RECEIVER AUTONOMOUS INDEPENDENT MONITORING (RAIM)

LECTURE 3.1
SGU 4823– SATELLITE NAVIGATION
INTRODUCTION

• GPS potential in civil aviation is great, but the basic GPS signals fails to satisfy FAA requirements for all phases of flight, especially for precision approach.

• Stand alone GPS fails to meet all the four requirements.
  – Availability
  – Accuracy
  – Integrity
  – Continuity

• The goal is that to provide an eventual GNSS that meets the RNP for every phase of flight.
• The major constraint on implementing GPS is that it must be safe and cost effective.

• The need to fulfill integrity, accuracy, availability and reliability while ensuring safety and affordability has led to an operational implementation of GPS services under four stages.

• Each stage is more and more dependent on GPS and its augmentation as FAA and the civil aviation build its confidence on GPS usage.
FOUR PHASES OF IMPLEMENTATION

– GPS without any Augmentation.
– GPS augmented with RAIM.
– GPS augmented with WAAS.
– GPS augmented with LAAS.
PHASE 1
GPS Without Augmentation

• GPS as a multi-sensor system.
• Example Oceanic phase: Integrity can be verified from other external source such as INS.
• Approved for oceanic phase February 1991
PHASE 2
GPS Augmented With RAIM

- GPS augmented by integrity and accuracy algorithms within the airborne receivers.
- This concept has been approved, tested and verified by FAA.
PHASE 3
GPS Augmented With WAAS

• Will improve the integrity, accuracy, availability and continuity.
• Can be used in all phases of navigation but only for Cat. I precision approach phase.
• Commissioned July 2003
PHASE 4
GPS Augmented With LAAS

• Will improve the integrity, accuracy, availability and continuity.
• Can be used in all phases of navigation including all precision approach phase.
• Still under testing phase.
GPS WITHOUT AUGMENTATION

GPS Standalone Positioning: Today

- Horizontal Errors
- Selective Availability Off
- C/A Code on L1

6-10 m
• As illustrated here is typical GPS worldwide accuracy which is 6 to 10 m horizontally. This assumes the civil user is receiving the L1 signal only.

• Prior to discontinuing selective availability (S/A) the accuracy was typically five to eight times worse.

• While this accuracy is acceptable for many flying operations, accuracy is not the main issue for aviation. Rather, it is creating a bound on inaccuracy that must be used to assure integrity for the flying user.

• The FAA’s WAAS is designed to provide that bound (or protection limit) to create the required level of integrity at every point within the WAAS service volume.
Receiver | Precision
-----------|-----------
Lawrance   | 13 (m)    | 20 (m)
Garmin     | 22 (m)    | 15 (m)
Magellan   | 18 (m)    | 15 (m)
Allstar    | 13 (m)    | 16 (m)
Ashtech    | 24 (m)    | 26 (m)

Receiver | Accuracy
-----------|-----------
Lawrance   | 22 (m)    | 32 (m)
Garmin     | 35 (m)    | 22 (m)
Magellan   | 34 (m)    | 28 (m)
Allstar    | 21 (m)    | 25 (m)
Ashtech    | 42 (m)    | 41 (m)
### Receiver Precision

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<th>Precision X (m)</th>
<th>Precision Y (m)</th>
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### Receiver Accuracy

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<tr>
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Real-Time Kinematic: Today

- Two Frequencies
- Carrier Tracking
- Special Data Link

2 cm accuracy

10 km
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<tr>
<th>Availability</th>
<th>Oceanic</th>
<th>En Route</th>
<th>Terminal</th>
<th>Non-Precision Approach</th>
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1. System Today
2. Selective Availability Off
3. SA Off Plus 30 Satellite Constellation
4. SA Off Plus 2nd Civil Frequency
5. SA Off, 2nd Civil Frequency, 30 Satellite Constellation

Maximum: 1
Mean: 3
Minimum: 4
For All Locations

* Signal-in-Space Error with Selective Availability, 24 Satellite Constellation
  Scheduled and Unscheduled Satellite Downings
  Atmospheric Errors and Multipath
  Receiver Thermal Noise
• Each vertical bar represents the range of availability values determined for a specific service using a particular system configuration (number key below table).

• For example, the first bar within the oceanic column represents the range of availability considering all locations and times using the current GPS constellation (i.e., 24 satellites, selective availability on, no second frequency).

• The mean value is indicated by the horizontal line (i.e., the system’s availability is less than 0.99).

• The performance of this system is seen to further degrade as more accurate service requirements are attempted (number 1 bar in successive columns). The number 2 bar represents the impact of turning selective availability off.
• While this definitely improves performance, the mean values continue to provide less than 0.99 availability (recall that the requirement for oceanic is 0.999 and for the other services it is 0.99999).

• The number 3 bars indicate the availability for a 30-satellite constellation with selective availability off. The numbers 4 and 5 bars indicate availability with selective availability off and with a second civil frequency for 24- and 30-satellite constellations, respectively.

• The analysis indicates that GPS without augmentation can only meet NAS oceanic requirements, and even then the constellation must be increased to 30 satellites.

• On the other hand, it should be noted that a considerable level of GPS service is already available to supplement existing capabilities, but it will not meet the availability objectives set for this study.
GPS AUGMENTED WITH RAIM

• It is essential that the satellite signals be monitored to ensure that no malfunctions have occurred.
• While the DoD Control Center takes care of most of the malfunctions, it is possible that subtle problems could occur before the CC had the satellite shut down or indicated poor health in the navigation data.
• This monitoring could be performed on the ground.
• However, receiver autonomous integrity monitoring (RAIM) is possible under certain conditions, allowing errors to be detected by the GPS receiver itself without expensive ground equipment.
• The RAIM method is applied within the user receiver to enable it to independently or autonomously establish system integrity.

• RAIM attempts to address two main concerns.
  – The existence of a bad measurement.
  – In the event that the above is true, the identification of the affected satellite.

• It important to note that if a GNSS is used for supplemental navigation, then addressing the first concern above is sufficient because an alternative navigation system is available and can be used instead.

• However, if the GNSS is used for primary-means navigation, then both concerns above must be fully addressed to identify and remove the affected measurement (satellite) from the solution allowing the aircraft to safely proceed.
• Addressing either concern requires redundant measurements, i.e. more than the minimum four measurements required for a position solution.

• Hence, measurements from at least five satellites are required to detect a satellite anomaly, and a minimum of six satellites to remove the affected satellite from the navigation solution.

• A RAIM technique must determine a position error and make a decision as to whether the level of error is acceptable by comparing it to the alert limit for a particular phase of flight.

• If this limit is exceeded, then a RAIM equipped receiver must issue a warning within the time-to-alert.
• Integrity refers to the capability of a navigation system to detect the condition when the system’s navigation accuracy is outside its specified limits for a given phase of flight and give timely warning to the user.

• In addition to providing a navigation capability, a navigation system must have the ability to provide timely warnings to users when the system should not be used for navigation.

• In July 1991, RTCA Special Committee completed the Minimum Operational Performance Standards (MOPS) for GPS as a supplemental navigation system.

• During the process of developing the MOPS, the committee focused heavily on determining GPS position integrity performance requirements for en route, terminal, and non-precision approach navigation.
• The GPS technical standard order (TSO) requires all IFR-approved receivers to have RAIM.

• A RAIM algorithm works by over determining position using at least five satellites or four satellites and a barometer altitude input from an encoding altimeter or altitude encoder.

• The receiver will sound a RAIM alarm (an annunciator light) if one or more satellites are providing questionable data.

• The RAIM alarm limit for en route operations is 30 seconds; for non precision approaches, it's 10 seconds, meaning the receiver must be capable of detecting an integrity fault in that amount of time.
• For future GPS precision approaches, the RAIM alarm limit will be six seconds.
• If a RAIM alarm is active, the receiver will continue to navigate in en route mode, but it will not operate in approach mode until the RAIM limitation is resolved.
• RAIM will be the primary means of assuring integrity until the wide area augmentation system (WAAS) is fully operational.
RAIM Warnings

- All IFR-approved GPS receivers are equipped with RAIM.
- Three levels of RAIM are used in receivers:
  - En Route
  - Terminal
  - Approach
- En route and terminal level RAIM provide integrity warnings within 30 seconds of detecting a suspected navigation error.
- For approach operations, the RAIM alarm will appear within 10 seconds.
Process of RAIM

- RAIM is a two-step process.
- First, the receiver has to determine if enough satellites are above the horizon and in the proper geometry to make RAIM available.
- Second, it must determine if the RAIM algorithm indicates a potential navigation error, based upon the range solutions from those satellites.
- In other words, when the receiver indicates a RAIM-not-available alarm, it's saying "there could be something wrong with the navigation solution, but I don't have enough satellite information to know for sure."
- If it indicates a RAIM error alarm, it's saying "I have enough satellites available and there's something wrong with one of them or the navigation solution in general."
RAIM Warnings

Always fly initial segment of published missed approach before proceeding direct to missed approach holding fix.

GEMINI (MAWP)

OGEE (FAF)

If RAIM warning occurs after FAF, climb and fly to missed approach waypoint. Follow missed approach procedure.

If RAIM warning occurs prior to FAF, abandon approach and fly to missed approach waypoint via FAF and missed approach procedure.
• At least one satellite, in addition to those required for navigation, must be in view for the GPS receiver to perform the RAIM function; thus, RAIM needs 5 satellites in view (or 4 satellites with barometer aiding) to work.
• A certified GPS receiver is constantly determining if it has RAIM (enough GPS satellite coverage to validly calculate position and altitude).
• No RAIM means no GPS approach.
• Since GPS satellites are constantly moving, and since these satellites will occasionally malfunction or go out of service for scheduled maintenance, RAIM capability may not be available at a given time for your destination.
Availability of Horizontal RAIM Ver1
Availability of Horizontal RAIM Ver2
• The GPS TSO requires receivers to have predictive RAIM, so that the pilot will know if RAIM will be available at the time he or she arrives at the destination airport.

• While en route to the destination, predictive RAIM is automatically revised as the receiver continually calculates a new ETA.

• It's critical to understand that just because the receiver predicts RAIM will be available at the destination, that doesn't guarantee you'll have sufficient satellite coverage when you arrive, only that the receiver expects to have sufficient coverage to calculate RAIM.

• It's possible, for example, that a satellite could go unhealthy while you're en route. Or signals from satellites low on the horizon could be masked by terrain. The receiver's RAIM function has no way of knowing about terrain masking.
• The power of autonomous integrity monitoring could be increased by adding measurements from other instruments on board the aircraft.
• The technique is then no longer receiver autonomous but aircraft autonomous, AAIM.
• AAIM can be applied either by comparing the position solution from GNSS with that obtained by other navigation sensors, such as a barometer, or an inertial navigation system (INS).
• Or by integrating the raw measurements from each system into a single solution (with appropriate weighting of the various measurements).