Chapter 10 RNP AR APCH

1. General

RNP AR APCH operations permit additional safety and efficiency to be achieved by the capability of advanced navigation equipment, aircraft systems and procedures design.

A large number of RNP AR approach and departure procedures have been developed by the industry; commonly sponsored by airlines and designed using commercially developed design criteria. These operations have been approved in a number of States following evaluation on a case-by-case basis, normally for a specific aircraft type and individual operator.

The RNP AR APCH navigation specification has been developed to provide ICAO guidance for similar RNP approach procedures that can be applied generally and to a range of qualified aircraft types.

Procedure design criteria have now been published in ICAO Doc 9905 RNP AR Procedure Design Manual.

2. Authorisation Required

All operations involve some form of authorisation, either specific or implied, and consequently questions are often raised with regard to the use of the term authorisation required in the context of RNP AR APCH operations.

Early development work on RNP approach procedures was carried out in the United States. Under the US Federal Aviation Regulations, all instrument approach procedures that are in the public domain are developed under FAR Part 97. Where approach procedures (for whatever reason) do not comply with FAR Part 97, the FAA can approve an operation (for a specific operator) as a Special Airworthiness and Aircrew Authorisation Required (SAAAR) procedure.

Accordingly as at the time (1995) the initial work on RNP approach development was undertaken there was no provision in FAR Part 97 for this type of operation, the FAA approved RNP approach operations as procedures with SAAAR.

Subsequently the FAA developed procedure design rules (FAA Order 8260.52) and airworthiness and operational rules (FAA AC90-101) to support FAA Part 97 RNP SAAAR operations, referred to Public RNP SAAAR.

In 2005, when the then Obstacle Clearance Panel (now Instrument Flight Procedures Panel) in ICAO decided to harmonise ICAO procedure design rules with FAA Order 8260.52, it was recognised that there was no equivalent process in ICAO which related to non-conforming or *Special* procedures. Consequently it was decided to abbreviate the term to Authorisation Required or AR for ICAO application.

The implication (whether SAAAR or AR) is that improvements in operational safety and efficiency gained by the utilisation of the capability of advanced navigation capability are matched by an appropriate level of detailed evaluation of aircraft, operations and procedure design.

AR therefore requires the State to conduct a full evaluation of all aspects of the operation before issuing an approval and only qualified operators are permitted to conduct RNP operations which are identified as *Authorisation Required*.

3. Characteristics

There are a number of characteristics of RNP AR APCH operations that combine to improve the capability of this type of operation, including;

- support for RNP less than 0.3 (RNP 0.1 is the lowest currently available)
- obstacle clearance lateral tolerance 2 x RNP
- final approach vertical obstacle clearance provided by a vertical error budget
- radius to fix (RF) legs enabling circular flight paths to be flown

It should be noted that while RNP AR APCH procedures support low RNP types, that this is only one characteristic and that many RNP AR APCH operations do not require RNP less than 0.3. An RNP 0.3 RNP AR APCH operation should not be confused with an RNP APCH which also uses RNP 0.3 capability.

4. Procedure Design

RNP AR APCH procedures are designed in accordance with ICAO Doc 9905 *REQUIRED NAVIGATION PERFORMANCE AUTHORIZATION REQUIRED (RNP AR) PROCEDURE DESIGN MANUAL*.

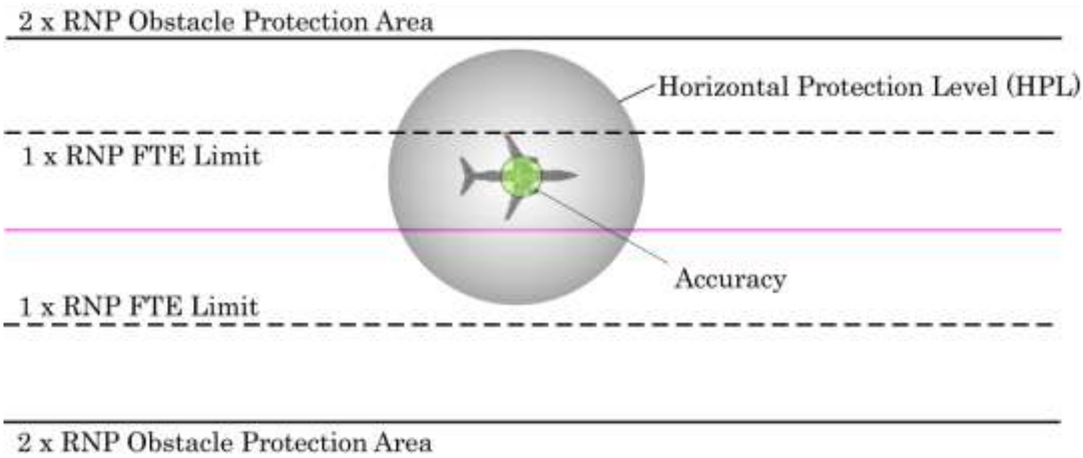

Figure 10.1: RNP AR APCH Obstacle Protection

It is advisable that inspectors are familiar with the basic principles of RNP AR APCH procedure design as AR operations are dependent upon the proper integration of aircraft capability, operating procedures and procedure design.

The design criteria for RNP AR APCH procedures has been derived from operational experience in a number of States which have generally been applied to individual operators, specific aircraft types, and industry developed design criteria. The ICAO RNP AR Procedure

Design Manual provides guidance to States on the early implementation of generic RNP AR approach procedures that can be applied to any appropriately capable aircraft and qualified operating crew.

The applicability of the design criteria to a broad range of capable aircraft does result in some operational limitations, particularly in areas of difficult terrain. In order to achieve a satisfactory operational outcome it may be necessary in such cases to approve variations to the design based on specific operational mitigations.

The RNP AR Procedure Design Manual makes reference to such circumstances as follows:

> 1.1.2.5 The design criteria in this manual are applicable to a range of aircraft types and cannot therefore; take into account the full capability of some aircraft types. Consequently procedures designed in accordance with this manual will provide an acceptable operational solution in many but not all circumstances. Where an operationally acceptable solution is not available through the application of the criteria in this manual, development of detailed procedures may be needed to satisfy local conditions. Alternative design solutions may be derived which specify aircraft type or specific performance parameters, special operating conditions or limitations, crew training, operational evaluation or other requirements that can be demonstrated to provide an equivalent level of safety. Such solutions are not the subject of this manual and will require case-by-case flight operational safety assessments and operational approval.

5. Operational Approval

RNP AR APCH procedures depend upon the integration of aircraft, operations and procedure design to deliver a safe and efficient outcome. Conventional navigation systems which have been in common usage for many years depend on aircraft equipment & avionics, operating procedures and procedure design that have benefited from many years of common usage and we are generally able to consider each element in isolation. For example ILS receivers are manufactured by many different companies, the operation and crew interface is standard, and a pilot qualified to fly ILS can do so on any aircraft with minimum of cross-training. ILS operating procedures are common and it is not necessary to apply different procedures for differing aircraft or avionics. Similarly the procedure designer develops ILS approaches without reference to specific avionics capabilities or operating procedures. All of these aspects are common, well understood, and standardised throughout the industry.

The same cannot be said of RNP AR APCH operations. In most cases, aircraft avionics were installed before the concept of RNP approaches was developed and equipment has been adapted to provide RNP AR APCH capability. Consequently there is no common standard yet available for RNP AR APCH avionics, cockpit displays, alerting and other functions. In some cases modification of upgrade of aircraft systems may be available, in other cases evaluation may be required for systems which cannot be upgraded.

Operating procedures also need to be matched to the aircraft, avionics, cockpit displays, etc., and will vary considerably between aircraft types, models and configurations. Both operating procedures and aircraft equipment/capability need to be evaluated against the basis upon which RNP AR APCH procedures are designed, and therefore consideration of the basic procedure design principles needs to be included in the operational approval process.

6. Evaluation Team

For many States, the first RNP AR APCH operational approval will be a new experience for both the operator and the regulator. Most regulatory authorities are structured to manage conventional operations and there are established procedures for approving operations. It is not uncommon for various departments (both in the airline and regulator) to carry out their work independently and there may be infrequent need to consult with technical experts in other fields of expertise.

It is recommended that a team approach is used in the conduct of an RNP AR APCH evaluation, and that cross-discipline dialogue and consultation is encouraged. As the first such operational experience will be a learning experience for all concerned it can be very useful to involve all parties, including the applicant, in a consultative approach to the approval process.

A project lead should be appointed to co-ordinate the combined efforts of the project team. As the outcome is an *operational* approval the project lead should be a person experienced in flight operations assisted by experts in other specialist fields as required. The project lead and other participants on the team should be encouraged to learn as much as possible about areas outside their immediate area of expertise. An vital part of a successful approval process is the synergy between all aspects of the operation that leads to a successful safety outcome.

7. Operator's Application

An important contributor to a successful RNP AR APCH implementation project is a well developed and comprehensive application. However it needs to be realised that the operator is likely to be inexperienced in this type of operation and will be developing their knowledge and expertise during the authorisation process, so some allowance will need to be made. The applicant should be encouraged to present as clearly as possible the details of how the operation is to be conducted, and be prepared to discuss the proposal with the regulator so that a satisfactory outcome is achieved. The regulator should also recognise that it may be difficult in the early stages for the applicant to clearly identify the requirements for approval and that the regulator may also have some similar difficulty in understanding the requirements.

It needs to be recognised that while the assistance of a competent operational approvals consultant can be very helpful, at the end of the operational approval process both the applicant and the approving authority need to ensure that they have comprehensive understanding of all aspects of the operation. Leaving it to a consultant to prepare a conforming application, and then just "ticking the boxes" does little to validate the Authorisation Required process.

8. Aircraft Eligibility

As the airworthiness requirements for RNP AR APCH operations are relatively recent (e.g. FAA AC 90-101 published December 2005) few aircraft have yet to be specifically approved for RNP AR APCH operations. Commonly the eligibility for an aircraft to conduct RNP AR APCH operations needs to be established during the operational approval process.

Some AFMs will contain a statement of RNP capability (AR may not be mentioned) which may have been approved or accepted by the regulatory authority in the State of manufacture however such statements need to be considered against the circumstances existing at the time of manufacture. Most RNP capability statements were made at a time when there was no international guidance and the basis for the capability statements are commonly developed by the manufacturer, and were accepted by the regulatory authority at the time as being reasonable, but of no specific relevance to operations being conducted at that time in history. Some manufacturers have applied for “RNP AR APCH approval” by their respective aviation authority, and where such documentation is available, the issue of aircraft eligibility is very much simpler to determine.

However there remain a significant number of aircraft that are RNP AR APCH capable but which do not have an RNP AR APCH airworthiness approval that is consistent with the requirements of the PBN Manual RNP AR APCH navigation specification. The reasons are varied, and may include a lack of operator demand leading the manufacturer to apply for approval, a disagreement between the manufacturer and approving authority, an inability to meet one or more specific requirements, or a lack of supporting data.

The absence of an RNP AR APCH airworthiness approval does not mean that the aircraft is not suitable for RNP AR APCH operations, but that this capability has not been demonstrated against available airworthiness guidelines. In many cases an operational procedure or mitigation is required to overcome the inability to obtain an airworthiness approval. In fact many operational approvals have been issued for aircraft that do not have an RNP AR APCH airworthiness approval.

Where the eligibility needs to be established by operational approval, the normal process is to obtain supporting data from the aircraft manufacturer. Leading manufacturers are increasingly coming under pressure from customers to provide support for RNP AR operations and the amount and detail for information available is increasing steadily.

States with limited resources may be able to request advice and assistance from States that have previously issued operational approvals in respect of specific aircraft. Care should be taken to identify the specific basis of such approvals as there are many variations in aircraft equipment, software, displays, options, and other relevant features that vary between aircraft of the same type and model.

9. Flight Technical Error

The manufacturer will normally use flight technical error data obtained during flight trials to establish the RNP capability depending upon the phase of flight and the method of control. Typically the lowest FTE and therefore the lowest RNP is obtained with auto-pilot coupled, however other values may be applicable to the use of flight director or map mode.

If there is any concern over the FTE data, then the operator can be required to gather additional in-service data. This can be achieved during initial operations, which should be limited to a conservative RNP (e.g. RNP 0.3). FTE data can be captured via on-board engineering monitoring systems or the Quick Access Recorder (QAR). The standard deviation of FTE observed can then be used to calculate the RNP capability based on the formula in Part 1 of this handbook.

Despite the values used for FTE, a further consideration is the monitoring of FTE performance in flight. To illustrate this point, an aircraft may demonstrate very low FTE values and therefore the calculated RNP capability could be low, but no cockpit display is available to permit the monitoring of this performance in real time. The aircraft, while able to meet RNP performance requirements would not qualify for RNP AR APCH because it could not meet the requirement for on board performance and monitoring of the FTE. As the standard of cockpit display varies, and the ability for the flight crew to monitor FTE also varies, this has a bearing on the RNP capability.

The PBN Manual RNP AR APCH navigation specification states:

> 6.3.3.3.1.3. a) *Continuous display of deviation*. The navigation system must provide the capability to continuously display to the pilot flying, on the primary flight instruments for navigation of the aircraft, the aircraft position relative to the RNP defined path (both lateral and vertical deviation). The display must allow the pilot to readily distinguish if the cross-track deviation exceeds the navigation accuracy (or a smaller value) or if the vertical deviation exceeds 22 m (75 ft) (or a smaller value). It is recommended that an appropriately scaled non-numeric deviation display (i.e. lateral deviation indicator and vertical deviation indicator) be located in the pilot's primary optimum field of view.
>
> 6.3.3.3.1.3 m) *Display of deviation*. The navigation system must provide a numeric display of the vertical deviation with a resolution of 3m (10ft) or less, and lateral deviation with a resolution of .01NM or less;

The preferred standard of display of lateral FTE is therefore:

- A lateral deviation indicator; and
- A numeric display of .01NM

However in many cases, particularly for older aircraft, this level of display is not available. The question then arises as to the eligibility and if so the RNP capability.

The purpose of the lateral display of deviation is (as stated above) to "*allow the pilot to readily distinguish if the cross-track deviation exceeds the navigation accuracy (or a similar value).*"

Where the specified standard of display is not provided, an operational evaluation needs to be conducted to determine if the display of information is adequate to support RNP AR APCH operations. The evaluation may determine, for example, that cross-track deviations of 0.3NM can be adequately monitored, but that less than that value the displays are considered inadequate. An operational approval might be given in these circumstances for RNP AR APCH operations limited to not less than RNP 0.3.

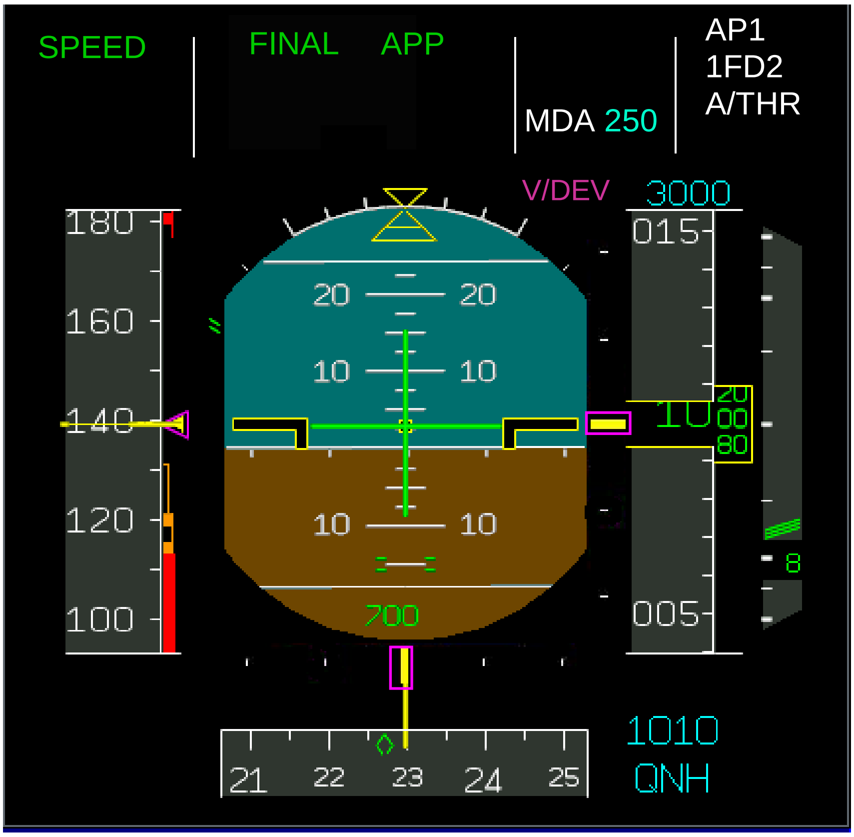

Figure 10.1: Primary Flight Display with lateral and vertical deviation indicators

Figure 10.2: Lateral deviation displayed on a navigation (map) display

10. Demonstration of Path Steering Performance

The PBN manual includes a requirement that path steering performance (i.e. FTE) is evaluated under a number of conditions, including non-normal conditions.

It should be noted that differences exists amongst regulatory authorities on the means of assessment of the management of FTE in non-normal conditions. European authorities take the view that the aircraft system should be capable of managing non-normal events, while the FAA considers that operational mitigations are acceptable.

The method(s) is used to demonstrate FTE performance must be taken into account when evaluating crew procedures.

11. Navigation System Monitoring and Alerting

In order to qualify for RNP operations of any kind the navigation system must incorporate a system to monitor the performance of the navigation system and provide an alert to the flight crew when the system no longer meets the specified performance requirements.

Two elements of navigation system performance are normally monitored, accuracy and integrity.

Depending upon the manufacturer the parameters used and the alerting levels will vary, however the method used is not normally an issue with regard to aircraft eligibility, although there can be implications in operating procedures. Information should be obtained on the parameters that are monitored, the relevant alert limits and the method of annunciation of the alert.

Navigation system accuracy is commonly represented by Horizontal Figure of Merit (HFOM) or Estimated Position Error (EPE). These parameters represent an estimate of the position solution assuming that the satellite system is operating within its specific performance. An alert is normally generated when HFOM or EPE equals or exceeds a limit, normally 1 x RNP. Integrity is commonly monitored by Horizontal Protection Level (HPL), sometimes called Horizontal Integrity Limit (HIL). An alert is provided when HPL equals of exceeds a limit relative to the selected RNP.

In at least one case the manufacturer derives a value for accuracy as a function of HPL. As both accuracy and integrity are dependent upon the same satellite constellation there is a relationship between derived parameters such as HFOM, EPE and HPL (HIL). Although each of these parameters measures different performance characteristics, each can be shown to be a function of another, within specified bounds.

Normally NSE integrity is monitored, but some systems monitor both accuracy and integrity and separate alerting limits are set for each parameter. In some (less common) cases HFOM is used and there may be no alert directly related to integrity. Such cases warrant further examination to ensure that integrity is adequately monitored and it may be necessary to implement supplementary procedures (e.g. ground monitoring) to ensure that integrity is available for all operations.

12. GNSS latent failure protection

GNSS systems must provide protection from latent GPS satellite failure. Protection is provided by an integrity monitoring system and the principles of integrity monitoring are discussed elsewhere in this handbook.

For RNP AR APCH operations the PBN Manual includes a requirement that when HIL = HAL that the probability that the aircraft remains within the obstacle clearance volume used to evaluate the procedure must be greater than 95 percent (both laterally and vertically) (Para 6.3.3.2.2 (b)). Normally the manufacturer will provide documentation that this condition is met.

An alternative means of compliance provided in the note attached to this paragraph is available if the HIL is less than 2 x RNP less 95% FTE.

It may be helpful to consider a typical case based upon the simple (alternative) case. The typical 95% FTE for a modern aircraft with AP engaged is of the order of .07NM/95%. To meet the alternative means of compliance HIL should not exceed 2 x RNP - .07NM. For the limiting case (currently) where RNP = 0.10NM, the maximum HIL is:

(2 x 0.10) - .07 = 0.13NM.

In most cases, HAL ≤ 1 x RNP and therefore this condition is met.

13. Operating Procedures

In recent years most manufacturers have developed recommendations for RNP AR APCH operating procedures. Although the manufacturer recommendations should be followed, the operational approval should include an independent evaluation of the operators' proposed procedures. RNP AR APCH operating procedures should be consistent with the operator's normal procedures where possible in order to minimise any human factors elements associated with the introduction of RNP AR APCH operations.

Vectoring. A procedure may be intercepted at a position inside the IAF but no later than the VIP when vectored by ATS. Descent on an approach procedure below the minimum vectoring altitude is not permitted until the aircraft is established within the vertical and lateral tolerances of the procedure and the appropriate navigation mode(s) is engaged.

14. RNP Availability Prediction.

As the current GPS constellation is unable to provide 100% availability of RNP at all levels of service, there a periods, depending upon a number of factors, when an RNP approach cannot be conducted. Consequently a prediction of availability is conducted to enable the flight crew and dispatchers (where applicable) to take into consideration the level of RNP capability that can be expected at any particular location.

Commonly, even for low RNP levels, the periods when an RNP service is unavailable are short, and a delay in departure or en-route, is often sufficient to schedule an arrival when the service is predicted to be available.

An operation is not available, or should be discontinued when an alert is displayed to the flight crew. Consequently availability is determined by the means used to generate an alert, which as discussed previously, varies between aircraft. In order to be most accurate and effective a prediction of availability needs to be based on the same parameters that are used in the particular aircraft systems, rather than a general prediction of a parameter such as HPL.

The operator needs to make arrangements for prediction service to be available that replicates the monitoring system on the aircraft. Prediction services are readily available from a number of commercial sources. The prediction should be based on the latest satellite health data, which is readily available, and take into account other factors such as high terrain. On board prediction programs are generally unsatisfactory in that they are unable to take account of satellite NOTAMS and terrain masking.

While satellite prediction services are normally accurate and reliable it should be noted that an unpredicted unavailability can occur at any time. However safety is not compromised (provided adequate fuel reserves are carried) and on-board monitoring assures that the crew will be alerted and the approach can be discounted, delayed or an alternative approach conducted.

ZULSARR: Predicted EPE values for (A319) from
Fri 30-Mar-2007 1700Z to Sat 31-Mar-2007 0600Z
RNP 0.15 available 1700Z to 0600Z
RNP 0.20 available 1700Z to 0600Z
RNP 0.30 available 1700Z to 0600Z

ZULSDEP: Predicted EPE values for (A319) from
Fri 30-Mar-2007 1700Z to Sat 31-Mar-2007 0600Z
RNP 0.15 available 1700Z to 0600Z
RNP 0.20 available 1700Z to 0600Z
RNP 0.30 available 1700Z to 0600Z

Figure 10.3: Example of an RNP availability forecast

Note: In Figure 10.3 EPE values are relevant to RNP for the A319

15. Radio updating.

The operational approval needs to consider the method used to determine the computed aircraft position.

The computed aircraft position is normally a mix of IRS/GPS and in some cases also DME and VOR combined using a Kalman filter. The manufacturer’s stated RNP capability should take into account the method used to compute position and any weighting of navigation sources.

In the typical case IRS position is updated continually by GNSS and radio aid updating is either inhibited or weighted so as to have little effect or none on the computed position. When a source of updating is lost the position will be determined in accordance with a reversionary mode. If GNSS updating is lost, IRS position is normally updated by DME if available and VOR if insufficient DME stations are in view. As DME and particular VOR updating is much less accurate than GNSS there is some potential for degradation in the position accuracy.

If it can be determined that radio updating has no detrimental effect on the accuracy of the computed position, then no action is required.

However, it can be difficult to obtain confirmation of the effect of radio updating, and where this cannot be determined, radio updating should be selected OFF. Most systems provide for a means for deselection of radio updating, either manually or by a pin selection option. Manual deselection can be an inconvenient additional crew procedure, although on at least one aircraft type a single button push selection is available. Where possible a default option where radio updating is normally OFF is preferred, with the option of crew selection to ON in the unlikely event of a loss of GNSS updating.

At least one manufacturer has identified that where reversion to updating from a single VOR is possible that significant position degradation may occur, and recommends that radio updating is selected OFF for all RNP AR APCH operations.

16. Procedure selection and review

Operating procedures need to address the selection of the approach from the navigation database and the verification and review of the displayed data. Commonly some changes to an operator's normal practice will be involved, and the regulator's evaluation will need to recognise that new techniques may be appropriate to RNP approach operations.

In most cases the instrument approach chart will contain RNAV (RNP) in the title and the clearance issued will refer to RNAV, the runway, and usually a suffix letter e.g. RNAV (RNP) RWY 20 X. Due to avionics limitations the available approaches may be displayed in an abbreviated format e.g. for RNVX. In some cases the suffix letters (X, Y, and Z etc) may not be supported. Care needs to be taken that flight crew procedures take into account these limitation and that the correct procedure is selected and then checked.

The procedures normally applied to the review and briefing for a conventional approach are typically not suitable for RNP AR APCH operations. Approach procedures can be complex, with numerous legs, tracks distances, fixes, altitude and speed constraints etc, which can result in a long, complex and ineffective briefing process.

Many of the parameters normally checked on a conventional procedure are contained within the navigational database which is subjected to a rigorous quality control process. Detailed checking of numerous individual data elements delivers no safety benefit and attention needs to be placed on the more important aspects of the approach. Of greater importance is the verification that the correct procedure is selected and this can be achieved by a review of the waypoint sequence.

Other key elements are:

- Minimum altitudes
- Location of VIP and FAF
- Speed limitations

It should be recognised that the approach chart assumes less importance for an RNP AR APCH procedure once the procedure is loaded in the FMS and checked. During the approach the only limited reference to the chart is normally required.

17. Required list of equipment.

Separate from the MEL, RNP AR APCH brings in the idea of *required equipment*. This list, which should be readily available to the crew, identifies the operator's policy in regard to items of equipment that must be serviceable prior to commencement of an RNP AR APCH. This list should be consistent with the requirements for conduct of the particular approach, and the operator's FOSA which will identify and asses the risks associated with equipment failure during an approach.

The PBN manual, for example, requires that for RNP AR APCH where RNP is less than 0.3 that there should be no single point of failure. Many operators will specify redundant equipment for approaches irrespective of the RNP, particularly where terrain is an issue.

18. Use of autopilot and flight director

The manufacturer's guidance will normally provide recommendations on the use of auto-pilot and/or flight director. Irrespective of this guidance, the underlying philosophy of RNP AR APCH is that maximum use is made of the aircraft systems and auto-coupled approaches should be regarded as standard practice. This should not preclude the use of flight director (consistent with manufacturer procedures) when autopilot is not available or in other circumstances (e.g. OEI operations).

Note: The FTE used by the aircraft manufacturer to demonstrate RNP capability may be dependent upon the use of a coupled auto-pilot. A lesser RNP capability may be applicable to procedures flown using flight director.

19. RNP selection.

The RNP for an approach or segment of an approach can be set by a number of means, including a default value (commonly RNP 0.3), automatic extraction from the navigation database or pilot selection.

In all cases a crew procedure is necessary to check that the required RNP is selected prior to commencement of the procedure.

It is common for more than one line of minima to be published with lower RNP associated with lower DAs. Standard practice is to select the highest RNP consistent with the operational requirement. For example if the RNP 0.3 DA is likely to permit a successful approach then a lower RNP would not be selected, as lowering RNP tightens the alerting limits and increases the possibility of an alert message.

20. GNSS updating

RNP AR APCH procedures are dependent on GNSS positioning, and the availability of GNSS, (as well as the available level of RNP) should be checked prior to commencement of an approach.

The failure of a GNSS receiver (i.e. an equipment failure) is commonly annunciated, but in the normal case where duplicated GNSS receivers are installed, the approach can continue normally using the serviceable receiver.

A loss of GNSS updating due to a loss of signal may occur at any time, but an alert will not normally be generated immediately. Where position integrity can be maintained following the loss of GNSS a valid position continues to be displayed.

When the required performance cannot be sustained an alert will be generated, and the normal procedure is to conduct a go-round, unless the approach can be conducted visually.

During the operational approval attention must be placed on determining the alerting protocol associated with both loss of a receiver and loss of signal and the operating procedures evaluated accordingly.

21. Track deviation monitoring.

A basic principle of RNP is performance monitoring and alerting. In most cases the monitoring of FTE is a flight crew responsibility and is not provided by an automated system. The acceptable tolerance for normal operations is ½ the navigation accuracy. In practice FTE, normally managed by the autopilot, is very small for both straight and turning flight. An observed cross-track standard deviation of less than .01NM is typical and while the flight crew must understand their responsibility in regard to monitoring of FTE, there is normally no action required at all.

Deviation from track is most likely to occur due to a loss of AP guidance (disconnection of failure to connect), inadvertent limitation of bank angle, incorrect or delayed mode selection, and in rare cases, excessive wind during turns. In the event of an excursion from the flight planned path, immediate action should be taken to regain track, or a go-round conducted if the cross-track error reaches 1 x RNP. The lateral navigation mode must be engaged (or re-engaged) during the go-round and accurate tracking regained.

Note that while the allowable tolerance is relative to RNP the actual FTE is independent of the selected RNP.

FTE monitoring and management is of greater interest in regard to non-normal events. Attention should be placed on OEI operations, autopilot disconnect, loss of lateral navigation guidance, go-round and similar events. FTE limits can also be exceeded in turns if bank angle is not maintained, airspeed is excessive or winds are stronger than designed.

Sound procedures need to be in place to recognise any deviation, including crew callouts and appropriate recovery or go-round actions.

Automation induced complacency given the accuracy and reliability of track adherence in normal operations is a concern and attention should be placed on awareness of potential factors that might lead to a FTE increase, rather than simple reliance upon crew monitoring.
The evaluation of cockpit displays (refer aircraft eligibility) should also be considered against the background that in normal circumstances track adherence is excellent and recognise that the primary function of cross-track error display is to provide adequate indication to the flight crew should a deviation occur.

22. Vertical Navigation

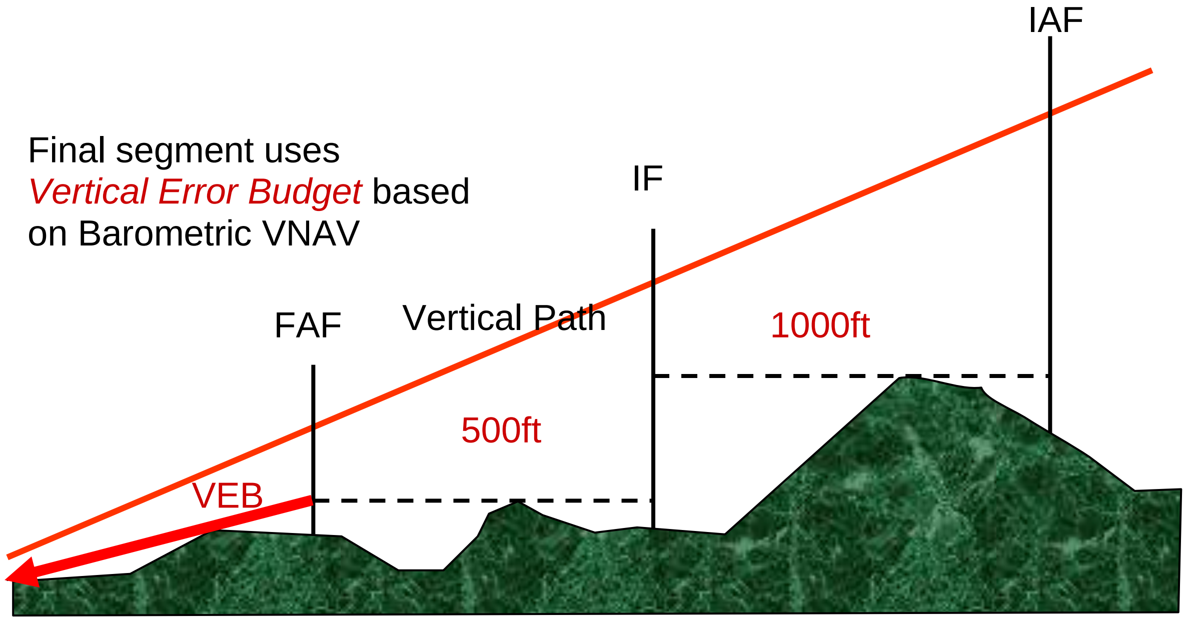

Figure 10.4: RNP AR APCH Vertical Navigation

At the present time RNP AR APCH uses barometric VNAV which is currently available on most aircraft otherwise capable of RNP AR APCH operations. Other VNAV systems will become available (e.g. SBAS) but only baro-VNAV is discussed in this section.

Most commercial jet transport aircraft are equipped with a baro VNAV system that is compliant with FAA AC 20-129 which has been in existence for many years. The vertical performance parameters contained in AC 20-129 were developed at a time when the use of baro-VNAV for RNP AR APCH operations had not been envisioned and do not match the requirements for RNP AR APCH.

However the actual performance of installed VNAV systems has been demonstrated to provide accurate vertical guidance which meets the standard necessary for RNP AR APCH.
It is therefore necessary to obtain data to substantiate the VNAV performance. The basis of the procedure design is the VEB which in comprised of the following elements:

- Altimetry System Error (ASE)
- Flight Technical Error (FTE)
- Horizontal coupling or Actual Navigation Performance Error (ANPE)
- Waypoint resolution error (WPR)
- Vertical angle error (VAE)
- Atis Error

The VEB is computed using the following formula:

$$VEB = BG + ISAD + \frac{4}{3}\sqrt{ANPE^2 + WPR^2 + FTE^2 + ASE^2 + VAE^2} + ATIS$$

Where:

BG is Body Geometry (allowance for wing span during turning flight)
ISAD is ISA Deviation which is the allowance for temperature effect

ANPE, WPR and ATIS errors are either fixed or independent of the aircraft. The elements that need to be evaluated are:
Altimetry system error (ASE);

- Flight technical error
- Vertical angle error

ASE should be determined by the manufacturer and documentation provided to show that the aircraft meets the minimum requirement;

The 99.7% altimetry system error for each aircraft (assuming the temperature and lapse rates of the ISA) shall be less or equal to than the following with the aircraft in the approach configuration:
$ASE = -8.8 \times 10^{-8} \times H^2 + 6.5 \times 10^{-3} \times H + 50$ (ft)
Where H is the true altitude of the aircraft

This information may be obtained from the manufacturers in most cases, or from other regulatory authorities that have conducted an operational approval for the particular aircraft. Where insufficient data exists, in-service data can be collected using on-board engineering or QAR data collection, during the initial implementation period.

Aircraft which are RVSM compliant should have no difficulty in meeting the ASE requirement.

The value for FTE used in the calculation of VEB is 23m (75ft)/ 99.7% (3σ) and it needs to be established that the aircraft can meet this requirement. Most manufacturers will provide a statement that the FTE/99.7% is less than this value, and performance is typically of the order of 50 – 60 ft. Where the manufacturer supplied data is unavailable, insufficient on inconclusive, the FTE values can be substantiated during initial operations by collecting on-board data from the engineering monitoring system or QAR. Operations may need to be limited to a high minima or visual conditions during the data collection periods.

Vertical angle error is a value normally set by the FMS manufacturer, and should be equal or less than 0.01°. As many FMSs were designed when there was no requirement for such as accurate definition of vertical flight path angle, the value could be as high as 0.1°. This of itself does not mean that the aircraft is unable to qualify as the VEB is a sum of all the contributing errors. An analysis of the sum of all the errors, including a high value of vae should demonstrate that the VEB remains with in the design limit.

23. Vertical deviation monitoring.

Although variations in FTE are accommodated in the VEB, it is a flight crew responsibility to monitor FTE and limit any excursions above and below the vertical flight path.

Most aircraft do not have a system for automatic monitoring and/or alerting of deviation from the vertical flight path and this function is a crew responsibility. The maximum acceptable deviation below the flight path is set at 23m (75ft). Crew procedures must detail the callouts required when a deviation is observed, and mandate a go-round if the deviation exceeds the maximum. Deviations above the flight path do not compromise obstacle clearance in the final approach, but can result in the aircraft arriving above the flight path, leading to destabilisation of the approach, a long landing, energy management issues and other effects. Sustained deviation above the flight path should be limited to less than 75ft.

During the evaluation of the aircraft systems attention should be placed on the vertical flight path and deviation displays which need to be adequate to allow flight crew monitoring of flight path deviations.

Although the design of an RNP AR APCH procedure uses the VEB obstacle clearance only in the final approach segment, it is operationally convenient to nominate a point prior to the FAF at which the aircraft is to be established on the lateral and vertical flight path, with the appropriate flight mode engaged (e.g. VNAV PATH or FINAL APP) in a suitable approach configuration, and in stable flight. Although various terms have been used for this point, Vertical Intercept Point (VIP) is becoming accepted in common use. This is also useful to indicate to ATC the latest point at which the approach can be joined if it is necessary to take the aircraft off-track after the IAF.

24. Maximum airspeeds

As the ability for an aircraft to remain on track during an RF leg is limited by angle of bank and groundspeed, it is important that the operational approval addresses both the aircraft capability and the flight crew responsibilities associated with this common manoeuvre.
Bank angle authority is subject to a number of factors including crew selection, airspeed, altitude, ground proximity, loss of systems (e.g. RADALT) and can result in an unplanned reduction of commanded bank angle leading to a deviation from track.

The minimum radius for an RF legs is determined by the assumed maximum bank angle (25°/ 8° above/below 121m (400ft) respectively) at the maximum design ground speed. The maximum groundspeed is a function of the assumed maximum true airspeed, (which is affected by altitude and temperature) and an assumed rare *normal* tailwind component. In normal operations, as flight is well within the maximum limits (i.e. light winds) observed bank angles are low. However should design rare normal tailwind conditions exist, and/or the maximum design airspeed is reached or exceeded, then the aircraft will command up to the maximum bank angle in order stay on the flight path. If the bank angle is reached, any further increase in groundspeed will result in a deviation from the flight path.

It is necessary that flight crews understand the effect of airspeed on track keeping in RF turns and limit speeds to the maximum used in design. The design airspeeds used for various phases of flight and aircraft category are published in the PBN Manual. Maximum airspeeds may also be programmed in the navigation database enabling less reliance on flight crew memory to manage airspeed.

Although not a mandatory function for RNP AR APCH the capability to fly an RF leg is commonly required for RNP AR APCH procedures. Consequently it is unusual for an operational approval to not cover operations with RF legs.

25. Limiting temperature

Obstacle clearance in the final approach segment is adjusted to allow for the change in flight path with temperature. In temperatures below ISA the actual vertical flight path is flatter than the nominal designed gradient and obstacle clearance is reduced. The procedure designer, in order to maintain minimum clearance from obstacles beneath the final approach path, may need to limit the operating temperature, and a minimum temperature is published on the approach chart.

Some aircraft systems incorporate a temperature compensation system which allows the design flight path gradient to be flown, removing the requirement to protect the final approach path from the effect of temperature. However the majority of air transport aircraft do not have temperature compensation installed.

Note: Some operations also incorporate provision for non-normal operations, and temperature limits may also be predicated on OEI climb performance.

26. Altimeter setting procedures

As the flight path guidance provided by a barometric VNAV system is directly affected by the barometric pressure subscale setting, particular attention needs to be placed to pressure setting procedures and associated aircraft systems.

27. TOGA Navigation Functionality

The Take-off Go Around (TOGA) function in most existing aircraft installations was designed to assist in the conduct of a missed approach in circumstances where the general requirement is to maintain the approach track during the missed approach. For RNP AR APCH operations this typical functionality is no longer an appropriate solution and the PBN Manual requirement is that missed approach guidance is provided such that continual lateral navigation guidance is provided in the go-round. The terms TOGA to LNAV or TOGA to NAV describe this functionality in common usage.

This feature is becoming standard on production aircraft and is available as an upgrade on many later model aircraft. Where the function is not available, special crew procedures and training may be developed to overcome this limitation. Normally it will be necessary to over-ride the normal TOGA track hold function and manually maintain the RNP track until the normal RNP navigation can be re-engaged.

28. Navigation Database

The PBN Manual includes a number of requirements associated with the navigation database as follows:

Data management process: Operators who are experienced in RNAV operations are likely to have sound procedures in place for the management of data. Less experienced operators may not fully understand the need for comprehensive management procedures and may need to develop or improve existing procedures.

Data Suppliers: The requirement for a data supplier to have an approval in accordance with RTCA DO200A/Eurocae ED76 is now common practice. It is common for States to recognise a LoA issued by the State where the data base supplier is located. It should be noted that despite the requirement for a LoA that data errors may still occur and dependence on quality management alone is not sufficient.

Initial Data Validation: The procedure designer is required conduct an initial flight validation in an RNP capable aircraft. Experience has been that despite the validity of the data originating in the design office errors can occur downstream in data packing, reading and interpreting of data, data execution and functionality, and it is necessary for each operator to conduct an initial data validation to ensure correct operation in the particular type/model of aircraft to be flown.

While this requirement is necessary it can present problems in practice. If the validation is to be done in a simulator, then the simulator should accurately replicate the aircraft. In many cases this is not possible as simulators tend to lag behind aircraft in terms of upgrades. Consideration may need to be made for the simulator compatibility, complexity of the procedure, past experience and other factors. If a suitable simulator is not available then validation may need to be conducted in the aircraft. This can be achieved with safety in visual conditions during normal revenue operations without incurring additional unnecessary expense.

Cyclic Data Validation: This is an important consideration in the management of navigation data as each update provides a subtle opportunity for data errors to occur. Various methods are used in an attempt to ensure that data remains valid, but the most reliable method involves an electronic comparison of the new database against a database of known validity. For this process to be successful, source data in electronic form is necessary, although most States have yet to implement facilities to enable the export of procedures in an electronic file.
(Note: The file should be derived directly from the procedure designers electronic data file without human intervention.).

Data Updates: Changes are routinely made to all approach procedures and unless there is a significant change to the flight path, either laterally or vertically, re-validation should not be necessary. The cyclic comparison of new versus old data must be designed to identify changes that have not been ordered prior to the effective date for each database cycle. Action can then be taken to rectify the problem before the effective date, or issue corrective action such as notices to flight crew, withdrawal of procedures etc.

In cases where an effective electronic cyclic data validation process is not available, it may be necessary to conduct re-validation of procedures at each cycle. This is a time-consuming and complex procedure which should be avoided wherever possible.

29. Flight crew training

Properly conducted RNP AR APCH operations are perhaps the simplest yet most efficient approach operation available. The fact that normal operations, routinely conducted using the aircraft auto-flight system, provide excellent repeatable and very accurate flight path guidance can mislead operators into a false sense of security.

It must be recognised that the improvements in operational capability and efficiency need to be matched by an enhanced awareness and sound operating procedures. One of the subtle risks to RNP AR APCH operations is the reduced levels of alertness that may occur simply due to the confidence that crews have in the operation.

Thorough flight crew training is essential to ensure that crews are fully conversant with the aircraft systems and operations and are able to manage all normal and non-normal operations with confidence. Training needs to emphasise the role of the flight crew to monitor the aircraft systems and a thorough understanding of aircraft systems management.

Training requirements will vary significantly depending on the operator's previous experience. Operators familiar with the conduct of RNP APCH (RNAV $_{GNSS}$) operations will find the transition to RNP AR APCH less demanding. Operators without relevant experience would be well advised to progress slowly and introduce RNP AR APCH operations under a phased implementation program.

As a guide, crews with previous relevant RNAV approach experience will typically require a minimum of one day ground briefing on RNP AR APCH principles, systems and operating procedures, and one or more 4hr simulator training sessions (per crew).

30. Flight Operational Safety Assessment (FOSA)

The improved capability of RNP AR APCH operations enables approach procedures to be designed to low decision altitudes at locations where conventional approach procedures are not possible. The ability to deliver an aircraft to a DA as low as 75m/250ft in close proximity to terrain brings with it increased exposure to risk in the event of a critical systems failure.
The safety of normal RNP AR APCH operations is not in question, and compliance with the requirements of the RNP AR APCH navigation specification is regarded as sufficient to meet the required level of safety. The FOSA is intended to provide assurance that the level of safety is maintained in the event of a non-normal event.

ICAO instrument approach procedure design criteria do not make provision for non-normal events and consequently approach procedures are designed without regard to the consequences of failures, and could therefore place an aircraft in a situation where there is increased exposure to risk in the event of a system failure.

While there are elements of an approach procedure that are associated with the air navigation service provider, the aircraft manufacturer, and the procedure designer, the fundamental responsibility for the FOSA rests with the operator.

The method used to conduct the FOSA is of less importance that the fact that an assessment of the hazards is conducted. There are generally accepted practices for risk assessment adopted by a number of industries which can be applied to the FOSA.

In general, the following basic principles should be applied.

1. Each of the hazards should be identified. Guidance on typical hazards is provided in the PBN Manual, but this list should not be regarded as exhaustive.
2. The probability of a hazard event occurring should be assessed. For example, probability may be assessed as:
    a. Almost certain
    b. Likely
    c. Possible
    d. Unlikely
    e. Rare
    f. Extremely Rare
3. Assess the consequences of each event, for example:
    a. Minor
    b. Moderate
    c. Major
    d. Severe
    e. Catastrophic
4. Identify risk mitigators (including documentation)
5. Evaluate the overall risk

At the end of this process all risk outcomes should be assessed as low or "as low as reasonably practical".

For example:

Hazard:	Loss of integrity during an approach with RF legs
Probability:	Rare
Consequences:	Minor (Go-round, IRS nav available)
Risk mitigators:	Availability prediction, TOGA to LNAV available, crew training
References:	OPS Manual Section 5 Ch 2 RNP availability program Fight crew operations manual Part II Section 3 para 7.4.3.1 Flight crew training Manual Section4 Chapter 1 para 1.9.3
Risk Assessment:	Low