Chapter 4 GNSS

4.1 General

The advent of satellite based navigation provides significant improvement in navigation performance which is available to aircraft of all types. While Performance Based Navigation in general is not dependent upon satellite navigation the benefits available within the PBN concept are multiplied by the use of GNSS.

It is not within the scope of this Handbook to cover the basics of GNSS navigation and it is assumed that readers have or will obtain knowledge and training in satellite based navigation principles and practice.

The discussion of satellite navigation will be related to specific elements of satellite based navigation that are relevant to PBN operational approvals.

GNSS systems range from stand-alone receivers, now in general use in general aviation to Flight Management Systems incorporating IRS systems updated by GNSS. Whatever the installation, the navigation capability of GNSS is excellent, and there is little variation in the positioning accuracy across the various types of installation. However there are considerable differences in functionality, cockpit displays, integrity monitoring, alerting and other characteristics that must be considered in the operational approval, depending upon the particular navigation specification.

Les paramètres requis sont manquants ou erronés.

4.2 Monitoring and alerting

An IFR GNSS navigation receiver incorporates by design a system to monitor the positioning performance and to provide an alert to the operating crew when the minimum requirements appropriate to the desired navigation performance is not available. Consequently a GNSS navigation system qualifies as an RNP navigation system as it is able to provide the necessary on board performance monitoring and alerting functions. However, the monitoring and alerting function of the navigation system alone is insufficient for RNP applications, and FTE must also be monitored. A number of aircraft equipped with GNSS fail to meet the monitoring requirements for RNP because of a lack of capability for the crew to monitor cross-track deviation.

Prior to the PBN Manual, many operations utilising GNSS were classified as RNAV operations, such as RNAV (GNSS) approach procedures. In order to be consistent with the PBN Manual definition of RNP, RNAV (GNSS) procedures are now classified as RNP APCH procedures, as they fulfil the on-board performance monitoring and alerting requirements associated with RNP systems.

4.3 GNSS Accuracy

The positioning accuracy of GNSS signal in space is dependent upon the satellite constellation and is generally independent of the aircraft systems. Positioning accuracy is excellent and a significant amount of data has now been accumulated which demonstrates that unaugmented GNSS is able to provide accuracy measured in metres with a high degree of availability over much of the earth's surface.

Whilst PBN Manual navigation specifications may contain an accuracy requirement specified as a 95% probability, when GNSS is used, the underlying accuracy is independent of the navigation specification requirement. An aircraft equipped with GNSS and approved for operations at a particular RNP level e.g. RNP 0.3 is capable of no less accurate navigation when operating to another navigation specification such as RNP 1.

It should be recognised that when GNSS is available navigation position accuracy remains high irrespective of the particular operation. However it should also be noted that accuracy is only one consideration in regard to a PBN operation and other factors may limit the approved operational capability.

4.4 Integrity Monitoring

All IFR lateral navigation systems, both conventional and performance based, are required to meet standards for integrity. Integrity represents the trust that we place in the ability of the system to provide navigation information that is not misleading. Whilst a navigation system may provide accurate guidance, in aviation we require assurance that the guidance is valid under all reasonable circumstances and various means have been implemented to provide that assurance.

Integrity for conventional navigation aids is indicated by the absence of a warning flag on a VOR or ILS indicator, or the presence of the Morse ident when using an ADF. For GNSS systems a loss of integrity availability is indicated by an annunciation (in various forms) displayed to the flight crew.

GNSS systems employ a variety of methods to monitor the integrity of the navigation solution, the most basic being Receiver Autonomous Integrity Monitoring or RAIM. This type of monitoring system is generally associated with (but not limited to) stand-alone general aviation receivers. Other types of integrity monitoring include proprietary hybrid systems which integrate inertial navigation with GNSS positioning to provide high levels of availability of navigation with integrity.

Unfortunately the term RAIM is erroneously used to describe integrity systems in general, and this can lead to some misconceptions of the role and application of integrity monitoring to performance based navigation.

4.5 Fault Detection

Integrity and accuracy are both required for valid GNSS navigation. However accuracy and integrity, although in some ways related, are entirely different parameters and should not be confused.

The GNSS receiver, GNSS satellites, ground monitoring and control stations all contribute to providing a valid navigation system and each element incorporates fault detection protection. A GNSS receiver continuously monitors the computed position and will detect and annunciate a fault if the position solution is not within defined limits.

However, the ability of a GNSS receiver to detect a fault is limited by the extremely low GNSS signal strength. GNSS satellites radiate a low power signal from some 20,000 km in space which reduces in inverse proportion to the square of the distance. The usable signal is therefore very weak and below the general ambient signal noise level. Normally a fault will be detected despite the low signal strength; however in rare circumstances the ability to detect a fault can be limited by the noise level, constellation geometry and other factors and for commercial aviation applications a means is necessary to protect the user against the unlikely but nevertheless real possibility that a fault might not be detected.

RAIM uses a mathematical solution to protect against this rare condition. The receiver calculates in real time a parameter called Horizontal Protection Level (HPL), in order to protect the navigation solution against a *potential* navigation fault.

4.6 Horizontal Protection Level

HPL is the radius of a circle in the horizontal plane, with its centre being at the true position, such that the probability that an indicated position being outside the circle but not detected is less than 1 in 1000. That is the receiver calculates a level of protection currently available based on the geometry of the satellite constellation. As the position of the satellites in view is constantly changing HPL also continually changes.

HPL is a parameter as the name suggests designed to provide integrity *protection* rather than error *detection*. Unfortunately it is a common misconception that the actual position "floats" anywhere within the HPL radius. The actual navigation solution, as evidenced by a substantial body of observations over many years, remains very accurate. The function of HPL is to *protect* the navigation solution against the possibility that in the *unlikely event that a satellite ranging error should occur that the risk of a missed detection is reduced to an acceptable probability.*

In normal circumstances, should a satellite ranging error occur which results in an out-of tolerance solution, the GNSS system will detect the fault and provide an alert to the user. The problem is that we cannot be certain that the fault detection system will always work, and as discussed, due the ambient noise level, under certain circumstances, a fault could be missed. So if we can't be 100% sure about the detection system, something else must be done, and that's where RAIM and HPL (or an equivalent protection system) comes in.

The way this is done is to program the receiver to calculate in real time, based on the actual satellite geometry, a worst case scenario which provides an acceptable level of confidence that *if a real fault was to occur* it would be detected. Note that we are not talking about detecting a fault right now, but rather that we are protecting a region around the indicated position, just in case a fault should happen at any time in the future. That potential fault many never occur, but we can be confident that if it did that we are protected.

HPL provides for a number of "worst case" circumstances. As GPS position is a triangulation of pseudo-range measurements from satellites, any ranging error from one of those satellites has the potential to result in an inaccurate solution. A failure in the US GPS satellite system is any ranging error greater than 150m, however as any position solution is a computation dependent on a number of range measurements the ranging error would need to be significantly greater to be a problem. In addition the HPL computation assumes that only the "worst" satellite fails, when in reality any one of the satellites used in the position solution has equal probability of failure. The "worst" satellite would be one lower to the horizon as any ranging error will bias the lateral position more than a satellite which is closer to overhead.

Depending on the date at which the receiver was manufactured, the HPL calculation may also assume that Selective Availability is still active. Consequently when conducting RNP operations observers may note differing "performance" displayed in the cockpit between aircraft operating in the same position and time, where SA is assumed active in the HPL calculated by one aircraft and not active in another. This effect also has a bearing on RNP availability prediction results.

Consequently there is some in-built conservatism in the computation of HPL.

For each phase of flight the maximum acceptable HPL is limited by a Horizontal Alarm Limit (HAL). For stand-alone GPS receivers, the HAL for each phase of flight is fixed (0.3 approach, 1.0 terminal. 2.0 en-route). For other navigation systems, the limit can be selected by database or crew input. For example, in an aircraft where the RNP is selectable, changing the RNP (in general) has the effect of changing the limiting HPL, but this selection has no effect on the accuracy of the position.

From an operational approval perspective, it important to understand that the GNSS position solution is very accurate, and that the aircraft position is reliably defined by the very small navigation system error and the relatively large flight technical error. Consequently operational considerations should be based on the acknowledged accurate and reliable guidance available, rather than the misconception that the actual position is randomly located within the area that is defined about the intended flight path that we ***protect***.

For example, when operating procedures rely on the alignment of an RNP approach with the landing runway, we can be confident that the aircraft will reliably be on track.

At the same time we must also understand that despite the observed accuracy, that it is necessary to provide an area of "protection" around the aircraft flight path, so that if at some time whether in the next 30 seconds or 30years a satellite ranging fault of sufficient magnitude was to occur, that the aircraft will be within the protected area, or a fault annunciated.

Integrity is our insurance policy and we do not operate without it in IFR aviation. But just as in day-to-day life although we make sure our policy is paid up we do not run our lives based on our insurance policies.

4.7 Integrity Alerting

For aviation applications, it is accepted that integrity is essential and therefore operations are predicated on the availability of an integrity monitoring system, and the absence of an alert. However, as discussed above the computed HPL will vary depending upon the geometry of the constellation and the maximum value of HPL is determined by the HAL appropriate to the particular operation. If the number of satellites in view is reduced, or the position of satellites is poor then the ability to detect a potential fault reduces and the computed HPL consequently increases. If, for example, for the particular phase of flight, the computed HPL exceeds the HAL, then the required level integrity is determined to be not available, and an alert is generated.

Note: The condition HPL <HAL is only one example of a limiting integrity condition. There are a number of systems which provide equal or better integrity monitoring which may not depend on HPL.

Alerts vary depending upon the type of system, aircraft and avionics manufacturer, but typical alerts are:

- RAIM NOT AVBL
- LOSS OF INTEGRITY
- UNABLE REQD NAV PERFORMANCE RNP
- GPS PRIMARY LOST

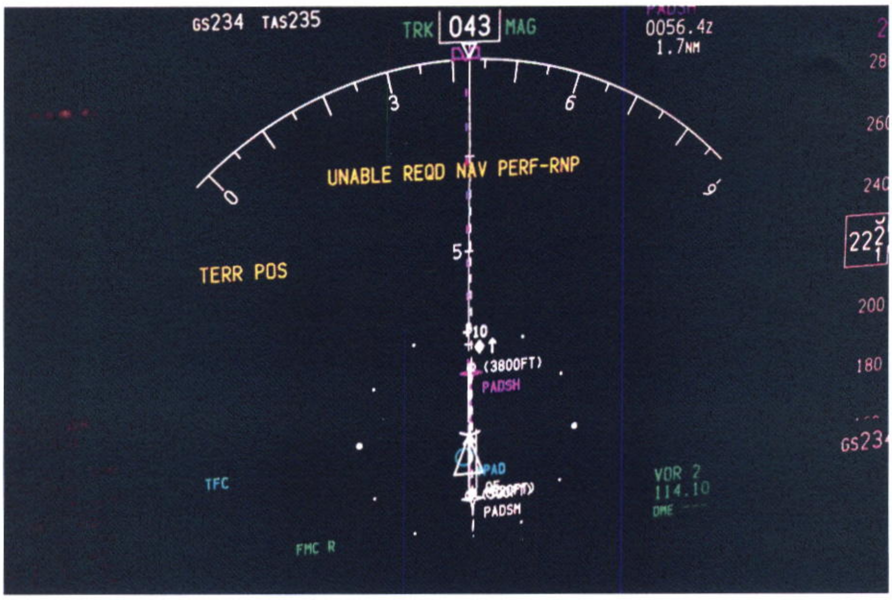


Fig 4.1: Alert annunciated on Boeing 737NG navigation display

4.8 Loss of Integrity Monitoring Function

Whilst it is accepted that integrity is fundamental to safe aviation operations, the unavailability of the integrity monitoring function is not of itself an indication of a degradation of navigation accuracy. Although both HPL and the computed position accuracy are both a function of satellite geometry, a loss of integrity monitoring is not normally accompanied by an observed degradation in accuracy. Integrity monitoring protects against a potential failure, and a loss of the integrity function means that protection is no longer available, not that a failure has necessarily occurred. The number of actual satellite failures in the US GPS system is small given the number of years since commissioning.

In normal operations, where the safety of flight is affected (e.g. approach operations), a loss of integrity protection is reason for discontinuation of a GNSS operation. However in an emergency situation a loss of integrity monitoring is unlikely to be accompanied by a loss of navigation accuracy and flight crews should exercise good judgement in selecting the best course of action given the circumstances of the emergency.

4.9 Availability Prediction

Commonly receivers include a prediction function, but their use is limited as information on known or planned satellite outages is not included. More accurate predictions are available from commercial and State sources which include up to date information on the health of the constellation.

Any prediction of availability needs to provide to the operating crew and dispatchers an accurate indication that the aircraft can conduct a particular operation ***without an alert being generated.*** Irrespective of the method used to predict availability it is the generation of a cockpit warning that precludes the successful completion of an operation. Therefore it is advantageous to ensure that the prediction method represents the aircraft alerting system as closely as possible.

The computation of availability is complicated by the variations in the methods used to provide integrity protection. For basic stand-alone GNSS receivers, alerting limits are fixed (e.g. HPL < 0.3 in approach mode), but for other installations integrity alerting is based on more complex analysis and/or more sophisticated integrity monitoring systems. Consequently for accurate integrity protection availability prediction the actual technique applicable to the particular aircraft and navigation equipment must be applied. For RNP AR APCH operations, where a number of lines of RNP minima may be available, availability prediction needs to be related to the various levels of RNP.

The prediction of the availability of a navigation service with integrity is useful as it permits the flight crew or dispatcher to take into account the probability of a loss of service and plan an alternative course of action such as delay, rescheduling or selection of an alternative means of navigation.

In some RNP systems, the required level of performance is able to be maintained for some time after the loss of the GNSS signal, (normally with IRS coasting) and an alert is not annunciated until the performance is computed to have reached the relevant limit. Advanced hybrid (IRS/GNSS) integrity monitoring systems are able to provide GNSS position with integrity for long periods (e.g. 45 minutes) after a loss of the GNSS signal.

4.10 Augmentation systems

The majority of Performance Based Navigation operations are able to be conducted using an unaugmented GNSS signal is space. The general GNSS signal is sometimes referred to as an Aircraft Based Augmentation System (ABAS) although this may lead to the misconception that some correction is made to the basic GNSS signal.

The currently available augmentation systems rely on either Ground-Based augmentation (GBAS) or Satellite Based augmentation (SBAS). GBAS relies on an array of receivers located close to the area of operations and supports operations such as GLS (GBAS Landing System). In the United States GBAS is referred to as the Local Area Augmentation system or LAAS. None of the PBN Manual operations currently depend upon GBAS.

SBAS, which is represented in the United States by the Wide Area Augmentation System, employs additional geo-stationary satellites and a network of ground-based reference stations, in North America and Hawaii, to measure small variations in the GPS satellites' signals in the western hemisphere. Measurements from the reference stations are routed to master stations, which queue the received Deviation Correction (DC) and send the correction messages to geostationary WAAS satellites in a timely manner (every 5 seconds or better). Those satellites broadcast the correction messages back to Earth, where WAAS-enabled GPS receivers use the corrections while computing their positions to improve accuracy and integrity.

An SBAS system is capable of supporting all navigation specifications requiring GNSS. In addition an SBAS system provides capability for Satellite based APV approach procedures which are classified in terms of the PBN Manual as a type of RNP APCH operations. This type of approach operation is referred to as Localiser Performance with Vertical guidance or LPV and provided ILS-like guidance to a DA of not lower than 200ft.

LPV operations are designed to be compatible with existing flight guidance installations and provide lateral and vertical course guidance which varies in sensitivity with distance from the runway, much like an ILS.

Chapter 5 ROUTE DESIGN

5.1 Protected Area

PBN flight paths are protected by an area surrounding the intended flight path based upon the navigation system performance, and other factors.

The protected area is used to assess clearance from terrain and obstacles, and may also be used to establish lateral separation between routes. Details on the computation of protected areas are contained in ICAO Doc 8168 PANS OPS Volume II and ICAO Doc 9905 RNP AR Procedure Design Manual.

5.2 RNP AR APCH

RNP AR APCH route segments are protected by rectangular volume defined by a minimum obstacle clearance (MOC) applied to distance 2 x RNP either side of track.

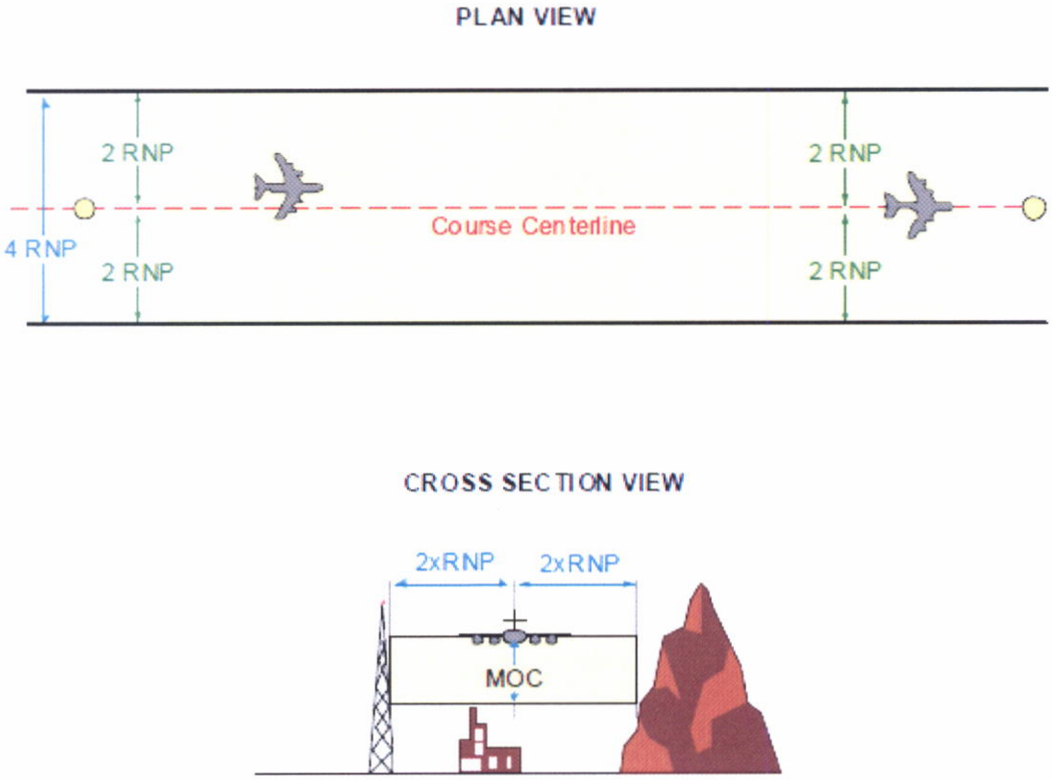


Figure 5.1 RNP AR APCH Obstacle Clearance

5.3 RNP APCH

RNP APCH route segments are protected by variable lateral areas and a minimum obstacle clearance (MOC) applied to primary and secondary areas. The lateral dimensions of the protected area are based on 1.5 x the navigation tolerance associated with the segment plus a buffer value.

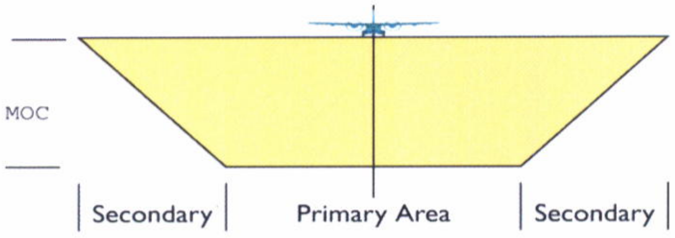


Figure 5.2: Primary and Secondary Areas

Segment	Navigation Tolerance	Buffer Value	Lateral Protection (either side of track)
Initial/intermediate	1.0	1.0	2.5
FAF	0.3	1.0	1.45
Final (MAPt)	0.3	0.5	0.95
Missed approach	1.0	0.5	2.0

Figure 5.3: Typical lateral protection values for RNP APCH (NM)

5.4 En-route and Terminal

RNAV and RNP terminal and en-route segments are protected in a similar manner to RNPAPCH. Lateral protection areas are defined by 1.5x the navigation accuracy plus a buffer value. Obstacle clearance protection is not included in PANS-OPS for RNAV 10.

Navspec	Navigation Tolerance	Buffer Value	Lateral Protection (either side of track)
RNAV 5[1] >30NM ARP	2.51	2	5.77
RNP 4	4	2	8
RNAV 1 (<15NM ARP)	1.0	0.5	2
RNP 1 (<15NM ARP)	1.0	0.5	2

[1] Based on GNSS. Different values apply to DME/DME routes.

Figure 5.4: Typical lateral protection values for En-route & Terminal Navspecs (NM)

Chapter 6 BAROMETRIC VERTICAL NAVIGATION

6.1 General

The PBN Manual does not include a navigation specification for Barometric Vertical Navigation however Baro-VNAV as it is commonly called, is integral to a number of PBN operations and warrants discussion in this Handbook. The PBN Manual includes an Attachment which provides guidance on the application of Baro-VNAV.

Baro-VNAV has application in PBN operations for RNP AR APCH and RNP APCH. For RNP AR APCH operations vertical guidance is currently dependent upon Baro-VNAV and is integral to this type of 3D or APV operation. For RNP APCH operations vertical guidance is not mandated but may be achieved by the use of Baro-VNAV. Other forms of vertical guidance for both RNP AR APCH and RNP APCH operations (e.g. SBAS) are expected to become available.

6.2 Baro-VNAV Principles

Barometric VNAV has been available for many years on a wide range of aircraft and was developed essentially to permit management of climb, cruise and descent in the en-route and arrival/departure phases of flight. More recently, Baro-VNAV systems have been adapted to provide vertical guidance in the approach phase and specifically in the final approach segment permitting vertically guided approach procedures, typically to a Decision Altitude as low as 75m (250ft).

There are a number of vertical navigation systems in use which provide some means of managing the flight path in the vertical plane. However many such systems are not able to provide guidance along a specific vertical flight path to a fixed point e.g. the runway threshold.

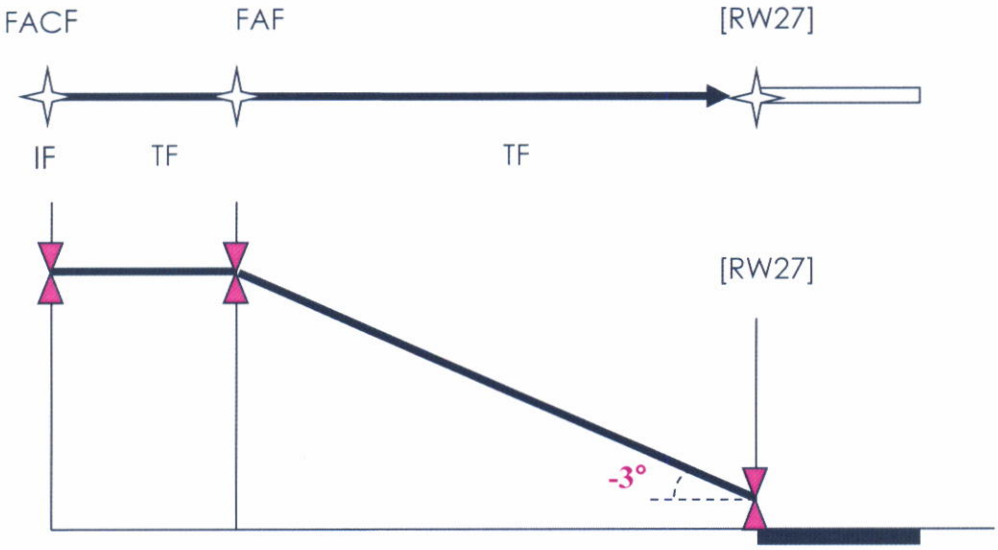


Figure 6.1: Construction of Vertical Flight Path

For Baro VNAV approach operations, the following elements are required:

- an area navigation system to enable distance to be determined to a waypoint which is the origin of the vertical flight path;
- the vertical flight path angle from the origin waypoint (normally the runway threshold) coded in the navigation database'
- a barometric air data system of sufficient accuracy;
- a flight guidance system able to provide vertical steering commands;
- cockpit control and monitoring displays.

Based on the distance to the origin of the vertical flight path, and the specified vertical flight path angle, the FMS computes the required height above the runway threshold or touchdown point and provides data to the aircraft flight guidance system and cockpit displays.

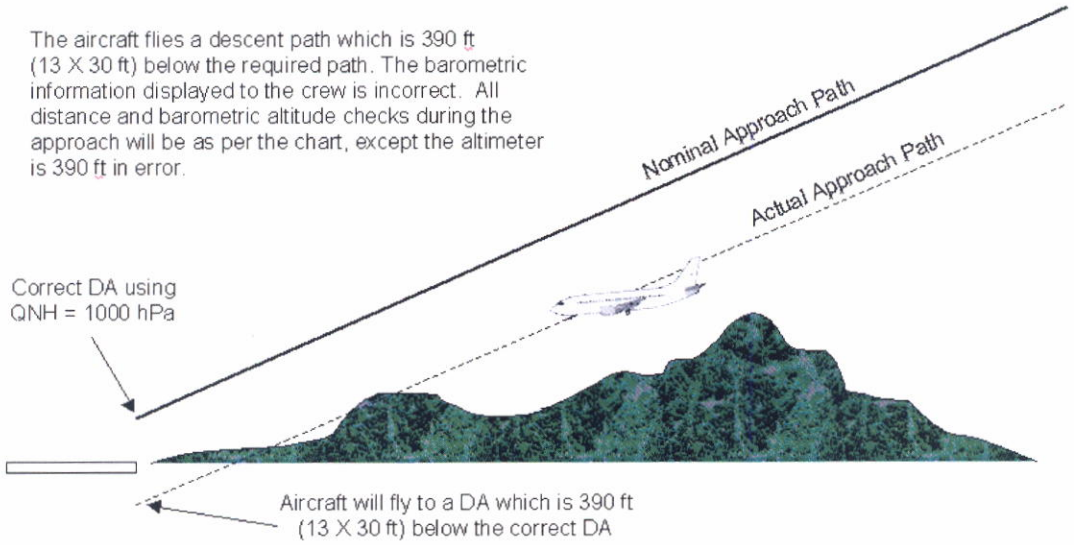
Although in some respects a baro VNAV guided approach procedure is similar to an ILS in operation, a fundamental difference is that the actual vertical flight path is dependent upon measurement of air density which changes with ambient conditions. Consequently the actual vertical flight path will vary 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.

Temperature is the major factor and in temperatures above ISA the actual flight path will be steeper than coded, and conversely below ISA temperatures will result in a lower flight path. Temperatures below ISA are therefore of concern because the clearance above terrain or obstacles will be reduced. Above ISA temperatures result in a steeper flight path which may lead to energy management issues. Temperature variations will also in lack of correlation of the barometric vertical flight path with fixed vertical flight path guidance provided by visual flight path guidance (VASIS) and ILS. Flight crew training must include a study of barometric VNAV principles and the effects of temperature, so that crews understand the variable nature of the barometric VNAV generated flight path.

Procedure design for approaches with barometric vertical guidance take in to account these effects and maximum and minimum temperature limits may be published on approach charts to ensure obstacle clearance is maintained and steep approach gradients are avoided. Some barometric vertical navigation systems incorporate temperature compensation which enables the coded flight path angle to be flown with out variations due to temperature. For such systems, temperature limits may not apply.

A number of barometric vertical navigation installations are limited by the cockpit indications and may not be suitable for approach operations. Many such systems, while able to provide adequate vertical navigation capability, were not designed with approach operations in mind and cockpit displays provide indications of deviation from the vertical flight path which may be adequate for climb, cruise and descent, but insufficient for monitoring of flight path in the approach phase.

As the vertical flight path is dependent upon the measurement of air density and the vertical flight path is generated in relation to a barometric datum, any error in the setting of barometric pressure result in a direct vertical error in the vertical flight path. An error in barometric subscale setting results in a vertical shift of the flight path of 9m (30ft) per HPa. An error of 10 HPa therefore can cause a vertical error throughout the approach of 90m (300ft). It is therefore necessary that the operational approval includes an evaluation of cockpit altimeter setting procedures, and the use of other mitigation systems such as RADALT and TAWS/EGPWS.



The aircraft flies a descent path which is 390 ft (13 X 30 ft) below the required path. The barometric information displayed to the crew is incorrect. All distance and barometric altitude checks during the approach will be as per the chart, except the altimeter is 390 ft in error.

Correct DA using QNH = 1000 hPa

Aircraft will fly to a DA which is 390 ft (13 X 30 ft) below the correct DA

Figure 6.2: Effect of miss-set altimeter subscale on Baro-VNAV vertical path

6.3 Limitations of the Baro VNAV System

- Non standard temperature effect
- Subscale setting round down
- Miss set altimeter subscale

Non standard temperature effect.

During ISA atmospheric conditions the altimeter will read correctly and cause the aircraft to fly along the design or nominal profile. If the temperature is above ISA the altimeter will under read causing the aircraft to fly an actual profile which is above the nominal profile. The altimeter error is in the order of 4% per each 10 degrees of ISA deviation times the height above the airport reference datum. As the altimeter error is related to height above the airport datum the vertical offset reduces as the aircraft nears the threshold. Typically on an ISA +20 day the aircraft will be 20 feet above the nominal profile at 250 feet reducing to only 4 feet at the threshold.

Similarly, for each 15° difference from ISA, the VPA will vary by approximately 0.2°. i.e. on an ISA + 15 day the actual flight path angle for a 3° nominal VPA will be 3.2°. Consequently, of the average operating conditions differ significantly from ISA conditions it is useful to use VPA which will result in an actual VPA in the most common conditions. In the case above, a design VPA of 2.8° would result in an actual VPA close to 3° in average operating conditions.

If the atmosphere is below ISA the effect is reversed with the aircraft below the nominal profile by the same amounts. It should be noted that this temperature effect is apparent on all approach which use barometric altimetry to derive a profile. Inspectors should consider that whilst this effect is not new, increased visibility of this effect should be considered during training where Baro VNAV is intended to be deployed.

Crews must understand this effect and be aware that a lack of harmonisation with visual approach slope aids may occur, and indeed should be anticipated in temperatures which are non-standard.

Subscale setting round down.

Air navigation service providers generally round subscale setting down. This has the effect of causing altimeters to under read causing the aircraft to fly above and parallel to the nominal profile. The effect is small but most pronounced when operating in HPA. If the tower read out is 1017.9 hPa the aerodrome QNH will be reported as 1017. This will cause an above nominal path offset of 27 feet. Inspectors should consider that whilst this effect is unlikely and small, increased visibility of this effect must be considered during training where Baro VNAV is intended to be deployed.

Miss-set altimeter subscale.

Altimeter subscales can be miss-set for a variety of reasons. The effect has been previously discussed. It is important to remember that this issue is not unique to Baro VNAV operations. Any approach which relies on barometric information for profile will be affected by a miss-set altimeter subscale.

Depending on the aircraft equipment, there are a number of mitigators that contribute to reducing the risks associated with miss-set altimeter subscale. Inspectors must consider the following mitigators when evaluating baro VNAV operations and flight crew training.

Barometric VNAV Mitigators

Procedural Mitigators:

- Independent crew check when recording destination altimeter subscale setting.
- Effective crew procedures for setting local altimeter subscale setting at transition level.

Electronic Mitigators:

- Electronic alerting if altimeter subscale setting is not reset at transition.
- Electronic alerting of altimeter differences.
- Terrain Awareness System (TAWS) which incorporates terrain clearance floors along with an accurate terrain model for the intended destination.

- Effective crew procedures in support of the TAWS alerts.

6.4 Aircraft Capability

Baro-VNAV systems in common use have normally been approved in accordance with airworthiness requirements that were developed prior to the application of Baro VNAV systems to approach operations. For example compliance with FAA AC 20-129 *Airworthiness Approval of Vertical Navigation (VNAV) Systems for use in the U.S. National Airspace system (NAS) and Alaska* is commonly used as the basis for the operational approval of Baro VNAV operations. The vertical navigation accuracy values for the VNAV system, flight technical error and altimetry contained in such documentation may not be considered sufficient to adequately demonstrate the required level of capability, and operational approval may need to take into account other data, operating procedures or other mitigations.

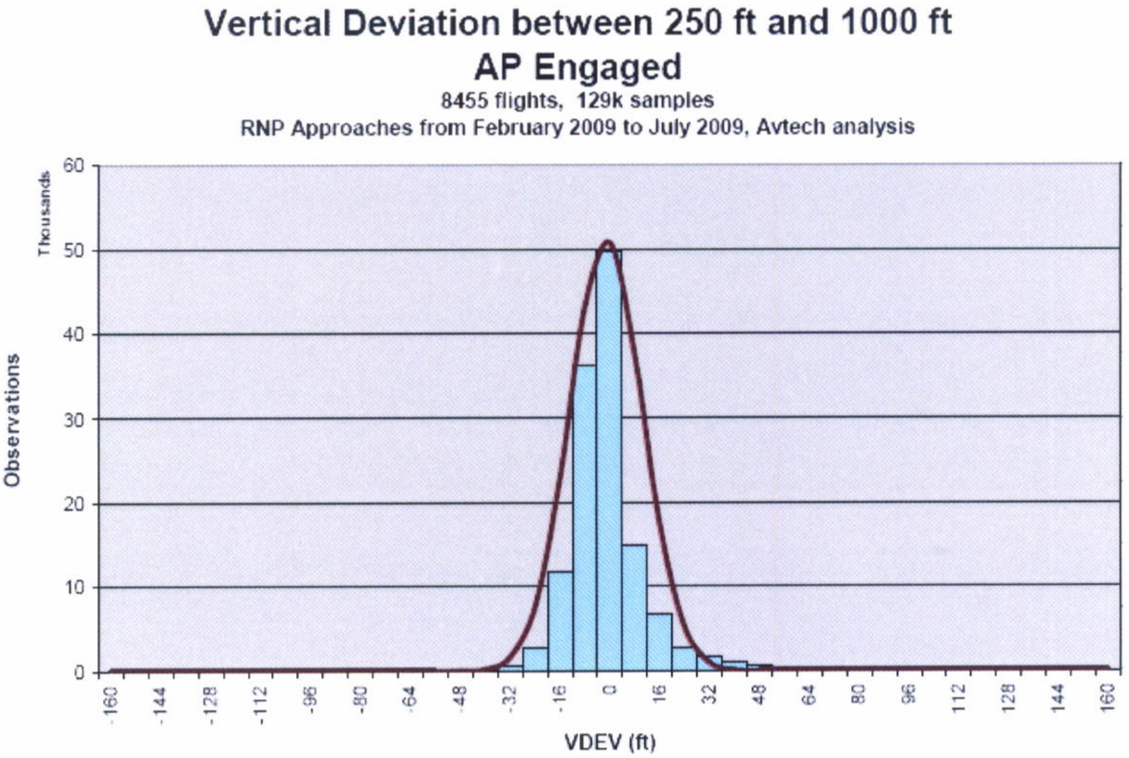


Figure 6.3: In-service Baro-VNAV FTE data

Despite any perceived limitation in the airworthiness documentation, properly managed Barometric VNAV operations in modern air transport aircraft have been demonstrated to provide a high standard of flight guidance and the availability of positive vertical flight guidance offers offer significant improvement in safety and efficiency over non-precision approach procedures.

Where documentation of barometric VNAV performance is considered insufficient, operational data from in-service trials (e.g. in visual conditions) may be useful in determining the actual in flight performance for some aircraft.

6.5 Flight Procedure Design

Although this Handbook deals with operational approval, some basic knowledge of barometric VNAV procedure design is necessary in order that operations are consistent with the assumptions made in the design of approach procedures.

ICAO Doc 8168 PANS OPS and ICAO Doc 9905 RNP AR Procedure Design Manual provide criteria for the design approaches using barometric vertical navigation. Baro VNAV criteria in PANS OPS is applied to the design of RNP APCH procedures, and RNP AR Procedure Design Manual criteria is applied to the design of RNP AR procedures.

The basis for VNAV design differs between PANS OPS and the RNP AR Procedure Design Manual.

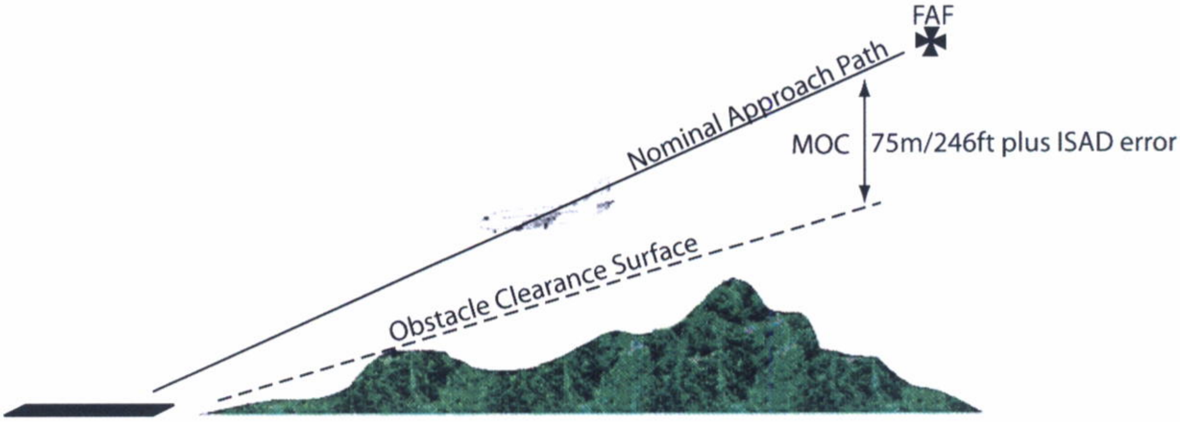


Figure 6.4: RNP APCH (LNAV/VNAV) Final Segment Obstacle Clearance

PANS OPS applies a fixed Minimum Obstacle Clearance (MOC) of 75m (246ft) to the VNAV flight path. This MOC is assumed to provide sufficient clearance from obstacles to accommodate all the errors associated with the ability of the aircraft to conform to the designed flight path. Adjustment to the obstacle clearance surface to allow for low temperature conditions is also applied. No analysis of the individual contributing errors including Flight Technical Error (FTE) is made. However guidance to pilots is provided in Volume 1 of Doc 8168 which requires that FTE is limited to 50ft below the VNAV profile. This value is not directly related to either the procedure design MOC or the aircraft capability.

RNP AR APCH procedures, which are designed in accordance with criteria in the RNP AR Procedure Design Manual utilise a variable obstacle clearance below the

VNAV flight path, called the Vertical Error Budget (VEB). The VEB is computed as the statistical sum of the individual contributing errors, including FTE, altimetry system error (ASE), and vertical angle error. The MOC is computed as 4 times the standard distribution of the combination of all the errors. Except for some fixed values the errors are combined by the root sum square method (RSS).

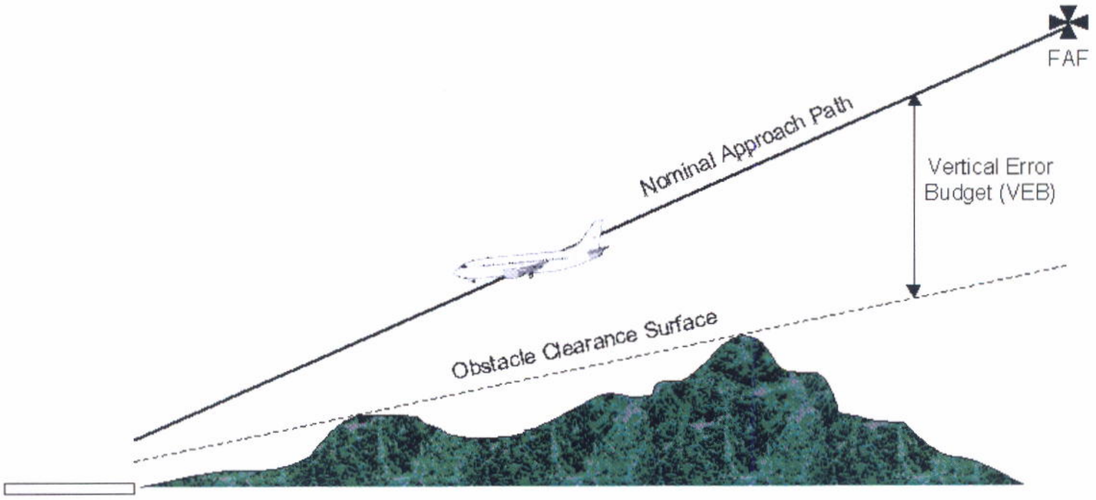


Figure 6.5: RNP AR APCH Vertical Error Budget

The value used for the 95% probability FTE is 23m (75ft). That is it is expected that an aircraft is capable of following the defined VNAV path +/- 23m for 95% of the time. For most aircraft, the manufacturer is able to provide data to show that this value can be met, and in many cases the capability is much better. In some cases the applicant for operational approval may need to provide additional information, analysis or data to substantiate the capability meet the required level of FTE. Despite the statistical computation of the VEB, the PBN Manual RNP AR APCH navigation specification also requires that flight crews monitor vertical FTE and limit deviations to less than 23m (75ft) below the VNAV profile. (Note: It is proposed that the limit on vertical FTE for RNP APCH operations is amended to 23m/75ft to be consistent with RNP AR APCH operations.

6.6 Baro VNAV Operations

Baro VNAV operating procedures for RNP APCH and RNP AR APCH operations are fundamentally the same, despite the differences in procedure design, and operators should be encouraged to adopt common standards in the cockpit.

The design of Baro VNAV approach procedures is applicable to the final approach segment (FAS), and outside the FAS procedure design is based on minimum altitudes. Consequently, while the aircraft's barometric vertical navigation system is normally available for use in all phases of flight, for an approach using Baro VNAV and all RNP AR APCH procedures, the aircraft must be established on the vertical flight profile with the appropriate vertical navigation mode engage prior to passing the FAF. (e.g. VNAV PATH or FINAL APP mode). Approach operations must not be conducted using modes that are not coupled to the VNAV flight path (e.g. VNAV SPD).

It is generally preferable that the aircraft is established on the vertical profile at some point prior to the FAF and it is becoming increasingly common to nominate on an approach chart a point known as the Vertical Intercept Point (VIP). The VIP location is best determined on a case by case basis by negotiation between procedure designer, operators, and ATC. The VIP is useful in identifying to ATC the latest point at which the aircraft needs to be established, and this concept is similar to the well established air traffic control practice of establishing an aircraft on an ILS prior to the glide path intercept point. ATC vectoring rules should also require that if an aircraft is taken off track, or is vectored to join the approach inside the IAF, then both lateral and vertical tracking is established at some distance (commonly 2NM) prior to the VIP.

As noted earlier, VNAV operating procedures must ensure that the correct altimeter subscale setting is used.

While barometric VNAV operations provide significant safety benefits over non-precision approaches, mismanagement of the VNAV function can introduce significant risk. During the operational approval process great care and attention should be made to examine the VNAV system management, mode control, annunciation and logic. Crews need to be well trained in recognising situations which can lead to difficulty such as VNAV path capture (from above or below), speed and altitude modification, on approach logic and other characteristics. In some installations, in order to protect the minimum airspeed, mode reversion will cause the aircraft to pitch for airspeed rather than to maintain the flight path and descent below the vertical flight path may not be obvious to the flight crew.

It is recommended that the final approach segment for barometric VNAV approach is flown with autopilot coupled. Consideration should also be given to the manufacturer's policy and the aircraft functioning at the DA. In some cases lateral and vertical flight guidance remains available and continued auto-flight below the DA is available. This can be of significant advantage, particularly is complex, difficult or limited terrain and runway environments and continued accurate flight path guidance is available below the DA, reducing potential deviations in the visual segment. Other manufacturer's (and States) adopt different policies and lateral and vertical flight guidance is not available below the DA. The evaluation of crew procedures and training must include an assessment of the effect that the loss of flight guidance has on safe operations, particularly where the approach procedure does not conform to the normal design rules (e.g. offset final approach or non standard approach gradient.)