Satellite Navigation

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Objectives & Agenda

Objectives

- Understand the origins of satellite navigation
- Understand the fundamentals how satellite navigation works
- Appreciate the differences between satellite navigation systems
- Get some tips on practical Satellite Navigation use for the Private Pilot
- Understand the risks and limitations of Satellite Navigation

Agenda

- Brief history of navigation
- Overview of Satellite Navigation
- How SatNav works
- Enhancements to basic SatNav
- How we use SatNav in aviation
- Satellite Navigation Options for the PPL
- Risks and Limitations
- Future of Satellite Navigation
- Questions

History of Navigation

First references to celestial navigation

John Bird invents the Sextant

First Radio Beacon

First SatNav system TRANSAT

750 BC

6th C BC

1757

1906

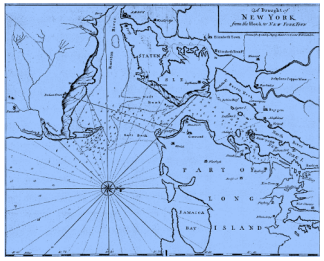
1921

1942

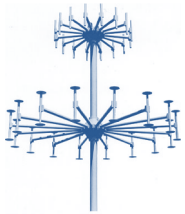
1962

1978

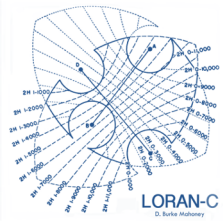
First nautical charts



First Radio DF



First LORAN system

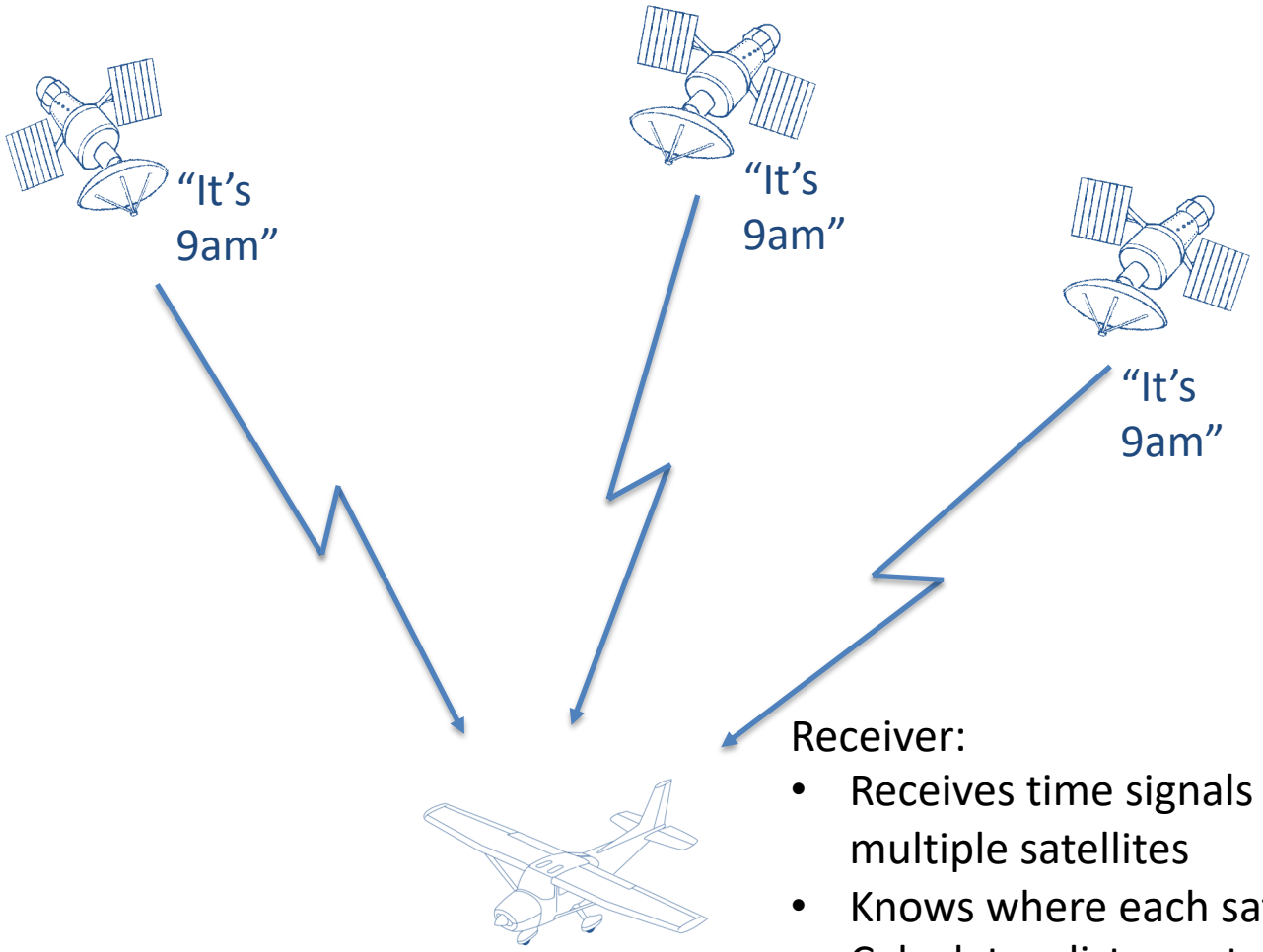


GPS NAVSTAR goes live

Overview of Satellite Navigation

- “GPS” is actually a name for the US NAVSTAR system
- There are at least 6 different Satellite Navigation systems, operated by different countries
- Most receivers today use at least the US GPS system and the Russian GLONASS system
- Collectively in aviation we use the term GNSS (Global Navigation Satellite System)
- GPS Satellites cost around $500m to build and $300m to launch (each)
  - Most systems have 24-30 satellites…

How it works



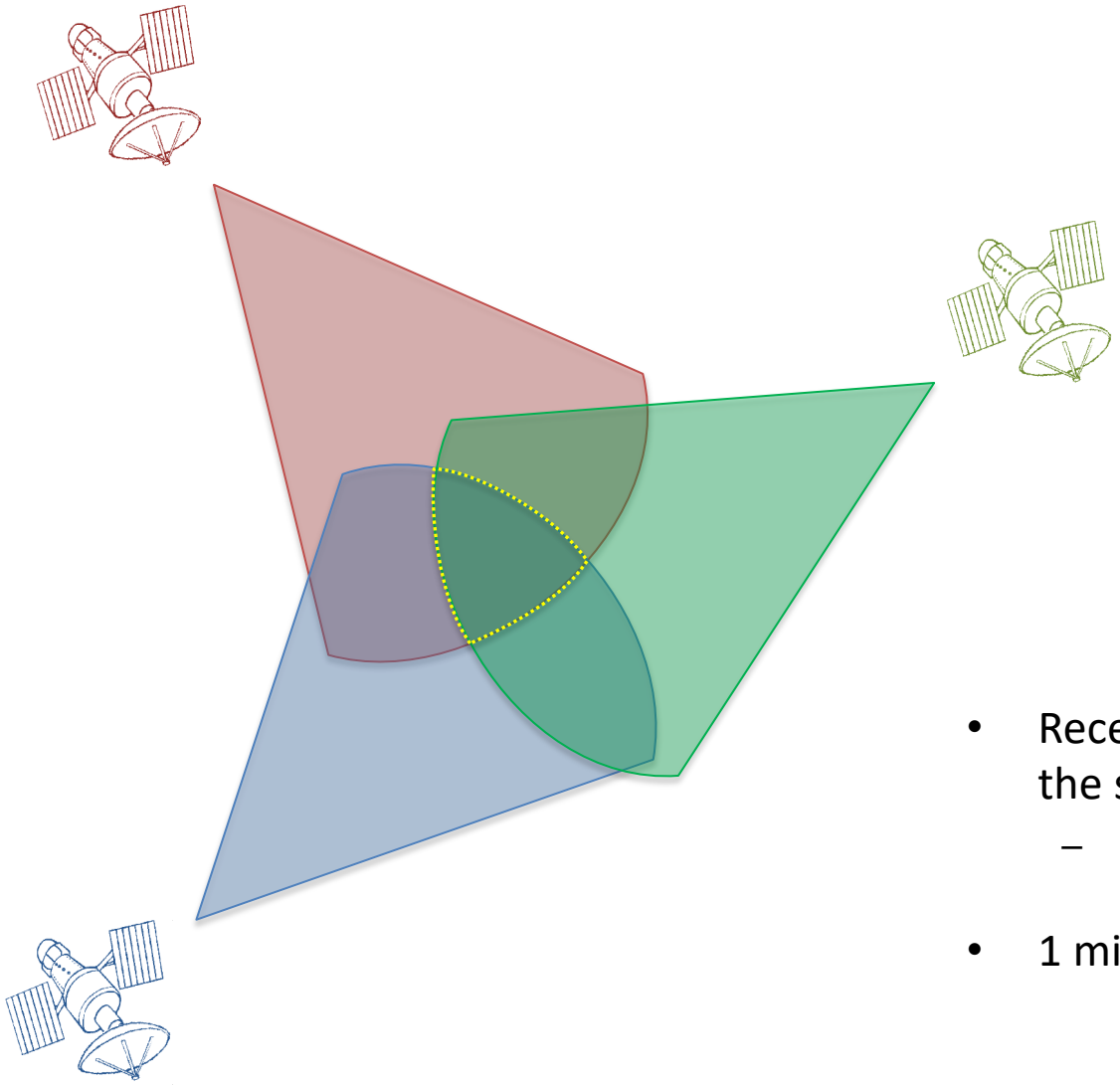
Satellite:

- Very accurate clock
- Controlled by base stations
- Sends the time

Receiver:

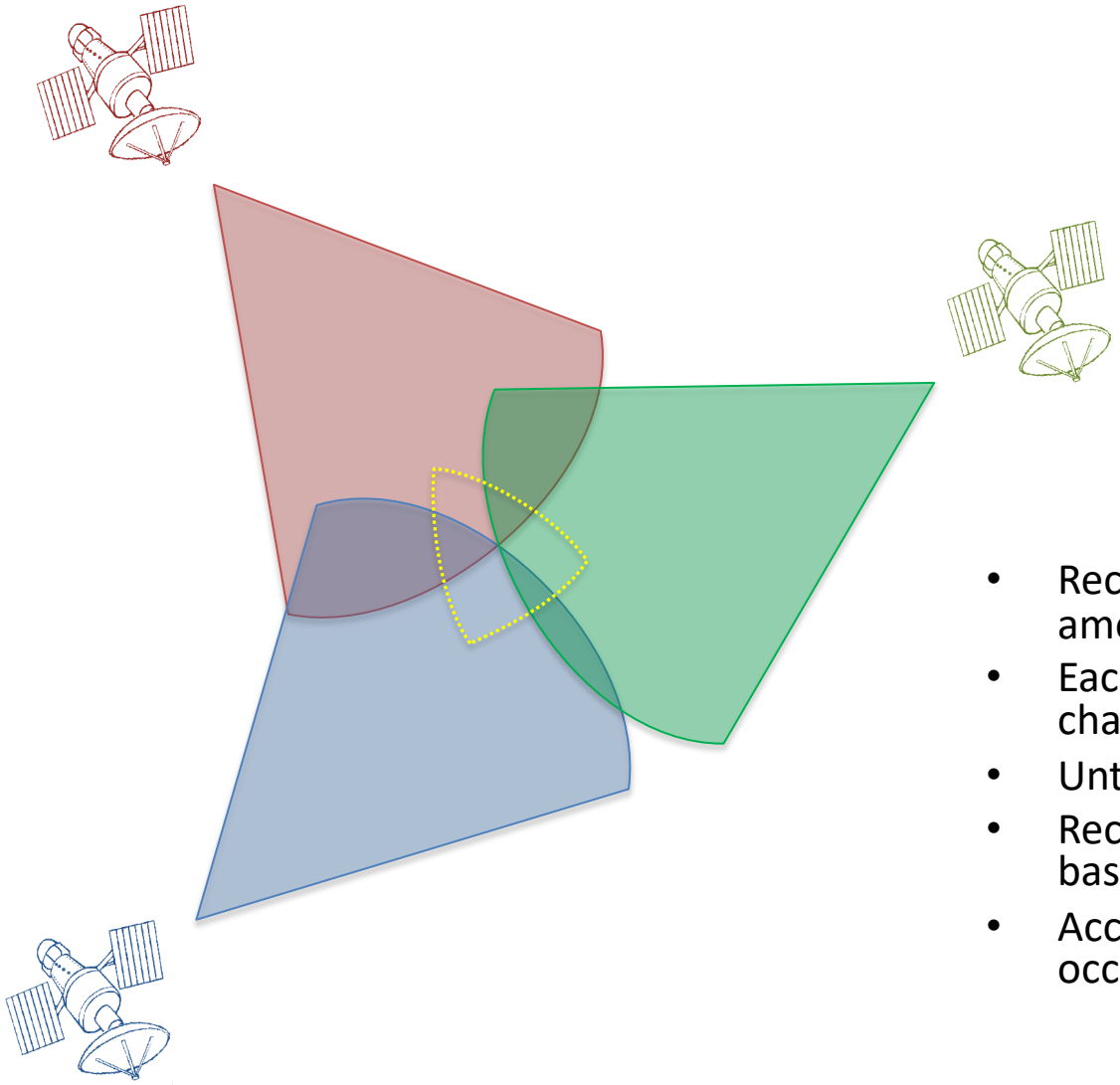
- Receives time signals from multiple satellites
- Knows where each satellite is
- Calculates distance to each satellite based on time delay

If only it was that simple…Pseudo Ranging



- Receiver has a less accurate clock than the satellite
  - So it needs to iterate its clock to find a position
- 1 millionth of a second = 300m range!

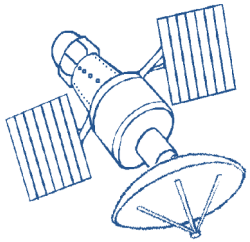
Pseudo Ranging



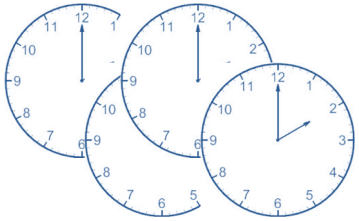
- Receiver clock adjusts itself by a tiny amount
- Each calculated satellite range distance changes by a fixed amount
- Until the ranges intersect at one point
- Receiver gives Lat, Lon, and altitude based on WGS84 datum
- Accuracy is +/- 13 metres on 95% of occasions

Note 3 satellites shown for clarity. 3D fix requires 4

Lots of information is actually sent and received



4 Atomic clocks



L1 1,575.42 MHz

PRN message

- Sat ID + Time
- C/A Code (SPS)
- P Code (PPS)

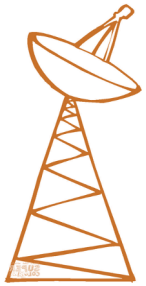
NAV Message

- 12.5 mins total
- Satellite clock correction
- Satellite position & status
- UTC corrections
- Ionospheric delays

L2 1,227.6 MHz

PRN message

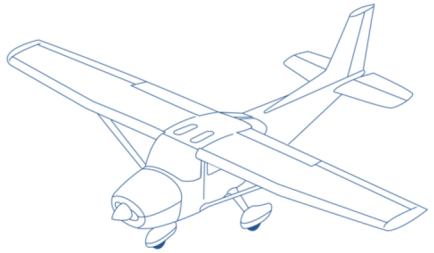
- P Code Only



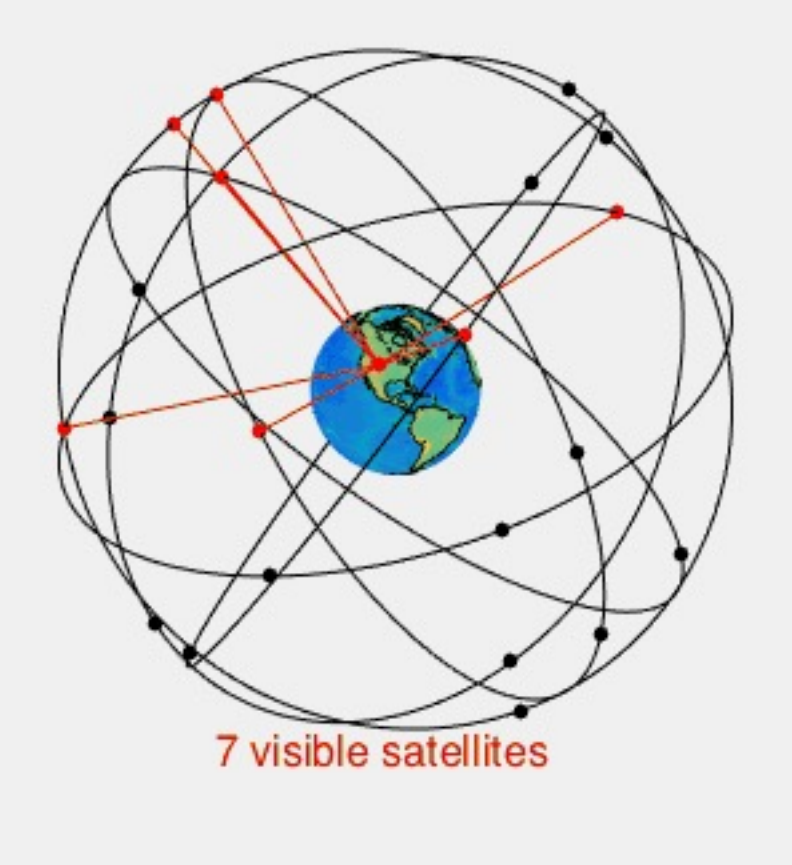
Master Control Stations

"Control segment"

- Clock corrections
- Navigation data



Visibility of Satellites – up to 6 visible are needed



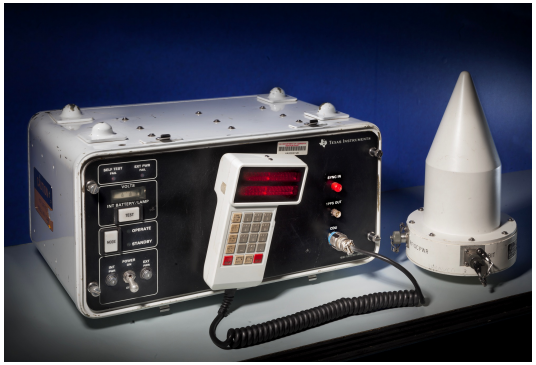
- GPS has 24 satellites (plus some spares)
- Orbit at 20,200km
- 6 orbital planes

Risks / Degradation / Errors / Limitations

- Ephemeris error
  - Satellite in the wrong place
  - +/- 0.5m
- Atmospheric / Ionospheric error
  - Civilian receivers have a model of the ionosphere on board
    - Gets to +/- 5m accuracy
  - Military ones use both frequencies to compute an error correction
- Instrument error
  - Noise, computation error
  - +/- 1m
- Multipath signals
  - Bouncing off terrain etc
  - +/- 0.5m
- DOP / Fixing error
  - Satellites close together give a low “angle of cut”
- Interference / Jamming
  - Signal is like a 20w lightbulb 15000 miles away

NOTAM INFO: NAV (CHLK GPS 16-08) GPS (INCLUDING WAAS, GBAS, AND ADSB) MAY NOT BE AVBL WI A **476NM RADIUS** CENTERED AT 360822N1173846W (BTY 214059) FL400-UNL DECREASING IN AREA WITH A DECREASE IN ALT DEFINED AS:
432NM RADIUS AT FL250
375NM RADIUS AT 10000FT
340NM RADIUS AT 4000FT AGL
253NM RADIUS AT 50FT AGL

Receivers



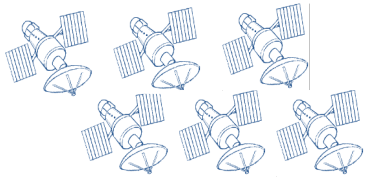
1981
TI-4100 Navigator
24kgs
$140,000
4 channel receiver

1989
Magellan GPS Nav 1000
First handheld
$3,000
Single channel receiver

2017
ORG1411
$20
Receiver and antenna in one
48 channel receiver
WAAS support

Augmentation

- ”Raw” GNSS signals are good but not good enough for precision approaches for example
- There are a number of ways to enhance the signals:
- Redundancy
  - Use multiple systems (e.g. GPS and GLONASS)
  - RAIM Receiver Autonomous Integrity Monitoring
  - AAIM Aircraft Autonomous Integrity Monitoring (big aircraft really)



- Differential information
  - GBAS Ground Based Augmentation System – potential for Cat III approaches
  - SBAS Satellite Based Augmentation System – Cat 1 approaches
    - WAAS in US, EGNOS in Europe

Wide Area Augmentation System
WAAS

EGNOS

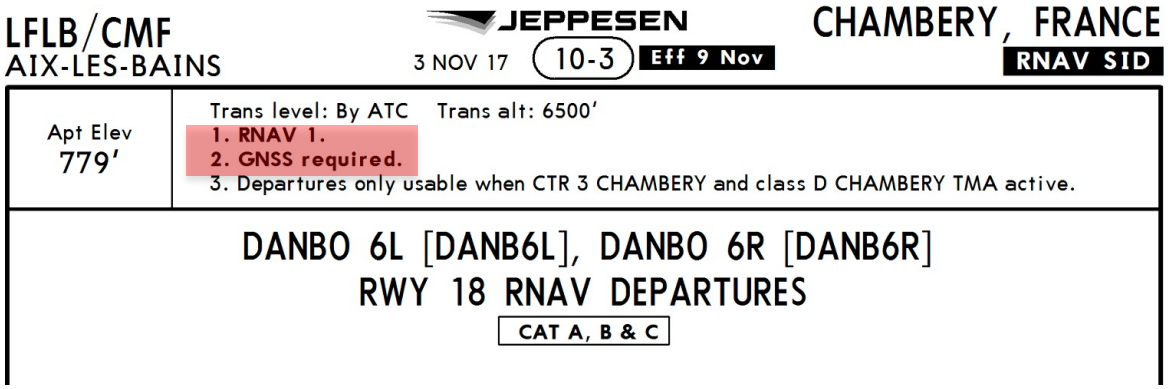
How we use GNSS in Aviation

- As a PPL you don't have to use Satellite Navigation at all
  - VFR flying is based Dead Reckoning with ground features and maps
  - But it is very effective as a backup, especially navigating around complex airspace

- But satellite based navigation is becoming increasingly used, especially in IFR flying

- PBN (Performance Based Navigation) is the "new" ICAO standard for Area Navigation for ATS routes, Instrument Approaches or in designated airspace

- RNAV and RNP are the performance specifications under PBN which basically define accuracy of flight required
  - Some of the RNP standards require Satellite Navigation (e.g RNP4, RNP2, RNP1)



LFLB/CMF
AIX-LES-BAINS

JEPPESEN
3 NOV 17 (10-3) Eff 9 Nov

CHAMBERY, FRANCE
RNAV SID

Apt Elev 779′	Trans level: By ATC Trans alt: 6500′ 1. RNAV 1. 2. GNSS required. 3. Departures only usable when CTR 3 CHAMBERY and class D CHAMBERY TMA active.

DANBO 6L [DANB6L], DANBO 6R [DANB6R]
RWY 18 RNAV DEPARTURES
CAT A, B & C

GPS options for the PPL - Hardware

Certified, installed GPS

- Equipment and installation is certified
- RAIM equipped
- SBAS: WAAS versions (<1.25m accuracy)
- 15 channel receiver
- Receiver and display in one
- Basic mapping included
- Updateable Navdata includes aviation waypoints

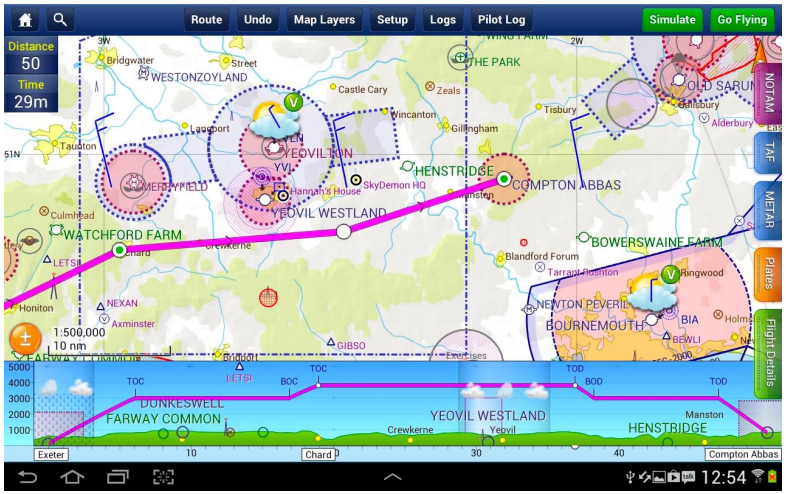
Bluetooth GPS

- Connects to Ipad / Tablet
- SBAS: WAAS / EGNOS
- 66 channel receiver

IPAD / Tablet Built In

- No extra kit (batteries)
- But may struggle with reception
- Often not SBAS

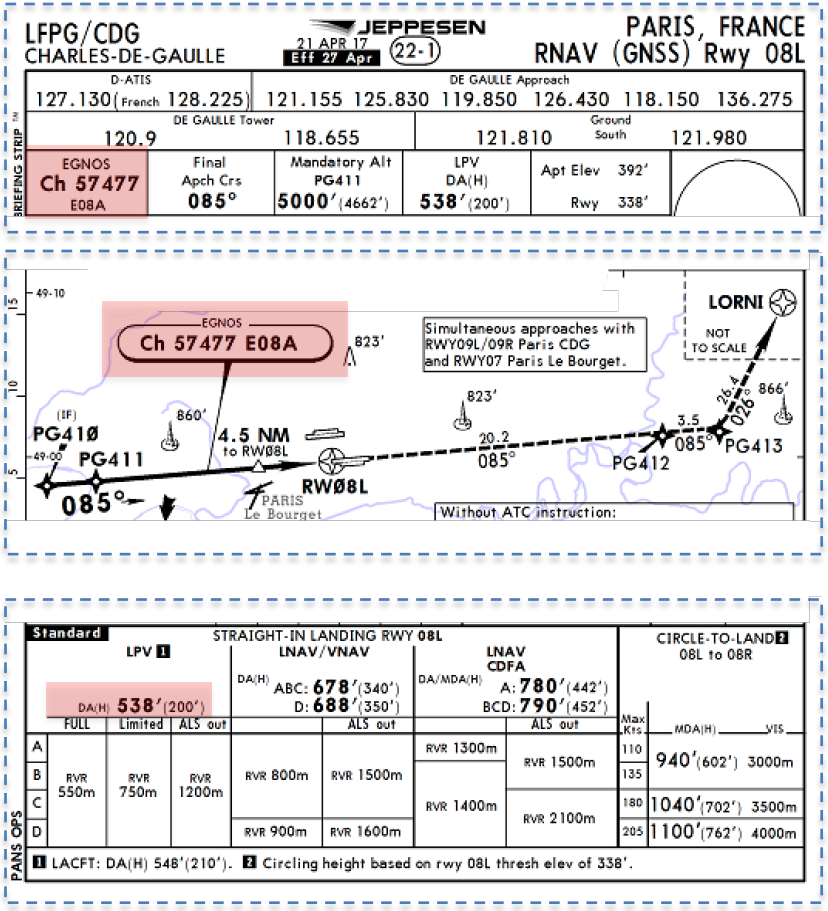
GPS options for the PPL – Tablet Applications



- Skydemon and RunwayHD are two of the market leaders
- Both offer lots of functionality
  - Vector airspace built in giving airspace warnings
  - Moving map display (Vector only for Skydemon, Raster / CAA maps for RunwayHD)
  - Graphical NOTAMs
  - Vertical profile (ADVISORY not accurate!!)
  - Flight planning and flight plan filing
  - Live PLOGing
  - Airfield plates
  - Terminal and En Route weather
  - Can be used on multiple devices e.g ipad and phone for backup
- Costs
  - Skydemon £89/year
  - RunwayHD £99/year (including CAA 500k maps)
  - Tablet ~£250

Future of GNSS

- Multiple systems
  - European Galileo half complete
  - Chinese system has 22 satellites
- Better technology
  - GPS III
    - Higher power
    - New signals & frequencies
    - Distress and Alerting system
    - Satellite to satellite cross links
    - Spot beams for military anti jamming
- More augmentation for approaches
  - GBAS being developed for Cat III approaches
- Cheaper devices for aviation
  - Handheld
  - Integrated
    - Synthetic vision



Advice on GNSS use for the private pilot

- Retain situational and positional awareness using a map and plog
  - CAA: **“GPS must not be relied upon as a sole navigation reference in flight-critical applications”**
- Understand and train on the capabilities and limitations of the equipment
  - Check databases are current
  - Cross check route and user waypoints with PLOG
- Don’t fix the device so that it gets in the way of piloting
- Learn how to do a RAIM check on certified equipment
- Check NOTAMS for GPS outages / jamming trials
- Look out for HIRTAS

- Backups: spare batteries, charging cables, multiple devices

Questions?

GNSS Systems

System	BeiDou	Galileo	GLONASS	GPS	NAVIC	QZSS
Owner	China	EU	Russia	United States	India	Japan
Coverage	Regional (Global by 2020)	Global	Global	Global	Regional	Regional
Orbital altitude	21,150 km	23,222 km	19,130 km	20,180 km	36,000 km	32,000 km
Period	12.63 h	14.08 h	11.26 h	11.97 h	1436.0m	
Number of satellites	5 geostationary orbit (GEO) satellites, 30 medium Earth orbit (MEO) satellites	24 by design, 14 operational, 4 commissioning,	**28** (at least 24 by design) including:[16] 24 operational	**31** (at least 24 by design)[17]	3 geostationary orbit (GEO) satellites, 5 geosynchronous (GSO) medium Earth orbit (MEO) satellites	7-satellite constellation in the future
Frequency	1.561098 GHz (B1) 1.589742 GHz (B1-2) 1.20714 GHz (B2) 1.26852 GHz (B3)	1.164–1.215 GHz (E5a and E5b) 1.260–1.300 GHz (E6) 1.559–1.592 GHz (E2-L1-E11)	Around 1.602 GHz (SP) Around 1.246 GHz (SP)	1.57542 GHz (L1 signal) 1.2276 GHz (L2 signal)	1176.45 MHz(L5 Band) 2492.028 MHz (S Band)	
Status	22 satellites operational, 40 additional satellites 2016-2020	18 satellites operational 12 additional satellites 2017-2020	Operational	Operational	6 satellites fully operational, IRNSS-1A partially operational	
Precision	10m (Public) 0.1m (Encrypted)	1m (Public) 0.01m (Encrypted)	4.5m – 7.4m	15m (Without DGPS or WAAS)	10m (Public) 0.1m (Encrypted)	1m (Public) 0.1m (Encrypted)

RAIM check

- You can check RAIM
  - On a RAIM prediciton website
  - On the equipment itself

- Why might RAIM fail
  - Insufficient satellites
  - Poor geometry

Note: doesn't mean the position is inaccurate, just means its accuracy cant be assured

- WAAS does not use RAIM

Garmin 430

- EPE = Estimated position error (horizontal position error in ft / m)
- DOP = Dilution of precision (scale of 1 best to 10 worst)
- HUL = Horizontal uncertainty level (99% confidence limit)

Errors – What does a 430 show. 430 RAIM page

- Is it free to use?
- How come you can use it?
- Doppler for speed?