Outline

• GNSS Theory
• GPS Segments
• GPS Position Determination
• GPS Receiver
• RAIM & FDE
• SBAS
• SBAS Coverage and Service Area
GNSS & GNSS Augmentation Systems

GNSS CORE CONSTELLATIONS
GNSS

• GNSS includes core satellite constellations such as:
  – GPS, GLONASS, Galileo, Compass (BeiDou)

• Core constellations have between 24 to 35 satellites

• GNSS also includes augmentation systems such as SBAS and GBAS
  – Types of SBAS are WAAS, EGNOS, MSAS and GAGAN
GPS is comprised of three segments or parts:

- The Space Segment;
- The Control Segment;
- The User Segment.
The Space Segment

• Design based on 24 satellites:
  – 4 satellites in each of 6 orbits.
• Orbits inclined at 55º to the equator;
• Orbit altitude - 20,200 km (10,900 miles)
• Satellites orbit about twice per 24-hr period;
• 4 atomic clocks;
• Very weak signal - equivalent to a 25-Watt light bulb observed at 10,000 ′
Visualization of GPS Satellites
Control Segment

• The ‘Control’ segment monitors the constellation, making sure the information transmitted by the satellites is accurate... mainly time information (has to be accurate to 1 nanosecond)

• 9 monitoring stations are located close to the equator
Control Segment Monitoring Stations
Control Segment Monitoring Stations
User Segment

• The ‘User’ segment;
  • **GPS receiver**
    – Navigator & processor
    – Database
  • **Antenna**
    – Position of antenna important
GNSS & GNSS Augmentation Systems

POSITION DETERMINATION
It is important...

• Knowing the precise location of each satellite, and

• Knowing when each satellite transmits the coded signal:
  – Time of Transmission message (TOT)
  – Almanac, Ephemeris data and Pseudorandom code

• The GPS receiver measures the length of time it takes to receive the signal
4 Satellites needed for 3D position

Overlapping pseudo ranges provided by GPS satellites are used to establish the probable position of the aircraft.
Position Determination

\[ D = V \times T_{11} \]

\[ V = 3 \times 10^8 \text{ m/sec} \]

\[ D = V \times T_{24} \]
Position Determination

• Need distances from at least three satellites for trilateration calculations
• 3 satellites for 2D position
• 1 extra satellite is used for height and also time synchronization
• 4 satellites needed for 3D position
GPS Navigation Accuracy

ANNEX 10 GPS accuracy

• Horizontal = $\pm 13\ m$ 95% of the flying time

• Vertical position is usually about 1.5 times the horizontal accuracy... $\pm 22\ m$ 95% of the flying time
GPS Levels of Service

- GPS provides two levels of service **Standard Positioning Service (SPS)** using a CA code, and **Precise Positioning Service (PPS)** using the Precision (P) Code.

- **SPS** is broadcast on L1 (for civilian use).

- **PPS** is broadcast on L1 and L2 (restricted for military use).

- Another civilian frequency L5 will be available with GPS III, planned for 2018.
GNSS & GNSS Augmentation Systems

GPS IFR RECEIVER
GPS Avionics - IFR Receiver

• TSO-C129 certified
• RAIM - Receiver Autonomous Integrity Monitor
• Drops one satellite at a time from position calculations to look for a possibility of a bad satellite
  – 5 satellites are needed for RAIM
• ...now TSO-C196
Integrity Limits

Also called Horizontal Alarm Limits (HAL)

- 2.0 NM for enroute
- 1.0 NM for terminal
- 0.3 NM for approach

This is where we get RNP 2, RNP 1 and RNP 0.3
Integrity Limits Transition

• In the enroute phase, the ‘default’ integrity limit is 2.0 NM;

• At 30 NM from the airport reference point (ARP) the integrity limit changes to the terminal mode = 1.0 NM

• At 2 NM from the FAF, the integrity limit changes to the approach mode = 0.3 NM

• If the aircraft executes a missed approach, once the aircraft passes the MAPt, the integrity limit changes back to terminal mode = 1.0 NM
Enroute 2 NM
Terminal 1 NM
Approach 0.3 NM
Terminal 1 NM
Enroute 2 NM
RAIM Prediction Function

• RAIM has a ‘prediction function’ for approach availability (0.3 NM)
  – 30 minutes before and after ETA in 15-min blocks
• Bad geometry does not last a long time... up to about 20 minutes
  – Pilots will usually adjust their ETAs
RAIM Prediction for Approach (0.3 NM)
Fault Detection And Exclusion (FDE)

• Through FDE, **GPS receiver can identify a bad (faulty) satellite and exclude it** from the position calculation.
• **receiver must track at least 6 satellites for FDE** to function.
• **receivers certified for OCEANIC/REMOTE OPERATIONS MUST HAVE FDE** function!
  – RNAV 10 dual GPS receivers must have FDE.
GNSS & GNSS Augmentation Systems

SUMMARY GNSS
Summary

• GNSS Theory
  – 24 satellites, 6 orbits, 53° inclination, satellite speed 4 Km/sec
• GPS Segments
  – Space Segment, Control Segment, and User Segment
• GPS Position Determination
  – 4 satellites needed for 3D position
• GPS Receiver
  – TSO-C129
• RAIM & FDE
  – 5 satellites needed for RAIM and 6 satellites needed for FDE
GNSS & GNSS Augmentation Systems

SBAS & EGNOS
SBAS Accuracy

- This requires a **dense network** of Ground Reference Stations (GRSs) and complex calculations
- SBAS delivers **improved accuracy** that supports approach minima to 200’
- SBAS yields accuracy of about **2 - 3 m** in the **horizontal plane**
  - thus **3 - 4.5 m** in the vertical plane
  - accuracy **meets ILS performance** (±7 m) at glide slope interception.
EGNOS

• The European Geostationary Navigation Overlay Service (EGNOS) is a satellite based augmentation system (SBAS) developed by the European Space Agency, the European Commission and EUROCONTROL.

• It supplements the GPS, GLONASS and Galileo systems by reporting on the reliability and accuracy of the positioning data.

• The official start of operations was announced by the European Commission on 1 October 2009.
SBAS RECEIVER

• TSO-C146 “Stand-Alone Airborne Nav Using GPS Augmented by WAAS)
SBAS RECEIVERS

• TSO-C145 “Integrated into an FMC”

• A350XWB is the first aircraft with SBAS (TSO-C145) to support RNP APCH LPV approaches.
SBAS Receiver

- SBAS receiver update rate can be **five times faster** than GPS because it can extrapolate the PRN code at **0.2 second intervals**, and transmit its position **5 times per second**... therefore it reduces the latency.
- It also reduces the **mask angle below 5 degrees** over the horizon.
- It has **FDE**
- It considers **SA off**
- Picks up Geo as **PRN 134**
GNSS & GNSS Augmentation Systems
Ground-based Augmentation

- Also referred to as GBAS, LAAS (local area augmentation system) or Differential GPS technique
- Can be used to achieve accuracy required for CAT I – III
  - Currently only CAT I is approved by the FAA
  - CAT III coming by 2014 - 2016
- Done by locating 4 receivers on the ground at a precisely-surveyed (centimetre accuracy) positions
- Receivers measure pseudoranges and compare the results to the actual ranges to the satellites in view.
GBAS Reference Station
GBAS Accuracy and Benefits

- Cost of one GBAS ground station is less than the cost of multiple ILSs for an airport
  - Honeywell Int. SLS-4000 ILS is now being implemented for about $2.5 M
- Another advantage of GBAS is that the accuracy enhancement is provided for the whole airport
  - approaches can be constructed for multiple runways using one ground station
- One GBAS supports all six precision approach landing operations at Sydney International airport
GBAS Accuracy and Benefits

• Expected accuracy – less than 1 m
• Has capability to supports CAT I, II and III
  – Currently only CAT I approved by FAA
  – Honeywell SLS received System Design Approval from the FAA in Sep 2009
• Minimal airport infrastructure required… cheaper for big airports
• Single VHF frequency can support up to 48 individual approach procedures
  (FAA limits this to about 24)
• Reduced flight inspection costs (approximately 1/9 the cost of ILS inspections)
Ground-based Augmentations

- GBAS is **available** on many new Boeing 747-8 and Boeing 787 aircraft. GBAS is an **option** on Boeing 737-NG, Airbus A320, A330/340, and A380 aircraft.
- Several airlines are using GBAS. **United Airlines** and **Air Berlin** have GBAS operational approval up to CAT-I, and **Qantas** and **Emirates** use GBAS CAT-I at Sydney Airport.
- At least two manufactures have approved GBAS avionics. These are **Rockwell Collins** Multi-Mode Receiver (MMR) GNLU 925 and GNLU 930 and **Honeywell’s Receiver**.
- **TSO C161a** provides approval criteria for the GBAS avionics navigation function, while **TSO-C162a**, provides the approval criteria for the data link equipment.
Ground-based Augmentations

• SOUTH AFRICA - GBAS feasibility study and trial project
  – Wednesday, August 31, 2016 6:37 PM - SOUTH AFRICA

• The Air Traffic & Navigation Services SOC Ltd (Reg. No. 1993/004150/06) invites service providers to registration interest (RoI) for GBAS feasibility study and trial project in partnership with ATNS.
Navigation Aid Costs

- **VOR**
  - Install = $250,000
  - 20-year life cycle cost = $1,100,000
- **ILS**
  - Install = $1,200,000
  - 20-year life cycle cost = $2,700,000 (mostly flight inspection costs)
- Neither figure considers the cost of real estate
SUMMARY GNSS AUGMENTATION SYSTEMS
Summary

• In this lesson you learned about GNSS Augmentation Systems
• You learned about SBAS (EGNOS) and GBAS
• Where would different types of GNSS Augmentation Systems benefit in Africa?
  – Northern and North-West Africa might benefit from EGNOS
  – The rest of the continent from GBAS
• Important to understand the difference between SBAS coverage and service areas
• Augmentations are important to achieving Precision Approaches to CAT I and better.
Questions?

THANK YOU