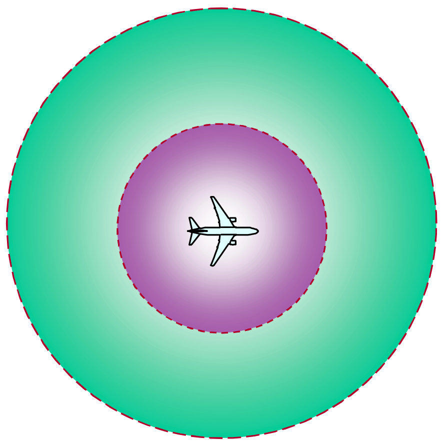
BOEING

FMS RNAV WORKSHOP

General Information on
the Functional and Technical Aspects of
Required Navigation Performance (RNP)
Area Navigation (RNAV)
And Applications



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CNS/ATM Technical Requirements and Standards

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Rev -

1. INTRODUCTION

Area navigation (RNAV) capability is an existing aircraft capability that supports airspace development in the form of improved design of procedures and more efficient operations. Required Navigation Performance (RNP) is an emerging tool for the development of more efficient airspace and operations. An aircraft area navigation system developed for RNP operations provides reliable, repeatable and predictable performance through specific RNP RNAV capabilities and features. One of the key attributes is what will be defined as RNP RNAV containment. RNP RNAV provides a means to meet the requirements of RNP airspace and operations. RNP RNAV and Vertical Navigation (VNAV) together enable further improvements in RNP airspace design and operations.

2. GENERAL BACKGROUND

2.1 RNAV

RNAV is defined as "a method of navigation that permits aircraft operations on any desired course within the coverage of station referenced navigation signals or within the limits of a self-contained system capability or combination of these." RNAV systems are recognized for their horizontal 2D capability to utilize one or more navigation sensor source to determine the aircraft position, compute flight paths referenced to navigation aids or points defined by latitude and longitude, and provide guidance cues or tracking of the flight path. In addition to this capability, many RNAV systems include a 3D capability to define vertical path profiles based upon altimetry and a built-in model of the aircraft and engine performance, and provide guidance cues or tracking of this vertical path. A more recent capability added to RNAV systems has been 4D, in the form of determining and managing time of arrival to a specific point along the flight profile.

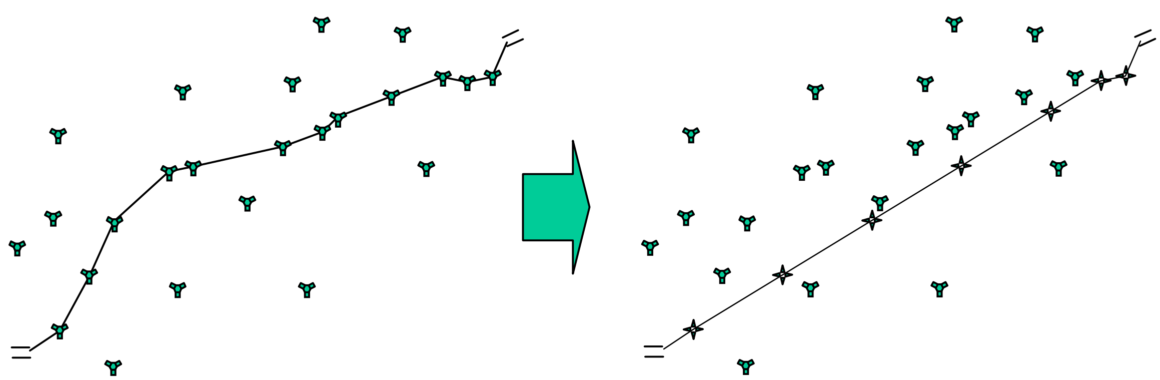


Figure 2-1

An RNAV system may determine position using any of a number of ground navigation aids including VOR, DME, Loran-C and Omega, self-contained systems such as inertial reference systems systems, and space based systems as GNSS. The combinations of navigation aids used in systems and architectures are varied. The use of multiple sensors is common because of the variety in navigation infrastructures from region to region or state to state, as well as being mandated through regulations.

The flight paths used for RNAV have been established in a number of ways. One form has been the use of an on-board navigation database, where pre-stored information and data such as for airports, navigation aids, departure/arrival procedures, routes/airways, altitudes, speed, frequencies, elevation, distance, and magnetic variation is located. The databases range from those with a small capacity for fix position and name only to ones that contain virtually all available aeronautical information that is published. The RNAV system uses this information to facilitate flight crew definition of the flight path for the operation. It is also common for the flight crew to alter the flight path through manual entry of fixes, and reporting points, as well as responding to ATC. Flight path capabilities range from a low end of 4 - 10 fixes to as many as necessary to support the flight e.g. 40, 100, 200, etc.

The information stored in navigation databases originates from many sources including states, airlines, and others. The navigation databases are subject to a 28 day update cycle.

The RNAV systems provide information such as path deviation (e.g. CDI) and speed commands, data interfaces for guidance cues such as flight director commands, and graphical map displays to enable the flight crew or system to follow and track the RNAV flight path. Further automation such as coupling of the RNAV system with an autoflight and autothrottle systems to facilitate flight path tracking and performance is also very common.

2.2 RNP

Required Navigation Performance was initially envisaged by ICAO as a means to avoid the inflexibility and slow changability of equipment mandates for airspace operation. ICAO recognized that starting with GNSS, the navigation infrastructure, operations, and aircraft systems were undergoing change quicker than could be supported by their traditional technical standards processes. RNP was developed to allow the specification of airspace and operation requirements without the constraints of the slow process for specifying equipment and systems.

Through the initial efforts of the ICAO Review of the General Concept of Separation Panel (RGCSP), RNP was further developed as a tool where specific levels of navigation performance would be specified in the development of airspace and to enhance operations. RNP was defined as a "statement of the navigation performance accuracy necessary for operation within a defined airspace."

By making RNP non-specific for equipment, the airspace designer was freed from equipment mandate concerns to apply RNP in specifying improved airspace or procedures that all users and their aircraft equipment would meet. RNP could be then applied as one consideration in requirements such as route widths, and traffic separation.

While the ICAO Manual on RNP (reference 1, Doc 9613-AN/937, dated 1999) clearly defined RNP as a 95% containment value and its relationship to navigation performance accuracy, it left the other aspects of integrity, availability, coverage, etc to other technical bodies to specify. This task was undertaken by RTCA Special Committee 181 and EUROCAE Working Group 13, Standards of Navigation Performance, in their development of a number of minimum standards documents for RNP Aviation Systems, Navigation Database processes, and Aeronautical Information.

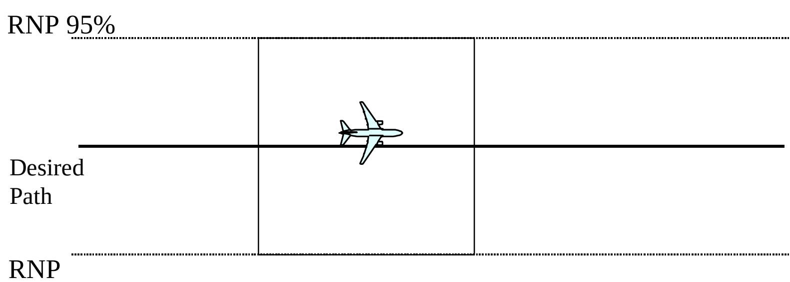


Figure 2-2

2.3 VNAV

Vertical Navigation (VNAV) capability enhances flight operations further by enabling the specification of a flight path vertically for the lateral flight path, as well as providing path deviation and guidance for tracking the path. The enhancements are in the form of:

- computed vertical paths as the basis for airplane guidance
- repeatability in performance
- tailoring the vertical path to specific types of aircraft/engine performance
- tailoring the vertical path to manual altitude constraints or angles
- situational awareness indications to the flight crew

2.4 Time of Arrival Control

Time of Arrival Control (TOAC) is a recent development that integrates the flight path definition and control capabilities of the system with performance management (e.g. algorithms that establish paths and speeds based upon economy) to better support airspace tactical operations including metering fixes and airway crossing.

3. FUNCTIONAL CHARACTERISTICS

3.1 Navigation Sensors

The navigation sensors typically used for RNAV have different performance accuracy characteristics. Generally, the dependencies of varying degree on geometry, distance, and altitude are well known. The integration of multiple sensors (e.g. IRS with DME, VOR, GNSS, ILS, etc) into an RNAV system allows implementations that automatically utilize the best sources available. Additionally, through other filtering schemes such as a Kalman, and database/source comparisons, the systems further improve the accuracy of the RNAV computed position and its integrity.

3.2 RNAV

Area navigation systems have historically been developed based upon criteria specifying positioning accuracy, cross track deviation accuracy, flight technical error (FTE), airborne sensor error and ground equipment error for a specific total system error.

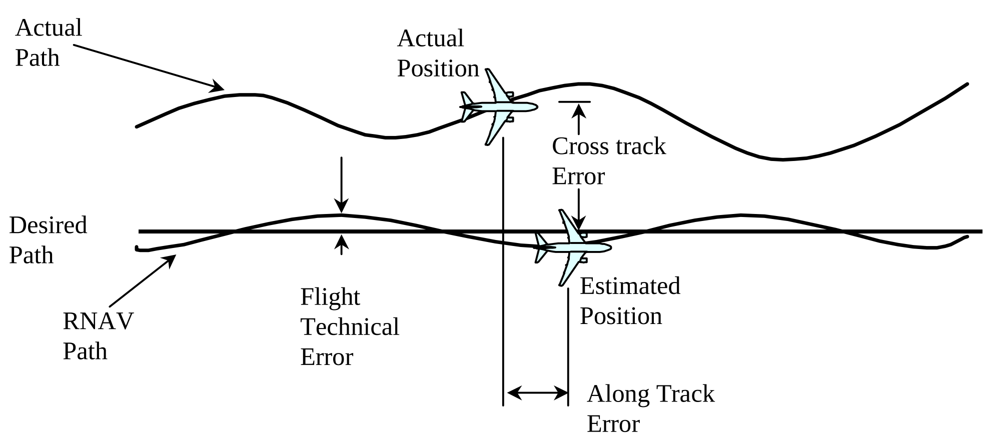


Figure 3-1

The navigation accuracy and FTE typically demonstrated for systems is as follows:

Table 3-1

Airspace/Operation	Accuracy (95%)	FTE
Oceanic/ En route Remote	± 3.8 NM	± 1.0 NM
Domestic Enroute	± 2.8 NM	± 1.0 NM
Terminal	± 1.7 NM	± 0.5 NM
Approach, VOR/DME	± 0.5 NM	± 0.125 NM
Approach, Multi-Sensor	± 0.3 NM	± 0.125 NM

2. availability of a navigation capability at 99.999%
3. integrity against misleading navigation information at 99.999%

4. functionality consistent with the application and systems integration

The flight path capabilities of systems encompassed up to 23 leg types that are described in more detail in Appendix B. These legs types have been used to develop pre-stored Navigation database procedures, that overlay or mimic conventional instrument procedures and ATC.

3.3 VNAV

Vertical navigation capability has been specified with the following:

1. 99.7% positioning accuracy RSS'ed with altimetry, path, and flight technical errors to obtain a specific total system error

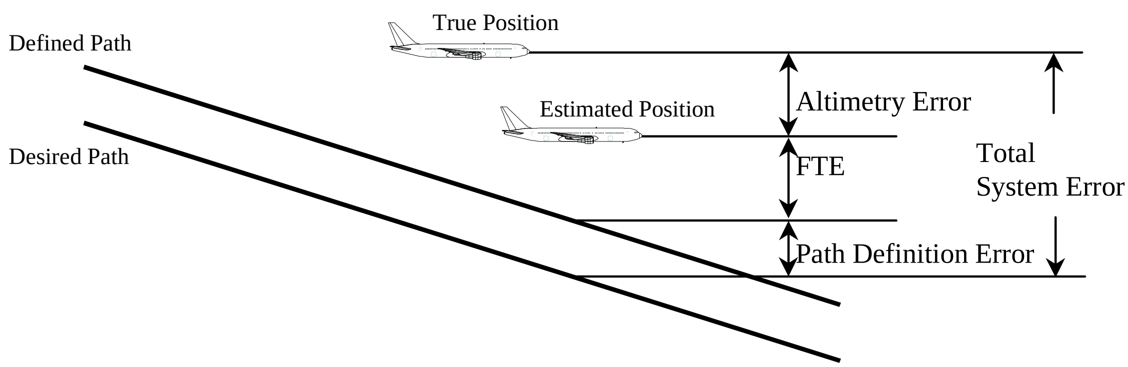


Figure 3-2

The vertical navigation performance typically demonstrated for systems is as follows:

Table 3-2

Airspace/Operation	Level 99.7%	Level/Intercept FTE	Climb/Descent 99.7%	Climb/Descent FTE
At or below 5000 ft	± 50 ft	± 150 ft	± 100 ft	± 200 ft
5000 to 10000 ft	± 50 ft	± 240 ft	± 150 ft	± 300 ft
Above 10000 ft	± 50 ft	± 240 ft	± 220 ft	± 300 ft

2. functionality consistent with the application and systems integration

VNAV performance is compatible with the recent and broadening application of 1000 foot vertical separation minima for flight levels 290 and above.

3.3.1 Path Definition and Tracking

For climb, it is expected that the space where the aircraft is located will be an envelope that represents the variability in climb profile based on any altitude constraints, aircraft performance or special airspace requirements (e.g. noise). A defined vertical path is only defined for descent and approach operations. The following figures are examples.

Figure 3-3

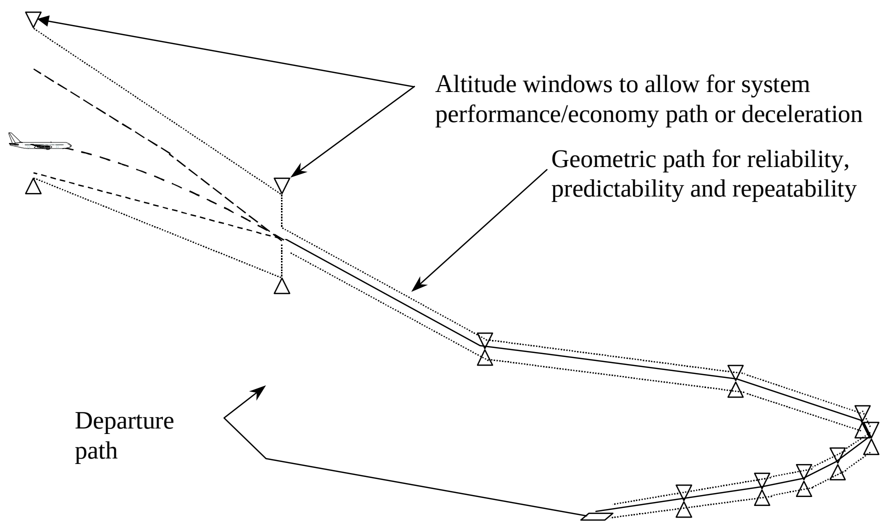


Figure 3-4

Paths may be defined by AT, BELOW, AT/ABOVE, AT/BELOW and WINDOW constraints. As shown in the figure, vertical airspace used is minimized from the point to point gradient path with its associated tracking performance. Where more latitude is allowed for the aircraft system to determine its best vertical path, use of window constraints provide the means to allow for a larger vertical area that also has performance limits to bound the area.

Where vertical fly-bys occur, a constant 0.03g path from one vertical path to the next is typical.

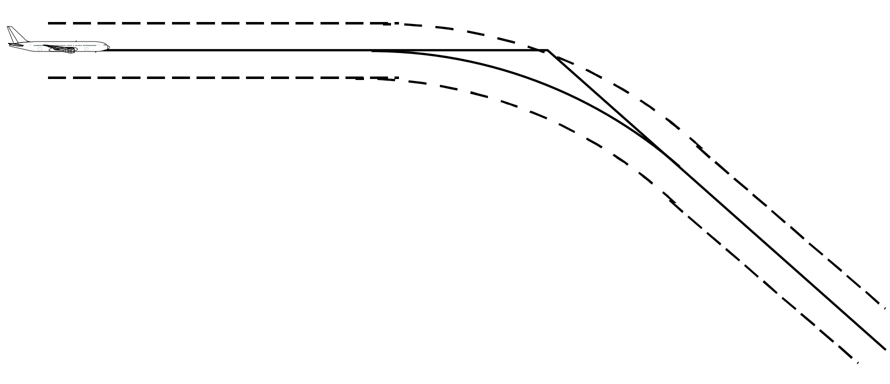


Figure 3-5

The relationship of the vertical path and transitions to the lateral path and its transitions must be recognized when defining VNAV operations.

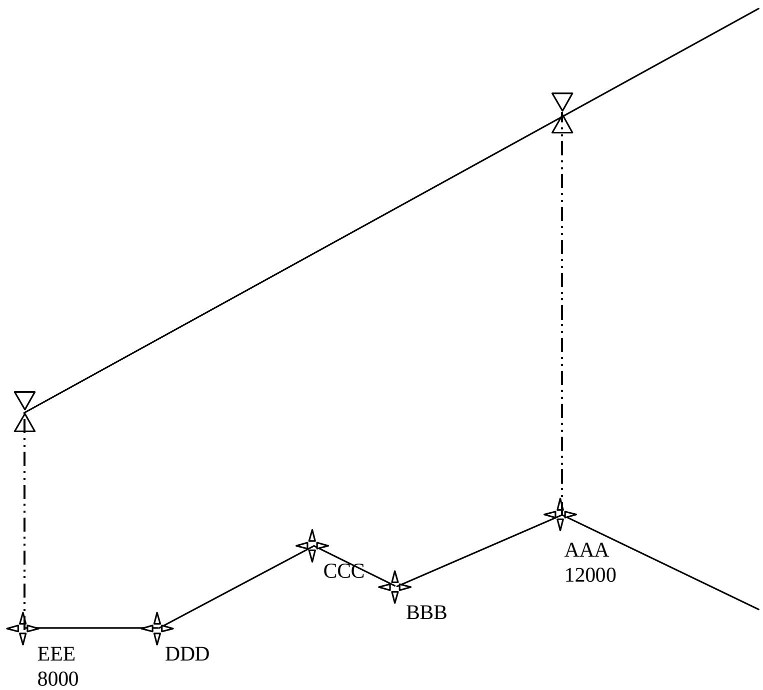


Figure 3-6

A stable path may be defined by altitudes an each end of the path segment, or by specifying a vertical angle on the leg types where it is allowed.

3.4 AIRSPACE

One reality has been that in defining airspace, empirical data for the least capable aircraft strongly influences the design of the airspace. The data statistics also include gross navigation errors with varying causes from failures to erroneous inputs from the flight crew. The better performing system is easily able to conform but receives little added value or benefit for a better capability and performance integrity. However, this is understandable as long as the airspace must allow for occupancy by traffic with a wide spread in performance and integrity. As an example, gross navigation error data for the North Atlantic shows the following:

Table 3-3
Gross Navigation Errors in the North Atlantic 1989 - 1993

Error Type	/G Aircraft IRS/FMS/Map	Classic Aircraft INS
1. Waypoint Insertion	8 (62%)	35 (60%)
2. Controller/Pilot Miscommunication	2 (15%)	5 (8%)
3. Equipment Failure	2 (15%)	6 (10%)
4. Mode Control	0	5 (8%)
5. Deliberate Pilot Action	1 (8%)	0
6. Unresolved	0	8 (14%)
TOTAL	13	59
No. of Flights	355,750	315,500
Error Rate/Flight	3.65 x 10-5	1.84 x 10-4

The general effect of this on airspace is inefficient airspace design and procedures in the form of large buffers and non-optimal minima.

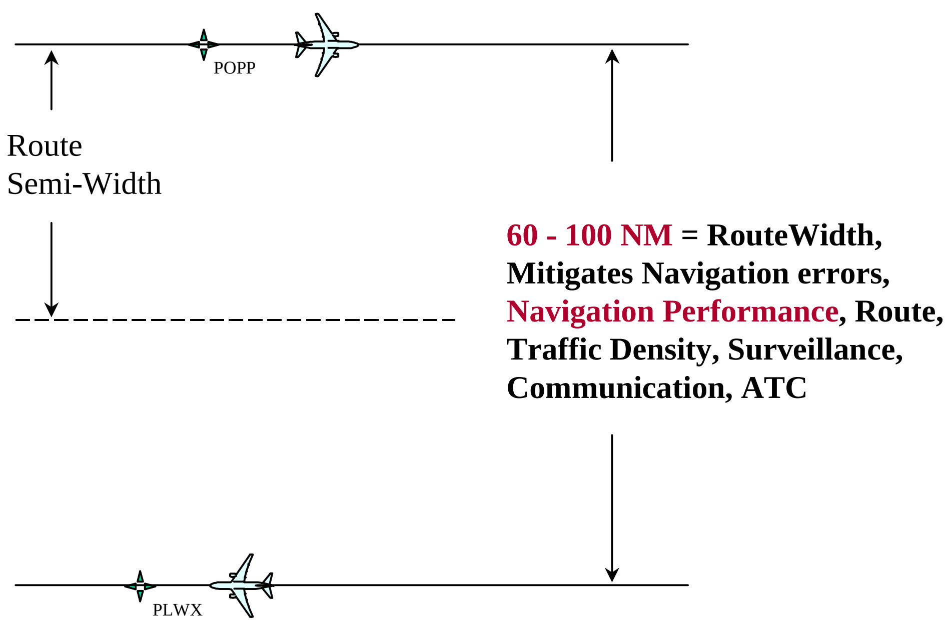


Figure 3-7

Additionally, the characterization of the performance resulting from different navigation system infrastructures also affects the route widths, airspace and buffers. Fix tolerance areas are determined to reflect the uncertainty resulting from distance and angular displacements from the sources being utilized.

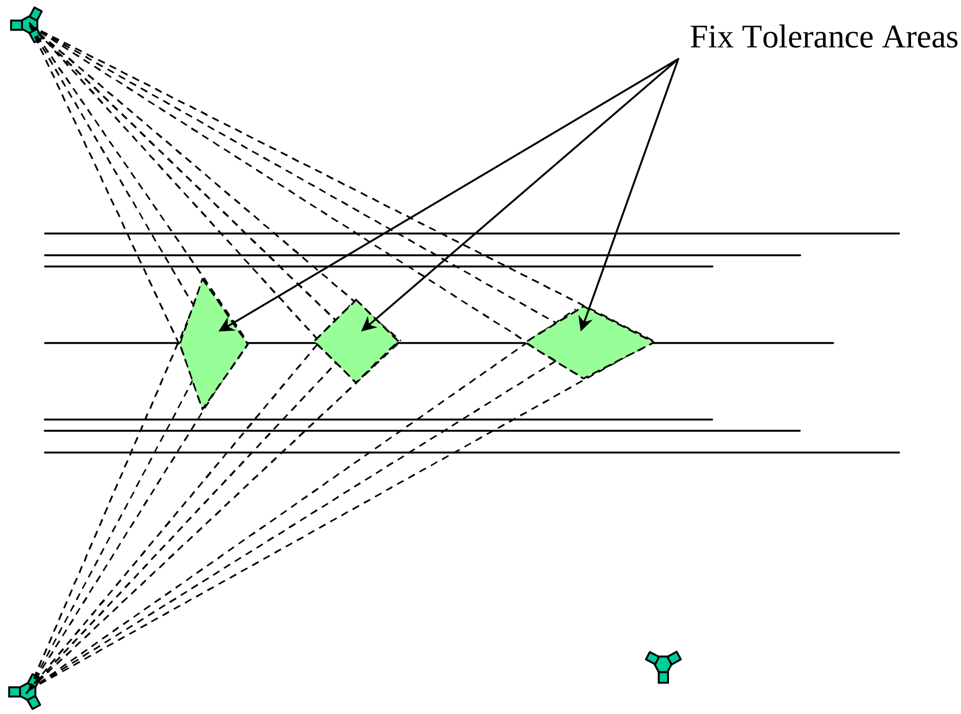


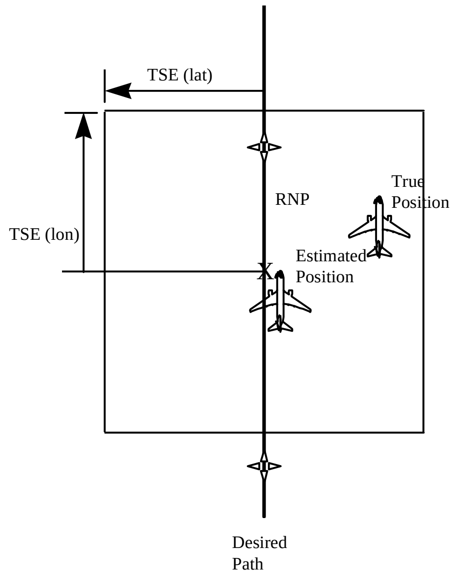
Figure 3-8

3.5 RNP

RNP as envisaged by ICAO in the Manual for RNP is a concept of navigation performance where an expected navigation performance accuracy value is expected to be achieved 95% of the time by the population of aircraft operating in the airspace. The 95% navigation performance accuracy is based upon the total error consisting of:

1. navigation system error
2. RNAV computation error
3. display system error
4. course selection error and
5. FTE

RNP is both a lateral and along-track specification. RNP is really a minimum performance standard which forms the basis for airspace design versus deriving airspace design from a broad population with widely varying performance. It should also be noted that the preceding error factors are identical to those for basic non-RNP area navigation.



RNP = total system error components in the along track and cross track dimensions from a a desired position such that the probability that the actual position lies within both dimensions is 95%, i.e. navigation performance relative to the desired path

Required Navigation Performance (RNP)

Figure 3-9

This leads to improvements as

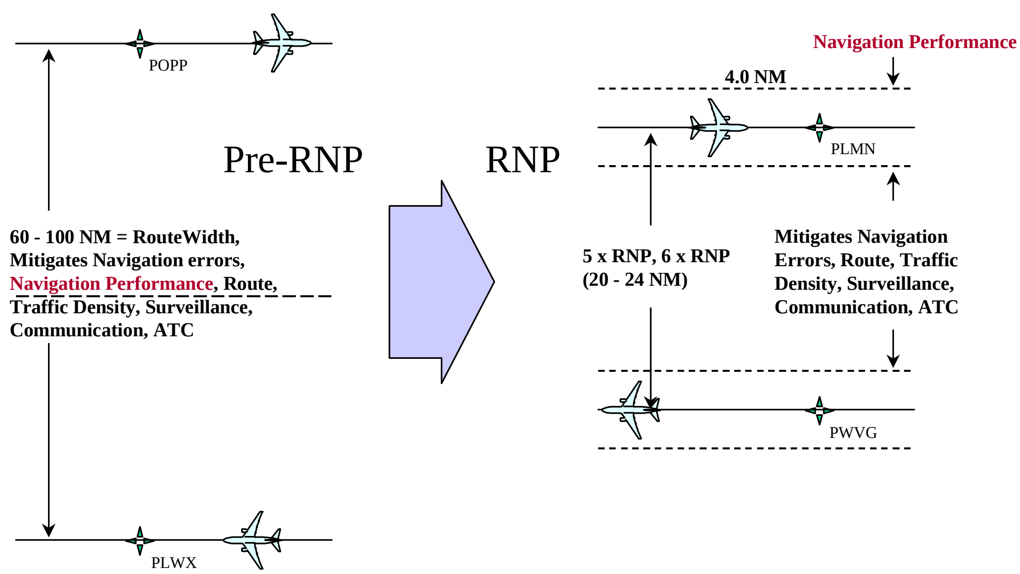


Figure 3-10

3.6 RNP RNAV

In the view of the RTCA/EUROCAE committees tasked with the development of an RNP RNAV Navigation Standard, existing area navigation systems are lacking in some key areas which are deemed essential to the intended operations for RNP. Additionally, the deficiencies in those key areas are critical to the ability of a systems integrator or aircraft manufacturer to certify the system and allow for operational approval. The specific areas that needed to be addressed are:

1. system performance integrity
2. system performance continuity
3. functional and operational integrity
4. consistency in systems capabilities and operation
5. changes which enhance both capability and ROI

RTCA SC-181 and EUROCAE WG-13 in developing a minimum aviation system performance standard (MASPS) for RNP area navigation, established requirements for:

1. 95% positioning accuracy linked to a specific total system error, where the TSE is comprised of position estimation error, path definition error and path steering error
2. integrity of the positioning accuracy of 99.999% at 2 x RNP
3. continuity of the required positioning accuracy at 99.99%
4. availability of a navigation capability at 99.999%
5. integrity against misleading navigation information at 99.999%
6. specific functionality consistent with RNP application and systems integration
7. standards for navigation database processes
8. standards for navigation data

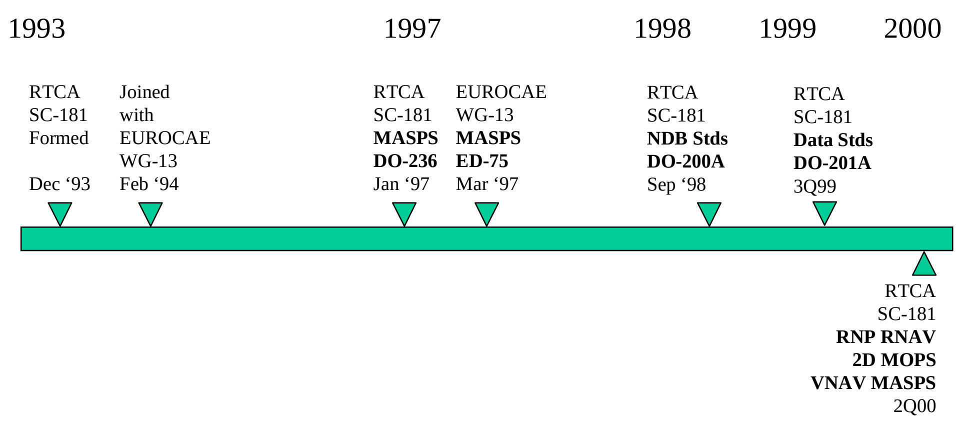


Figure 3-11

These requirements are viewed as an extension of the existing navigation criteria applied for RNAV in an RNP environment, designated RNP-(x) RNAV. They provide assurance by design, performance and operation, including significant improvements in the necessary situational awareness information needed by the flight crew. The difference between this and the ICAO concept is as shown.

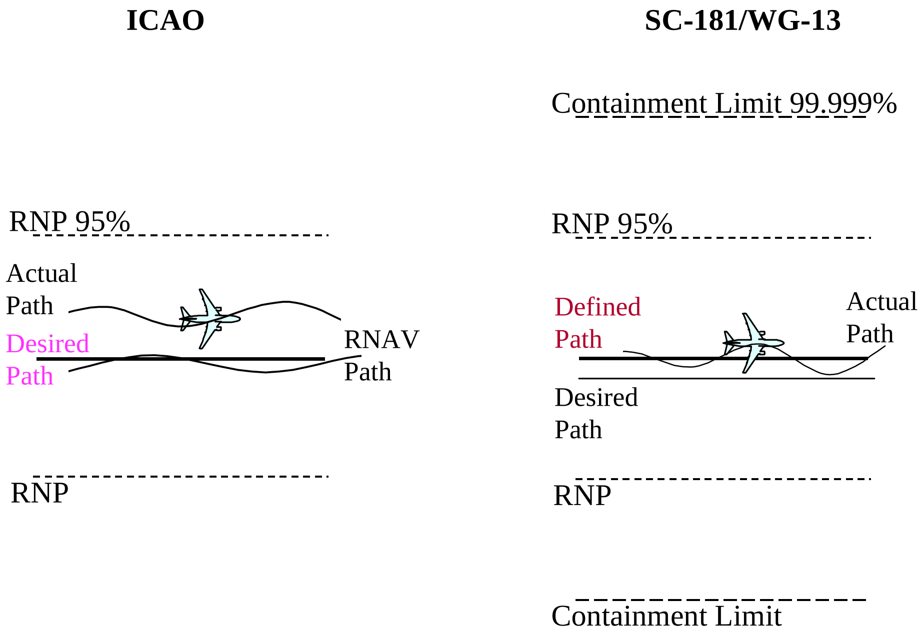
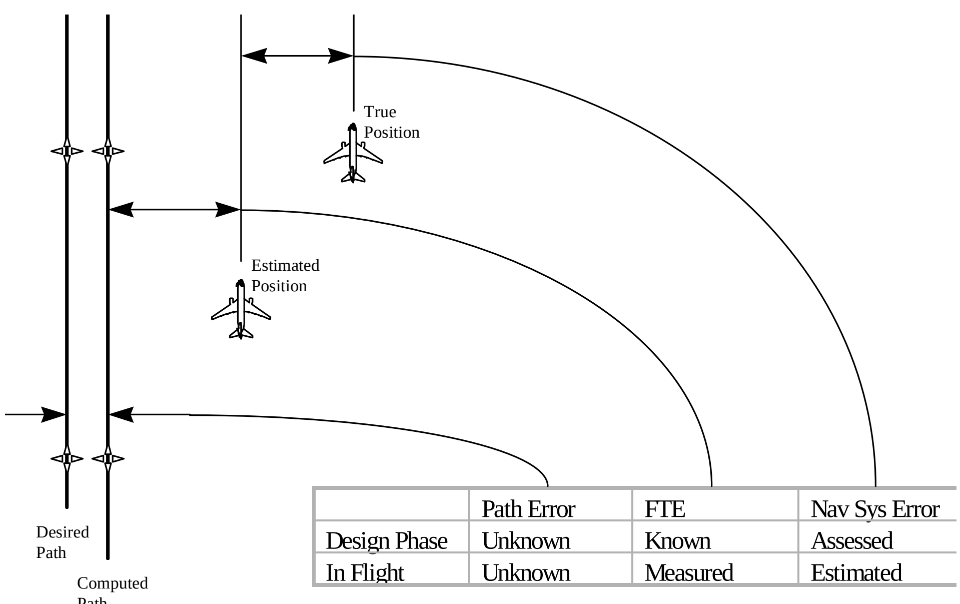


Figure 3-12

3.7 TOTAL SYSTEM ERROR COMPONENTS FOR RNP-(x) RNAV



	Path Error	FTE	Nav Sys Error
Design Phase	Unknown	Known	Assessed
In Flight	Unknown	Measured	Estimated

Navigation Performance

Figure 3-13

3.7.1 Path Definition Error

To reduce path definition error, use of certain leg types are discouraged in order to achieve reliable, repeatable, and consistent system performance. Eliminated for RNP applications are flight path leg types which are inherently unstable due to factors such as magnetic variation, and dependencies on altitude and distance crossings. Retained are those flight path leg types whose reliability, repeatability and predictability as a path in space are maximized. From this, the path definition error is negligible. Additionally, the navigation data contained in a database used for RNP operations is now required to have the data integrity, resolution, geodetic references and procedure designs consistent with minimized variance effects on the path in space. The the leg types acceptable for RNP RNAV operations are as shown in Figure 3-14. The leg types shown in Figure 3-15 represent ones that will still be necessary for operations but are characterized by greater variability in the flight path. These are not desired for RNP RNAV flight paths. However, in the case where they must be used, the variability must be accounted for in the airspace criteria.

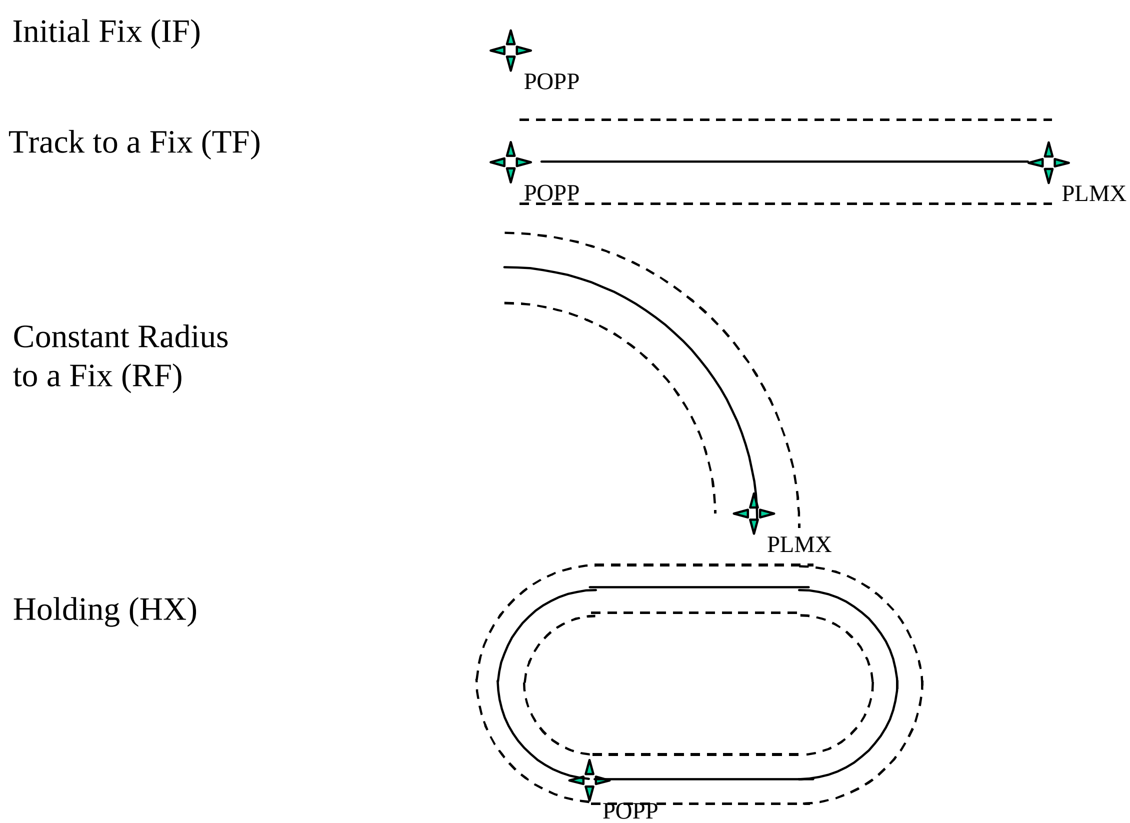


Figure 3-14
Preferred RNP RNAV Leg Types

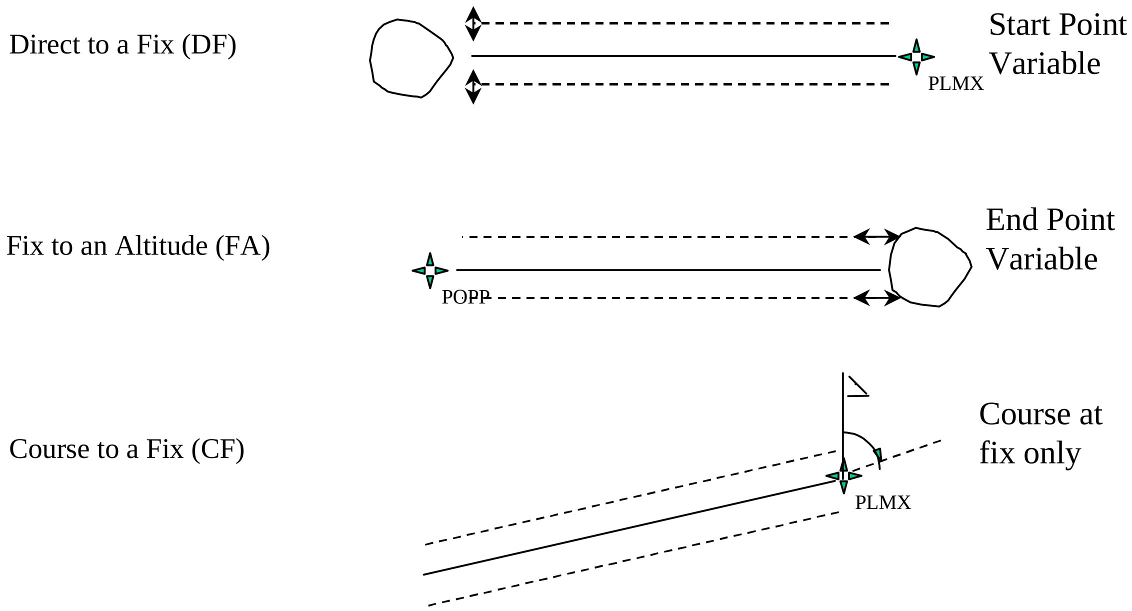


Figure 3-15
Other RNP RNAV Leg Types

Put some together for a procedure and the result is a very stable path In space.

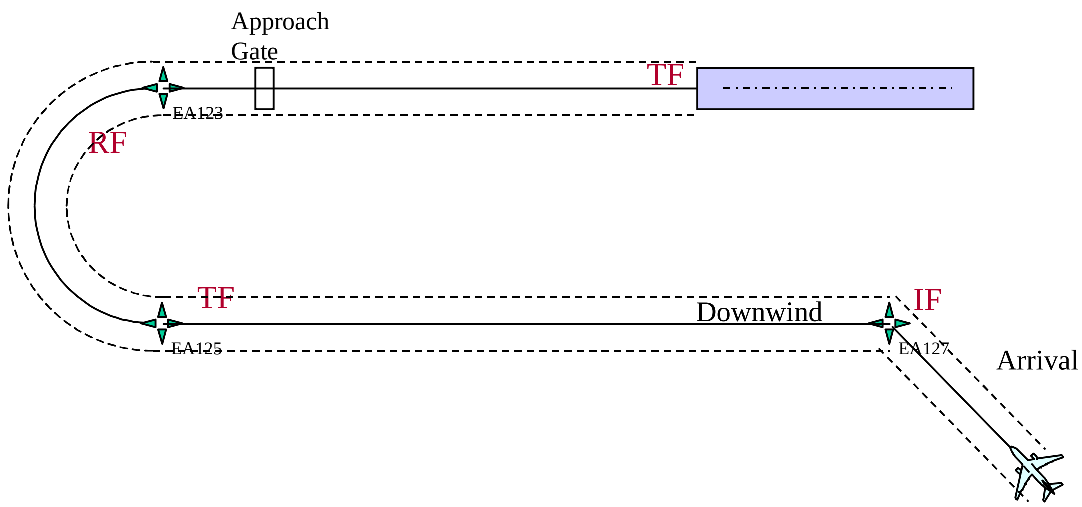


Figure 3-16
Example of RNP Legs and Procedure

3.7.2 Path Steering Error

Path steering criteria allow for manual or automatic flight control as means of operating in RNP airspace. However, the performance assessment and system error analysis requirements are intended to lead to appropriate constraints in aircraft operation and operating modes depending on the RNP type. For example, the FTE budget for a specific aircraft may be such that for RNP 1 operations, the navigation system can only be utilized when coupled to the autopilot system. This type of limitation would be reflected in the operational approval for the aircraft and the aircraft flight manual.

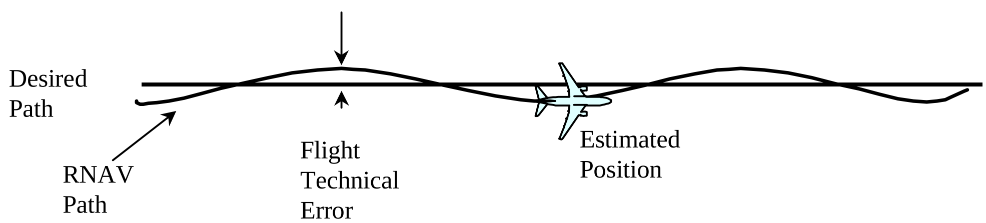


Figure 3-17

Additionally, the FTE assumptions used for assessing an aircraft's capability to conform to the requirements of RNP airspace have tended to be conservative, again reflecting the characteristics of a very broad population of aircraft.

Table 3-5
Assumed FTE Values (95% Probability, Manual on RNP)

Flight Phase	Manual	Flight Director	Autopilot
Oceanic	2.0 NM	0.50 NM	0.25 NM
En-route	1.0	0.50	0.25
Terminal	1.0	0.50	0.25
Approach	0.50	0.25	0.125

A recent study conducted on both large and small transport aircraft (747 and 737 size) produced the following information. The better values could form the basis for increased confidence in the aircraft and also factor into improved target levels of safety.

Table 3-6
FTE Values, Boeing Study

	Manual Flight with Map Display	LNAV with Flight Director Coupled	LNAV with Autopilot Coupled
Enroute	0.502 - 0.918 NM	0.111 - 0.232 NM	0.055 - 0.109 NM
Terminal	0.208 - 0.402	0.073 - 0.206	0.068 - 0.088

For RNP 1 enroute operations and RNP < 1, the differences in the FTE for flight director and autopilot coupled operation are quite significant from the current defaults.

3.7.3 Position Estimation Error

Positioning error must be estimated based upon the navigation sensor(s) used to compute aircraft position. Additionally, the navigation system must also provide a means of assuring the integrity of the positioning performance. These are all reflected in displayed information of the positioning performance and conformance to the requirements of the RNP airspace.

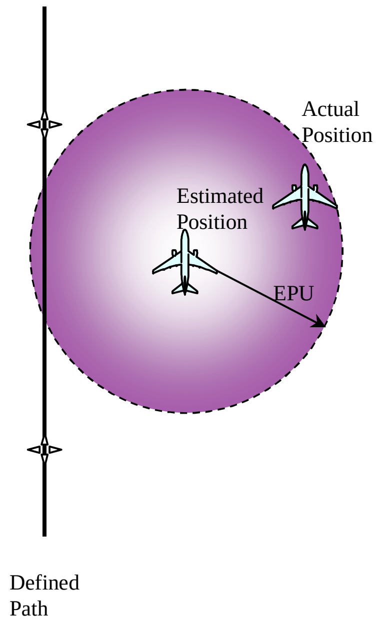


Figure 3-18

RNAV systems have many sensors from which to choose for estimating position. The sensors range from IRS/INS, DME, VOR, Loran-C and Omega to GPS and provide a wide range of possible performance. The estimations are enhanced by many methods including characterizations of the sensor and installation, geometry, location, integrity and other reasonableness checks. When these factors are taken into account, some typical levels of performance per sensors are:

Table 3-7
Navigation Sensor Position Accuracy

Navigation Position Basis	Range of Typical Values of Performance Accuracy
IRS/VOR/DME	0.50 - 1.65 NM
IRS/DME/DME	0.2 - 0.48 NM
IRS/GPS	0.04 - 0.15 NM

The ranges in possible performance are quite different from and improved over the current established defaults used for procedure and airspace design.

Table 3-8
Current Navigation Accuracy Requirements

	95% Performance Accuracy
En route Random	3.8 NM
En route Airways	2.8 NM
Terminal	NM
Approach	0.5 NM

3.8 RNP RNAV SYSTEM CONFIGURATIONS

RNAV systems configurations and architectures are varied, reflecting requirements from regulations, customers and manufacturers. In many cases, the equipment and architecture not only reflect what is needed for normal operation but also account for conditions where failures may occur, replacement is not possible, and the operators need for little or no disruptions of their operations due to aircraft equipment.

Example

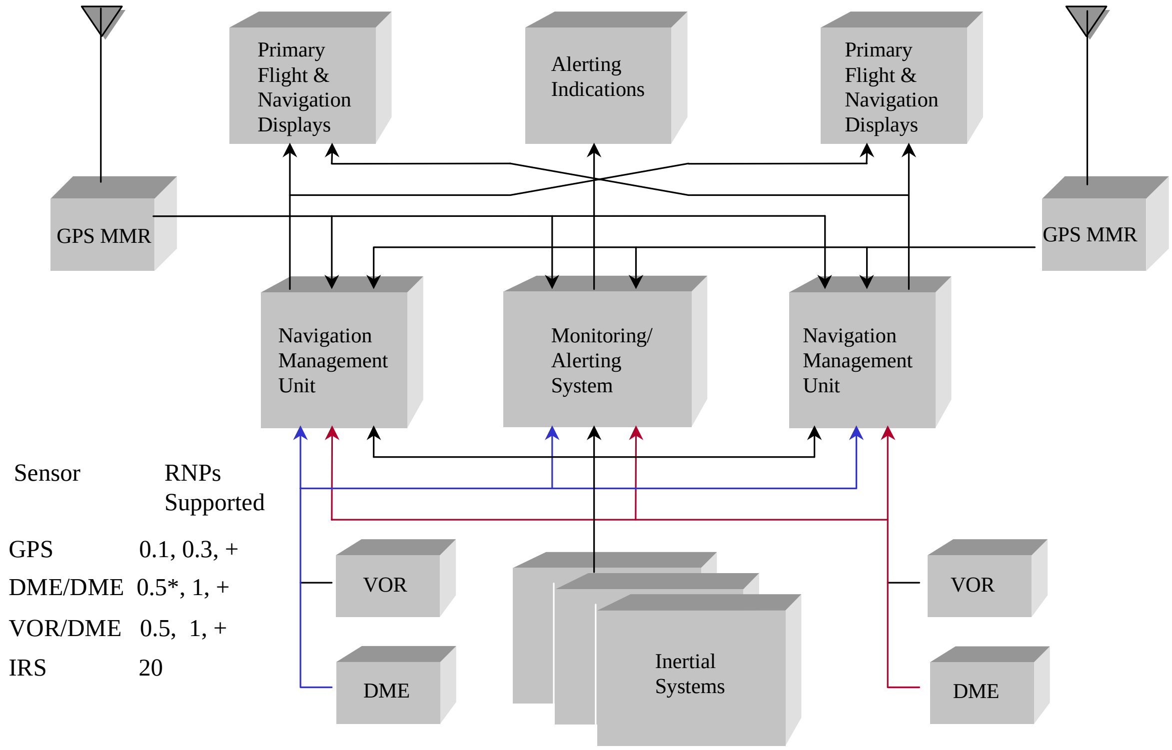


Figure 3-19

4. NAVIGATION PERFORMANCE CONTRIBUTION TO AIRSPACE DESIGN

4.1 Traditional

One of the standard tools for enroute airspace design is the assessing the target level of safety using a collision risk model (CRM). The CRM applies:

1. traffic density,
2. lateral overlap probability as a measure of navigation performance of the aircraft population
3. vertical overlap probabilities
4. average dimensions of the aircraft
5. average velocities of the aircraft
6. plus numerous other assumption for route configuration, ATC performance, aircraft system faults and errors in performance, characteristics of deviations, etc.

such that:

Risk for operation = **f**(navigation performance, airspace, traffic character, monitoring, communication, ATC)

4.2 RNP RNAV

The one area that RNP-x RNAV aircraft navigation systems influence and possibly improve collision risk is via the lateral overlap probability. The navigation system affects lateral overlap probability due to the improved navigation performance accuracy specification of RNP-(x) RNAV along with associated design or procedural mitigation of certain error classes that are considered in the CRM assessment.

The specific error classes which are applied to the performance distribution are:

1. aircraft not certified for operation in the airspace
2. ATC system loop error
3. equipment control error including inadvertent waypoint error
4. waypoint insertion error due to the correct entry of incorrect position
5. other with failure notified to ATC in time for action
6. other with failure notified to ATC too late for action
7. other with failure not notified/received by ATC

RNP-x RNAV navigation performance provides the following to reduce collision risk:

1. 95% navigation performance accuracy AND performance assurance for the aircraft position at 10-5 per flight hour. The performance assurance limit, designated by SC-181 as the containment limit, is equal to 2 x RNP.
2. continuity of navigation performance at 10-4 per flight hour for the RNP type
3. actual levels of performance which better the standards on which RNP was based.

RNP-x RNAV includes requirements to mitigate specific types of errors including:

1. obtaining RNP requirements for the area, airspace and route defined within a database for the aircraft navigation system instead of requiring manual entry where insertion errors may occur. This RNP requirement is also attached to the flight plan or route with specific qualifications for filing for use and operation. The RNP requirement as well as the current navigation performance level is known to the flight crew by suitable displays and indications on the aircraft flight deck.
2. elimination of selected sources of waypoint insertion errors by specification of capabilities for automatic insertion of along track fixes, and automatic loading of predefined flight plan procedures. Additionally, actions to establish set names and coordinates for many unnamed fixes will also aid in the reduced exposure to insertion error problems.
3. system monitoring, displays of actual navigation performance, displays of the required navigation performance and alerting for conformance to RNP-x RNAV requirements are required and provided.
4. communication of flight plan changes and clearances by datalink is identified as a probable CNS requirement, and significantly reduces exposure to existing ATC system errors by integrity checks in the data path, as well as independent verification by the aircraft flight crew. This is not a minimum requirement for RNP-x RNAV systems. However, in the commercial transport category aircraft equipped with FANS1/A capable systems, air/ground datalink communications have been required to provide greater integrity in the ATC system loop.

The RNP-(x) RNAV concept for system performance and assurance may be used as a tool in developing procedures and the airspace about them. Specifically, the RNP and 2 x RNP limits could form the base on which buffers are added as necessary due to factors such as limitations in available airspace, sparce navigation infrastructure, to compensate for the reduced levels of conformance monitoring, or as a factor in obstacle assessment criteria.

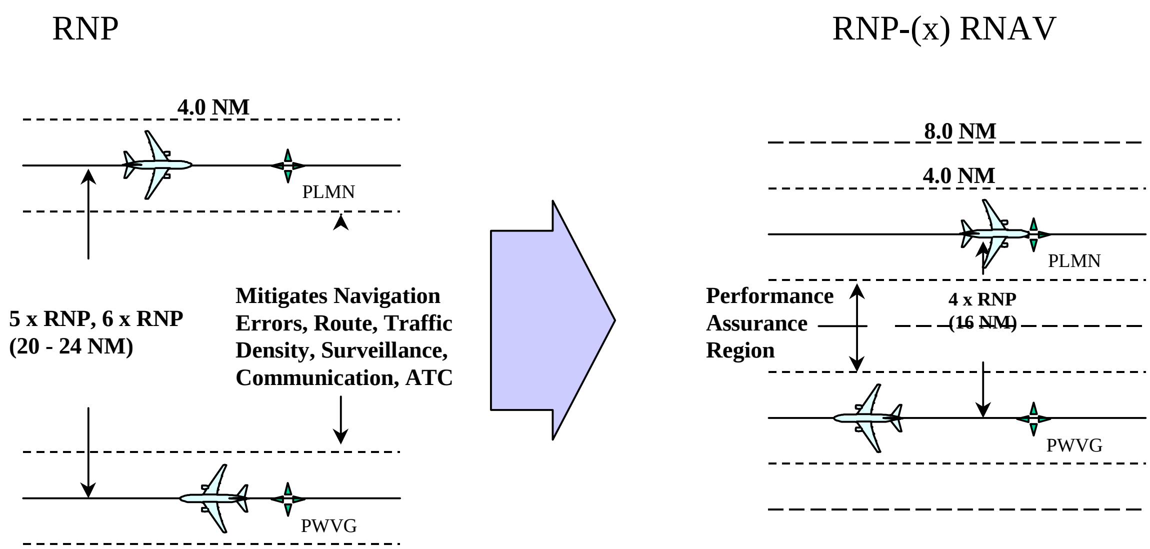


Figure 4-1

As stated previously, the MASPS specifies both a 95% containment value and a 10^{-5} containment limit equal to 2 x RNP. The requirements for the aircraft system support the specification of airspace about a straight path segment as well as a turn segment such that a larger protection area is not required for turns.

Figure 4-2 reflects the following assumptions and requirements:

1. Path definition error is essentially zero; for RNP operations, the same survey data and references are reflected in the ground system and aircraft system databases for the procedure being flown. The path is defined point to point and the turn is a fixed radius turn. Variation in the expected path is eliminated or negligible
2. Path steering error is negligible or zero with the pilot or coupled autoflight system. Note: The amount of deviation resulting from manual flight or using flight director guidance will vary. The manner in which RNP is implemented is expected to determine which mode (e.g. manual, flight director or autopilot) is allowed for specific RNP values.
3. The uncertainty of the position estimate is small but greater than zero, leading to a small offset of the true aircraft position from estimated position. The offset is exaggerated in the figure to show this effect. While the pilot's situation information would show the aircraft on track on the flight path, the real situation would be the physical offset shown. Since the

aircraft will provide the tracking performance necessary to remain on path for straight and turn

4. The airspace limits happen to coincide with the 2 x RNP limit because the environment is characterized by any one or more of: low-medium traffic density, suitable levels of sites for conformance monitoring, and means of communication with ATS. In order to mitigate the increased risk from increased traffic, reduced capabilities in monitoring and communication, additional airspace buffers might be warranted for acceptable spacing.

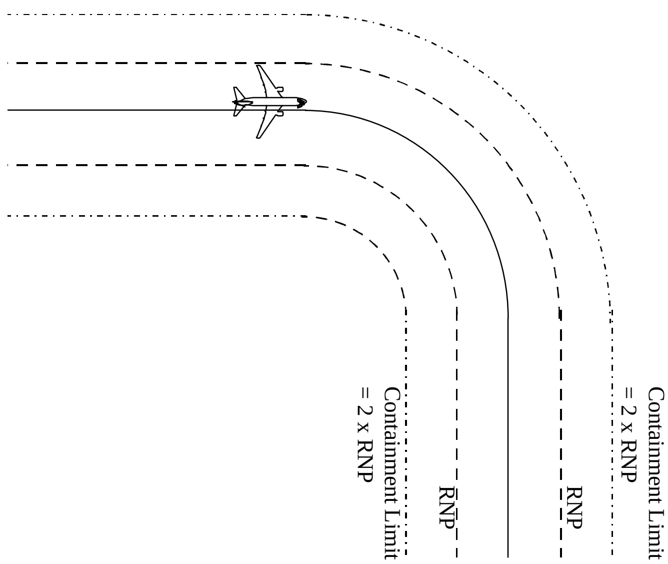


Figure 4-2

Otherwise, the only case where extra airspace beyond the 95% containment value and containment limit identified by SC-181 is for fly-over turns, turns where the aircraft must fly over a fix before proceeding to fly to the next leg. However, this is not considered a controlled turn. Note: In the initial development of the RNP based procedures, in some cases an additional buffer has been added to account for early/late turns and wind. The amount of buffer may be determined by the RNP value e.g. negligible for RNP20 or fixed by procedure criteria where defined.

4.3 Protected Airspace in Turns

The preceding example is based upon a constant RNP type prior to, during and after the fixed radius turn. It is being suggested that the protected airspace for the turn be different than that for the straight segments due to concerns about aircraft exceeding the RNP and 2 x RNP limits. However, it should be noted that the turn definition as either a 15 NM or 22.5 NM fixed radius turn, as planned in Europe, coupled with the aircraft navigation system's turn and roll anticipation capabilities results in tracking performance that is no different than that into and out of the turn.

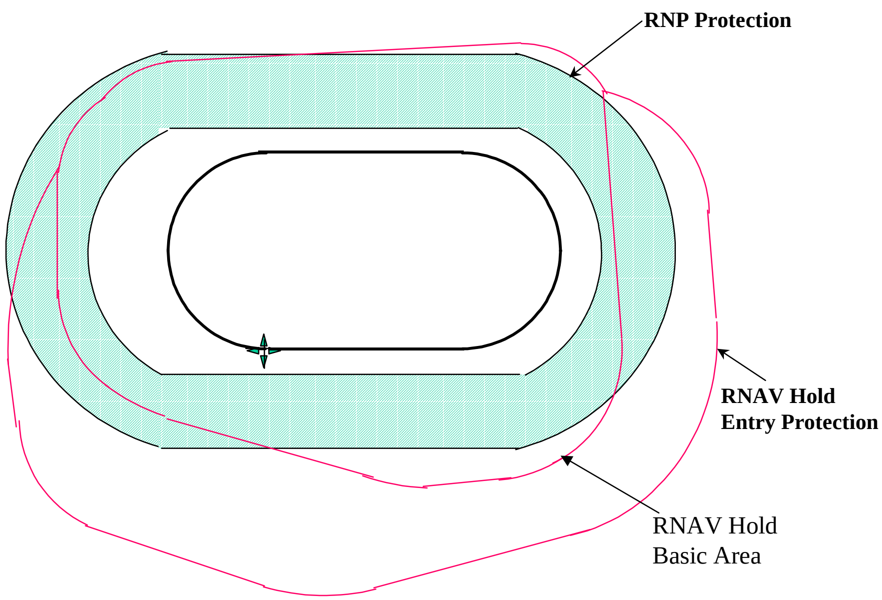
It is suggested that care be exercised in the definition of the protected airspace area in the turn. It is not clear what specific aircraft capability is being factored into the obstacle assessment and determination of the protected airspace. The current implication is that only navigation performance accuracy with generalized assumptions for tracking performance form the basis for the results. The specific RNP-(x) RNAV criteria from the RTCA SC181/EUROCAE WG 13 MASPS and EUROCONTROL RNAV Standard both are not given consideration in the assessment. Yet it is these standards that will guide the development and capabilities of aircraft navigation systems intended for RNP airspace operations. RNP as a variable of turn should not be advanced.

4.4 Holding

The buffers for holding are subject to the same comments as for turns; the RNP type should simply form a larger racetrack about the hold. The previously stated reasons for how the aircraft system will define its path and RNP limits, and the need for consistency with the procedure apply here as well.

It should be noted that from SC181 studies, there is little utility for holding RNP greater than 1. For RNP greater than one, the amount of airspace which the aircraft systems 2 x RNP containment protects becomes greater than conventional holding airspace.

While the RNP 1 plus containment limit airspace is comparable to that for conventional holds, there are differences required in the location of the hold. For RNP 1, the amount of airspace on the non-holding side is much smaller than allocated for the conventional, such that the fix location must be changed or the offset of the area be accounted for in the airspace allocation.



Example of Conventional ICAO RNAV and RNP hold compared
Figure 4-3

Initial ICAO specification for RNP holding have established that a 2 NM buffer will be added to the 2x RNP containment. It is expected that as more experience is gained with RNP, the buffer may be minimized.

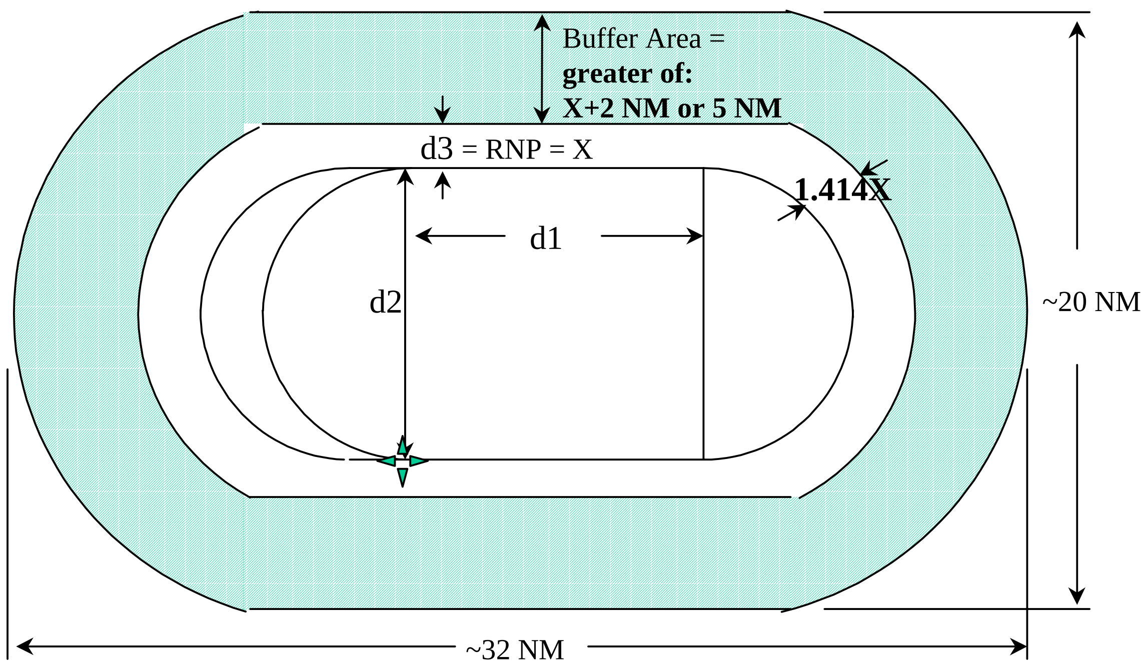


Figure 4-4

4.5 VNAV

A significant aspect of VNAV is the path definition requirement to apply constraints that bound the aircraft relative to a path or area. This provides different levels of optimizing use of the airspace for procedures. The minimal vertical airspace is derived from the point to point gradient path with its associated tracking performance. Where more latitude is allowed for the aircraft system to determine its best vertical path, use of window constraints provide the means to allow for a larger vertical area that also has performance limits to bound the area.

4.5.1 Vertical Navigation Performance

The requirements for VNAV, currently under industry development, address vertical path performance limits, performance that supports RVSM, Path Definition, Path Tracking, and the User Interface. VNAV is intended to support descent and approach operations where the procedural specification of geometric vertical paths and vertical path angles must be support by reliable, predictable and repeatable system performance.

Vertical path performance limits (VPPL) are defined as a 99.7% vertical total system error. This limit applies to point to point path segments as well as the "edges" defining an area of airspace. VPPL is the same as the performance requirements for existing VNAV systems. How and where it applies differs.

The vertical performance limits are as follows:

Table 4-1
Total System Error Requirements for Vertical Navigation

Altitude Region	Level Flight Segments and Descent Intercept of Clearance Altitudes	Approach Along Specified Vertical Profile
At or Below 5000 ft	150	160
5000 ft to 10000 ft	200	210
10000 ft to FL290	200	210
Above FL290	200	260

Note: These requirements are based upon airborne altimetry and avionics systems that provide performance consistent with RVSM requirements.

More importantly, neither containment integrity or containment continuity concepts as applied to lateral performance are applied to vertical performance.

4.5.2 Path Definition and Tracking

For VNAV, the chosen vertical path transition is expected to be a fly-by instead of the fly-through. This is due to the airborne systems capability to anticipate changes in the vertical path (e.g. transition from level to descent, changes in descent gradient, and descent to level segment).

The fly-by height loss figures are expected to be a basis for establishing vertical altitude constraint requirements and fix locations to allow vertical fly-bys in procedures.

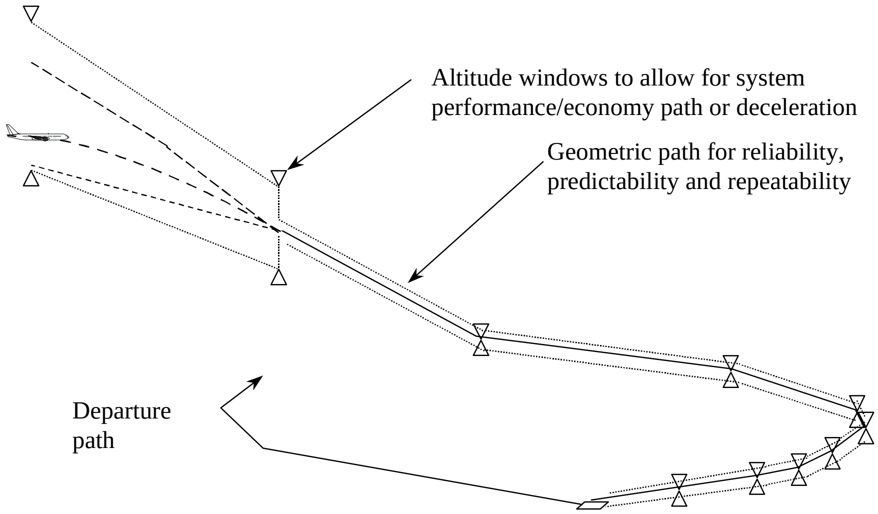


Figure 4-5 VNAV Path Defined by Constraints

4.6 Time of Arrival Control

Time of Arrival Control is viewed as a tool that supports improved traffic capacity and efficiency in airspace operations.

Some of the applications where TOAC is expected to be an aid include enroute traffic crossing, longitudinal traffic separation, approach metering, support for CTAS, etc.

The current system tolerances for time requirements are 30 seconds enroute and 6 seconds in the terminal maneuvering area.

At this time, little has been achieved in integrating this capability into RNP RNAV operations. Related changes in surveillance, computing systems, establishing common time references, and ATC are considered necessary.

5. APPLICATION

5.1 Approach

Approach procedures are typically developed using TERPS (in the US) and PANS-Ops (outside US). These criteria are similar in that they apply very specific criteria for procedure design and obstacle assessment. They are based on factors including traditional ground navigation aids characteristics, aircraft performance, and navigation capabilities and performance of the least capable aircraft. To simplify the task of design, the criteria are reduced to a simpler set of requirements that must be met. This results in procedure design criteria that are accompanied by generalized, large trapezoidal surfaces and shapes where obstacles are excluded. Where obstacles may exist, the criteria allows for accommodation by raising minima for the operation.

While simpler to apply, the TERPS/PANS-OPS criteria precludes any optimization of the procedures or operations because of the large protection surfaces that are applied. With RNP RNAV, the 2 x RNP containment limit provides for performance assurance. The systems also include monitors and alerts for the flight crew when the actual performance of the aircraft exceeds the RNP for the operation. The navigation performance assurance provided is considered to be equivalent to that reflected in the generalized TERPS surfaces. The significant differences is that RNP RNAV has linear and smaller total surfaces. The linearity of the RNP RNAV containment limits enables improvements in the design and location of procedures and lower minima that could be achieved with conventional criteria. The following examples compare TERPS surfaces and RNP RNAV containment surfaces

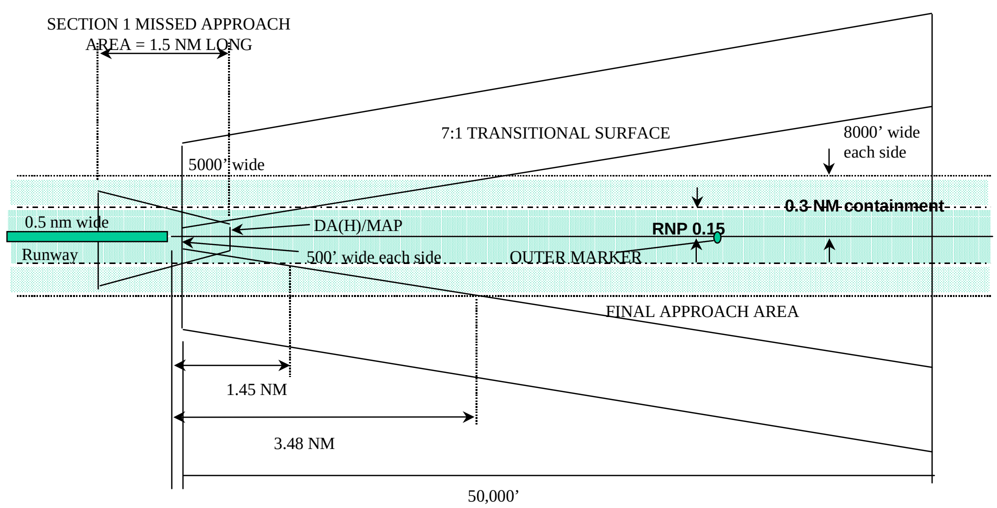


Figure 5-1
TERPS versus RNP, Approach

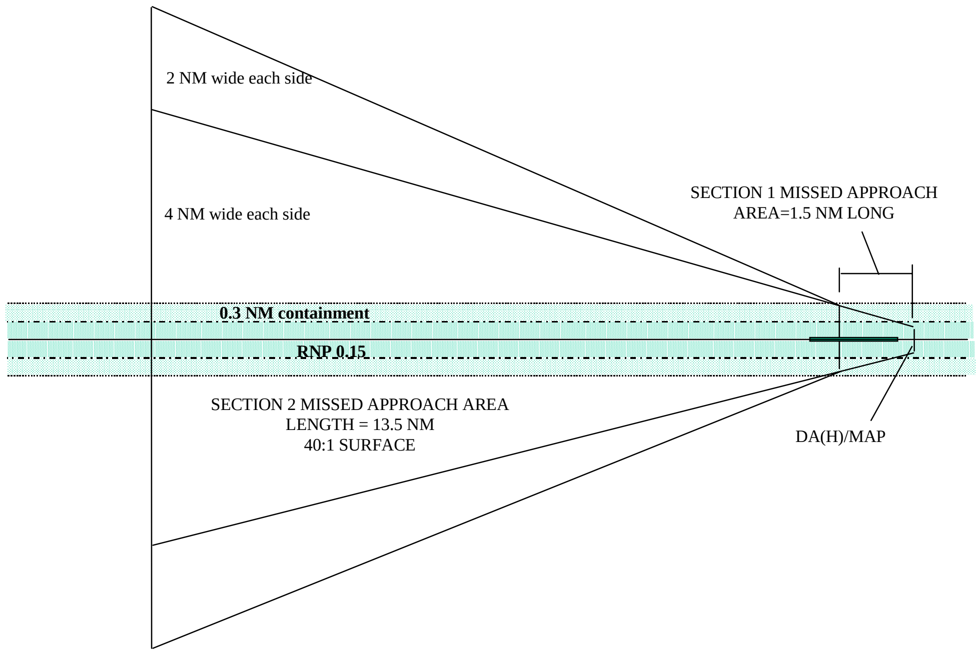


Figure 5-2
TERPS versus RNP, Missed Approach

5.2 Alaska Example

The following illustrates the improvements possible with RNP RNAV. For Alaska Airlines, operations to Juneau were affected and limited by airspace operations criteria, procedure design, weather and terrain. The RNP RNAV capability of their aircraft enabled the development of both approach and departure procedures that were previously not possible.

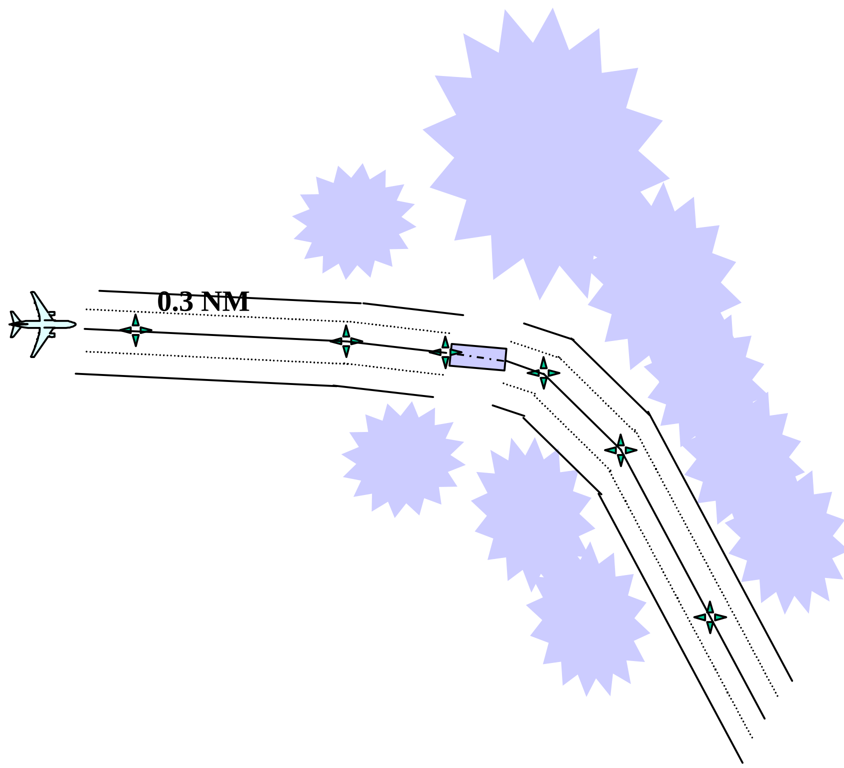


Figure 5-3

5.3 Lower Minima, Converging Approach Example

Special cases of converging approach operations have been evaluated using RNP and RNAV. The performance integrity provided by the aircraft system, allows for smaller protection surfaces for the missed approach, leading to reduction in the missed approach altitude, and increased opportunity to land.

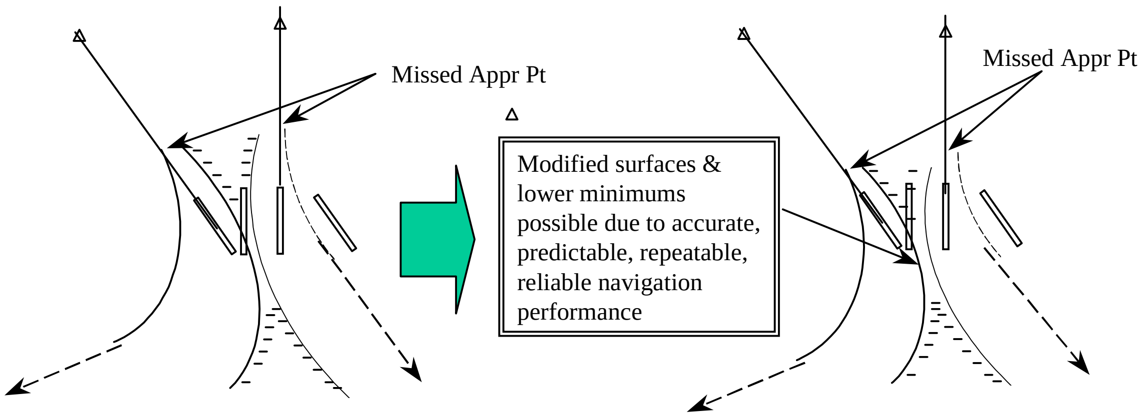


Figure 5-4

5.4 IMPROVED DEPARTURE Example

The uncertainty of the aircraft location traditionally results in large airspace areas to protect separation. VNAV together with RNAV results in a much better predictable and repeatable confinement of the aircraft on a procedure. This presents the potential to utilize existing airspace to create more efficient procedures.

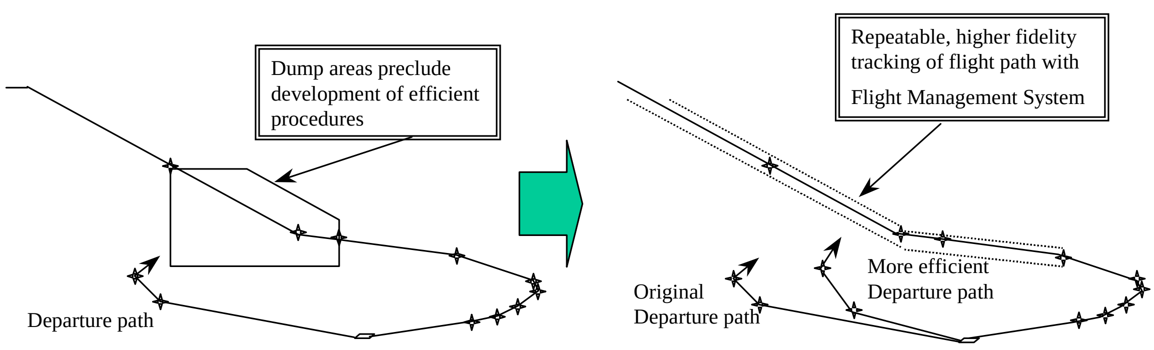


Figure 5-5

5.5 STABILIZED DESCENT

5.5.1 Conventional NPA

The conventional non-precision approach as a method for landing presents a number of challenges for the operation. It is up to the crew to change and manage the aircraft flaps configuration, approach speeds, descent rates and any necessary maneuvers to line up to the runway while looking to visually acquire the runway before the missed approach point.

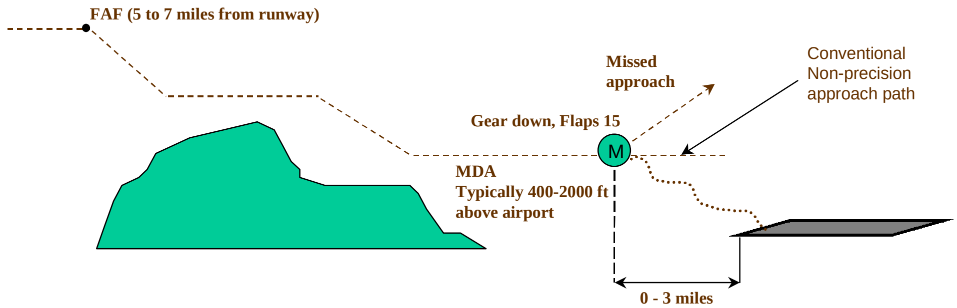


Figure 5-6

5.5.2 VNAV Stabilized Descent Path

The computed flight path used for a VNAV descent provides a number of improvements in approach operations. Flight guidance relative to a stabilized vertical path in space, reduces flight technical error and improves the safety of the operation. The improved navigaton performance may also allows for lower operating minima.

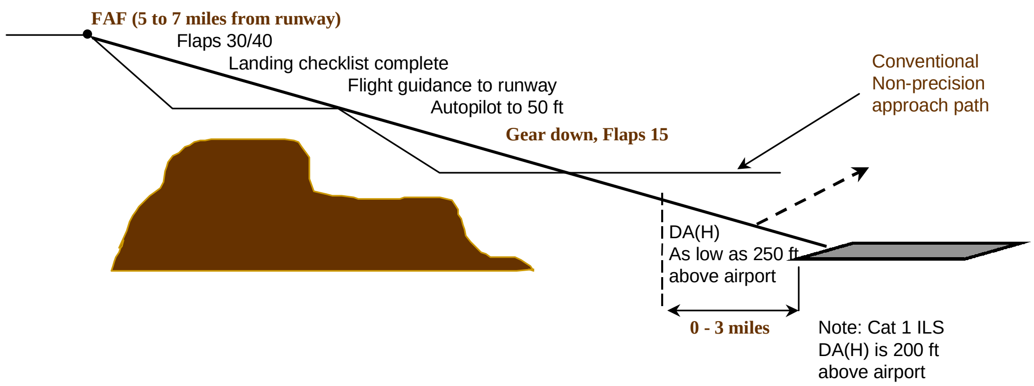


Figure 5-7

5.6 CURRENT SYSTEMS EQUIVALENCE

Existing RNAV systems include many of the performance and capabilities of a certified RNP RNAV system. The primary difference lies in the RNAV systems lack of navigation performance information to the flight crew, built in monitoring and RNP alerting. These differences and others do not preclude the systems and aircraft from conducting RNP procedures. However, there is additional rigor necessary in determining the acceptability and limitations for these systems to conduct RNP RNAV operations. The added steps include evaluation of the navigation infrastructure for the operation, flyability of the procedure, training and continued qualification for flight crews, geographic reference system effects, etc,

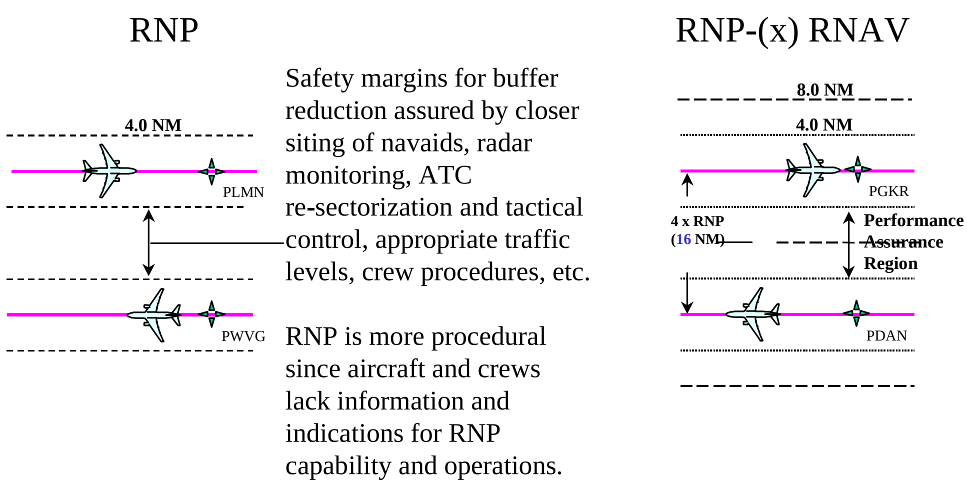


Figure 5-8

6. SYSTEM QUALIFICATION INFORMATION

This section is intended to provide additional information to clarify considerations, methods and other issues related to the RNP qualfication of a system.

As in current practice, the system performance compliance assessment and substantiation will still include the following or equivalent as prescribed by ACs, ACJs, AMJs, TSOs, etc:

- System Description
- Development Methodology
- Certification Methods
- Functional Hazard Assessment
- System Safety Assessment
- Certification Basis and Means of Compliance
- Applicable Regulations
- Certification Documentation
- Demonstrations

The associated system development, safety assessment and validation processes are as shown in Figures 4.1-1 and 4.1-2, or equivalent. These processes cover all aspects of the software, hardware and data which are a part of the navigation system. The remainder of this section will extend current practice to the concept of containment as specified in Section 2.0 of this document.

1. Loss of Function/ *Performance*

a. Requirement for probability of loss of navigation less than 10^{-5} per flight hour
b. Determination of LRU failure rates for assessing probability of loss of navigation
c. Determination of probability of unacceptable level of performance
d. Develop system architecture based failure tree in which to insert faults in combination with probability of additional failures

2. Misleading Navigation Data

a. Requirement for probability of undetected, misleading data without warning to pilot less than 10^{-5} per flight hour
b. Determination of undetected failure rates for each navigation system unit
c. *Determination of undetected failure rates for sensor/ system performance*

d. Develop failure trees in which to insert faults in combination with probability of undetected fault combinations

1. Design-in integrity into system architecture and for various system configurations

2. Identify fault combinations and conditions which need to be managed by equipage or procedure

3. Design systems, displays, indications and alerting based upon RNP and criticality of condition

4. Clear and unambiguous actions and operations

Designed-in considerations for Loss of Function, Continuity of Function and Misleading Navigation data by:

Annunciation/Alerting
Redundancy (system, data bus, sensor)
Data bus isolation
Automatic & manual source selection
Performance and function monitor/comparison
Minimum Equipment

Designed-in considerations for:

Pos Est Errors:
- Incorrect locations in NDB, geometry, signal in space, satellite constellation*, IRS drift*, VOR/DME/IRS position and data latencies, internal latencies

Path Def Errors:
- NDB using standard datum (WGS84)*, leg types-fewer/ RNP*, path data resolution*, manual entry limitations*

FTE:
- Reduction in standard error based upon substantiation

Software Errors:
- Design and Functional V & V methodologies

Integrity error sources not accounted for:

ATC System Loop Errors
- Controller-Pilot miscommunications, ATC induced conflicts, data link induced conflicts, timing

Random System Error
- Design, latent

Manual Errors
- Waypoint selection/flight planning, data base, update, initialization, modes, sensor selection

Mitigation/Elimination of Integrity error sources:

ATC System Loop Errors
- Controller Pilot Data Link Communications (CPDLC), ADS, AFN

Random System Error
- System verification and validation methodology

Manual Errors
- CPDLC, Navigation data and Data Base processes, ADS, AFN, Improved status annunciation/alerting

System function and performance have integrity based upon:

Substantiation of:
- Annunciation/Alerting
- Redundancy
- Data bus isolation
- Automatic & manual source selection
- Performance and function monitor & comparison
- Minimum Equipment configuration
- System navigation performance
- Hardware fault detection
- Software (Verification)
- Integrated systems operation (CNS)

Appendix A Frequently Asked Questions

Airplane Flight Manual

Q: What RNP operations information is provided in the AFM?

A: Boeing aircraft that have been certified for an RNP (RNAV) capability include the following type of information in the AFM:

1. the minimum demonstrated RNP associated with GPS enabled or disabled, as well as the mode of operation (autopilot engaged, flight director or manual with Map display)
2. RNP flight operations may be limited by GPS satellite availability and/or navaid coverage for the selected route.
3. If the FMC database and charts are not referenced to the WGS-84 reference datum and other appropriate compensation procedures are not used, GPS updating must be disable for approach operation when operating outside the United States National Airspace.
4. The RNPs equivalent and necessary for the FMCS to conduct approach types including NDB, NDB/DME, VOR, VOR/DME, RNAV and GPS.
5. The avionics equipment required for RNP primary operations.
6. The FMCS has been demonstrated for vertical navigation (VNAV) for enroute and terminal area operation and instrument approaches (excluding ILS G/S).

BRNAV (Basic Area Navigation)

Q: What aircraft system changes are required to comply with the European BRNAV requirements in JAA Temporary Guidance Leaflet No 2 Rev 1.

A: The following Boeing airplanes delivered with Flight Management Computers installed (along with their installed sensors, control display units, and navigation displays), in their various certified production versions are considered BRNAV compliant.

- 717
- 737-300/-400/-500/-600/-700/-800/-900
- 747-400
- 757/767
- 777
- MD11

The 707, 727, 737-100/200, 747-100/200/300 lacking an RNAV system with DME radio updating capability are most likely not compliant with BRNAV. However, specific systems configuration information must be reviewed on a case by case basis to make any specific conclusions.

Q: What is required to obtain approval for BRNAV operations?

A: The process for BRNAV operational approval is designed for operators to interact directly with their civil aviation authorities. For the above compliant airplane systems, airplane flight manual (AFM's), operations manuals, operator minimum equipment lists (MEL's), along with operator specification documents will be a part of the approval process. With the exception of some B737-300 AFM's, Boeing has developed AFM's that support the operators in this effort. For affected operators, B737-300 AFM's without reference to the acceptable advisory circular or RNP performance data compliance will be revised to include BRNAV compliance references.

Navigation System Capability

Q: How do our installations differ in certified RNAV and RNP capability from type to type?

A: Boeing FMC systems have been certified for RNAV operations. Additionally, some versions e.g FANS1, U7.4/U8.4, U10 have explicit RNP capability. Others such as 200K, PIP, U5/U6.2 provide a conditional RNP capability, limited by the ops approval for the type of application and operating environment.

A conditional RNP capability may require additional data, analysis, descriptive material, and demonstration to show how the system is equivalent to an RNP certified system, how the flight crew is able to perform and manage the RNP operation, how the infrastructure supports the operation, and the procedures necessary to conduct the operation.

Q: Must RNP approaches only be selected from the NavDB?

A: Yes.

Q: What typical ANPs can be achieved on each of our airplanes using DME-DME and GPS updating?

A: For DME-DME, possible ANP minimums range from 0.2 NM on the 737 to 0.24 NM on 747/757/767. For GPS, the possible minimums are in the range of 0.04 - 0.05 NM However, it should be recognized that this position estimation accuracy is but one factor of RNP. The total system error including position estimation error, display errors, path errors and flight technical error must be determined. For the smaller RNP types, FTE has been found to be the deciding factor in the minimum RNP that can be achieved.

Q: Which Boeing airplanes are/will be certified for RNP operations?

A: 747-400 FANS1, 777 FMF 757/767 Pegasus and 737 w/ GPS/RNP are allowed to perform limited RNP primary means operations, subject to special operations approvals. Obsolete or limited capability versions such as 200K and U5/6.2 or earlier will not have RNP/GPS versions.

Q: How does the pilot know if a terminal procedure/ approach has RNP?
A: It should be indicated in the procedure/approach charts and reflected by the system RNP from the NavDB shown on the CDU.

RNAV and TSO-C129

Q: Is TSO-C129 approval needed for RNP or RNAV operations?
A: No. Both the RNAV and RNP capability are demonstrated during type certification where AC 20-130A is the basis, augmented by an RNP Capability document. AC 20-130A establishes criteria for a multi-sensor navigation system that may use GPS as an input.

Q: What TSO-C129 equipment classes, if any, could apply to the Boeing installations?
A: The applicable classes would be B1/C1 for the sensor and B3/C3 for the integrated navigation system, with some exceptions. However, Boeing FMS w/ GPS installations are certified per AC 20-130A.

Navigation Infrastructure

Q: What countries have implemented WGS-84 or equivalent? Who should an airline contact to find out about a particular country?

A: 68 as of November, 1999: Argentina, Australia, Austria, Bahrain, Barbados, Belgium, Bermuda, Brazil, Brunei, Burundi, Canada, Canary Island, Cape Verde Islands, Croatia, Cyprus, Czech Republic, Denmark, Ecuador, Egypt, Fiji, Finland, France, French Antilles, French Guyana, French Pacific, Gambia, Germany, Guatemala, Hong Kong, Hungary, Iceland, Indonesia, Ireland, Japan, Jordan, Korea, Kuwait, Latvia, Lithuania, Luxembourg, Macau, Macedonia, Maldives, Mongolia, Myanmar, Nepal, Netherlands, New Zealand, Poland, Portugal, Romania, St Pierre and Miquelon, Sao Tome and Principe, Singapore, Slovakia, Slovenia, Spain, Sri Lanka, Sweden, Switzerland, Taiwan, Tunisia, Turks and Caicos, United Arab Emirates, United Kingdom, United States, Uruguay, and Vietna. Up to date information can be obtained from Jeppesen or ICAO.

Operations Approval

Q: How does an operator seek operational approval for RNP operations?
A: Today in the US, this is addressed through the operations authorization for a specific air carrier. In the future, this will be standardized in criteria for aircraft and systems demonstrated for type certification. Similar steps are required in other states.

Operations - Systems

Q: What are dual/single systems requirements for approach operations (ie capabilities & navaid monitoring)?

A: In general, dual systems are required except where it is demonstrated that safe operations may be conducted with a single system, considering factors such as terrain, applications and required operations. For critical RNP RNAV approaches that must rely on low ANPs supported by GPS, redundant FMC, IRU, GPS, VOR, DME, autopilot and displays are often required. The operating limitations and equipment requirements would appear in the operational authorization, MEL, and in some instances the AFM.

For approaches other than ILS, MLS & GLS, it is business as usual, the underlying sensor on which it is based must be available, as well as suitable displays (e.g. VOR & Map or RDMI). If the approach can be flown as an RNAV approach, provision may be made for verification of suitable navigation system performance rather than continuous monitoring of a raw data facility.

Q: What are the system equipment requirements for RNP primary means of navigation using GPS?

A: This is dictated by the type of operation intended and the necessity for performance availability. This leads to requirements for redundant FMC, CDU, IRU, GPS, VOR, DME, autopilot and display systems.

Q: What EICAS messages/Caution lights occur due to loss of RNP capability or other related malfunctions? What is the associated crew action during an RNP or non-RNP approach?

A: For 747/757/767/777: "UNABLE RNP", "L GPS", "R GPS" messages or similar occur on EICAS. Additionally, "FMC Message" occurs when RNP based "VERIFY POSITION", "VERIFY RNP-POS REF 2" and "VERIFY RNP ENTRY" CDU messages occur.

For 737: GPS failures are indicated by a dedicated light on the IRS Mode Select unit. An FMC light occurs for FMC RNP conditions for: " IRS NAV ONLY", UNABLE REQD NAV PERF-RNP", "VERIFY POSITION", "VERIFY RNP", "VERIFY RNP VALUE" & "NAV INVALID TUNE XXXX" GPS failures are indicated by a dedicated light on the IRS Mode Select unit. An FMC light occurs for FMC RNP conditions for: " IRS NAV ONLY", UNABLE REQD NAV PERF-RNP", "VERIFY POSITION", "VERIFY RNP", "VERIFY RNP VALUE" & "NAV INVALID TUNE XXXX".

The required crew action will vary. For example on RNP approaches, with the UNABLE RNP message, it is expected that coordination with Air Traffic Services may be required and a new approach selection or missed approach may occur. If a required sensor such as GPS fails, the crew could be precluded from operating on an RNP procedure where the actual performance depends on GPS. For non-RNP approaches, it is expected that the approach operations will continue as long as the underlying navaids and associated flight systems are available.

Operations - Approach

Q: Are we legal to fly RNAV approaches? If so, do we have to monitor the associated navigation aid?
A: Yes, RNAV approaches may be flown and they are typically specified in the operations approval of the aircraft system. Where an RNAV approach is predicated upon a specific navaid, there may be a requirement to monitor it or ensure that there is a suitable navigation system mode (e.g. DME-DME).

Q: What are the navaid monitoring requirements for non-RNP operations?
A: The same as they are today (see above)

Q: What are the lowest allowable approach minima for Boeing airplanes certified for RNP primary means of navigation with or without GPS?
A: This is dictated by the type of operation, approach, and intended location, including obstacle assessment. It is intended that a DA(H) of at least 250 feet can be achieved with or without GPS.
Q: Are there some approaches where use of the autopilot is required to meet the associated RNP?
A: Yes. The AFM provides limitations based upon the RNP that establish when the autopilot must be used.

Q: What approaches do not require RNP?
A: At this time, it is anticipated that ILS, MLS & GLS procedures will not require RNP except for the lead-in transition & initial segments of the approach and possibly the missed approach segments. In the future, RNP may be applied for all approach segments.

Training and Qualification

Q: What pilot training requirements must be met?
A: Formal criteria is under development. However, it is expected that pilots must be familiar with the RNP information available, indications and alerts provided, and associated operating procedures. Simulator training may be necessary where additional pilot procedures for assuring the appropriate flight plan, navigation conditions, etc are required.

Q: Has any government, ICAO or other agency established pilot currency and/or qualification requirements or recommendations?

A: Not at this time but they are being developed.

Appendix B Path Terminators

1.0 Introduction

1.1 This attachment contains information on the aviation industry's navigation database requirements that are necessary in order to support operational airborne navigation system software. To achieve the objectives of the ICAO FANS working group, future navigation systems must compute flight paths that are consistent and flown in the same manner by all aircraft. To accomplish this, the flight paths must be accurate, reliable, and repeatable. It is necessary, therefore, that all future navigation systems perform certain flight path functions in the same manner.

1.2 A route of flight (airway, air route, SID, STAR, approach or departure procedure) appropriately designed in terms of its usability in navigation databases, provides for consistent aircraft performance on the required flight path.

2.0 Path Terminators

2.1 The aviation industry applies a "path and terminator concept" for transforming arrival, departure and approach procedures into coded flight paths that can be interpreted and used by a computer-based navigation system. The path and terminator concept includes a set of defined codes referred to as "path terminators". A path terminator instructs and aircraft to navigate from a starting point along a defined path to a specific point or terminating condition. A sequence of path terminators defines the intended route from take-off, through each departure segment, to a point on the en-route airway, or from the en-route airway through each arrival segment and approach segment, to the missed approach point, landing runway end point or the missed approach hold point.

2.2 The path and terminator concept used is a set of two alphabetic characters, each of which has meaning when describing a flight manoeuvre to a computer. The first character indicates the type of flight path to be flown and the second character indicates where the route segment terminates. For example, a direct track from one explicit fix to another would be coded with a "TF" path terminator. The "T" represents the type of flight path to be flown (a track in this case) and the "F" indicates that the segment terminates at a fix.

2.3 There are 23 different path and terminator sets used by the aviation industry to accommodate the coding of procedure route segments. The 23 different path terminator sets are shown in the Table below and explained in the following sections. Only 9 of the 23 path terminator sets are usable in defining RNP procedures and airspace. These are indicated in the following table as RNP Significant.

Table B2-1

Leg Types	Description	RNP Significant
IF	Initial Fix	Yes (preferred)
TF	Track to Fix	Yes (preferred)
RF	Radius to Fix	Yes (preferred)
DF	Direct to Fix	Yes (discouraged)
FA	Fix to Altitude	Yes (discouraged)
CF	Course to Fix	Yes (to be phased out)
HF	Hold to Fix (and exit)	Yes (new RNP hold criteria)
HA	Hold to Altitude (climb)	Yes (new RNP hold criteria)
HM	Hold for Clearance	Yes (new RNP hold criteria)
PI	Procedure Turn to Intercept	No
CA	Course to Altitude (climb)	No
CI	Course to Intercept	No
CD	Course to DME Arc	No
CR	Course to VOR Radial	No
FC	Course from Fix	No
FD	Fix to DME Arc	No
FM	Vectors from Fix	No
AF	DME Arc to Fix	No
VD	Heading to DME Arc	No
VA	Heading to Altitude (climb)	No
VM	Heading (vectors)	No
VI	Heading to Intercept	No
VR	Heading to VOR Radial	No

Additional information and guidance is available in RTCA Document DO-201A/ EUROCAE Document ED-77, Standards for Aeronautical Information, or in ICAO PANS-OPS Document #8168, Volume II.

Appendix C APPLICATION AND USE OF RNP FOR EXISTING AIRCRAFT SYSTEMS

During the transition phase to RNP, the aircraft qualification basis will be but one factor which must addressed in order to allow existing aircraft to operate in RNP airspace. In addition to the qualification basis, the following need to be addressed by operators, applicants, field offices, airworthiness authorities, etc in the allowances and tradeoffs made for existing aircraft capabilities:

C1.0 Establish Aircraft Systems Qualification Basis.
Determine aircraft eligibility and associated required assessments for the intended procedures.

C2.0 Determine General Application/Objective.
Perform an applications assessment to identify the procedure, or site/location application to determine the approximate nature of the RNP procedure, route, approach, missed approach, departure, transition, or other application needed. Consider Terrain, Airspace restrictions, EPU availability from navaids/IRSs etc. necessary to support the application. Consider reference datums to be used.

C3.0 Complete an RNP Assessment
Perform a preliminary analysis of the level of RNP needed (by segment, route, area, or operation) to support the intended task or application sought.

C4.0 Resolve Datum Issues.
Resolve Datum issues per Appendix D.

C5.0 Resolve Specific Waypoint Issues
Determine specific waypoints resolution, accuracy, distances, angles, no discontinuities, VNAV constraints/paths, and NDB integrity procedures.

C6.0 Assure Basic Flyability.
Determine that the intended procedures can be flown by intended aircraft to use it regarding FMS capability, Flight Control Computer capability, modes to be used (e.g. coupled LNAV/VNAV, FD) etc. Consider Normal and Rare Normal Operations (e.g. reference/limit winds/gradients, turbulence, etc), along with possible need hot bench tests, or even FBS validation if a new application for a particular aircraft type.

C7.0 Construct Specific Procedure
Draw Procedure (if applicable), perform surveys, identify any special crew procedures, set VNAV gradients needed, complete chart/map development, defne containment surfaces, assure navaid ANP availability of DMEs etc.

C8.0 Complete Obstacle Assessment
If applicable, complete the necessary obstacle assessment, reference the containment surfaces and required obstacle clearance (ROC) necessary, consider longitudinal ANP effects if applicable

C9.0 Address Contingencies.
Address defined contingencies to cover: Engine failure, Electrical power source loss, electrical Bus loss, FMS failure, HMI/Procedure failures, limited to realistic, agreed, defined failures at the probable level [Do not need to address terrorist bombs...etc.]. Address a go-around (GA) from 50 ft below DA(H) with engine failure and GA from end of TDZ (rejected landing. including engine failure (but only to 35' NFP Clearance as for Takeoff case).

C10.0 Specify and Address Crew Qualification/Training.
Address standard or special crew qualification and 121.445 (if applicable)... Address any special cockpit procedures, IOE, etc.

C11.0 Air Traffic Facility Coordination.
As required. For enroute/ terminal, applications and international enroute applications much of this process needs to be done very early in the process (e.g. ISPACG coordination, DOC 7030 changes, etc) and it may have a major role in setting RNP levels required, particularly if the RNP levels are intended to relate to separation standards...

CI2.0 Testing/Demonstration.
Some procedures may require ops-validation (e.g.. FAR 121.445 airports . Fleet qualification...)

C13.0 Authorization and Approval.
Discuss operations and approvals re: FAR 121 Part B and Part C Op-Specs, FAR 129 Op-Specs.

C14.0 Operational Use/Feedback.
Some procedures may require in service validation (e.g. FAR 121.445 airports, Fleet qualification...) before ultimate minima objectives are achieved, or separation standards attained (e.g. FANS I limited implementation program (LIP). for 50/50, 30/30...).

Appendix D CHECKLIST FOR EVALUATING USE OF GPS/WGS-84 DURING APPROACH OPERATIONS

The following checklist should assist operators using systems with GPS sensor inputs to obtain operational approvals when using GPS updating in the approach environment when the navigation data base and charts are not referenced to WGS 84 reference datum. The following guidance may be used as an acceptable means to address provisions for enabling or disabling GPS updating when on approach; it is predicated on the assumption that GPS updating must be disabled for approach operations when the navigation data base and charts are not referenced to WGS 84 reference datum, unless other appropriate procedures are used.

For each pertinent approach, the operator should address the following:

Determine surveyed Datum of the approach. If the Datum is WGS-84 or equivalent, then it is acceptable to use the navigation system with GPS updating enabled for the approach operations. If the reference Datum for the approach is not WGS-84 or equivalent, then accomplish steps (1) or (2). If acceptable to the applicable authority, approved contractors may be used to obtain WGS-84 Datum information.

(1) For each pertinent approach do either (a, b, c, or d):
   a. Measure or analytically determine the differnce between the local Datum and WGS-84 at the runway threshold or missed approach point, and then evaluate whether the difference is significant with respect to local conditions such as terrain, air traffic, typical weather minimums, RNP, etc. This process should consider conditions or circumstances identified by airline operations, operations inspectors, and appropriate authorities for the procedures in question.
   b. Generate a special RNAV procedure that would be referenced to WGS-84 or equivalent. See related issues below.
   c. Manually inhibit GPS when flying the approach
   d. Do not use the navigation system to fly the approach

(2) For approach procedures established along pathsdefined by radiated ground signals, such as VOR radials, conduct a “proving flight(s)”. The “proving flight(s) must include an estimate of the difference beteween the path(s) defined by the radiated ground signal and the path defined by the navigation system using GPS for updating. An acceptable method to estimate during “proving flight(s)” is by flying the approach using the navigation system with GPS updating inhibited and monitoring the distance and bearing of the GPS position relative to the computed position by the navigation system.

   An estimate may be made as to whether the difference is significant with respect to local conditions (terrain, traffic, typical weather, minimums, RNP, etc). This evaluation should consider any special factors defined by the operator, the operating inspector, and other authorities responsible for these procedures. If the difference is not significant, the navigation system with GPS updating enabled my be used for the approach operations. If the difference is determined to be significant then either do (a, b, or c).

a. Generate a special RNAV procedure that would be referenced to the WGS-84 Datum. See related issues below.
b. Manually inhibit GPS updating when flying the approach, or
c. Do not use the navigation system to fly this approach.

Other acceptable means to determine Datum difference effects may be used by the operator if they provide at least an equivalent assessment as compared with the methods defined above.

(3) In the event that procedure development or evaluation requires a survey of waypoint locality, such information may be acceptable when derived from a variety of sources. Acceptable sources may include the state of the operator, approved contractors, and approved sources of navigation information (e.g. Jeppessen, etc) if they hav a means to verify source data.

Issues to consider and constraints for special procedures and operator generated approaches in the navigation system data base.

1. Issues that must be addressed when developing special approach procedures:

   a. Navigation System Navigation Data Base Runway Records

   The navigation data base contains data that is referred to as “standard data”, and has the capability to contain operator-unique “tailored data”. The standard data items are the official source data as received from the individual states. The file of standard data items is used by data base suppliers as a baseline to build all Navigation Data Bases. Each of the standard data items can only have one set of attributes for each item. For example, a runway can only have one set of position coordinates. If a runway has any of its attributes changed in standard data, it affects all users of that standard data. Thus, if it is desireable to change the coordinates of a runway to be compatible with the WGS-84 datum, consideratio would need to be given on how to accomplish this without adversely affecting non-GPS operators.

2. Operational Requirements when flying a special RNAV approach that has been generated in response to a datum difference betwen local datum and WGS-84:
   a. The special approach procedure and/or criteria must be acceptable to the appropriate authority.
   b. “GPS” must be the navigation system position updating mode when flying the special approach procedure.
   c. The operator must have a process in place with their navigation data base suppliers to assure the special approach procedure is properly entered for every navigation data base cycle update.

References

1. RTCA/EUROCAE Document DO-236/ED-75, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation

2. RTCA/EUROCAE Document DO-200A/ED-76, Standards for Processing Aeronautical Data

3. RTCA/EUROCAE Document DO-201A/ED-77, Standards for Aeronautical Information

4. ICAO, Manual on Required Navigation Performance (Document # 9613-AN/937)

5. FAA Order 7100.11A *Flight Management System Procedures Program,* Appendix 1, May 22, 1996

6. ICAO, Manual on the Implementation of 1000 Ft Vertical Separation Minimum Between FL290 -FL410 Inclusive, Document #9574,

7. ICAO Procedures for Air Navigation Services, Aircraft Operations (PANS-Ops) Document #8168

8. EUROCONTROL Standard Document for Area Navigation Equipment, Operational Requirements and Functional Requirements, #003-93, Edition 2