ADS-B) where the aircraft transmits (or 'squits') its GPS position and Identification (among other optional data) as digital packets (56 and 112 bits) on 1090 Mhz. This is a more modern form of surveillance and being digital in format, any errors or corrupt packets can be easily identified and discarded. Hence this method is not dependent upon the transport medium for direct positional measurements.
- Mode S Radar – This is a selective mode of interrogating aircraft, and minimises cross talk and garbling issues with the older Mode A Radar. The aircraft slant range is calculated by measuring the time delay of that aircraft's transponder to reply to an interrogation. This time delay is converted to distance by an average speed of light measurement (C/2) through a model of the atmosphere. This estimate So there is a physical relationship between the atmosphere and the measurement of position. This means there is a relationship between the characteristics of the atmosphere and the error of position calculated by the Radar.

    - Note another form of surveillance, Primary Radar, for non-compliant aircraft that have no transponder, or ADS-B system, is only used around landing and departure at airports. As such the range will be very close, so this error will be negligible.

Appendix – Range Range Error Calculation

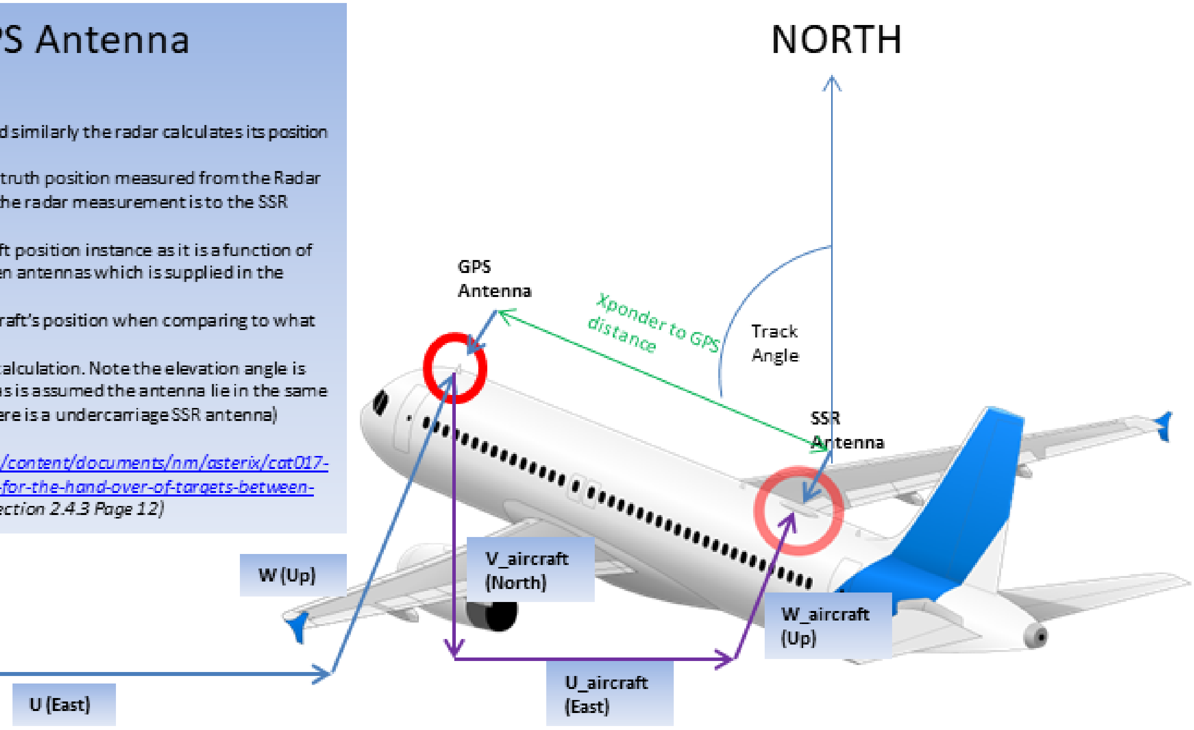


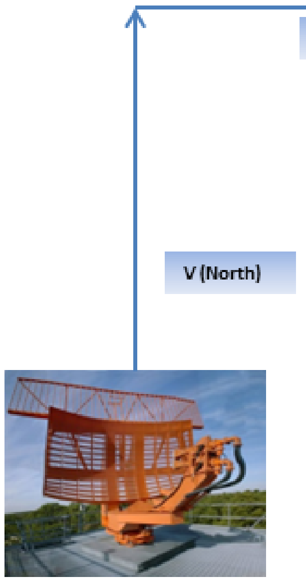

5/17/2013
2. Truth Correction of Aircraft
The below truth data is corrected position is corrected in time
Ground Speed
Track Angle
Latitude
Longitude
WGS84 Height
Atmospheric Altitude
This is done by applying a ratio of the corresponding element's difference between the two raw truth readings.
The ratio is defined by the where the Radar reading occurred between the two Truth readings.
Aircraft GPS correlated position at UTC time 13958.30469
N


3. Geographic to Topocentric Conversion
Decompose the correlated truth data from Latitude Longitude coordinates to relative Cartesian coordinates from the radar
Ref: http://www.epsg.org/guides/docs/g7-2.pdf (section 2.2.3 Page 95)
Amity
W (Up)
U (East)
Point Lookout
North Stradbroke Island
V (North)
-27.49997983, 153.4531951
N

4. Transponder to GPS Antenna Correction

The GPS resolves its position at its antenna and similarly the radar calculates its position from its transponder antenna.
The coordinate transform done in (3) is of the truth position measured from the Radar to the GPS antenna on the aircraft. However the radar measurement is to the SSR antenna.
This relative offset is calculated at each aircraft position instance as it is a function of the aircraft's track angle (and distance between antennas which is supplied in the vortex.cfg file).
And is later applied as a translation to the aircraft's position when comparing to what the radar measured.
This is a simple Polar to Cartesian coordinate calculation. Note the elevation angle is taken as zero (giving a W_aircraft zero value) as is assumed the antenna lie in the same plane (Note some small error may occur as there is a undercarriage SSR antenna)
Ref:
http://www.eurocontrol.int/sites/default/files/content/documents/nm/asterix/cat017-asterix-coordinate-transformation-algorithms-for-the-hand-over-of-targets-between-poems-interrogators-part-5-appendix-a.pdf *(section 2.4.3 Page 12)*





5. Latency Component Calculation

For ADSB measurements there is a time lag between the GPS receiver fix on the aircraft and the timestamp of that position at the ADSB receiver. This lag corresponds to a change in aircraft position. (For FIS and GPS calculations the latency is set to zero, resulting in all these components as zero.)

The position correction by latency is calculated as another Polar to Cartesian coordinate offset, where the distance component is the Aircraft's Ground Speed multiplied by the latency time lag, and the azimuth component is the Track Angle (and again Elevation angle is taken as zero) This could be extended later by including this as the climb/descent rate multiplied by the latency.

Ref:
http://www.eurocontrol.int/sites/default/files/content/documents/nm/asterix/cat017-asterix-coordinate-transformation-algorithms-for-the-hand-over-of-targets-between-poems-interrogators-part-5-appendix-a.pdf *(section 2.4.3 Page 12)*
http://fmamwww/nas/surv/general/guide/surv-guide-0001/surv-guide-0001.pdf
(Section 9, Page 21)

6. Aircraft Adjusted Truth Position converted to Range, Elevation and Azimuth

All cartesian components that represent the corrected truth position that is time correlated, antenna corrected and latency corrected (U, U_aircraft, U_latency etc) are added.

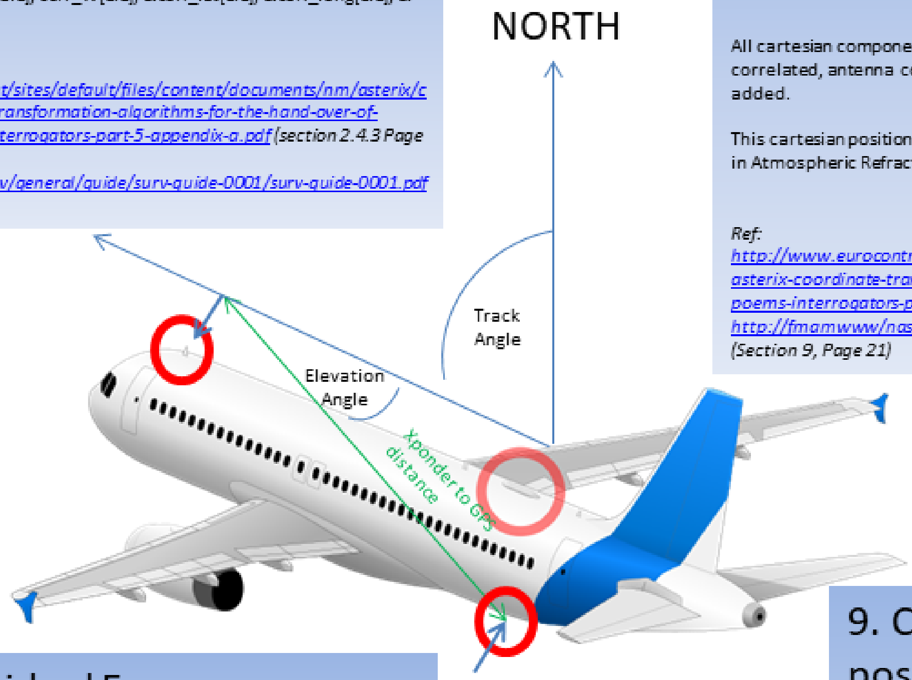
This cartesian position is then converted to polar coordinates for the purpose of using in Atmospheric Refraction Modelling

Ref:
http://www.eurocontrol.int/sites/default/files/content/documents/nm/asterix/cat017-asterix-coordinate-transformation-algorithms-for-the-hand-over-of-targets-between-poems-interrogators-part-5-appendix-a.pdf (section 2.4.3 Page 12)
http://fmamwww/nas/surv/general/guide/surv-guide-0001/surv-guide-0001.pdf
(Section 9, Page 21)

7. Calculate Range Error

Cartesian2Geodetic(Lpo[lpo_used].lat, Lpo[lpo_used].lon, Lpo[lpo_used].ssr_h_zero, corr_U[ele], corr_V[ele], corr_W[ele], &corr_lat[ele], &corr_long[ele], &corr_height[ele]);

Ref:
http://www.eurocontrol.int/sites/default/files/content/documents/nm/asterix/cat017-asterix-coordinate-transformation-algorithms-for-the-hand-over-of-targets-between-poems-interrogators-part-5-appendix-a.pdf (section 2.4.3 Page 12)
http://fmamwww/nas/surv/general/guide/surv-guide-0001/surv-guide-0001.pdf
(Section 9, Page 21)



8. Calculate Residual Error

This is used for ADSB latency calculations. Done over many iterations, the residual error is calculated at differing latency values. Statistics done on the residual error will determine the exact latency value.

For each population of residual errors at a given latency, the standard deviation is taken. The smallest standard deviation over the population of latency values, gives the latency value.

Ref:
http://www.eurocontrol.int/sites/default/files/content/documents/nm/asterix/cat017-asterix-coordinate-transformation-algorithms-for-the-hand-over-of-targets-between-poems-interrogators-part-5-appendix-a.pdf (section 2.4.3 Page 12)
http://fmamwww/nas/surv/general/guide/surv-guide-0001/surv-guide-0001.pdf
(Section 9, Page 21)

9. Convert Cartesian Truth position to Latitude & Longitude

Cartesian2Geodetic(Lpo[lpo_used].lat, Lpo[lpo_used].lon, Lpo[lpo_used].ssr_h_zero, corr_U[ele], corr_V[ele], corr_W[ele], &corr_lat[ele], &corr_long[ele], &corr_height[ele]);

Ref:
http://www.eurocontrol.int/sites/default/files/content/documents/nm/asterix/cat017-asterix-coordinate-transformation-algorithms-for-the-hand-over-of-targets-between-poems-interrogators-part-5-appendix-a.pdf (section 2.4.3 Page 12)
http://fmamwww/nas/surv/general/guide/surv-guide-0001/surv-guide-0001.pdf (Section 9, Page 21)

Radar Calibration Process

When Radars are commissioned for use, a range of tests are performed to ensure accuracy. One test is flight trials where a specially equipped aircraft is chartered to fly orbits and overhead passes of the Radar to verify alignment. This is quite expensive to do and is not done again unless the Radar is taken out of service.

A similar ongoing alignment verification activity can be performed during normal operations. That is the comparison of aircraft's Mode S Radar and ADS-B Reports. This is performed daily on all Radars country wide, and for this project I am utilising the last 12 months of this data.

Here we treat ADS-B data as truth data and compare to the Radar reported position, from which the Radar error is calculated. This process is detailed in the Appendix

These aircraft tracks will not, or very unlikely to fly the optimal path for the commissioning tests, which is a specific geometry around the Radar. So while not optimal for error measurements, it is still valid measuring especially for obtaining long term trends, and for statistical comparison, such as here.

Figure 1 Indra MSSR Radar type used in this analysis