* + GNSS (Global Navigation Satellite System)
		- GNSS refers collectively to the worldwide positioning, navigation, and timing determination capability available from one or more satellite constellation in conjunction with a network of ground stations. P/CG
		- Can be augmented as necessary to support the required navigation performance for the actual phase of operation.
		- GNSS includes:
			* GPS (USA)
			* SBAS (Satellite Based Augmentation System) e.g. WAAS
			* GBAS (Ground Based Augmentation System) e.g. LAAS
			* GLONASS (Russia)
			* Galileo (Europe)
		- International Civil Aviation Organization (ICAO), as well as other international user groups, have accepted GPS and GLONASS as the core for an international civil satellite navigation capability known as the GNSS.
	+ GPS (Global Positioning System) AIM 1-1-17
		- Space-based radio-navigation system consisting of a constellation of satellites, a network of ground stations used for monitoring and control, and an end user segment.
		- Currently 32 GPS satellites orbit the Earth at an altitude of approximately 11,000 miles providing users with accurate information on position, velocity, and time anywhere in the world and in all weather conditions. [FAA GPS info](http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/gps/)
		- How it works:
			* Satellites emit signals to receivers that determine their location by computing the difference between the time that a signal is sent and the time it is received.
				+ The satellites have atomic clocks providing extremely accurate time information that is placed in the signal
				+ Receiver uses the time between the broadcast and reception to compute the distance to the satellites
				+ Knowing the distance from each satellite in view the receiver triangulates it’s position
				+ The receiver must also account for propagation delays, or decreases in the signal's speed caused by the ionosphere and the troposphere.
		- Maintaining availability of at least 24 satellites to ensure that a minimum of 5 are in receiver's usable view worldwide
			* 3 satellites – 2 dimensional (car)
			* 4 satellites – 3 dimensional (altitude)
			* 5 satellites – RAIM Time coded with orbital position of satellite
		- RAIM (Receiver Autonomous Integrity Monitoring)
			* GPS signal integrity monitoring achieved by capable receivers; satellite signal “fault detection”
			* Critical function for Performance Based Navigation (PBN)
			* Needs 5 satellites in view or 4 satellites and a barometric altimeter
			* FDE (Fault Detection and Exclusion)
				+ Capable receivers can remove corrupt signal from the navigation solution with 6 satellites, or 5 satellites and Baro-aiding
			* 2 types of RAIM fault messages
				+ Not enough satellites to compute RAIM or detection of a potential signal error
			* FAA website to check RAIM prediction during preflight: <http://sapt.faa.gov/default.php>
				+ Pilot must review appropriate NOTAMs before flight (GPS NOTAMs)
		- Use of GPS for IFR operations
			* Properly certified GPS equipment may be used for domestic en route, terminal operations and certain IAPs.
			* GPS equipment must be approved in accordance with the requirements specified in Technical Service Order TSO-C129( ), TSO-C196( ), TSO-C145( ), or TSO-C146( ) and installation must conform to AC 20-138( ).
			* VFR and handheld GPS equipment not authorized for IFR navigation, IFR approaches, or as a principal flight reference
			* If aircraft is equipped with an un-augmented GPS receiver (TSO-C129 or TSO-C196), there must be an alternate approved means of navigation for the proposed operation, (e.g. VOR or DME/DME/IRU capability), in case of the loss of RAIM capability
			* Operating with an approved GPS is considered PBN and have appropriate equipment suffixes for flight plan
			* Any approach procedure to be flown must be found by name in the current GPS equipment database
				+ Manual entry of waypoints, lat/long or place/bearing not permitted for approach procedures
* **Satellite Based Augmentation System (SBAS) and Ground Based Augmentation System (GBAS)**
	+ WAAS (Wide Area Augmentation System) 1-1-18
		- WAAS is a (SBAS) designed to improve the accuracy, integrity, and availability of GPS signals
			* Improves GPS signal accuracy from 100 meters to approximately 7 meters
		- How it works:
			* Wide-area Reference Stations (WRS) monitor GPS satellite signals to determine position errors
			* Information collected at WRS is uploaded to a WAAS Master Stations (WMS) which corrects and augments the data for an increase location accuracy and reliability
			* The augmented data is then sent a GEO up-link station (GUS) located at a Ground Earth Stations (GES)
			* Data is then uploaded to geostationary satellite (GEO)
			* GPS/WAAS equipment receives the augmented signal from the GEO satellite
		- Equipment and facilities
			* 3 GEO up-link satellites (Geostationary Satellite)
			* 38 WRS's (Wide-area Reference Station)
			* 3 WMS's (WAAS Master Station)
			* 6 GES's (Ground Earth Station)
				+ GUS (GEO Uplink Station)
			* 2 operational control centers
			* GPS/WAAS capable receiver in aircraft
		- WAAS avionics must be certified in accordance with TSO-C145A, Airborne Navigation Sensors Using the GPS Augmented by the WAAS; or TSO-146A for stand-alone systems.
		- GPS/WAAS operation must be conducted in accordance with the FAA-approved aircraft flight manual (AFM) and flight manual supplements.
		- Flight manual supplements must state the level of approach procedure that the receiver supports.
		- Instrument approach capabilities
			* Though approaches with WAAS use vertical guidance they are not considered precision approaches as they do not meet ICAO Annex 10 precision approach requirements
			* Approaches referred to as Approach with Vertical Guidance (APV)
			* Approaches include LNAV/VNAV, LP, and LPV
		- Europe, Japan, and India are building similar SBAS's to the FAA's WAAS that will merge to create expansive navigation capabilities similar to GPS but with greater accuracy, availability, and integrity.
			* Europe: EGNOS (European Geostationary Navigation Overlay System)
			* India: GAGAN (GPS And GEO-Augmented Navigation system)
			* Japan: MSAS [Multi-functional Transport Satellite-based (MTSAT) Satellite Augmentation System]
	+ GLS (GBAS Landing System)
		- * GBAS is the ICAO term for LAAS (Local Area Augmentation System)
			* GBAS augments GPS signals to provide guidance for GLS precision approaches at host airport
			* Similar to ILS approaches
			* How it works:
				+ GBAS ground facility uses 4 GPS reference antennas with known position to receive GPS signals
				+ The ground facility then determines the error between the actual antenna position and the GPS broadcast signal's position
				+ Ground facility then sends the correction message to GBAS equipped aircraft via a VHF Data Broadcast transmitter
			* Facilities and equipment:
				+ GGF (GBAS Ground Facility)
				+ 4 Reference Receiver antennas
				+ VDB (VHF Data Broadcast uplink antenna)
				+ An aircraft GBAS receiver
			* GBAS produces the extremely high accuracy, availability, and integrity necessary for Category I, and eventually Category II, and III precision approaches
			* Demonstrated accuracy is less than one meter in both the horizontal and vertical axis
			* FAA website about [GBAS](http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/laas/)
	+ Area Navigation (RNAV)
		- AIM 1-2-1
		- A method of navigation which permits aircraft operation on any desired flight path within the coverage of ground or space-based navigation aids or within the limits of the capability of self-contained aids (e.g. INS), or a combination of these.
		- Area navigation includes legacy and PBN (Performance-Based Navigation) methods
			* Legacy
				+ 2D RNAV

Operations incorporating systems approved under AC 90-45

VOR/DME

INS (Inertial Navigation Systems): an RNAV system which is a form of self-contained navigation

* + - * PBN
				+ PBN: Area navigation based on performance requirements for aircraft operating along an ATS (Air Traffic Services) route, on an instrument approach procedure or in a designated airspace.

Use satellites and onboard equipment for navigation with greater accuracy

* + - * + Requirements expressed for specifications in terms of accuracy, integrity, continuity, availability, and functionality needed for the proposed operation in the context of a particular airspace concept.
				+ 2 main categories within PBN are RNAV and RNP (Required Navigation Performance)
				+ RNAV and RNP numerical designations refer to lateral navigation accuracy in nautical miles that is expected to be achieved ≥95% of the time. 1-2-1
				+ RNP is an RNAV system including onboard performance monitoring and alerting capability (e.g. RAIM)

RNP also introduces certain navigation specifications for equipment and aircrew requirements

* + - RNAV (Area Navigation) Operations
			* DP's, STAR's, En route, and Oceanic
				+ Pilots need an understanding of various waypoint and leg types used in RNAV procedures
				+ Waypoints

Fly-by waypoints (turn anticipation)

Fly-over waypoints

* + - * + RNAV Leg Types

Track to Fix leg (TF)

Direct to Fix leg (DF)

Course to Fix (CF)

Radius to Fix (RF)

Heading

* + - * RNAV Nav Specs
				+ RNAV 1 – used for DPs and STARs; ≤1 NM error ≥95% of the time
				+ RNAV 2 – used for en route operations, e.g. T-Routes and Q-Routes; ≤2 NM error ≥95% of the time
				+ RNAV 10 – Oceanic operations

* + As a current pilot using the NAS, you need to have a clear understanding of the aircraft equipment requirements for operating in a given RNP environment.
		- You must understand the type of navigation system installed in your aircraft, and furthermore, you must know how your system operates to ensure that you can comply with all RNAV requirements.
		- Operational information should be included in your AFM or its supplements.
	+ RNP (Required Navigation Performance): A statement of the navigation performance necessary for operation within a defined airspace. P/CG, AIM 1-2-2
		- A critical component of RNP is the ability of the aircraft navigation system to monitor its achieved navigation performance, and to identify for the pilot whether the operational requirement is or is not being met during an operation.
		- The on-board performance monitoring allows for less reliance on ATC for the safety of the operation
		- RNP capability will vary depending on aircraft equipment and navigation infrastructure.
		- Following terms are often associated with RNP
			* RNP Level or Type (e.g. RNP 2). A value, in nautical miles, from the intended horizontal position within which an aircraft would be at least 95% of the total flying time.
			* RNP Airspace: Generic term designating airspace, route(s), leg(s), operation(s), or procedure(s) where minimum RNP has been established.
			* ANP (Actual Navigation Performance): A measure of the current navigational performance; also known as EPE (Estimated Position Error)
			* LNAV (Lateral Navigation): a function of area navigation (RNAV) equipment that calculates, displays, and provides lateral guidance to a profile or path.
			* VNAV (Vertical Navigation): a function of area navigation (RNAV) equipment that calculates, displays, and provides vertical guidance to a profile or path.
		- RNP procedures are in the category of RNP AR. Operators who seek to take advantage of RNP approach procedures must meet the special RNP requirements outlined in FAA AC 90-101
		- To attain the benefits of RNP approach procedures, a key component is curved flight tracks. Constant radius turns around a fix are called “radius-to-fix legs (RF legs).” These turns, which are encoded into the navigation database, allow the aircraft to avoid critical areas of terrain or conflicting airspace while preserving positional accuracy by maintaining precise, positive course guidance along the curved track.
		- RNP (Required Navigation Performance) operation Nav Specs and Standard Lateral Accuracy Values
			* RNP APCH – “RNAV (GPS)”: offer several minima for varying aircraft equipment
			* RNP AR APCH – “RNAV (RNP)”: Authorization Required vertical navigation based on barometric VNAV or WAAS
			* A-RNP (Advanced RNP) – Lateral accuracy of 2 for oceanic and remote operations, 2 or 1 for domestic en route segments, except for final approach.
			* RNP 1 – arrival to and departure from terminal area and initial and intermediate approach phase
			* RNP 2 – domestic and oceanic remote operations
			* RNP 4 – oceanic and remote operations
			* RNP 0.3 – rotorcraft only; for all phases of flight except remote/oceanic and final approach segment
			* AIM 1-2-2
* There are three types of procedures based on the final approach course guidance:
	+ - PA (Precision Approach) - provides course and glidepath deviation information meeting precision standards of ICAO Annex 10. (E.g. PAR, ILS, and GLS)
		- APV (Approach with Vertical Guidance) - provides course and glidepath deviation information but are not required to meet the precision approach standards of ICAO Annex 10. (E.g. Baro-VNAV, LDA with glidepath, LNAV/VNAV and LPV)
		- NPA (Non-precision approach) - provides only lateral course deviation information, no glidepath. (E.g. VOR, TACAN, LNAV, NDB, LOC, and ASR)
	+ Overlay Approaches
		- Identified by “or GPS” in approach title
		- With "or GPS" in the approach name, this allowed the use of certified GPS receivers to fly the approach rather than relying on the VOR, VOR/DME or NDB signal.
		- Designated non-precision approaches that are authorized to fly as a GPS procedure; GPS overlay of a non precision approach
		- Based on conventional ground-based NAVAIDS
		- Remaining few of original approaches were converted to stand-alone procedures
		- Overlay approaches do not fit into the criteria for RNAV stand-alone GPS procedures
		- 1-1-17
	+ Stand-Alone Approach
		- Identified as "GPS RWY \_\_" or contain "GPS" in the title
		- Have replaced many overlay approaches
		- Will eventually be converted to RNAV (GPS) procedures. [faa.gov](http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/nas/procedures/gpsStandAlone/)
		- 1-1-17
	+ Approach Minima Lines
		- GLS (GBAS Landing System)
			* An instrument approach with lateral and vertical guidance with integrity limits; similar to barometric vertical navigation (Baro-VNAV)
			* Need a GBAS equipped receiver
			* Approach flown using same techniques as an ILS
		- LPV (Localizer Performance with Vertical Guidance) 5-4-5
			* LPV requires WAAS
			* Baro-VNAV not authorized for LPV minima (8083-16)
			* A type of approach with vertical guidance (APV) based on WAAS, published on RNAV (GPS) approach charts. This procedure takes advantage of the precise lateral guidance available from WAAS.
			* The minima are published as a DA.
			* Basically like an ILS but uses GPS instead of ground-based navaids
				+ Designed like this to readily transfer skills needed to fly an ILS to an RNAV (GPS) approach’s LPV minima
				+ LPV requires WAAS, Baro-VNAV not adequate (AC 20-138D); provide ILS equivalent minimums as low as 200’ ceiling and ½ SM visibility
			* Needs to be stated in the Aircraft Flight Manual that the installed equipment supports LPV approaches
				+ Includes Class 3 & 4 TSO C-146 GPS/WAAS equipment
			* See Terminal Procedures book Terms/Landing Minima Data for other navigation systems that may be authorized for this line of minima
		- LNAV/VNAV (Lateral Navigation/Vertical Navigation)
			* APV minimums for RNAV IAP with vertical guidance usually provided by Baro-VNAV
				+ Check for temperature limitations
				+ Also supported by WAAS (except for approaches in P/CS)
			* Larger integrity limits than a precision approach or LPV
			* Need statement in AFM that installed equipment supports GPS approaches and has an approach approved barometric VNAV, or aircraft has demonstrated to support LNAV/VNAV approaches
				+ Includes Class 2,3, and 4 TSO-C146 GPS/WAAS equipment
			* Minima published as a DA because of electronic vertical guidance
		- LNAV
			* Lateral navigation only
			* Uses an MDA
			* Same service level as GPS stand alone approaches
			* LNAV minimums support the following navigation systems:
				+ WAAS – when the navigation solution will not support vertical navigation
				+ GPS navigation systems that are authorized to conduct GPS approaches
			* WAAS navigation equipment must be approved by TSO-C145( ) or TSO-C146( )
		- LP (Localizer Performance without Vertical Guidance):
			* Non-Precision Approach with WAAS lateral guidance
			* Uses angular guidance, not glideslope angle, but an increased lateral sensitivity as aircraft gets closer to runway
				+ CDI sensitivity continues to increase from FAF to MAP; like a triangle
			* Uses an MDA
			* Published if terrain, obstructions, or some other reason prevent a vertically guided approach being published.
			* LP is not a fail-down mode for LPV; they are independent
			* Barometric altimeter is primary altitude compliance
			* Some WAAS equipment may not support; if approved prior to TSO C-145b and TSO C-146b
				+ Must have an approval for LP approaches in the Flight Manual or Supplemental Flight Manual
	+ Baro-VNAV
		- An RNAV function that uses barometric altitude information from the aircraft's altimeter to compute and present a vertical guidance path to the pilot
		- Barometric VNAV eligible aircraft are those with an Aircraft Flight Manual (AFM) or AFM Supplement that explicitly states that the VNAV system is approved for approach operations in accordance with AC 20-129 or AC 20-138.
			* Special approval for Part 91 operators, if the FAA determines that the navigation equipment is eligible for Baro-VNAV instrument approach operations to a published DA, the FSDO will provide documentation that the aircraft equipment is approved for these Baro-VNAV operations.
		- For a VNAV system to be approved for approach operations under AC 20-129, or AC 20-138 it must have a vertical deviation indicator (VDI)
		- AC 90-105
	+ Inertial Reference Unit (IRU)
		- A sensor inside the aircraft that uses gyroscopes to determine the aircraft’s position
		- The IRU’s position is updated on regular intervals by either the aircraft’s DME/DME position or when equipped, the aircraft’s GPS position
		- An aircraft with DME/DME and IRU position updating achieves the same performance as an aircraft with DME/DME position updating except the IRU can be used in areas of limited DME coverage
		- Since IRU position information degrades over time, IRU position information cannot be used for long periods of time without updating.
	+ Radar approaches:
		- Precision Approach Radar (PAR) and Airport Surveillance Radar (ASR).
		- PAR: a controller provides highly accurate lateral and vertical guidance to a pilot
		- ASR: a controller provides lateral guidance only
		- A radar approach may be given to any aircraft upon request and may be offered to pilots of aircraft in distress or to expedite traffic; however, an ASR might not be approved unless there is an ATC operational requirement or in an unusual or emergency situation
		- Acceptance of a PAR or ASR by a pilot does not waive the prescribed weather minimums for the airport or for the particular aircraft operator concerned
			* Decision to make a radar approach when the reported weather is below the established minimums rests with the pilot.
		- PAR and ASR minimums are published on separate pages in the FAA TPP. Figure 10-10.
		- Radar minimums for Troy, AL



* + NextGen (Next Generation Air Transportation System)
		- Overhaul of the National Airspace System to make navigation more dependable and convenient while ensuring safety
		- Moves from ground based systems to satellite based systems
		- Changes will occur in stages between 2012 and 2025
		- Benefits of NextGen:
			* Aircraft can fly closer together
			* More direct routes
			* Reduced delays/more reliable
			* Environmental and economical benefits such as lower fuel consumption, reduced carbon emissions, and less noise
			* Will also include new technologies for weather forecasting, digital communications, and networking
		- NextGen Programs
			* ADS-B (Automatic Dependent Surveillance Broadcast)
				+ Uses GPS satellites to provide accurate air and runway separation information to ATC and pilots
				+ Necessary avionics will be mandated by FAA
			* CATMT (Collaborative Air Traffic Management Technologies)
				+ Enhancements to the decision-support and data-sharing tools used by air traffic management personnel
			* SWIM (System Wide Information Management)
				+ A single infrastructure and information management system
			* Data Comm Next Generation data communications
				+ Enable controllers to send digital instructions and clearances to pilots
				+ Precise visual messages that appear on a cockpit display can interact with an aircraft's flight computer
			* NNEW (NextGen Network Enabled Weather)
				+ Provide a common weather picture across the NAS enabling better decision making
			* NVS (NAS Voice Switch)
				+ A single air-to-ground and ground-to-ground voice communications system
	+ More references:
		- [FAA.gov Performance Based Flight Systems Branch Satellite Based Navigation (SatNav)](https://www.faa.gov/about/office_org/headquarters_offices/avs/offices/afs/afs400/afs470/media/NAS.pdf)
		- [AC 90-105 Approval Guidance for RNP Operations and Barometric Vertical Navigation](http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC%2090-105.pdf)
		- [AC 20-138D - Airworthiness Approval of Positioning and Navigation Systems (Including Change 1)](http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_20-138D_Change_1.pdf)
		- [FAA list of all published SIAPs](http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/approaches/media/MasterRNAVs.xlsx)
		- [RNAV Approaches: Overview and Approval Process](https://www.faa.gov/about/office_org/headquarters_offices/avs/offices/afs/afs400/afs470/pbn/media/RNAV_Approaches/movie.swf)