Modern Navigation. [Approaches]
Preface

These are some of my personal notes. It is not a text book for learning. Not to be used for Navigation. NOT FAA, NOT JAR specific.

Most of the material extracted (or copy-pasted) from various official and unofficial sources including:

5. FAA, Aeronautical Information Manual (AIM), FAA 2015 (updated 26 May 2016)
6. FAA, GBAS Fact Sheet, GBAS FAQ, RNAV Fact Sheet
7. FAA, Satellite Navigation – GPS/WAAS – Approaches
8. FAA, Ground Based Augmentation System. Concept of operations (CAST-D)
10. Boeing Aero magazine. (Articles)
12. Euro control, Introducing Performance Based Navigation (PBN) and Advanced RNP (A-RNP)
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14. Bill Royce, RNAV/RNP Operations & VNAV Approaches, Boeing
15. CAP 773, Flying RNAV (GNSS) Approaches in Private and General Aviation Aircraft, Civil Aviation Authority, 2014
17. COSCAP, Performance Based Navigation operational Approval Handbook, 2010
18. flaps2approach.com, Articles
19. Airbus, From Non-Precision to Precision-Like Approaches.
20. E. Tarinowski, From no precision approaches to precision-like approaches, Flightsafety.org

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**Satellite Navigation Systems**

Contrary to the widely-held view that all satellite navigation can be subsumed under the “GPS” banner, aviation actually has a range of satellite navigation systems and procedures at its disposal today, all of which offer more possibilities than conventional navigation technologies.

Here we provide an overview of the most important satellite navigation systems, and explain how the corresponding new procedures are developed.

**GNSS (Global Navigation Satellite System)**

GNSS is an umbrella term for systems which are used to navigate and determine current position based on signals received from dedicated navigation satellites. GNSS satellites transmit navigation signals and their position by radio. An aircraft needs to receive such signals from at least four satellites simultaneously to determine its position. GNSS includes one or more satellite constellations, aircraft receivers, and system integrity monitoring augmented as necessary to support the required navigation performance for the intended operation. The key word is "Global" vice "Regional" navigation systems.

There are currently four GNSSs in use or being developed worldwide:

**GPS (Global Positioning System)**

GPS is a system that has been developed by the US Department of Defense since the 1970s, and has been fully functioning since the mid-1990s.

**GLONASS (GLObal Navigation Satellite System)**

GLONASS is a system developed by the Russian Ministry of Defense since the 1970s that became fully operational in 2012.

**GALILEO**

GALILEO is a project co-launched by the European Union and the European Space Agency at the beginning of 2000 to develop a satellite navigation system for civil purposes. The first Galileo services should be available in 2014, but the system will not be complete until 2020.

**COMPASS**

COMPASS is China’s satellite navigation system, which has also been under development since the beginning of 2000 and should also be fully functioning by 2020.
Supplementary systems

To verify the accuracy and reliability of the signals they use, the existing satellite navigation systems are further supported by three types of “augmentation system”. ABAS (Aircraft-Based Augmentation System), SBAS (Satellite-Based Augmentation system) and GBAS (Ground-Based augmentation system).

**ABAS (Aircraft-Based Augmentation System)**

ABAS is an augmentation system that augments and/or integrates the information obtained from the other GNSS elements with information available on board the aircraft.

ABASs use sensors on the aircraft to give pilots additional information that can help them check the GNSS data they receive. ABASs are installed aboard most modern aircraft today.

The Aircraft Based Augmentation System can be implemented by:

**RAIM (Receiver Autonomous Integrity Monitoring)** whereby a GNSS receiver processor determines the integrity of GNSS position using GPS signals or GPS signals augmented with altitude (Baro-aiding). RAIM is a mandatory part of the software function of the IFR certified GPS receivers. The RAIM function is intended to provide integrity by detecting the failure of a GPS satellite (Fault Detection (FD) RAIM). Some provide subsequent exclusion of the faulty satellite, allowing the possibility of continued navigation following a satellite anomaly or failure FDE RAIM). FDE RAIM is recommended to improve continuity of function as, with FD RAIM only, a faulty satellite remains in the navigation computation and integrity will be lost.

Barometric aiding is an integrity augmentation that allows a GPS system to use a non-satellite input source (e.g. the aircraft pitot-static system) to provide vertical reference and reduces the number of required satellites from five (four plus integrity) to four. Baro-aiding requires four satellites and a barometric altimeter input to detect an integrity anomaly. The current altimeter setting may need to be entered into the receiver as described in the operating manual. Baro-aiding satisfies the Receiver Autonomous Integrity Monitoring (RAIM) requirement in lieu of a fifth satellite.

**AAIM (Aircraft Autonomous Integrity Monitoring)** whereby the GNSS signal is integrated with other navigation sensors, such as the Inertial Navigation System (INS), VOR / DME which can perform an integrity check on GNSS data when RAIM is unavailable.

Most of European flights are made by aircraft equipped with GPS and RAIM.
SBAS (Satellite-Based Augmentation System)

SBAS is a wide coverage augmentation system in which the user receives augmentation from a satellite-based transmitter. SBAS augments the core satellite constellation by providing ranging, integrity and correction information via geostationary satellites. Unlike the global GNSSs, however, SBASs are limited to certain regions of the world. This system comprises a network of ground reference stations that observe the satellites’ signals, and master stations that process this observed data and generate SBAS messages for uplink to the geostationary satellites which, in turn, broadcast the SBAS message to the users.

SBAS systems implemented in several regions improves the accuracy, reliability and integrity of the GPS signal. GNSS-SBAS navigators that meet international organizations regulations (such as ICAO, FAA, Euro control) may be used for sole means of navigation for all phases of flight, including precision approach at airports.

The SBAS systems offer an opportunity for airports to gain Instrument Landing System (ILS) approach capability without the purchase or installation of any ground-based navigation equipment at the airport.

The SBAS vertically guided approach procedures are considered LPV (Localizer Performance with Vertical guidance) and provide ILS (Instrument Landing System) equivalent approach minimums as low as 200 feet at qualifying airports. Actual minimums are based on an airport’s current infrastructure, as well as an evaluation of any existing obstructions.

There are currently many SBASs that are of relevance to the aviation sector. Some of them that are in service are:

- WAAS (Wide Area Augmentation System) is the USA’s SBAS system.
- EGNOS (European Geostationary Navigation Overlay Service), the European Commission’s SBAS system. In Europe the EGNOS signal was formally declared available to aviation in March 2011. For the first time, space-based navigation signals augmented by this system have become officially usable for the critical task of vertically guiding aircraft during landing approaches.
- MSAS (Multi-functional Satellite Augmentation System), Japan’s SBAS system.
- SDCM (System for Differential Corrections and Monitoring) in Russia.
- GAGAN (GPS Aided Geo Augmented Navigation) in India.

These services are expected to be ‘interoperable’, meaning the receivers should interpret whichever signal(s) they ‘see’ providing an apparently seamless operation from one area of coverage to another.

SBAS sensors provide correction information via geostationary satellites. SBAS is a mandatory part of the software function of the ETSO C146 (c) standard receivers.
In an airborne receiver, three satellites are needed for a two-dimensional fix and four for a three-dimensional fix. The elevation above the horizon (mask angle) and the geometry of the satellites’ positions, relative to the receiver must meet certain alignment criteria before they are included in the navigation solution and the system accuracy can be achieved. One additional satellite is required to perform the FD RAIM function and a further (sixth satellite) is required for FDE RAIM. Where a GPS receiver uses barometric altitude to augment the RAIM function (so-called baro-aided) the number of satellites needed to perform the RAIM function may be reduced by one. If barometric altitude input is used to contribute to the RAIM function itself, loss of this altitude information should be indicated to the pilot by the RNAV system.

The term ‘WAAS’ also tends to be used in a wider generic reference to SBAS services.

![Figure 1 SBAS Architecture](image-url)
But what exactly is integrity?
In the context of GPS, integrity is the system’s own ability to identify when it may be unreliable for navigation and to provide timely and appropriate warning to the user. There always remains, of course, the possibility of a false alarm and a failure of the monitor itself, to provide such an alarm. Without integrity monitoring, the pilot has no assurance as to the accuracy of the GPS position.

GBAS (Ground-Based Augmentation System).
The United States version of the Ground-Based Augmentation System (GBAS) has traditionally been referred to as the Local Area Augmentation System (LAAS). The worldwide community has adopted GBAS as the official term for this type of navigation system. To coincide with international terminology, the FAA is also adopting the term GBAS to be consistent with the international community. GBAS is a ground-based augmentation to GPS that focuses its service on the airport area (approximately a 20–30 mile radius) for precision approach, departure procedures (DPs), and terminal area operations. It broadcasts its correction message via a very high frequency (VHF) radio data link from a ground-based transmitter. GBAS yields the extremely high accuracy, availability, and integrity necessary for Category I, II, and III precision approaches and provides the ability for flexible, curved approach paths. GBAS demonstrated accuracy is less than one meter in both the horizontal and vertical axis.

The GBAS augments the GPS to improve aircraft safety during airport approaches and landings. It is expected that the end state configuration will pinpoint the aircraft’s position to within one meter or less with a significant improvement in service flexibility and user operating costs.

GBAS is comprised of ground equipment and avionics.

The ground equipment includes four reference receivers, a GBAS ground facility, and a VHF data broadcast transmitter. This ground equipment is complemented by GBAS avionics installed on the aircraft. Signals from GPS satellites are received by the GBAS GPS reference receivers (four receivers for each GBAS) at the GBAS equipped airport. The reference receivers calculate their position using GPS. The GPS reference receivers and GBAS ground facility work together to measure errors in GPS provided position.

The GBAS ground facility produces a GBAS correction message based on the difference between actual and GPS calculated position. Included in this message is suitable integrity parameters and approach path information. This GBAS correction message is then sent to a VHF data broadcast (VDB) transmitter. The VDB broadcasts the GBAS signal throughout the GBAS coverage area to avionics in GBAS equipped aircraft. GBAS provides its service to a local area (approximately a 20–30 mile radius). The signal coverage is designed support the aircraft’s transition from en route airspace into and throughout the terminal area airspace. GBAS reference point, is typically located on the airport within three nautical miles of all supported runways.
Unlike SBASs, however, GBASs are generally limited in their use to the areas around airports.

GBASs are also seen as a supplement to (and a long-term replacement for) the present instrument landing systems (ILSs) used with airport runways. As such, GBASs provide the foundation for precision landings using satellite navigation technology. GBAS is the only feasible satellite-based navigation capability for Category II/III precision approach operations to permit low visibility operations to touchdown and rollout.

The Federal Aviation Administration (FAA) work program is now focused on validating standards for a GBAS Approach Service Type-D (GAST-D) (CAT-III minima) service. The program currently projects a GAST-D GBAS system can be available in 2018. It is assumed that all GBAS stations for CAT I operations will be upgraded to CATII/III operations.
GPS Approach equipment

To fly RNAV(GPS) approach, GPS equipment must be certified not just for IFR en-route and terminal navigation but also be approved for IFR approaches. One of the major differences between IFR-certified GPS avionics and other GPS systems is that IFR GPS avionics provide alerting by using Receiver Autonomous Integrity Monitoring (RAIM) algorithms to detect any system faults. Non-IFR certified GPS units do not have this alerting capability.

The primary types of equipment used to perform GPS approaches with vertical navigation are barometric vertical navigation (Baro-Vnav) systems or WASS-Certified GPS equipment.

Baro-VNAV

Baro-VNAV uses barometric altitude information from the aircraft’s pitot-static system and air data computer to compute vertical guidance for the pilot. The specified vertical path is typically computed between two waypoints or an angle from a single way point. When using baro-VNAV guidance, the pilots should check for any published temperature limitations on the approach chart which may result in approach restrictions.

Baro-VNAV equipment builds a glide path by sensing and then comparing the aircraft’s altitude with a calculated altitude for the aircraft’s position on the glide path. You must enter the current local altimeter setting on the GPS equipment to ensure an accurate glide path. In addition there are high and low temperature limitations for the use of baro-Vnav equipment.

Although in some respects a baro VNAV guided approach procedure is similar to an ILS in operation, a fundamental difference is that the actual vertical flight path is dependent upon measurement of air density which changes with ambient conditions. Consequently the actual vertical flight path will vary depending on the surrounding air mass conditions and the specified vertical flight path angle is relevant only to ISA conditions. In anything other than ISA conditions the actual flight path angle will be higher or lower than designed.
**WAAS certified GPS**
WAAS certified GPS equipment determines a glide path by its vertical and horizontal GPS position and eliminates the errors caused by barometric altimetry. This equipment computes a glide path independent of the altimetry settings and its operation is not limited by temperature.

**BASIC IFR EN-ROUTE AND APPROACH CERTIFIED EQUIPMENT**
CERTIFIED BY: TSO-C129()
APPROVED FOR: Lateral Navigation

Destination Airport: May perform an RNAV (GPS) approach. Not required to monitor or have ground-based navigation equipment.

Alternate Airport: May perform an RNAV (GPS) approach. Instrument approach procedure other than GPS and appropriate navigation equipment required. That is, in addition to checking RAIM availability and GPS NOTAMs, if an alternate airport is required, this airfield must have a non-GPS approach and the ground-based and associated aircraft navigation equipment installed and operational.

**WAAS-CERTIFIED EQUIPMENT**
CERTIFIED BY: TSO-C145() OR TSO-C146()
APPROVED FOR: Lateral and Vertical Navigation

Destination Airport: May perform an RNAV (GPS) approach. Not required to monitor or have ground-based navigation equipment. Must use Lateral navigation (LNAV) minimums for flight planning.

Alternate Airport: May perform an RNAV (GPS) approach. Not required to have Instrument approach procedure other than GPS. Must use lateral navigation (LNAV) minimums for flight planning.
Approach Procedure Types

The three instrument approach procedure (IAP) types are based on the final approach course guidance provided and are further classified according to the primary navigation system:

**Precision Approach (PA)**

Precision Approach (PA) – provides lateral guidance and vertical guidance in the form of a glide slope. This approach provides the most accurate guidance and must meet specific standards of precision and integrity limits. The most common precision approach is the ILS. Other precision approaches are PAR (Precision Approach Radar) and GLS (GBAS Landing System).

**Approach with Vertical Guidance (APV)**

Approach with vertical guidance (APV) - sometimes referred to as “semi-precision” - provides lateral guidance and vertical guidance in the form of a glide path display. APVs do not meet precision approach criteria to be classified as precision approaches. RNAV(GPS) and RNAV (RNP) approaches that use vertical guidance are APVs. Baro-Vnav, LDA with Glide Path, Lnav/Vnav and LPV are APV approaches. (see later).

There are actually two types of APV procedure, APV/SBAS and APV/Baro, which use different sensors to provide the vertical guidance during the approach. Both approaches use RNAV onboard the aircraft (which may be part of the FMS) and do not rely on ground navigation infrastructure such as an ILS. They are published on an approach chart titled RNAV (GNNS), RNAV(GPS) which have several different minima lines.

APV Baro; Is a vertically guided approach that can be flown by modern aircraft with VNAV functionality using barometric inputs. Most Boeing and Airbus aircraft already have the capability meaning that a large part of the fleet is already equipped.

APV/SBAS; Is supported by satellite based augmentation systems such as WAAS in the USA to provide lateral and vertical guidance. The lateral guidance is equivalent to an ILS localizer and the vertical guidance is provided against a geometrical path in space rather than a barometric altitude.

**Non precision approach (NPA)**

Nonprecision approach (NPA) – provides only lateral guidance. Examples of nonprecision approaches include localizer, VOR, and NDB approaches and RNAV (GPS) approaches without vertical guidance.
**Some definitions**

**TAA (Terminal Arrival Area)**
The objective of the Terminal Arrival Area (TAA) is to provide a new transition method for arriving aircraft equipped with FMS and/or GPS navigational equipment. [Figure 3]. The TAA contains within it a “T” structure that normally provides a NoPT (No Procedure Turn) for aircraft using the approach. The Basic T approach segment configuration is the standard configuration for transition from the en-route to the terminal environment. The TAA provides the pilot and air traffic controller with an efficient method for routing traffic from en-route to terminal structures. TAAs may appear on both current and new format GPS and RNAV IAP charts. The TAA normally consists of three areas: the straight-in area, the left base area, and the right base area. Operating procedures for the TAA are contained in the Aeronautical Information Manual (AIM).

**ATS ROUTE (AIR TRAFFIC SERVICES) route**
ATS ROUTE (AIR TRAFFIC SERVICES) route is a specified route designed for channeling the flow of traffic as necessary for the provision of air traffic services. The term 'ATS route' is used to mean variously, airway, advisory route, controlled or uncontrolled route, arrival or departure route, etc.

**Visual Glide Slope Indicator (VGSI)**
VGSI is a ground device that uses lights to assist a pilot in landing an airplane at an airport. (e.g. VASI, PAPI)

**Continuous Descent Final Approach (CDFA)**
CDFA is a technique for flying the final approach segment of an NPA as a continuous descent. The technique is consistent with stabilized approach procedures and has no level-off. A CDFA starts from an altitude/height at or above the FAF and proceeds to an altitude/height approximately 50 feet (15 meters) above the landing runway threshold or to a point where the flare maneuver should begin for the type of aircraft being flown. This definition harmonizes with the ICAO and the European Aviation Safety Agency (EASA).

**Operation Specifications (Op Specs)**
FAA: The standard paragraphs for parts 121, 125, 135, and 145 are called operations specifications (OpSpecs).
RNAV (Area Navigation)

Area navigation (RNAV) is a method of navigation which permits aircraft operation on any desired flight path within the coverage of ground-based or spaced-based navigation aids or within the limits of the capability of self-contained aids, or a combination of these. An RNAV system may be included as part of a flight management system (FMS). Note— Area navigation includes performance-based navigation as well as other operations that do not meet the definition of performance-based navigation.

RNAV Approach Types

RNAV encompasses a variety of underlying navigation systems and, therefore, approach criteria. This results in different sets of criteria for the final approach segment of various RNAV approaches. RNAV instrument approach criteria address the following procedures:

**GPS overlay** of pre-existing non precision approaches. These are procedures that are based on pre-existing non precision approaches. For instance the title VOR/DME or GPS A denotes that the procedure can be used as a GPS approach or as a traditional VOR/DME approach. These GPS non-precision approaches are predicated upon the design criteria of the ground-based NAVAID used as the basis of the approach. As such, they do not always adhere to the RNAV design criteria for stand-alone GPS approaches, and are not considered part of the RNAV (GPS) approach classification for determining design criteria. Many GPS overlay procedures have been replaced by stand —alone GPS or RNAV(GPS) procedure.

**VOR/DME based RNAV approaches.** These approaches use collocated VOR and DME information to construct RNAV approaches and are named VOR/DME RNAV RWY XX where XX stands for the runway number for which the approach provides guidance.

A.I.M &1-2-3. (There is a change effective since May 2016)

Use of a suitable RNAV system as a means to navigate on the final approach segment of an instrument approach procedure based on a VOR, TACAN or NDB signal, is allowable. The underlying NAVAID must be operational and the NAVAID monitored for final segment course alignment.

For the purpose of paragraph c, “VOR” includes VOR, VOR/DME, and VORTAC facilities and “compass locator” includes locator outer marker and locator middle marker.

**Stand-alone RNAV (GPS) approaches.** These procedures are not based on any other procedures, but they may replace other procedures. The naming convention used for stand-alone GPS approaches is “GPS RWY XX”. The coding for the approach in the database does not accommodate multi-sensor FMSs because these procedures are designed only to accommodate aircraft using GPS equipment. These procedures will eventually be converted to RNAV (GPS) approaches. The number of GPS stand-
alone approaches continues to decrease as they are replaced by RNAV approaches. RNAV (GPS) approaches are named so that airborne navigation databases can use either GPS or RNAV as the title of the approach. The plan view of the stand-alone GPS procedures uses a “T” design to develop more standardized final and missed approach fix location based on RNAV criteria. [Figure 3]

For a non-vertically guided straight-in RNAV (GPS) approach, the final approach course must be aligned within 15° of the extended runway centerline. The final approach segment should not exceed 10 NM, and when it exceeds 6 NM, a stepdown fix is typically incorporated. A minimum of 250 feet obstacle clearance is also incorporated into the final approach segment for straight-in approaches, and a maximum 400-Feet Per Nautical Mile (FPNM) descent gradient is permitted.

**RNAV (GPS) approaches with vertical guidance (APV).** (See later)

**RNAV (RNP) approaches.** (See later)

**GLS precision approaches.** (See later)

Where multiple RNAV procedures exist to the same runway, subsequent RNAV procedure titles will be “RNAV Z RWY 22,” “RNAV Y RWY 22. ATC clearance for the RNAV procedure will authorize the pilot to utilize any landing minimums for which the aircraft is capable, or the pilot and aircraft have been authorized.

RNAV (GPS) approaches may offer several lines of minima [Figure 7] to accommodate varying levels of aircraft equipage and airport environments without requiring additional navigation equipment at the airport. This promotes airport efficiency and access, pilot flexibility and operational safety.
Figure 3
PBN (Performance Based Navigation) is area navigation based on performance requirements for aircraft operating along an ATS route, on an instrument approach procedure or in a designated airspace. Note. — Performance requirements are expressed in navigation specifications in terms of accuracy, integrity, continuity, availability and functionality needed for the proposed operation in the context of a particular airspace concept.

Required navigation performance (RNP) RNAV approaches are basically defined as RNAV approaches within a performance based navigation concept.

In early 2013, the ICAO PBN Manual contains 11 navigation specifications: 4 of these are RNAV specifications and 7 of these are RNP specifications:
The PBN Manual also defines additional functionalities (required or optional) which can be used in association with several of the navigation specifications:

Note: The old European Basic RNAV (B-RNAV) is now known as RNAV 5. The old Precision RNAV (P-RNAV) is closest to RNAV 1 and the main difference is that P-RNAV permits the use of VOR/DME in limited circumstances.

This concept means that the airplane is able to fly the RNAV approach trajectory and to meet the specified RNP criterion — for example, RNP 0.15 nm. Thus, the airplane’s navigation system has to monitor its Actual Navigation Performance (ANP) — typically, total navigation error, including system and flight technical error — and has to show whether the RNP is actually being met during the approach. The performance-based navigation concept ensures that the airplane remains “contained” within a specific volume of airspace, without requiring an outside agent to monitor its accuracy and integrity. This concept provides great flexibility for approach designers; indeed, the notion of the approach may be either straight or curved but are all geographically defined. The approach vertical path is a constant angle.

Herein lies the essential difference between an RNAV and an RNP navigation specification. An RNAV specification requires no on-board augmentation of the navigation solution whereas RNP specification does. All the RNAV (GNSS) approach procedures published in the UK are compliant with the PBN Navigation Specification.
RAIM (Receiver Autonomous Integrity Monitoring) is a form of augmentation that enables a GPS system to be RNP compliant.

RNP is a means of specifying the performance for a particular type of operation. In order to meet a particular performance level a number of requirements must be met.

a) **Accuracy**: Position accuracy can be defined as the probability that the computed position will be within a specified distance of the actual position. This performance measure assumes that the reliability of the computation (i.e. the system is operating within its specification without fault).

b) **Integrity**: Integrity for aviation purposes which are safety critical we must be assured that the navigation system can be trusted. Even though we may be satisfied as to the accuracy of the determination of position, we must also ensure that the computation is based on valid or “trusted” information. Various methods (e.g. RAIM) are used to protect the position solution against the possibility of invalid position measurements.

c) **Availability**: Availability means that the system is usable when required. For GNSS operations, unless augmented, availability is high but normally less than 100%. Operational means are commonly needed to manage this limitation.

d) **Continuity**: Continuity refers to the probability that a loss of service will occur whilst in use. For RNP operations the navigation system must meet accuracy and integrity requirements but operational procedures may be used to overcome limitations in availability and continuity.

In addition to the four performance parameters RNP also requires **on-board performance monitoring and alerting**. In practice, RNP capability is determined by the most limiting of the characteristics listed above. In the general case RNP is based on GNSS. The position accuracy for GNSS is excellent and can support operations with low RNP. The lowest current RNP in use is RNP 0.10, although considering position accuracy alone, GNSS would be able to support lower RNP. However it will be recalled that accuracy is also dependent on FTE (Flight Technical Error) and this component is by far the dominant factor. Consequently, the RNP capability of GNSS equipped aircraft is dependent not on navigation system accuracy, but the ability for the aircraft to follow the defined path. FTE is commonly determined by the ability of the aircraft flight control system, and the lowest FTE values are commonly achieved with auto-pilot coupled. A further consideration is the requirement for on-board performance monitoring and alerting. For GNSS systems, navigation system performance monitoring and alerting is automatic. Except in some specific installations, FTE monitoring and alerting is a crew responsibility, and the ability of the crew to perform this function depends on the quality of information displayed to the crew. While an aircraft may be capable of a particular RNP capability, it is not always necessary or desirable that the full capability is applied. In addition to the consideration of accuracy and performance monitoring, the operation must always
be protected against invalid positioning information, i.e. integrity is required. In order to support low RNP operations, an appropriate level of integrity protection is necessary. The lower the RNP type, the greater level of integrity protection is required, which in turn reduces the availability and continuity of the service. Consequently a trade-off needs to be made between the RNP selected and availability. ICAO PBN Manual (Performance Based Navigation Manual) specifications, are based on a level of navigation performance appropriate to the intended purpose, rather than the inherent capability of the navigation system. For example a GNSS equipped aircraft has very high positioning accuracy, and if flown using autopilot exhibits low FTE, however for terminal SID/STAR operations, RNP 1 is adequate for the intended purpose, resulting in virtually 100% availability, and reduced crew workload in FTE performance monitoring.

Performance Components

Navigation performance is computed by considering the following components:

**Navigation System Error (NSE).** Sometimes called PEE or Position Estimation Error, this value represents the capability of the navigation avionics to determine position, relative to the aircraft’s actual position. NSE is dependent on the accuracy of the inputs to the position solution, such as the accepted accuracy of DME or GNSS measurements.

**Flight Technical Error (FTE).** Also referred to as Path Steering Error, this value represents the ability of the aircraft guidance system to follow the computed flight path. FTE is normally evaluated by the aircraft manufacturer based on flight trials, although in cases where the manufacturer is not able to provide adequate data the operator may need to collect in-service data. FTE values will usually vary for a particular aircraft depending on the flight control method, and for example, a lower FTE may be applicable to operations where the autopilot is coupled compared to the FTE for manual flight using flight director. This variation may in turn lead to different overall performance values depending on the method of control.

Flight technical error (FTE) is a measure of how well the airplane is tracking the lateral and vertical paths estimated by the navigation system. The flight crew observes FTE with deviation scales by using digital CDU readouts or by noting how far the airplane symbol on the navigation display is off the route. FTE is the one component of the error budget that can be controlled by the flight crew. To ensure that the airplane remains on the desired path, the flight crew limits the errors in total navigation performance over which it has control and monitors the errors that it cannot control. FTE can be controlled by the flight crew and should be minimized. Navigation system error cannot be controlled by the flight crew but should be monitored to ensure that it remains within acceptable limits.

**Path Definition Error (PDE).** An area navigation route is defined by segments between waypoints. The definition of the path therefore is dependent on the
resolution of the waypoint, and the ability of the navigation system to manage the waypoint data. However, as waypoints can be defined very accurately, and a high level of accuracy is able to be managed by most navigation systems this error is minimal and is generally considered to be zero. Path computation (Definition) error is a measure of how closely the airspace definition of the flight path matches that used by the FMC. Path computation error cannot be monitored or controlled but generally is sufficiently small that it can be ignored.

**Total System Error (TSE)** is computed as the **statistical** sum of the component errors. An accepted method of computing the sum of a number of independent statistical measurements is to compute **the square root of the sum of the squares** of the component values, or the Root Sum Square (RSS) method.

### RNP versus ANP (Actual Navigation Performance)

If RNP is a measure of how good the airplane’s navigation system must be, then ANP is the estimated real-time measure of how good the airplane’s navigation system actually is. Whereas RNP defines the allowable airplane error in terms of distance and probability relative to the procedurally defined path, ANP is based on probable airplane position determination and on guidance errors.

Neither RNP nor ANP contains any data that indicate how close the airplane is flying to the desired track.

RNP tells the flight crew how accurate the navigation system needs to be, and ANP tells the flight crew how accurate the system currently is. RNP and ANP do not indicate to the crew where the airplane is relative to the center of the desired flight path. To explain how ANP and RNP relate to the relative position of the airplane requires a discussion of the concept of error budget.

On Boeing airplanes, multiple sources of navigation data are integrated to determine the system navigation solution. Inertial systems initially are very accurate but may tend to drift if not updated accurately throughout the flight. Global positioning system (GPS) units generally provide exceptionally accurate data but must be monitored for undetected failures and lack of satellite coverage. Ground-based radio navigation aids vary in accuracy and availability. These sources of data are analyzed continuously by the FMC to calculate the best estimate of current airplane position and estimated airplane position uncertainty. If any one source is deleted, the confidence in the navigation position will decrease. Thus, the ANP value will increase. Displaying ANP can be a great help to the flight crew when trying to verify airplane position because the crew no longer must tune, identify, and cross-plot navigation aids. The FMC logic uses the best sources of data available to provide the flight crew with a real-time navigation solution.

For example, an ANP value of 0.06 nmi means that the airplane very probably is within a 720-ft-diameter circle of its estimated position. **If this is the only error** in
the total navigation system, the runway probably will be at most 360 ft to the left or right when the airplane breaks out of the clouds at the minimum descent altitude.

Recommended: Boeing aero magazine, Lateral and Vertical Navigation, 2001

**RNP APCH (RNP Approach)**

RNP APCH is defined as an RNP approach procedure that requires a latera TSE (Total System Error) of +/- 1 NM (a standard navigation accuracy of 1.0 NM) in the initial, intermediate and missed approach segments (MAS) and a lateral TSE of ±0.3 NM in the FAS (Final Approach Segment).

**NOTE**: The instrument approach procedures associated with RNP APCH are entitled RNAV (GNSS) to reflect that GNSS is the primary navigation system. With the inherent onboard performance monitoring and alerting provided by GNSS, the navigation specification qualifies as RNP, however these procedures predate PBN, so the chart name has remained as RNAV.

**RNP AR APCH (RNP Authorization Required Approach)**

RNP AR APCH where previously known as Special Aircraft and Aircrew Authorization Required or SAAAR approach procedures.

RNP AR APCH is defined as an RNP approach procedure that requires a lateral TSE as low as ±0.1 NM on any segment of the approach procedure [Figure 5]. RNP AR APCH procedures also require that a specific vertical accuracy be maintained as detailed in the ICAO PBN Manual (Performance Based Navigation Manual). The vertical datum for RNP AR procedures is the landing threshold point (LTP). The RNP AR APCH criteria apply only to those aircraft and operators complying with specified additional certification, approval and training requirements. RNP AR APCH procedures are only published where significant operational advantages can be achieved while preserving or improving safety of operation.

RNP AR APCH procedures may be designed to support multiple minima for various appropriate RNP, e.g. RNP 0.3, RNP 0.2, down to RNP 0.1. However, designers should not promulgate procedures with RNP less than 0.3 unless there is an operational benefit. Reductions in RNP reduce the alert limits and increase the possibility of an alert and a consequent go-around; therefore, the minimum RNP published should not be smaller than necessary to provide the required operational capability.

The RNP AR certification and approval requirements are contained in the PBN Manual. For the purposes of applying the criteria contained in this manual, RNP levels address obstacle protection associated with RNP values. The RNP level is used to determine the area semi-width value (in NM) of a protection area associated with a segment of an instrument procedure RNP availability check. Prior to the commencement of an approach, the crew is responsible for ensuring that the appropriate RNP is selected. The highest RNP consistent with the operating
conditions should be selected to reduce the possibility of alerts and consequent missed approaches.

Crews will ensure prior to commencement of a procedure that the required navigation system performance is available and can be expected to be available through the conduct of the procedure. RNP should not be changed after commencement of the procedure.

All RNP AR approaches have reduced lateral obstacle evaluation areas and vertical obstacle clearance surfaces predicated on the aircraft and aircrew performance requirements. The following characteristics differ from RNP APCH:

- RF leg segments may be used after PFAF (precise final approach fix).
- Lateral TSE values as low as 0.10 NM on any segment of the approach procedure (initial, intermediate, final or missed).

Note: Precision approach and landing systems such as the Instrument Landing System (ILS), Microwave Landing System (MLS) and GNSS Landing System (GLS) form part of the navigation suite, but are not included within the concept of PBN. Whilst GLS is based on satellite navigation, it differs from PBN applications in that it is not based on area navigation techniques.

Approach applications based on GNSS are classified RNP Approach (RNP APCH) in accordance with the PBN concept and include existing RNAV (GNSS) approach procedures designed with a straight segment. The flight deck displays and charting will likely retain the RNAV (GNSS) label for some time and until standardisation can be achieved, pilots should expect to use the terms RNP APCH and RNAV (GNSS) interchangeably.
RNAV versus RNP

A Navigation Specification is either a Required Navigation Performance (RNP) specification or an RNAV specification. An RNP specification includes a requirement for On board Performance Monitoring and Alerting (OPMA) where the receiver provides an alert to the flight crew if the navigation position is in error, while an RNAV specification does not.

Performance Based Navigation Performance Based Navigation encompasses a range of operations which are all based upon Area Navigation. Area navigation, commonly abbreviated as RNAV, has been available for around 30 years using a variety of technologies, however some difficulties arise in the dual application of the term RNAV as a fundamental method of navigation (area navigation) and also as a particular type of operation (e.g. RNAV 5). Further complications arise with the implementation of Required Navigation Performance (RNP) operations which by definition are also area navigation operations. There has been some difficulty in identifying the differences between RNAV operations and RNP operations, and some lack of definition in the requirements for both RNAV and RNP operations. A number of regions established local RNAV and RNP standards which led to complexity in international operations and operational approvals.

ICAO established the Required Navigation and Special Operational Requirements Study Group (RNPSORSG) to resolve these issues. The RNPSORSG (now called the PBN Study Group) developed the concept of Performance Based Navigation to encompass both RNAV and RNP operations. One of the issues that the RNPSORSG had to deal with was to differentiate between area navigation operations which are described as either RNAV or RNP. It was recognized that while both RNAV and RNP operations could be described in terms of navigation performance (e.g. accuracy), RNP operations can be identified by the capability of the onboard navigation system to monitor in real time the achieved navigation performance and to alert the operating crew when the specified minimum performance appropriate to a particular operation could not be met. This additional functionality provided by RNP allows the flight crew to intervene and to take appropriate mitigating action (e.g. a go-round), thereby allowing RNP operations to provide an additional level of safety and capability over RNAV operations. As GNSS systems incorporate performance monitoring and alerting, the distinction between RNAV and RNP operations in practice is the requirement for GNSS. While there are exceptions to this rule, in simple terms RNP operations are GNSS based, and for RNAV operations are based on older technology. RNAV navigation specifications have been developed to support existing capability in aircraft equipped with systems which in the general case were not designed to provide onboard performance monitoring and alerting.
Figure 4
Figure 5
Do not use for flight.
**TSO (Technical Standard orders) / ETSO (European TSO) authorizations**

**GNSS stand-alone navigation systems**

If the RNAV installation is based on GNSS stand-alone system, the equipment shall be approved in accordance with TSO-C129a/ETSO-C129a Class A1 or ETSO-C146()/TSO(C146) Class Gamma, operational class 1, 2 or 3.

**Multi-sensor navigation systems**

If the RNAV installation is based on GNSS sensor equipment used in a multi-sensor system (e.g. FMS), the GNSS sensor shall be approved in accordance with TSO-C129()/ETSO-C129() Class B1, C1, B3, C3 or ETSO-C145()/TSO-C145() class Beta, operational class 1, 2 or 3.

Multi-sensor systems using GNSS should be approved in accordance with AC20-138C or TSO-C115c/ETSO-C115c, as well as having been demonstrated for RNP capability.

**RNP in other words**

The operational advantages of RNP include accuracy, onboard performance monitoring and alerting which provide increased navigation precision and lower minimums than conventional RNAV. RNP DAs can be as low as 250 feet with visibilities as low as 3/4 SM. Besides lower minimums, the benefits of RNP include improved obstacle clearance limits, as well as reduced pilot workload. When RNP capable aircraft fly an accurate, repeatable path, ATC can be confident that these aircraft are at a specific position, thus maximizing safety and increasing capacity.

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 [Figure 5 & 6]. The introduction of RF legs into the design of terminal RNAV procedures results in improved use of airspace and allows procedures to be developed to and from runways that are otherwise limited to traditional linear flight paths or, in some cases, not served by an IFR procedure at all. Navigation systems with RF capability are a prerequisite to flying a procedure that includes an RF leg. Refer to the notes box of the pilot briefing portion of the approach chart in [Figure 8].
In the United States, operators who seek to take advantage of RNP approach procedures must meet the special RNP requirements outlined in FAA AC 90-101, Approval Guidance for RNP Procedures with Authorization Required (AR). Currently, most new transport category airplanes receive an airworthiness approval for RNP operations. However, differences can exist in the level of precision that each system is qualified to meet. Each individual operator is responsible for obtaining the
necessary approval and authorization to use these instrument flight procedures with navigation databases.

RNP required sensors, FMS capabilities, and relevant procedure notes are included in the Pilot Briefing Information procedure notes section. [Figure 8] RNP AR requirements are highlighted in large, bold print. RNP procedures are sequenced in the same manner as RNAV (GPS) procedures. Procedure title “RNAV” includes parenthetical “(RNP)” terminology. RF legs can be used in any segment of the procedure (transition, intermediate, final, or missed approach). RF leg turn directions (left or right) are not noted in the plan view because the graphic depiction of the flight tracks is intuitive. Likewise, the arc center points, arc radius, and associated RF leg performance limits, such as bank angles and speeds are not depicted because these aircraft performance characteristics are encoded in the navigation database. RNP values for each individual leg of the procedure, defined by the procedure design criteria for containment purposes, are encoded into the aircraft’s navigation database. Applicable landing minimums are shown in a normal manner along with the associated RNP value in the landing minimums section.

When more than one set of RNP landing minimums is available and an aircrew is able to achieve lower RNP through approved means, the available (multiple) sets of RNP minimums are listed with the lowest set shown first; remaining sets shown in ascending order, based on the RNP value. On this particular procedure, lateral and vertical course guidance from the DA to the Runway Waypoint (LTP) is provided by the aircraft’s FMS and onboard navigation database; however, any continued flight below the DA to the landing threshold is to be conducted under VMC. [Figure 8]

**RNAV Approach Authorization**

The authorization to use VNAV on a conventional non-precision approach, RNAV approaches, or LNAV/VNAV approaches is found in that operator’s Op Specs, AFM (Aircraft Flight Manual), or other FAA-approved documents. There are many different levels of authorizations when it comes to the use of RNAV approach systems. The type of equipment installed in the aircraft, the redundancy of that equipment, its operational status, the level of flight crew training, and the level of the operator’s FAA authorization are all factors that can affect a pilot’s ability to use VNAV information on an approach.

Because most Part 121, 125, 135, and 91 flight departments include RNAV approach information in their pilot training programs, a flight crew considering an approach to North Platte, Nebraska, using the RNAV (GPS) RWY 30 approach shown in [Figure 9] would already know which minimums they were authorized to use.

The company’s OpSpecs (Operation Specifications), FOM (Flight Operations Manual), and the AFM (Aircraft Flight Manual) for the pilot’s aircraft would dictate the specific operational conditions and procedures by which this type of approach could be flown. For example your company may not have authorization to fly...
approaches with vertical guidance. The luck of authorization may be found in the Opspecs of the company.

There are several items of note that are specific to this type of approach that should be considered and briefed. One is the Terminal Arrival Area (TAA) that is displayed in the approach plan view. TAAs, depict the boundaries of specific arrival areas, and the Minimum IFR Altitude (MIA) for those areas. The TAAs should be included in an IAP (Instrument Approach Procedure) briefing in the same manner as any other IFR transition altitude. It is also important to note that the altitudes listed in the TAAs should be referenced in place of the MSAs on the approach chart for use in emergency situations. For RNAV approaches with a TAA the MSA (Minimum Safe/Sector Altitude) circle is replaced with a reference to the TAA 30nm boundary within witch you proceed to an IAF (Initial Approach Fix). [Figure 9]

In addition to the obvious differences contained in the plan view of [Figure 9], RNAV (GPS) approach procedure example, pilots should be aware of the issues related to Baro- VNAV and RNP. The notes section of the procedure in the example contains restrictions relating to these topics.
Figure 10
Approaches and landing minimums

An RNAV (GPS) approach chart might indicate several different landing minimums for the approach based on whether the procedure uses vertical guidance. The GPS equipment only displays the approach procedures available for the particular equipment capabilities. For example, if your GPS equipment is not WASS-Certified, approach procedures that incorporate landing minimums based on vertical guidance are not available for you to select and activate. You use the appropriate minimums for the approach based on the GPS equipment capabilities.

LNAV

This is a Non-Precision or 2D Approach with Lateral only navigation guidance provided by GNSS and an Aircraft Based Augmentation System (ABAS). Receiver Autonomous Integrity Monitoring (RAIM) is a form of ABAS. Lateral guidance is linear with accuracy to within +/- 0.3 NM parallel to either side of the final approach track. LNAV course guidance has larger limits than those of a localizer. An RNAV approach chart that just depicts LNAV minimums means that the procedure is based on lateral guidance only [Figure 3]. You can fly approaches to LNAV minimums with GPS equipment certified for IFR approach procedures by TSO-C129. LNAV course guidance has larger integrity limits than those of a localizer. You fly the LNAV approach to an MDA (Minimum Descent Altitude).

LNAV+V

If you have WAASS certified GPS equipment, it might provide advisory vertical guidance for an LNAV approach indicated as LNAV+V on the GPS display. In this case the landing minimum is still MDA even though the GPS receiver shows a vertical path that provides a stabilized descent. It is your responsibility to ensure compliance with altitude restrictions. Advisory vertical guidance is an optional capability implemented at the manufacturer’s discretion; not a requirement for GPS equipment. The type of equipment required is WASS GPS or Baro-VNAV (for advisory vertical guidance). Integrity limits are larger than localizer.

Depending on the manufacturer, WAAS-enabled GPS units might provide advisory vertical guidance in association with LP or LNAV minima. The manufacturer should use a notation to distinguish advisory vertical guidance (e.g. LNAV+V). The system includes an artificially created advisory glide path from the final approach fix to the touchdown point on the runway. The intent is to aid the pilot in flying constant descent to the MDA. LNAV+V is not the same as LNAV/VNAV or LPV.

LNAV/VNAV

This is a 3D Approach Procedure with Vertical Guidance (APV). Lateral navigation /Vertical Navigation landing minimums apply to approaches that provide lateral and vertical guidance that is displayed using baro_Vnav or WAAS –certified equipment. The integrity limits for LNAV/VNAV approaches are larger than those of a precision
approach. However, the LNAV/VNAV landing minimum is a DA, not an MDA.

LNAV/VNAV (lateral navigation/vertical navigation) equipment is similar to ILS in that it provides both lateral and vertical approach course guidance. Since precise vertical position information is beyond the current capabilities of the global positioning system, approaches with LNAV/VNAV minimums make use of certified barometric VNAV (baro-VNAV) systems for vertical guidance and/or the wide area augmentation system (WAAS) to improve GPS accuracy for this purpose. (Note: WAAS makes use of a collection of ground stations that are used to detect and correct inaccuracies in the position information derived from the global positioning system. Using WAAS, the accuracy of vertical position information is increased to within 3 meters.) To make use of WAAS, however, the aircraft must be equipped with an IFR approved GPS receiver with WAAS signal reception that integrates WAAS error correction signals into its position determining processing. It is very important to know what kind of equipment is installed in an aircraft, and what it is approved to do. It is also important to understand that the VNAV function of non-WAAS-capable or non-WAAS-equipped IFR approved GPS receivers does not make the aircraft capable of flying approaches to LNAV/VNAV minimums. Lateral guidance is normally linear with accuracy to within +/- 0.3 NM parallel to either side of the final approach track. If the vertical guidance is provided by a Barometric Altimeter then that type of approach is commonly known as APV/Baro VNAV. When conducting these operations to a DA, the pilot must adhere to any procedural temperature limitations unless employing temperature compensation under an authorization from ATC [Figure 7]

Airplanes that are commonly approved in these types of operations include Boeing 737NG, 767, and 777, as well as the Airbus A300 series. Landing minimums are shown as DAs because the approaches are flown using an electronic glide path. Other RNAV systems require special approval. In some cases, the visibility minimums for LNAV/VNAV might be greater than those for LNAV only. This situation occurs because DA on the LNAV/VNAV vertical descent path is farther away from the runway threshold than the LNAV MDA missed approach point.

**LPV (Localizer Performance with Vertical Guidance)**

This is an Approach Procedure with Vertical Guidance (APV). The Lateral and Vertical guidance is provided by GPS and SBAS. Lateral and vertical guidance are angular with increasing sensitivity as the aircraft progresses down the final approach track; much like an ILS indication. An LPV approach is an approach procedure designed specifically for SBAS environments. WAAS/LPV procedures are RNAV approaches defined by the FAA as one of four possible lines of approach minimums found on an RNAV approach chart.

The terms SBAS Approach or SBAS approach operations are used interchangeably with WAAS/LPV approach, or simply, LPV approach.
Localizer Performance with Vertical Guidance (LPV) minimums are also provided for RNAV (GPS) approach procedures that have vertical capability. These minimums apply to approaches that provide lateral and vertical guidance with integrity limits close to an ILS precision approach. **The LPV landing minimum is a DA.** Your GPS equipment must be WAAS-certified to fly approaches to LPV minimums; **Baro-Vnav equipment does not provide the required precision.** If WASS is not available you must fly the approach to LNAV minimums; **WAAS capability does not downgrade from LPV precision to LNAV/VNAV integrity.** The lateral guidance is equivalent to localizer accuracy, and the protected area is considerably smaller than the protected area for the present LNAV and LNAV/VNAV lateral protection.

Pilots can take advantage of the improved accuracy of Wide Area Augmentation System (WAAS) lateral and vertical guidance with LPV minimums. Pilots fly to a decision altitude (DA) and the angular guidance provided increases in sensitivity as the aircraft gets closer to the runway (or point in space for helicopters). To aid pilots in transferring their ILS flying skills to these vertically guided RNP approaches, lateral and vertical deviations are nearly identical at similar distances. As of February 2016 there are over 3,600 LPV lines of minima serving 1,762 airports.

**LP (Localizer Performance)**

This is a Non-Precision or 2D Approach with Lateral only navigation guidance provided by GNSS and SBAS. The EGNOS is a form of SBAS in Europe. The lateral guidance is angular with increasing sensitivity as the aircraft continues along the final approach track; much like a localizer indication. Approaches to localizer performance minimums are commonly referred to as WAAS procedures without vertical guidance.

**You cannot use baro-VNAV equipment to fly approaches to LP minimums.** These approaches have integrity limits close to a localizer and have smaller lateral protection areas than approaches to LNAV minimums. **LP and LPV minimums are NOT published as part of the same approach**—each procedure has a different WASS channel. This means that you cannot perform an LPV approach with vertical guidance and, upon loosing WASS capability, switch to an LP approach. The LP minimum is an MDA that is associated with a similar non precision approach procedure. This altitude is often lower than an MDA that is associated with a similar non precision approach. Some MDAs are as low as 300ft above touchdown. RNAV (GPS) approaches to LP minimums are typically published in locations where vertical guidance is not feasible due to terrain, obstacles or other operations limitations.

Both LP and LNAV lines of minima are Minimum Descent Altitudes (MDA) rather than DAs. It is possible to have LP and LNAV minima published on the same approach chart. Based on criteria, designers should only publish LP minima if it provides lower minima than LNAV.
Pilots may use WAAS-enabled GPS systems for LNAV, but WAAS is not mandatory. WAAS equipment is mandatory for LP. LP minima are added in locations where terrain or obstructions do not allow publication of vertically guided LPV minima. Lateral sensitivity increases as an aircraft gets closer to the runway (or point in space for helicopters). LP is not a fail-down mode for LPV; LP and LPV are independent. LNAV is not a fail-down mode for LP. LP will not be published with lines of minima that contain approved vertical guidance (i.e. LNAV/VNAV or LPV) [Figure 11].

As of February 2016 there are over 600 LP lines of minima at 436 airports and over 6,000 LNAV lines of minima at 2,747 airports.

### Landing minimums for RNAV (GPS) approach procedures

<table>
<thead>
<tr>
<th>RNAV (GPS) Approach Minimums</th>
<th>Type of Minimum</th>
<th>Type of equipment required</th>
<th>Guidance</th>
<th>Integrity limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNAV</td>
<td>MDA</td>
<td>GPS certified for IFR operations</td>
<td>Lateral only</td>
<td>Larger than a localizer</td>
</tr>
<tr>
<td>LNAV+V</td>
<td>MDA</td>
<td>WASS or baro-VNAV (for advisory guidance)</td>
<td>Lateral &amp; Advisory vertical guidance</td>
<td>Larger than a localizer</td>
</tr>
<tr>
<td>LNAV/VNAV</td>
<td>DA</td>
<td>WASS or baro-VNAV</td>
<td>Lateral &amp; Vertical</td>
<td>Larger than an ILS approach</td>
</tr>
<tr>
<td>LPV</td>
<td>DA</td>
<td>WASS</td>
<td>Lateral &amp; Vertical</td>
<td>Close to an ILS approach</td>
</tr>
<tr>
<td>LP</td>
<td>MDA</td>
<td>WASS</td>
<td>Lateral only</td>
<td>Close to a localizer</td>
</tr>
</tbody>
</table>
GLS (GBAS Landing System)

GLS is the official term for a GBAS instrument approach procedure. The individual procedures are published as GBAS Landing System (GLS) approaches. Each approach has a unique channel number identifier [Figure 12].

A single GBAS system is able to support multiple runways/approaches at the installed airport.

GBAS siting eliminates critical areas which impede aircraft/equipment movement around an instrumented airfield. This can improve airport capacity during low-visibility conditions.

Demonstrated accuracy of GBAS is less than 1-meter in both vertical and horizontal directions.

GBAS uses less radio frequency spectrum, with a single frequency supporting all system approaches.

GBAS is able to support use of displaced thresholds and/or variable glide slopes.

For a GLS approach a pilot selects the five digit number channel through the GLS Channel Number Selector. Alternatively he may select the GLS approach ID through the FMS of the airplane. The Approach ID is a unique 4-letter combination for verifying selection of the correct procedure.
Currently (2016) in Europe, GBAS Category I operations are implemented at the following airports: Bremen, Malaga, Frankfurt, Zurich.

GBAS further increases the accuracy of GPS and improves signal integrity warnings. Precision approach capability requires obstruction planes and approach lighting systems to meet standards for ILS approaches. This delays the implementation of RNAV (GPS) precision approach capability due to the cost of certifying each runway.

**What is the difference between GBAS and GLS?**
GBAS is the name of the navigation system which provides precision GBAS corrections from a ground-based transmitter. GBAS corrections can provide position, navigation, and precision approach services. GLS is the name assigned to the instrument approach procedure/capability provided by GBAS.

**GBAS avionics**
At least two manufactures have FAA approved GBAS avionics. These are Rockwell Collins' (Multi-Mode Receiver (MMR) GNLU 925 and GNLU 930 and Honeywell International's Integrated Navigation Receiver (INR).

In the air transport industry there are Integrated Multi-Mode Receivers (IMMR) that integrate instrument landing systems (ILS), global positioning systems (GPS), GBAS landing system (GLS) and VHF omnidirectional radio range (VOR) functionality into a single receiver.

Recommended: Boeing aero magazine, Global navigation satellite system, 2003
Bremen, Germany

D-ATIS 121.750
Bremen Radar (APP) 120.325
Bremen Tower 124.8

GBAS Final Apch Crs 266° Minimum Alt 214° Dw709 Dw710
Apt Elev 14' Dw709 1610' (1596') Dw710 214° (200') Rwy 14'

Missed Apch: Climb on 266° to Dw560, then turn LEFT direct to Dw561 and then to BMN climbing to 3000'.

Alt Set: If PAPI on req. Rwy Elev: 1 Aprt. Trans level: By ATC. Trans alt: 5000'.

Parts of IFR profiles within Airspace Class E. Watch out for VFR traffic unknown to ATC.

Do not use for flight.
Some more limitations

Approved Vertical Guidance

Approved vertical guidance provides operational benefit permitting the use of the LPV, LNAV/VNAV and ILS lines of minima. WAAS vertical guidance can support LPV minima as low as 200 feet AGL. Approved vertical guidance is available on LNAV/VNAV minima and existed before the WAAS system was certified. At that time, only aircraft equipped with a flight management system (FMS) and certified baro-VNAV systems could use the LNAV/VNAV minimums. Today, LNAV/VNAV minima may be flown using approved WAAS equipment. Pilots must use the barometric altimeter in a similar fashion for ILS, LPV, and LNAV/VNAV minima.

DME/DME RNP

For the RNAV (GPS) approach, the note “DME/ DME RNP-0.3 NA” prohibits aircraft that use only DME/ DME sensors for RNAV from conducting the approach. [Figure 10]

Because these procedures can be flown with an approach approved RNP system and “RNP” is not sensor specific, it was necessary to add this note to make it clear that those aircraft deriving RNP 0.3 using DME/DME only are not authorized to conduct the procedure.

The least accurate sensor authorized for RNP navigation is DME/DME. The necessary DME NAVAID ground infrastructure may or may not be available at the airport of intended landing. The procedure designer has a computer program for determining the usability of DME based on geometry and coverage. Where FAA flight inspection successfully determines that the coverage and accuracy of DME facilities support RNP, and that the DME signal meets inspection tolerances, although there are none currently published, the note “DME/DME RNP 0.3 Authorized” would be charted. Where DME facility availability is a factor, the note would read, “DME/DME RNP 0.3 Authorized; ABC and XYZ required,” meaning that ABC and XYZ DME facilities are required to assure RNP 0.3.

Hot and Cold Temperature Limitations

A minimum and maximum temperature limitation is published on procedures that authorize Baro−VNAV operation. These temperatures represent the airport temperature above or below which Baro−VNAV is not authorized to LNAV/VNAV minimums unless temperature compensation can be accomplished. As an example, the limitation will read, uncompensated Baro−VNAV NA below −21 °C (5 °F) or above 54 °C (130 °F) [Figure 13]. Extra caution should be used in the visual segment to ensure a vertical correction is not required. If the VGSI is aligned with the published glide path, and the aircraft instruments indicate on glide path, an above or below glide path indication on the VGSI may indicate that temperature error is causing
deviations to the glide path. These deviations should be considered if the approach is continued below the MDA.

Many systems which apply Baro–VNAV temperature compensation only correct for cold temperature. In this case, the high temperature limitation still applies. Also, temperature compensation may require activation by maintenance personnel during installation in order to be functional, even though the system has the feature. Some systems may have a temperature correction capability, but correct the Baro–altimeter all the time, rather than just on the final, which would create conflicts with other aircraft if the feature were activated. Pilots should be aware of compensation capabilities of the system prior to disregarding the temperature limitations.

No extrapolation above the 5000 ft column required. Pilots should use the 5000 feet “height above airport in feet” column for calculating corrections of greater than 5000 feet above reporting station. Pilots will add correction(s) from the table to the segment altitude(s) and fly at the new corrected altitude. PILOTS SHOULD NOT MAKE AN ALTIMETER CHANGE to accomplish an altitude correction.

Pilots with temperature compensating aircraft must ensure the system is on and operating for each segment requiring an altitude correction. Pilots must ensure they are flying at corrected altitude. If the system is not operating, the pilot is responsible to calculate and apply a manual cold weather altitude correction using the AIM 7-2-3 ICAO Cold Temperature Error Table.

![ICAO Cold Temperature Error Table](image)

**EXAMPLE** -

Temperature -10 degrees Celsius, and the aircraft altitude is 1,000 feet above the airport elevation. The chart shows that the reported current altimeter setting may place the aircraft as much as 100 feet below the altitude indicated by the altimeter.

Pilots must report cold temperature corrected altitudes to Air Traffic Control (ATC) whenever applying a cold temperature correction on an intermediate segment and/or a published missed approach final altitude. This should be done on initial radio contact with the ATC issuing approach clearance. ATC requires this information in order to ensure appropriate vertical separation between known traffic. ATC will not be providing a cold temperature correction to Minimum Vectoring Altitudes (MVA).
Pilots must not apply cold temperature compensation to ATC assigned altitudes or when flying on radar vectors in lieu of a published missed approach procedure unless cleared by ATC.

Pilots should query ATC when vectors to an intermediate segment are lower than the requested intermediate segment altitude corrected for temperature. Pilots are encouraged to self-announce corrected altitude when flying into uncontrolled airfields.

The following are examples of appropriate pilot-to-ATC communication when applying cold-temperature altitude corrections:

On initial check-in with ATC providing approach clearance: Hayden, CO [Figure 14]. [KHDN HAYDEN COLORADO RNAV GPS 28]

Intermediate segment: “Require 10600 ft. for cold temperature operations until BEEAR”.

Missed Approach segment: “Require final holding altitude, 10600 ft. on missed approach for cold temperature operations”

Pilots cleared by ATC for an instrument approach procedure; “Cleared the RNAV RWY 28 approach (from any IAF)”. Hayden, CO

Intermediate Segment: “Level 10600 ft. for cold temperature operations inside HIPNA to BEEAR

Pilots are not required to advise ATC if correcting on the final segment only. Pilots must use the corrected MDA or DA/DH as the minimum for an approach. Pilots must meet the requirements in 14 CFR Part 91.175 in order to operate below the corrected MDA or DA/DH. Pilots must see and avoid obstacles when descending below the MDA.

The charted temperature restriction for uncompensated baro-VNAV systems is applicable to the final segment LNAV/VNAV minima. The charted temperature restriction must be followed regardless of the cold temperature restricted airport temperature.
Figure 13
Some facts

Every IFR-certified and installed GPS unit allows the pilot to descend to LNAV (or Straight-in) and circling approaches.

Baro-VNAV-equipped GPS systems can also descend to LNAV/VNAV minima.

WAAS receivers can descend to LNAV, LNAV/VNAV, and LPV minima.

Only procedures with vertical guidance have DAs. A descent angle may be provided on procedures which have only LNAV minima, to aid in a stabilized descent, but the MDA must still be respected.
**Integrated Approach Navigation (IAN)**

Integrated Approach Navigation (IAN) is an approach option designed for airlines that want to use ILS-like pilot procedures, display features, and autopilot control laws for nonprecision (Category I) approaches. This option does not require additional ground facility support.

The FMC transmits IAN deviations to the autopilot and display system. The pilot procedures for IAN are derived from current ILS pilot procedures and are consistent for all approach types: Select the approach on the FMC control display unit, tune the appropriate station, and arm the autopilot **approach mode**. The IAN function can be used for the following approach types. RNAV, VOR approach, GPS, NDB approach, ILS for glideslope inoperative, localizer only, and back course approach types.

The IAN function will alert the crew to approach selection or tuning inconsistencies. For example, if an ILS station is tuned and an area navigation (RNAV) approach also is selected on the FMC, the flight crew will be alerted and the ILS approach mode will take precedence automatically, with the appropriate display format.

While the IAN display is similar to an ILS display, there are sufficient visual differences to ensure that the crew does not confuse a nonprecision IAN approach for a precision ILS or GLS approach. As on all non-precision approaches, the altimeter is the primary method of ensuring that altitude constraints are honored.
FAC: Final Approach course, G/P: Glide Path.

A change in barometric pressure or temperature can cause the VNAV path to be slightly different than the Visual Glide Slope Indicator, i.e., PAPI or VASI, path or Instrument Landing System (ILS) glideslope. When these situations occur and the crew elects to modify the flight path below the VNAV path in order to follow the Visual Glide Slope Indicator (VGSI) or ILS guidance, the IAN glideslope protection feature can issue a GLIDESLOPE advisory even though the aircraft may be on a safe and appropriate flight path in visual conditions. This is because the barometric VNAV path defined by the IAN feature does not necessarily exactly coincide with the VGSI path or ILS glideslope.

Recommended: Boeing aero magazine, 737 Approach navigation options, 2003
Flightsafety.org, From nonprecision approaches to precision-like approaches, 2007