GNSS & GNSS Augmentation Systems

Lesson 4

Facilitator: Ed Hajek

April 2019

Outline

- GNSS Theory
- GPS Segments
- GPS Position Determination
- GPS Receiver
- RAIM & FDE
- SBAS
- SBAS Coverage and Service Area

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GNSS & GNSS Augmentation Systems

GNSS CORE CONSTELLATIONS

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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**

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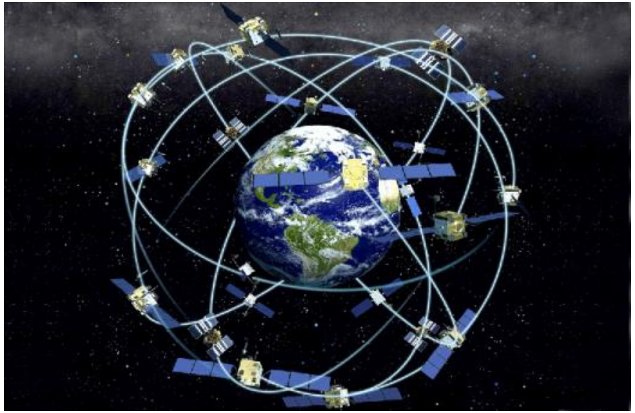
GPS Segments

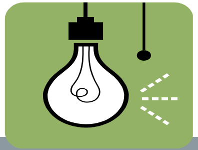
GPS is comprised of three segments or parts:

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

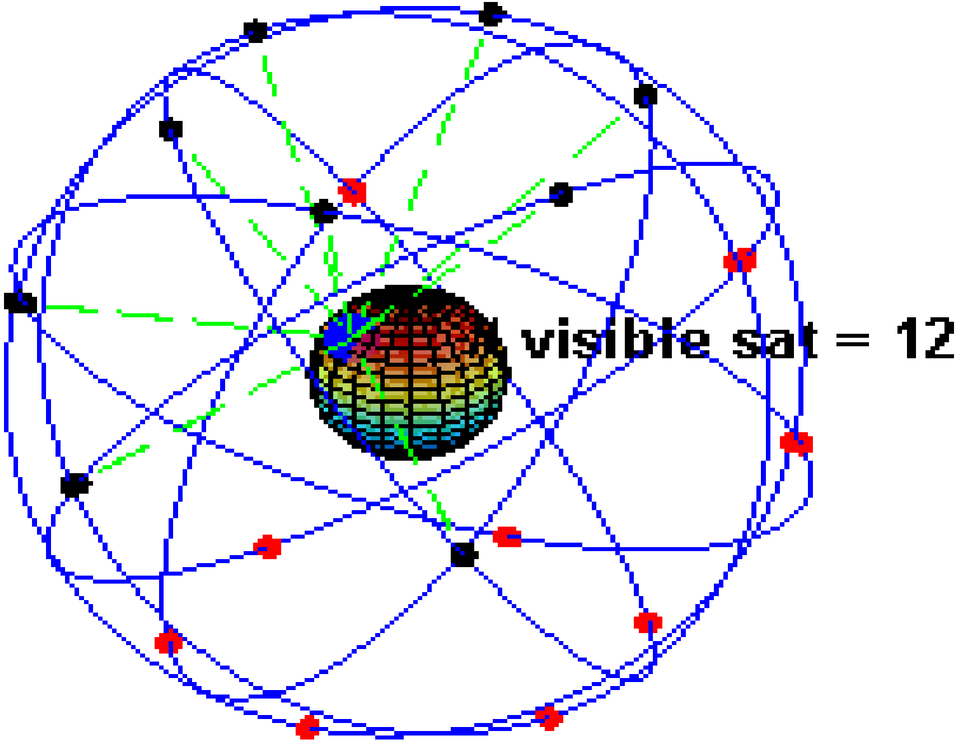
The Space Segment



- 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

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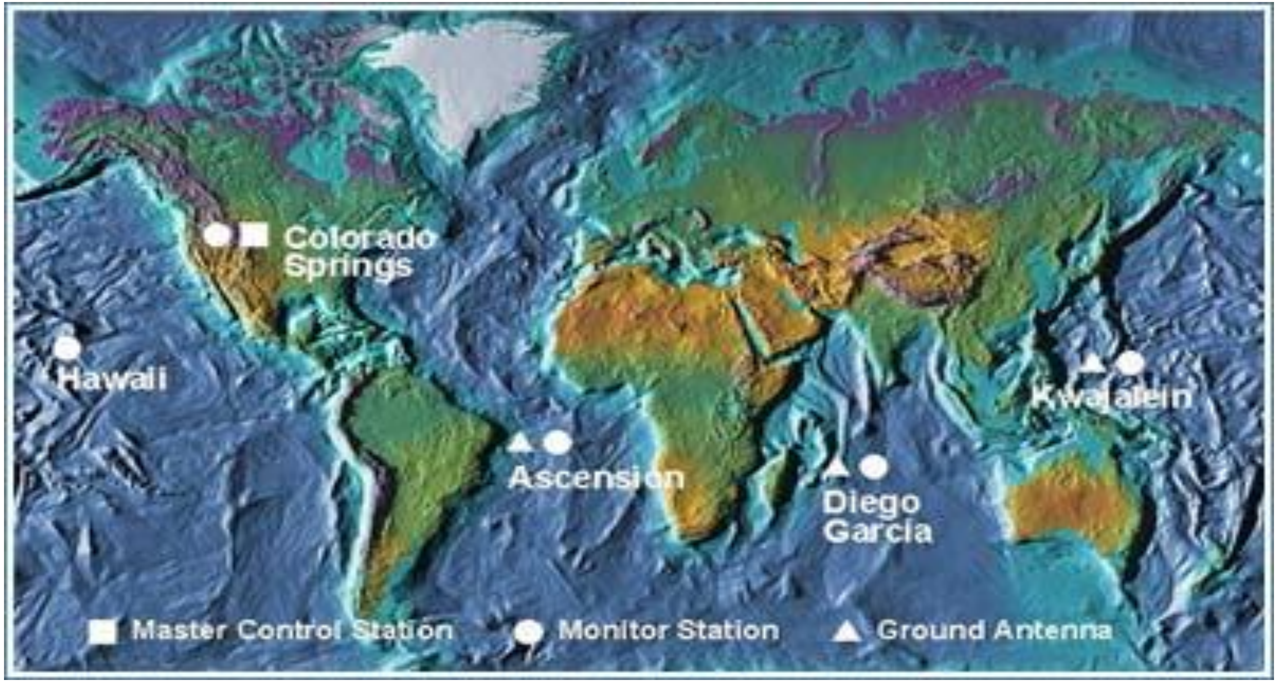
Control Segment Monitoring Stations



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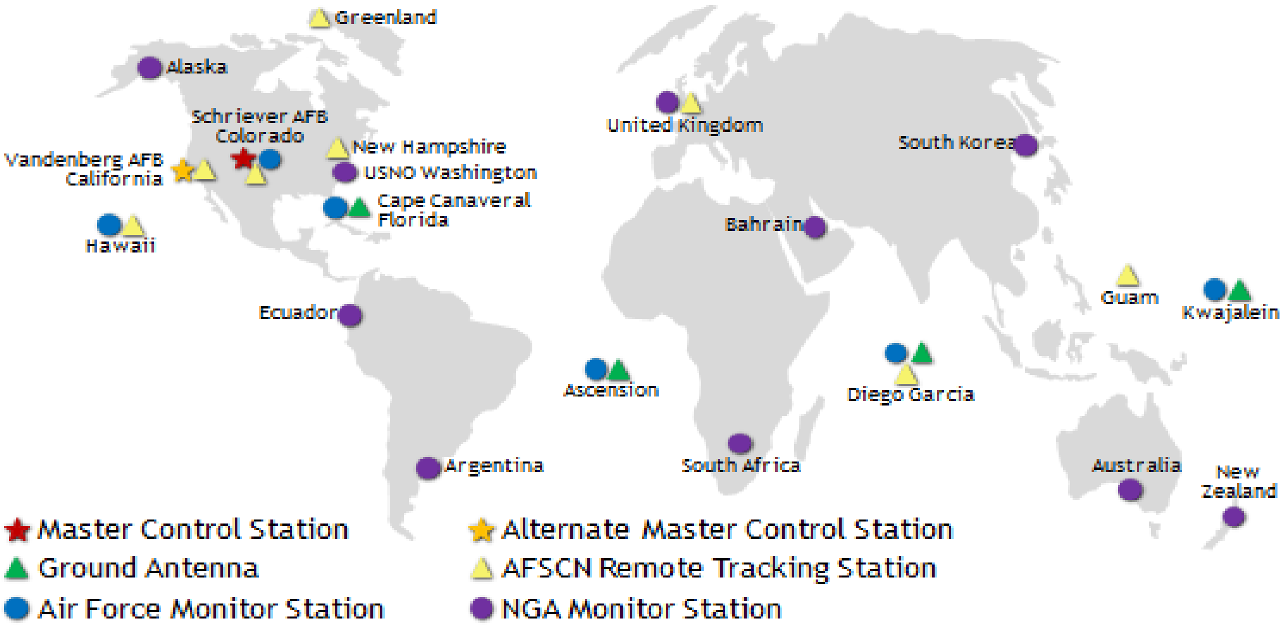
Control Segment Monitoring Stations



User Segment

- The 'User' segment;
- **GPS receiver**
  - Navigator & processor
  - Database
- **Antenna**
  - Position of antenna important

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POSITION DETERMINATION

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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

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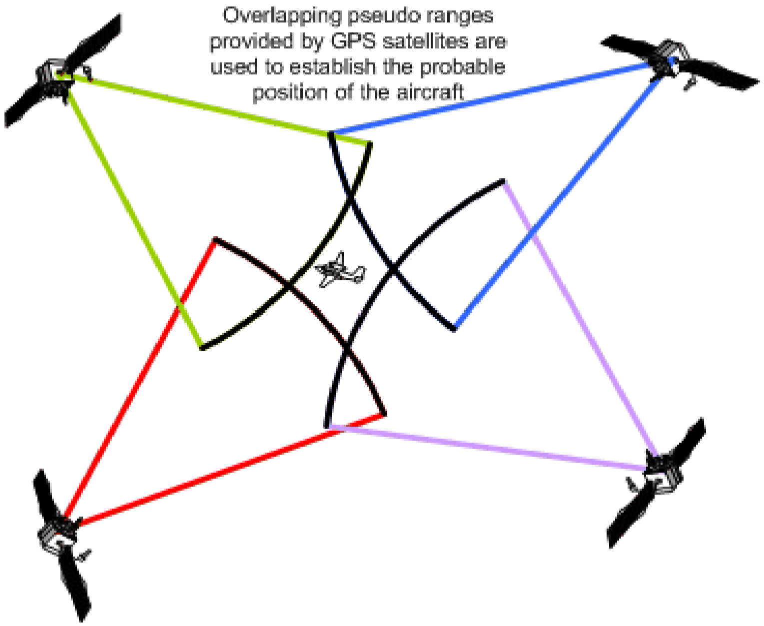
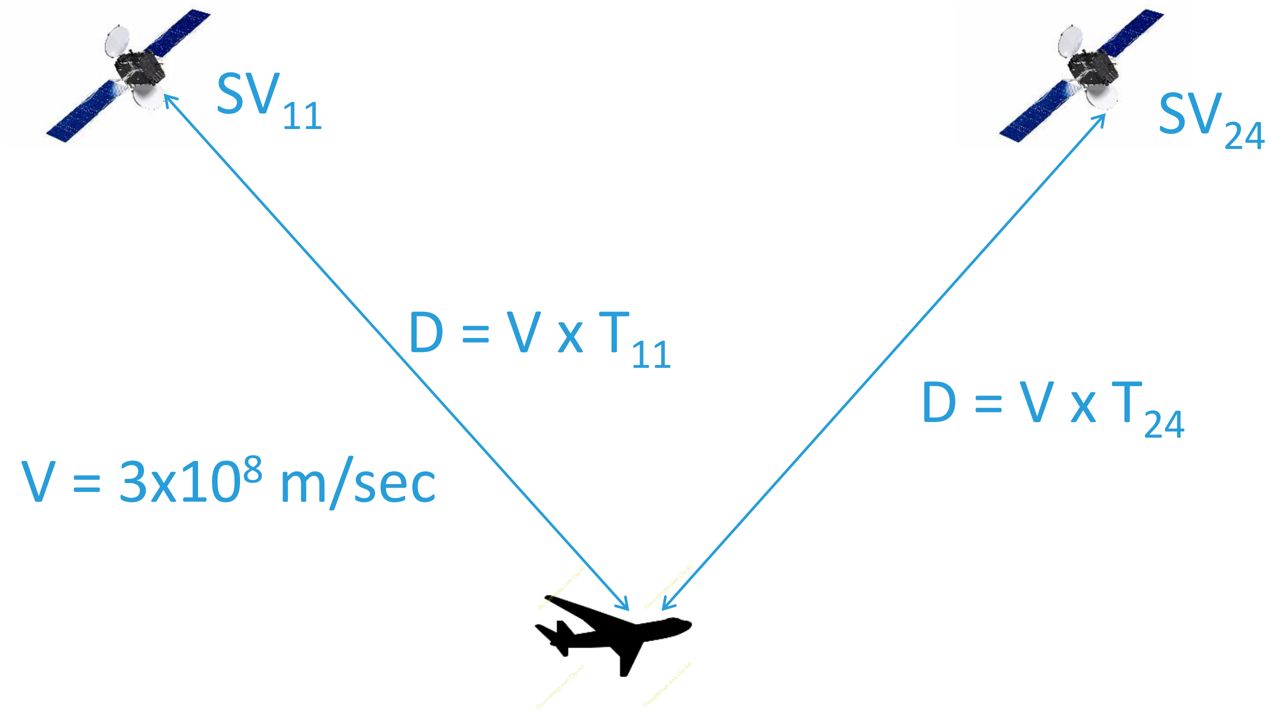
4 Satellites needed for 3D position



Position Determination



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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**

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GPS Navigation Accuracy

ANNEX 10 GPS accuracy

- Horizontal = **±13 m 95% of the flying time**
- Vertical position is usually about 1.5 times the horizontal accuracy… **± 22 m 95% of the flying time**

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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

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GPS IFR RECEIVER

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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

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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**

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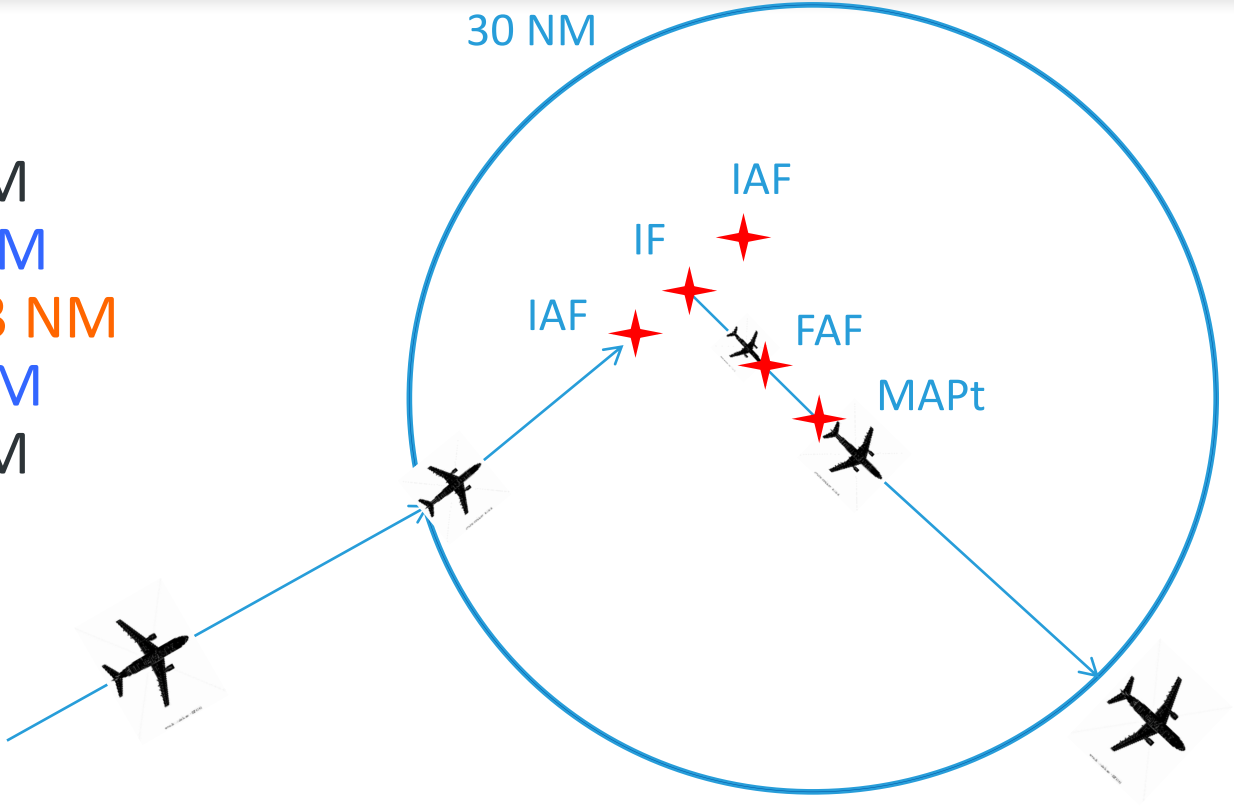
Enroute 2 NM
Terminal 1 NM
Approach 0.3 NM
Terminal 1 NM
Enroute 2 NM



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

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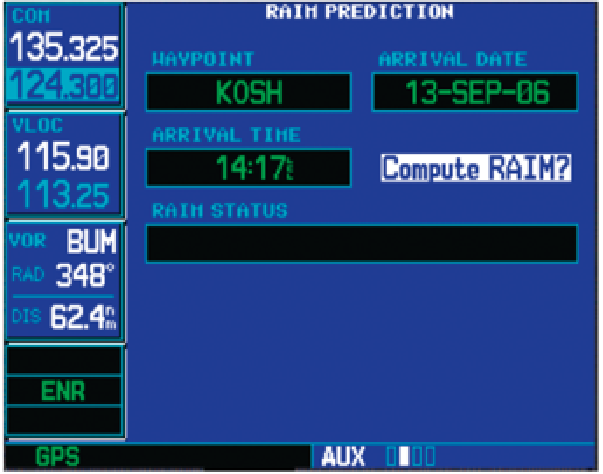
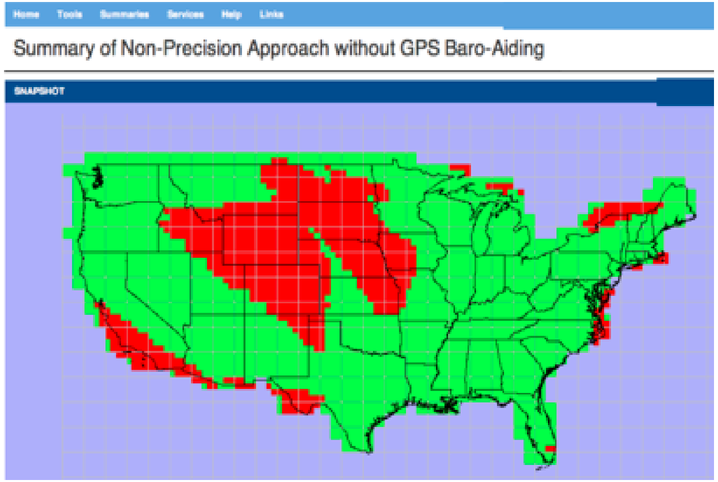
RAIM Prediction for Approach (0.3 NM)





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

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SUMMARY GNSS

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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

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GNSS & GNSS Augmentation Systems

SBAS & EGNOS

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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.

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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**.

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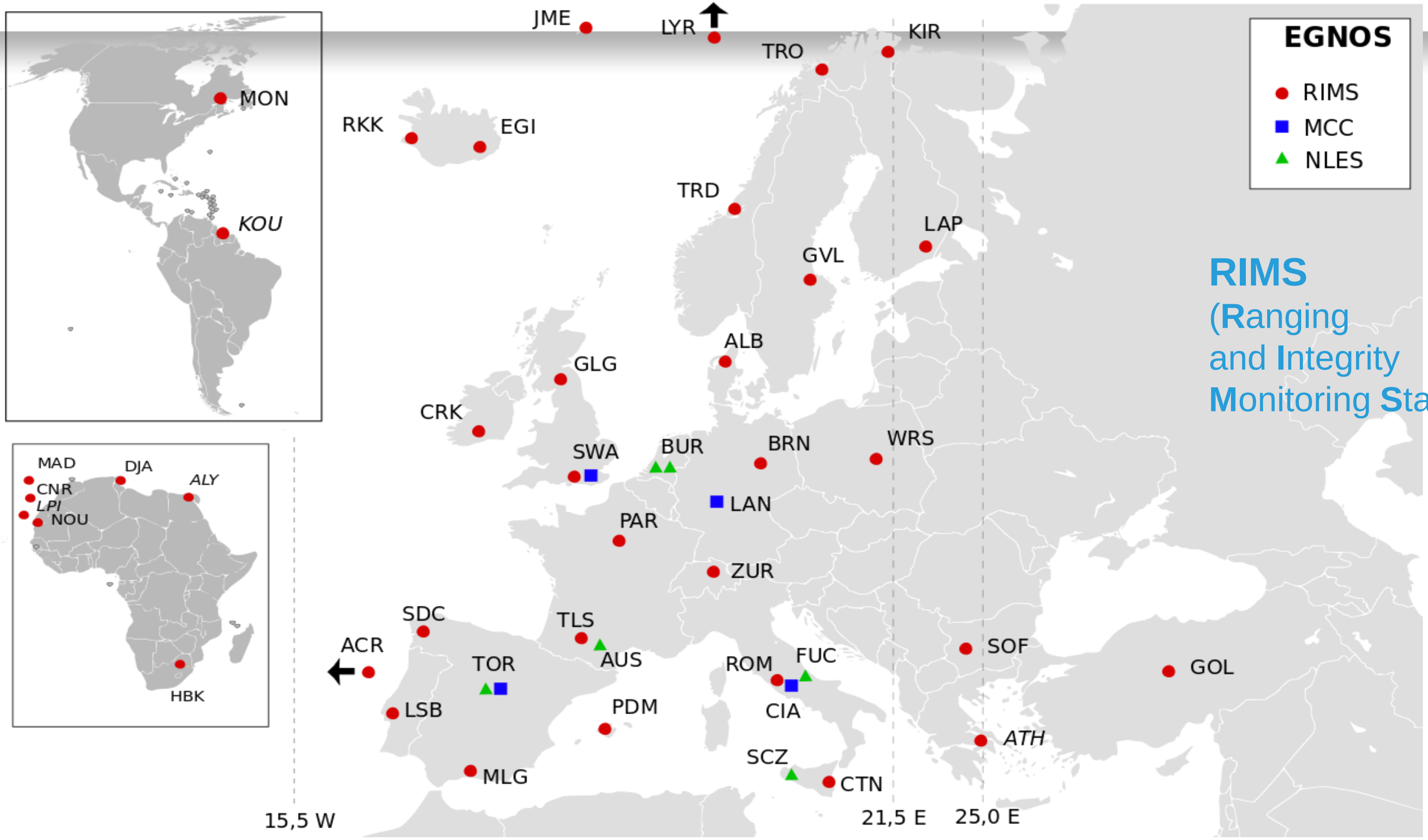
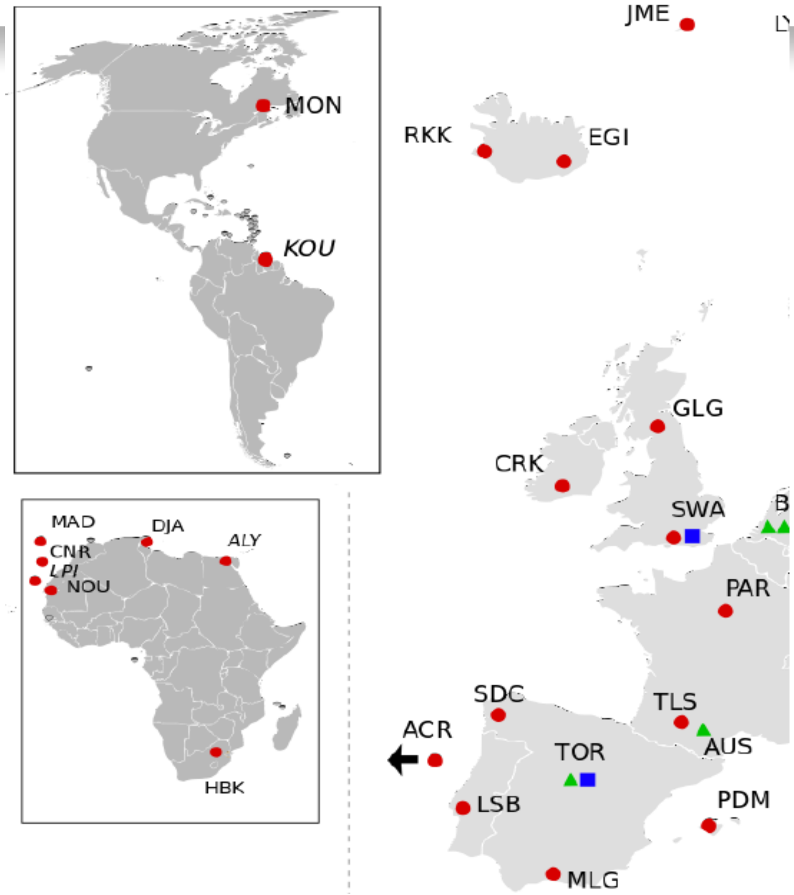


RIMS
(**R**anging and **I**ntegrity **M**onitoring **S**tations)

CAPACITY & EFFICIENCY



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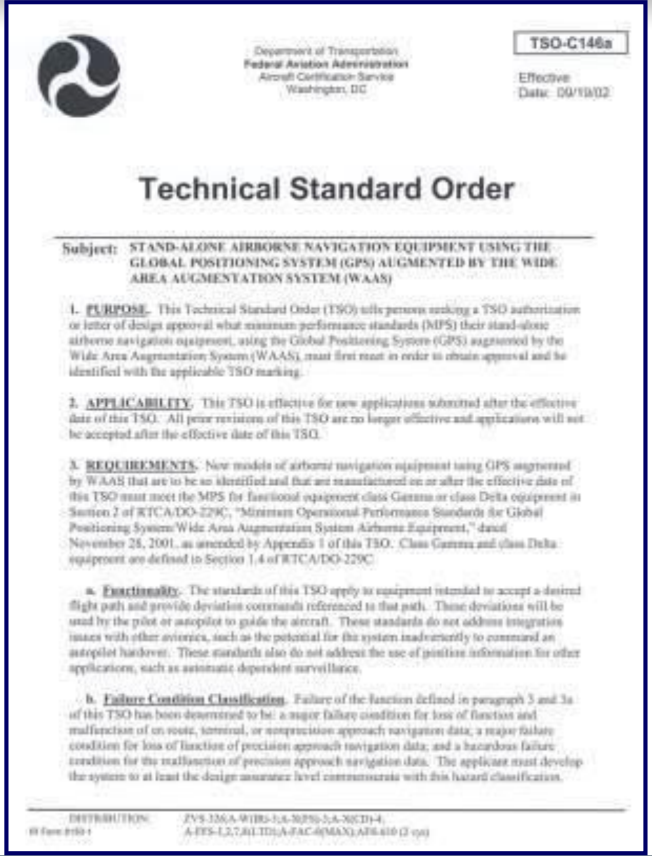
SBAS RECEIVER

- TSO-C146 "Stand-Alone Airborne Nav Using GPS Augmented by WAAS)



Department of Transportation
Federal Aviation Administration
Aircraft Certification Service
Washington, DC

TSO-C146a

Effective Date: 09/19/02

Technical Standard Order

Subject: STAND-ALONE AIRBORNE NAVIGATION EQUIPMENT USING THE GLOBAL POSITIONING SYSTEM (GPS) AUGMENTED BY THE WIDE AREA AUGMENTATION SYSTEM (WAAS)

1. PURPOSE. This Technical Standard Order (TSO) tells persons seeking a TSO authorization or letter of design approval what minimum performance standards (MPS) their stand-alone airborne navigation equipment, using the Global Positioning System (GPS) augmented by the Wide Area Augmentation System (WAAS), must first meet in order to obtain approval and be identified with the applicable TSO marking.

2. APPLICABILITY. This TSO is effective for new applications submitted after the effective date of this TSO. All prior revisions of this TSO are no longer effective and applications will not be accepted after the effective date of this TSO.

3. REQUIREMENTS. New models of airborne navigation equipment using GPS augmented by WAAS that are to be so identified and that are manufactured on or after the effective date of this TSO must meet the MPS for functional equipment class Gamma or class Delta equipment in Section 2 of RTCA/DO-229C, "Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment," dated November 28, 2001, as amended by Appendix 1 of this TSO. Class Gamma and class Delta equipment are defined in Section 1.4 of RTCA/DO-229C.

a. Functionality. The standards of this TSO apply to equipment intended to accept a desired flight path and provide deviation commands referenced to that path. These deviations will be used by the pilot or autopilot to guide the aircraft. These standards do not address integration issues with other avionics, such as the potential for the system inadvertently to command an autopilot hardover. These standards also do not address the use of position information for other applications, such as automatic dependent surveillance.

b. Failure Condition Classification. Failure of the function defined in paragraph 3 and 3a of this TSO has been determined to be: a major failure condition for loss of function and malfunction of en route, terminal, or nonprecision approach navigation data; a major failure condition for loss of function of precision approach navigation data; and a hazardous failure condition for the malfunction of precision approach navigation data. The applicant must develop the system to at least the design assurance level commensurate with this hazard classification.

DISTRIBUTION: [illegible]

SBAS RECEIVERS

- TSO-C145 "Integrated into an FMC"
- **A350XWB** is the first aircraft with **SBAS** (TSO-C145) to **support RNP APCH LPV** approaches.

Department of Transportation
Federal Aviation Administration
Aircraft Certification Service
Washington, DC

TSO-C145a

Effective
Date:

Technical Standard Order

Subject: AIRBORNE NAVIGATION SENSORS USING THE GLOBAL POSITIONING SYSTEM (GPS) AUGMENTED BY THE WIDE AREA AUGMENTATION SYSTEM (WAAS)

1. PURPOSE. This Technical Standard Order (TSO) tells persons seeking a TSO authorization or letter of design approval what minimum performance standards (MPS) their airborne navigation sensors, using the Global Positioning System (GPS) augmented by the Wide Area Augmentation System (WAAS), must first meet in order to obtain approval and be identified with the applicable TSO marking.

2. APPLICABILITY. This TSO is effective for new applications submitted after the effective date of this TSO. All prior revisions to this TSO are no longer effective and applications will not be accepted after the effective date of this TSO.

3. REQUIREMENTS. New models of Airborne navigation sensors using GPS augmented by WAAS that are to be so identified and that are manufactured on or after the effective date of this TSO must meet the MPS for Class Beta equipment in Section 2 of RTCA/DO-229C, "Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment," dated November 28, 2001. Class Beta equipment is defined in Section 1 of RTCA/DO-229C.

a. Functionality. The standards of this TSO apply to equipment intended to provide position information to a navigation management unit that outputs deviation commands referenced to a desired flight path. These deviations will be used by the pilot or autopilot to guide the aircraft. These standards do not address integration issues with other avionics, such as the potential for the sensor to inadvertently command an autopilot hardover. These standards also do not address the use of position information for other applications such as automatic dependent surveillance.

b. Failure Condition Classification. Failure of the function defined in paragraph 3 and 3a of this TSO has been determined to be: a major failure condition for loss of function and malfunction of en route, terminal, or nonprecision approach position data; a major failure condition for loss of function of precision approach position data; and a hazardous failure condition for the malfunction of precision approach position data. The applicant must develop the system to at least the design assurance level commensurate with this hazard classification.

c. Functional Qualification. The required performance shall be demonstrated under the test conditions and procedures specified in RTCA/DO-229C, Section 2.5. The use of test procedures

DISTRIBUTION: ZVS-326; A-W(IR)-3; A-X(FS)-3; A-X(CD)-4; A-FFS-1,2,7,8(LTD); A-FAC-0(MAX); AFS-610 (2 cys)

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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**

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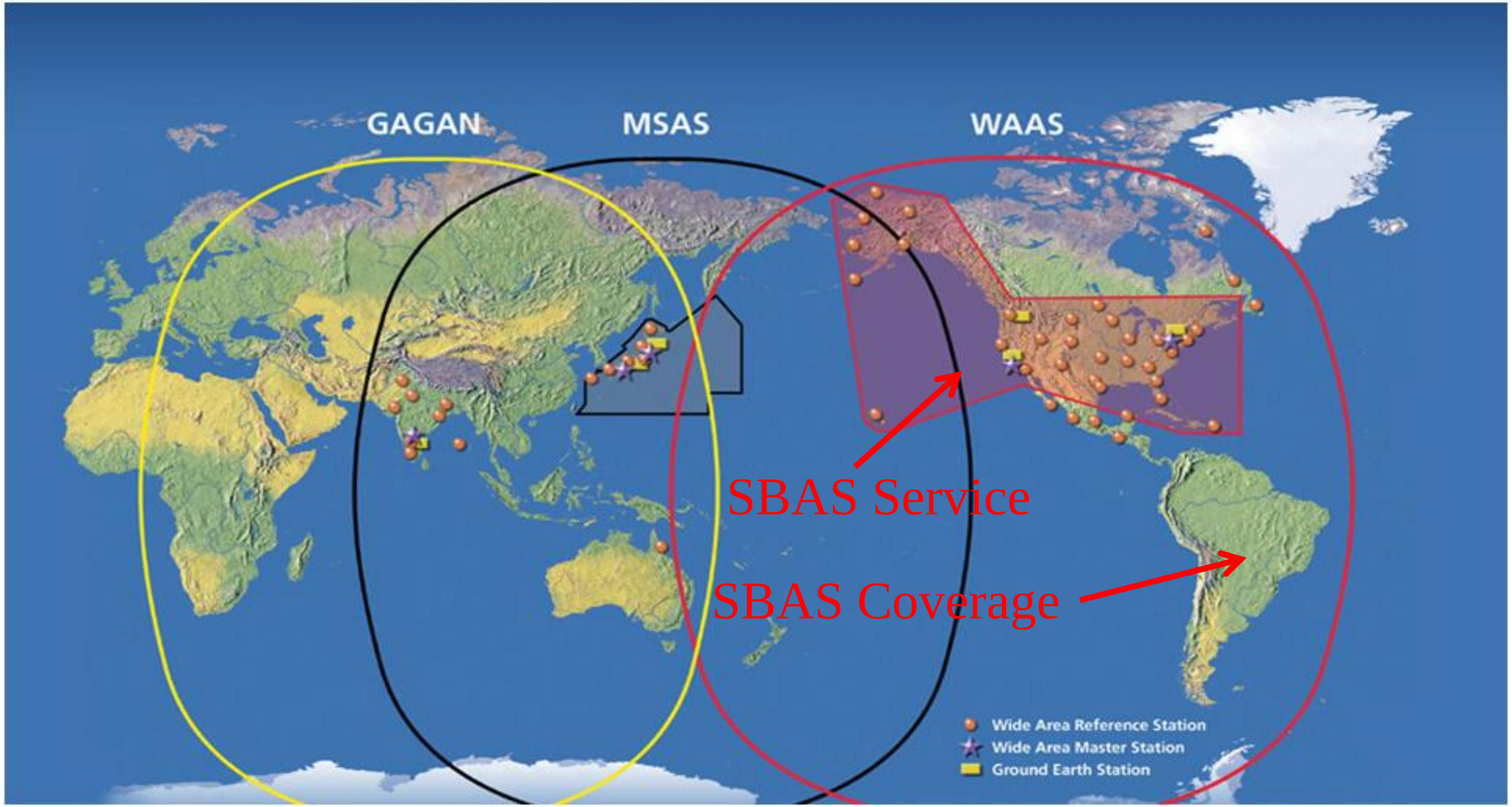
GAGAN
MSAS
WAAS
SBAS Service
SBAS Coverage
Wide Area Reference Station
Wide Area Master Station
Ground Earth Station

GNSS & GNSS Augmentation Systems

GBAS

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.

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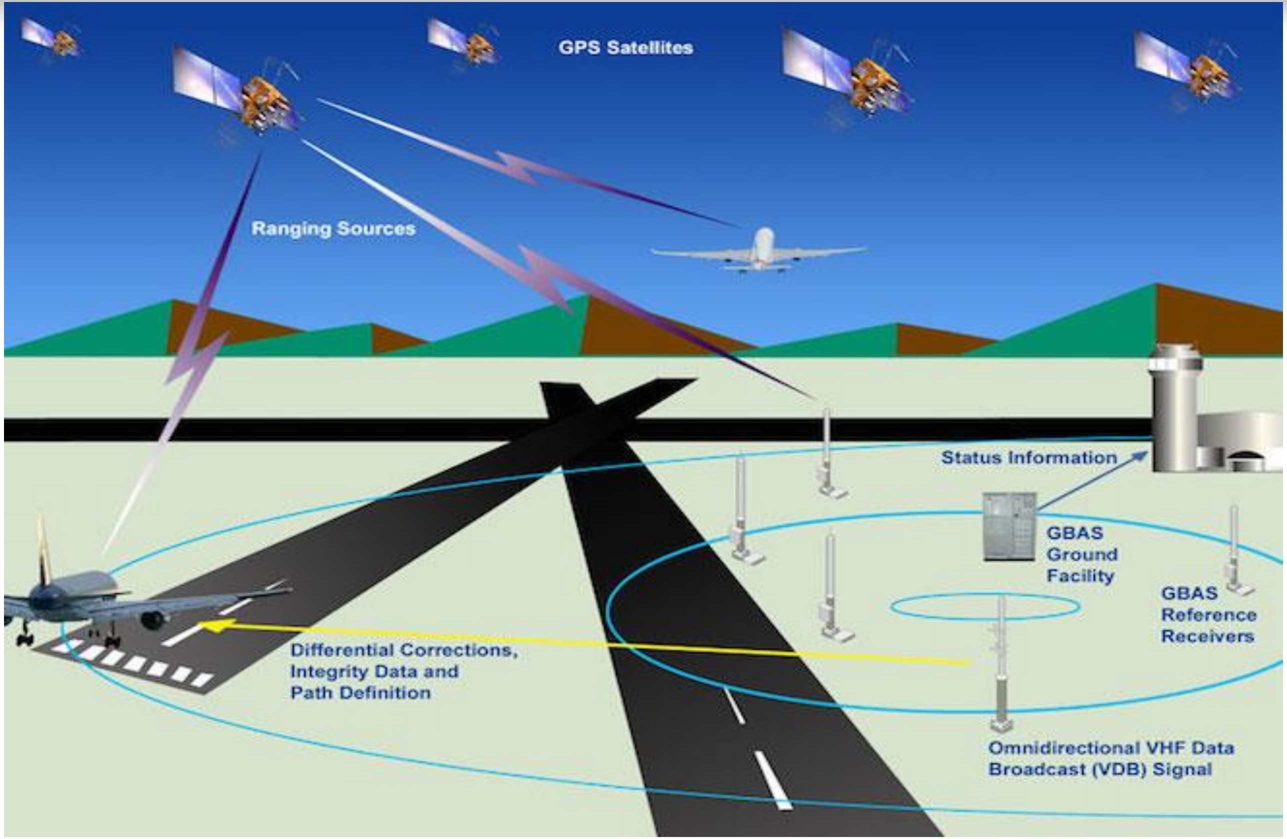
CAPACITY & EFFICIENCY



GBAS Reference Station

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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

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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)

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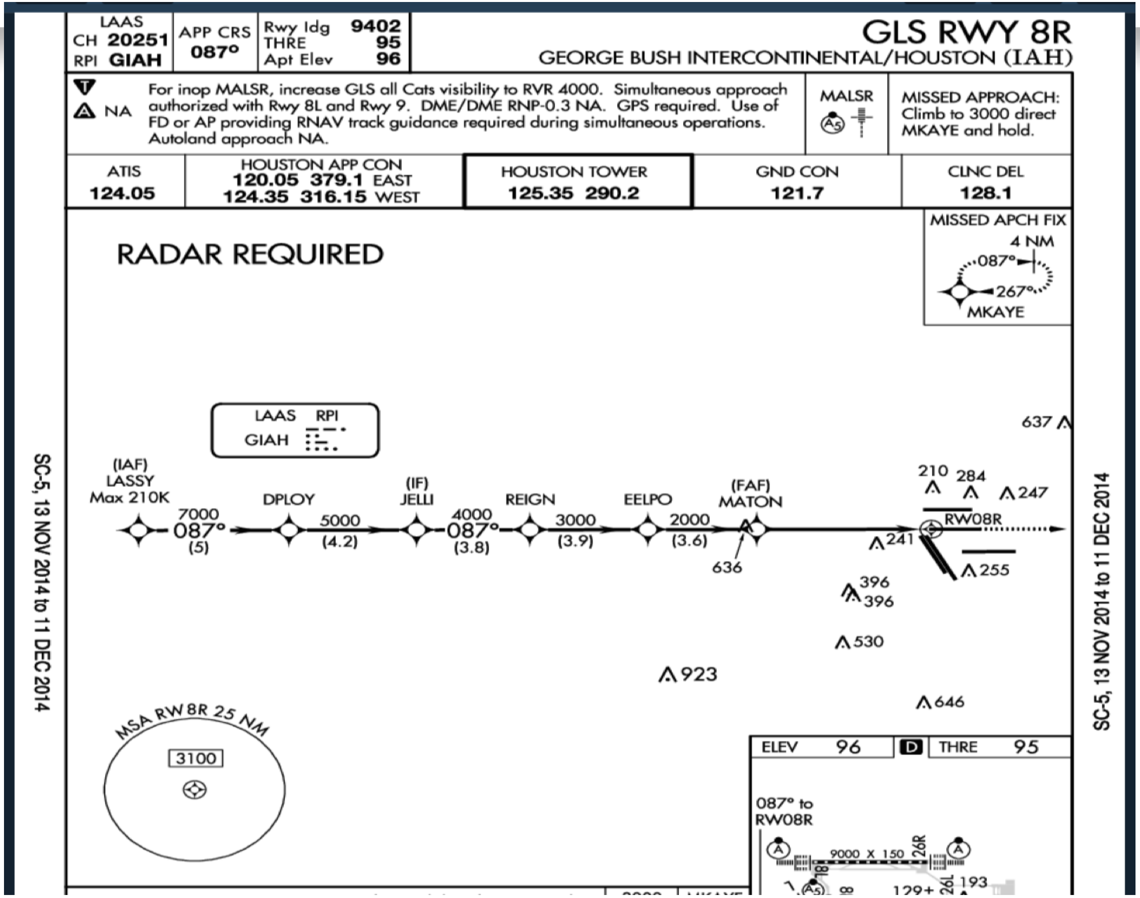
Ground-based Augmentations

- 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.



LAAS
CH 20251
RPI GIAH
APP CRS
087°
Rwy ldg 9402
THRE 95
Apt Elev 96
GLS RWY 8R
GEORGE BUSH INTERCONTINENTAL/HOUSTON (IAH)
NA
For inop MALSR, increase GLS all Cats visibility to RVR 4000. Simultaneous approach authorized with Rwy 8L and Rwy 9. DME/DME RNP-0.3 NA. GPS required. Use of FD or AP providing RNAV track guidance required during simultaneous operations. Autoland approach NA.
MALSR
MISSED APPROACH: Climb to 3000 direct MKAYE and hold.
ATIS
124.05
HOUSTON APP CON
120.05 379.1 EAST
124.35 316.15 WEST
HOUSTON TOWER
125.35 290.2
GND CON
121.7
CLNC DEL
128.1
MISSED APCH FIX
4 NM
087°
267°
MKAYE
RADAR REQUIRED
LAAS RPI
GIAH
(IAF)
LASSY
Max 210K
7000
087°
(5)
DPLOY
5000
(4.2)
(IF)
JELLI
4000
087°
(3.8)
REIGN
3000
(3.9)
EELPO
2000
(3.6)
(FAF)
MATON
636
210
284
247
RW08R
241
255
396
396
530
923
646
637
MSA RW8R 25 NM
3100
ELEV 96
THRE 95
087° to
RW08R
9000 X 150
26R
193
SC-5, 13 NOV 2014 to 11 DEC 2014
SC-5, 13 NOV 2014 to 11 DEC 2014

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

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SUMMARY GNSS AUGMENTATION SYSTEMS

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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.

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ICAO

Questions?

THANK YOU