Understanding GPS, WAAS, RAIM, RNP, and PBN

GNSS - Global Navigation Satellite Systems

- **GPS – United States**
- GLONASS - Russian Federation
- Galileo - European Union
- BeiDou - China

GPS - Global Positioning System (U.S.)

- How it works:
    1. GPS Satellites broadcast a time stamped signal from atomic clocks onboard the satellite (extremely accurate)
    2. Aircraft GPS receiver uses the time difference between the time the signal is received and the time the signal was sent to find the distance of the aircraft from the satellite
    3. This distance only determines that you are somewhere on a sphere with that radius from the satellite
    4. Trilateration is used to determine a precise location through using multiple satellites to pinpoint where you are. Trilateration requires:
        1. 3 satellites for 2D coverage
        2. 4 satellites for 3D coverage
        3. 5 satellites for RAIM Fault Detection
        4. 6 satellites for RAIM Fault Detection and Exclusion
        5. One less satellite is required if baro-aiding is available
- GPS Segments:
    1. Space Segment
        - Consists of 31 operational satellites
        - The US is committed to maintaining at least 24 operational GPS satellites, 95% of the time.
        - GPS satellites orbit the earth twice a day in 6 orbital planes at 10,900 NM providing full global coverage
        - Each satellite contains 4 atomic clocks accurate to at least a billionth of a second
    2. Control Segment - Operational Control Segment
        - 16 Monitor Stations - monitor the orbits and clocks of the satellites to ensure they stay within limits
        - 11 Ground Antennas - track satellites and transmit correction information to them
        - 1 Master Control Station (Colorado) - provides overall management of remote monitoring and transmission (& 1 alternate master control station)
    3. User Segment – Aircraft Onboard Equipment - GPS / WAAS Receiver

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WAAS - Wide Area Augmentation System

- Covers the entirety of the national airspace system
- *Enables Performance Based Navigation (PBN)*
- *Enables Automatic Dependent Surveillance Broadcast (ADS-B)*
- Augments information to GPS/WAAS receivers to enhance accuracy and integrity in the departure, en route, and arrival phases
- Eliminates RAIM check requirement (AC 90-100A)
- Accurate to 1.5 meters horizontally and 2 meters vertically
- Allow for LPV approaches into over 4000 runways with minimums as low as 200’ AGL
- Alerts aircraft within 6 seconds if GPS/WAAS becomes unusable due to errors or outages
- Reduces costs associated with ground based navaids allowing for more airports with precision like approaches
- WAAS Technical Standard Orders; TSO-C145c and TSO-C146c
- Allows you to plan on GPS approaches at both your destination (LPV mins) and your alternate (LNAV mins)

- How it works:
    - GPS Satellite - > WRS -> WMS -> Uplink Stations -> GEO Satellites -> GPS/WAAS Receiver
        1. 38 Wide Area Reference Stations (WRS) across the US detect errors of satellites
        2. 3 Wide Area Master Stations (WMS) receive information collected by reference stations and generate a correction message to allow the GPS/WAAS receiver to remove the error increasing accuracy and integrity
        3. 6 Uplink Stations receive WMS correction messages and uplink them to 3 geostationary satellites
        4. 3 Geostationary Satellites (do not move relative to the Earth) send the correction messages to the GPS/WAAS receiver onboard aircraft

PBN - Performance Based Navigation

- *PBN is an "umbrella" term that encompasses RNAV and RNP*
- ICAO Definition of PBN
  - Area navigation based on performance requirements for aircraft operating along an ATS route, on an instrument approach procedure or in a designated airspace.

RNAV - Area Navigation

- Allows aircraft to fly on any flight path within coverage of navaids and limitations of GPS systems
- Benefits
  - Time and fuel savings
  - Reduced dependence on radar vectorings, altitude, and speed assignments leading to reduced ATC radio transmissions
  - More efficient use of airspace
- Suitable RNAV AIM 1-2-3
  - Operational and airworthiness guidance regarding use of RNAV systems on (or transitioning to) conventional NAVAIDs and Non-RNAV Routes
  - Types of Suitable RNAV Systems: TSO-C129/-C145/-C146
    - Reference Garmin Pilot's Guide Page 628
  - Uses
    - Determine aircraft position or distance from a VOR, NDB, ADF, Marker Beacon, or DME fix
    - Navigate to or from a VOR
    - Hold over a VOR or DME fix
    - Cannot be used to fly the final approach segment of an ILS/LOC approach without reference to raw localizer data or the final approach segment of a VOR approach without monitoring the underlying (operational) navaid

RNP - Required Navigation Performance

- RNAV plus onboard performance monitoring and alerting capabilities
- Monitors and informs crew if RNP is not met at least 95% of the time
  - RNP 0.3 - Approach Phase
    - 0.3 NM lateral accuracy
  - RNP 1.0 - Terminal, Departure, Missed Approach
    - 1.0 NM lateral accuracy
  - RNP 2.0 - Enroute
    - 2.0 NM lateral accuracy
- PBN requires RNP accuracy to be met at least 95% of the time
- RAIM is an example of RNP
  - Receiver Autonomous Integrity Monitoring (RAIM) - Capability of a GPS receiver to perform integrity monitoring on itself by ensuring available satellite signals meet the integrity requirements for a given phase of flight
  - Active monitoring of an alternate means of navigation is required when the GPS RAIM capability is lost.
- LPV approach requires RNP and satellite-based augmentation system (SBAS)
- RNAV (RNP) approaches require FAA authorization, special equipment, and training to fly
- RNP AR: AC 90-101, AIM 5-4-18

GBAS - Ground Based Augmentation System

- Augments GPS by providing corrections to aircraft in the vicinity of an airport in order to improve the accuracy of, and provide integrity for, these aircrafts' GPS navigational position
- The goal of GBAS implementation is to provide an alternative to the Instrument Landing System (ILS) supporting the full range of approach and landing operations.
- More information: https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/laas/howitworks

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References

AIM 1-2-1, AIM 1-2-3, AIM 1-1-17, AIM 1-1-18, AC 90-100, FAA Form 7233−4 International Flight Plan, ICAO Doc 9613, FAA Flight Operations Group, GPS.gov, FAA Air Traffic Organization Navigation Programs