February 23, 2011

Ms. Peggy Gilligan
Associate Administrator for Aviation Safety
Federal Aviation Administration
800 Independence Ave, S.W.
Washington, D.C.

Dear Peggy,

The Performance-based operations Aviation Rulemaking Committee (PARC) has developed an operational concept referred to as "RNP Established". This concept uses RNP technology to safely direct aircraft to simultaneous independent and dependent parallel approach paths with no required vertical separation with aircraft on adjacent approaches. In short, the concept considers aircraft on an RNP approach established or stabilized therefore not required to maintain radar separation (3 NM lateral or 1,000 ft vertical) with aircraft on the approach course to an adjacent parallel runway. RNP Established will provide the industry with a significant efficiency increase during operations to parallel runways while retaining safety and capacity.

The RNP Established Action Team developed a concept of operations and conducted an unofficial hazard assessment process with a broad cross section of industry representatives. The input received and potential mitigations of hazard causes served as the basis for provisions in the concept of operations. Because mitigations were identified to address industry concerns and with the existing high level of confidence in RNP operations, the PARC SG is recommending that the FAA initiate action to implement this capability.

The RNP Established Action Team summarized its analysis in the attached report. The report includes a concept of operations and recommendations for the FAA to consider to during its safety analysis of the RNP Established concept. It also includes an Implementation Plan. Hopefully the FAA will find this report useful when it initiates its deliberations on this capability.

Additionally, the PARC SG is recommending that members on the RNP Established Action Team be included in the FAA evaluation process. This would provide continuity between the PARC activity and FAA's evaluation of the concept. Additionally, the action team expertise may enhance the understanding of pilot and aircraft capability.

The completion of RNP Established Action Team tasks and the resulting documented consensus on concept and recommendations is significant in that a basis and guidance to implement and manage operational capabilities are now defined. Its positive impact on the implementation of Performance-based Navigation is due to the efforts of Sarah Dalton, and the other members of the RNP Established Action Team.

The PARC appreciates your continued support of our activities and requests that the FAA provide a response on next steps and plans with regard to the concept and recommendations. Please call me if you have any questions.

Sincerely,

Dave Nakamura
Chairman
Performance-based operations Aviation
Rulemaking Committee

PARC RNP Benefits Sub-Team
“RNP Established-Parallel Approach”

Report dated January 10, 2011

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1 Concept Overview

The RNP Established concept considers aircraft on an RNP approach established or stabilized thus allowed to lose standard radar separation (3 NM lateral or 1,000 ft vertical) with aircraft on the approach course to an adjacent parallel runway. Thus the name of the concept is "RNP Established." The RNP Established proposal uses RNP technology to safely direct aircraft to simultaneous independent and dependent parallel approach paths with no required vertical separation with aircraft on adjacent approaches. RNP Established will result in shorter downwind legs and optimized profile descents thus increasing operational efficiency while maintaining safety.

2 Objectives of RNP Established

- Utilize RNP aircraft and procedure design technologies to provide precise, consistent, and predictable flight paths onto a final approach segment
- Reduce the length of downwind segments on the path to final parallel approaches
- Minimize level-off segments during descent to parallel approaches
- Reduce community noise and Green House Gas Emissions

3 Concept of Operations

3.1 Background-Current Operations

Current standards for simultaneous independent and parallel dependent approaches require that air traffic control (ATC) maintain a minimum of 1000 ft vertical separation or a minimum of 3 miles radar separation between aircraft during turn - on and until established on parallel ILS final approach courses.[1] During triple simultaneous independent parallel approaches, no two aircraft will be assigned the same altitude during turn on.[2] All three aircraft must be assigned altitudes which differ by a minimum of 1,000 feet. During independent approaches, localizer intercept must be accomplished several miles before altitude separation is lost by aircraft descending on the glide slope due to the FAA Joint Order (FAA JO) 7110.65 requirements that communications transfer to the tower controller's frequency shall be completed prior to losing vertical separation between aircraft. The turn-on angle is restricted to a maximum of 30º for approaches to two runways and a maximum of 20º degrees for approaches to three runways. See Figure 1 for a depiction of turn-on rules for

[1] It is anticipated that RNAV and RNP straight-in approaches will be allowed to substitute for ILS in the future.
[2] Parallel dependent approaches are conducted to two parallel runways only.

simultaneous approaches to three runways. These restrictions allow aircraft to become stabilized on their respective approach paths prior to the loss of vertical separation that occurs when descending on their respective glide slopes. This is particularly important since most of the current turn-on procedures involve radar vectors to an ILS localizer, and the nature of the radar vector/ILS combination inherently requires stabilization on the localizer path. However, these restrictions also result in very long final approach paths—normally 20 - 25 NM for triples, for example. This requires aircraft to fly extended downwind paths when approaching the airport from the departure side of the airport (e.g., from the right in Figure 1). Current methodologies require aircraft and pilots to utilize two different flight modes: Heading and Localizer Intercept. In some cases, tailwinds, airspeed, radio congestion, and Flight Director/Autopilot capture parameters can cause an aircraft to overshoot the localizer.

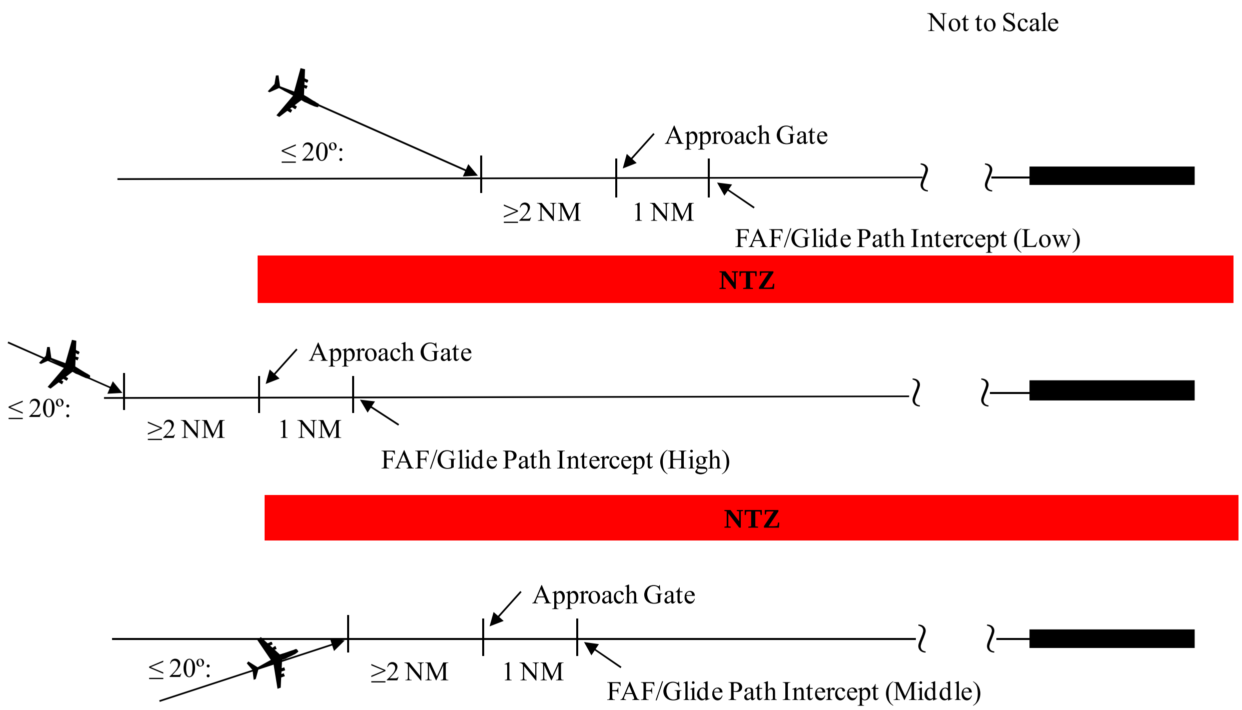

Figure 1 Simultaneous Triple Approach Turn-On Geometry

3.2 RNP Established Concept

The RNP Established procedure is new rule-set for operating normal triple and dual simultaneous parallel approaches and parallel dependent approach procedures. The RNP Established procedure only changes the separation requirement during the turn-on phase parallel approach operations. The proposed RNP Established rule-set gives credit for the RNP aircrafts' ability to maintain lateral path containment during the entire RNP approach procedure (i.e. from the Initial Approach Fix (IAF) to the Decision Height) sufficient to supplant the need to maintain 3 miles lateral or 1,000 foot vertical radar separation until the aircraft are established on the parallel course. Other procedures contained in FAA JO 7110.65 for simultaneous independent and dependent parallel approaches will continue to be in force. No additional ATC equipment and staffing changes are proposed. For example, if the runway configuration at the airport requires a Precision Runway Monitor (PRM) for simultaneous independent approaches, then that requirement would continue, and those controllers would continue to monitor for exceptions to aircraft flying the approach paths. Monitor controllers will continue to monitor simultaneous independent approaches, as currently required. Diagonal spacing and controller requirements for parallel dependent approaches will also remain as currently specified.

To better understand the RNP Established Concept the following discussion is provided:

3.2.1 Prior to initiation of the procedure

Figure 2 shows a notional RNP Established environment, with a published RNP instrument procedure to the right runway extending from the IAF on the left downwind, through one or more curved Radius-to-Fix (RF) legs, to a straight final segment. There is an ILS instrument procedure to the parallel left runway. The RNP aircraft will transition to its RNP procedure by flying a published Standard Terminal Arrival Route (STAR-Purple segment); the ILS aircraft will transition to the ILS course by following ATC radar vectors. The procedure geometry enables the aircraft to maintain either 3 mile lateral separation or 1,000 foot vertical separation while transitioning on the STARS or radar vector, prior to both being established on their respective instrument approach procedures.

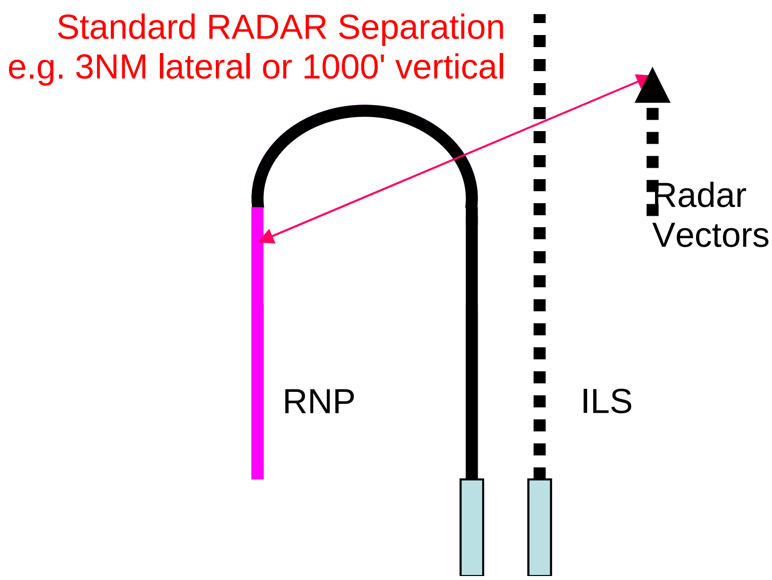

Figure 2 Notional RNP Established Environment

3.2.2 Both aircraft are established on their respective RNP and ILS procedures

Figure 3 illustrates the RNP Established concept, showing the RNP path an aircraft would fly on the approach to the right runway, and the aircraft on the straight-in ILS course would fly to the left runway.

The RNP aircraft will descend via a STAR that terminates at the RNP approach procedure IAF. Prior to this point, the crew of the RNP aircraft will load the RNP approach procedure into the FMS approach function, and when the approach is executed it provides navigation inputs to the autoflight system or flight director steering commands to enable precise lateral and vertical path tracking. Unlike the vector to ILS aircraft, there are no aircraft-mode changes required throughout the turn to the runway alignment.

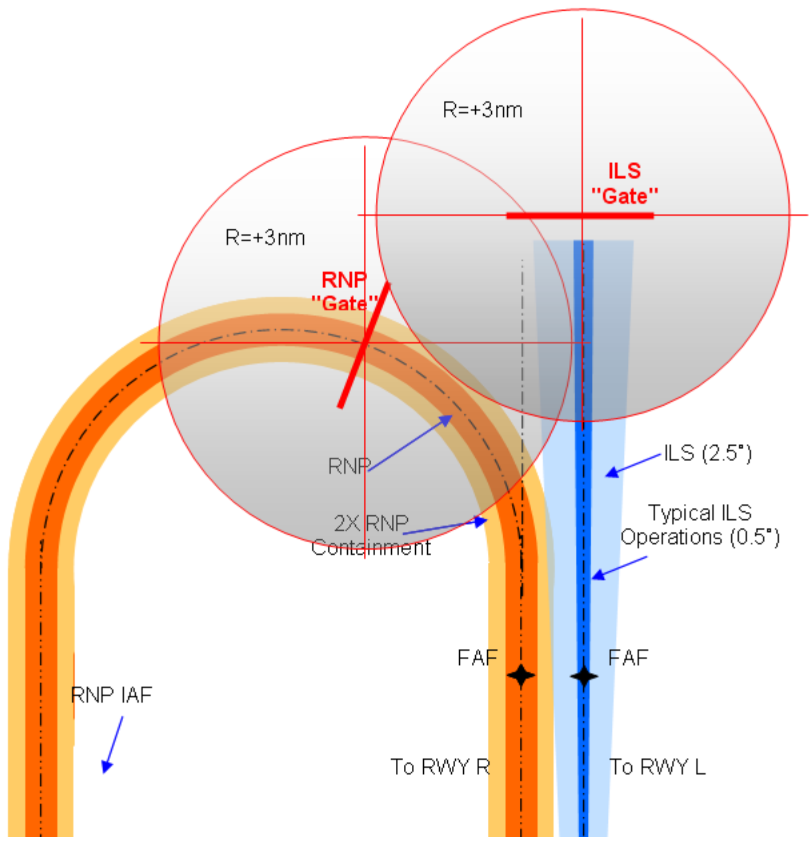

Figure 3 RNP Established Concept

The RNP aircraft is considered established on the procedure when it has successfully initiated tracking on the published lateral and vertical path of the active leg of the procedure. Note this will typically occur at the IAF.   The aircraft on the ILS procedure is required to be established on the localizer at a point prior to the *ILS gate* in Figure 3, which is a design point that provides geometry for a minimum of three miles lateral separation from the RNP track.

Once established on their approach paths, no altitude separation will be required between aircraft joining parallel final approach courses and aircraft can be descending during the turn to align with the runway. The flight crews of both the RNP and ILS aircraft have primary responsibility for path conformity, the same as crews do in today's parallel ILS operations. If any path deviations are observed, the flight crew makes course corrections to stay on the path. Inherent to the RNP system, there are on-board systems that monitor actual navigation performance, providing flight crews with real time indications of the aircraft's navigation capability. Flight crews are tasked with monitoring the Actual Navigation Performance (ANP). If ANP performance exceeds acceptable limits, the flight crew notifies ATC and executes a missed approach.

Air traffic controllers will provide radar surveillance and should they detect any significant track deviations, they will alert flight crews and request corrections back to the path. Should the deviations not be corrected, they will break out an aircraft to ensure adequate separation.

The aircraft that will be approved to fly the RNP procedures will have demonstrated compliance with FAA requirements for RNP AR under FAA AC90-101, or basic RNP under FAA AC90-105.

Figure 4 shows an example of RNP instrument procedures with RF turns for use with simultaneous independent approaches to three runways, and see Figure 5 for RNP instrument procedures with RF turns for dependent approaches.

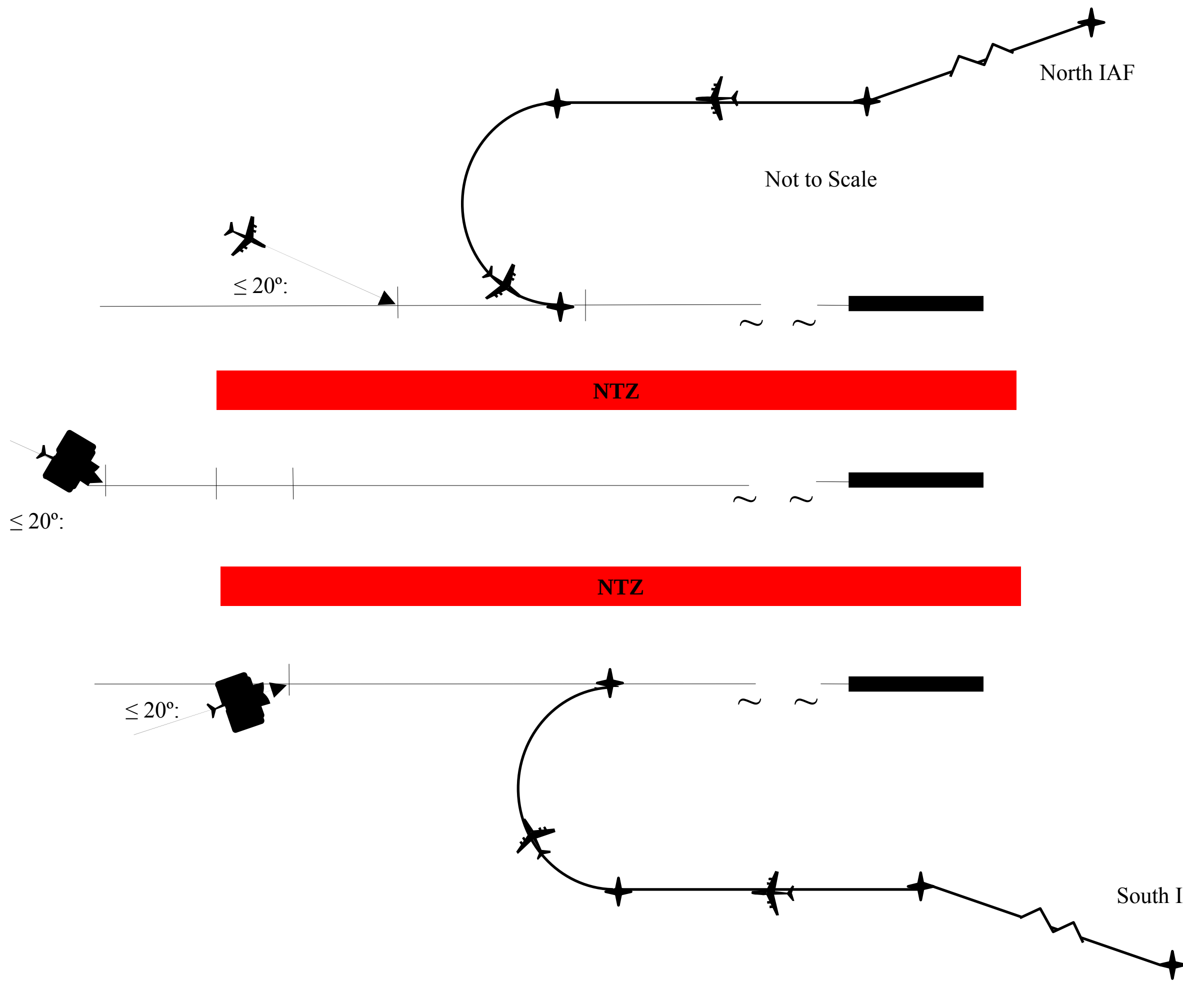

Figure 4 RF Turns onto Triple Simultaneous Approaches

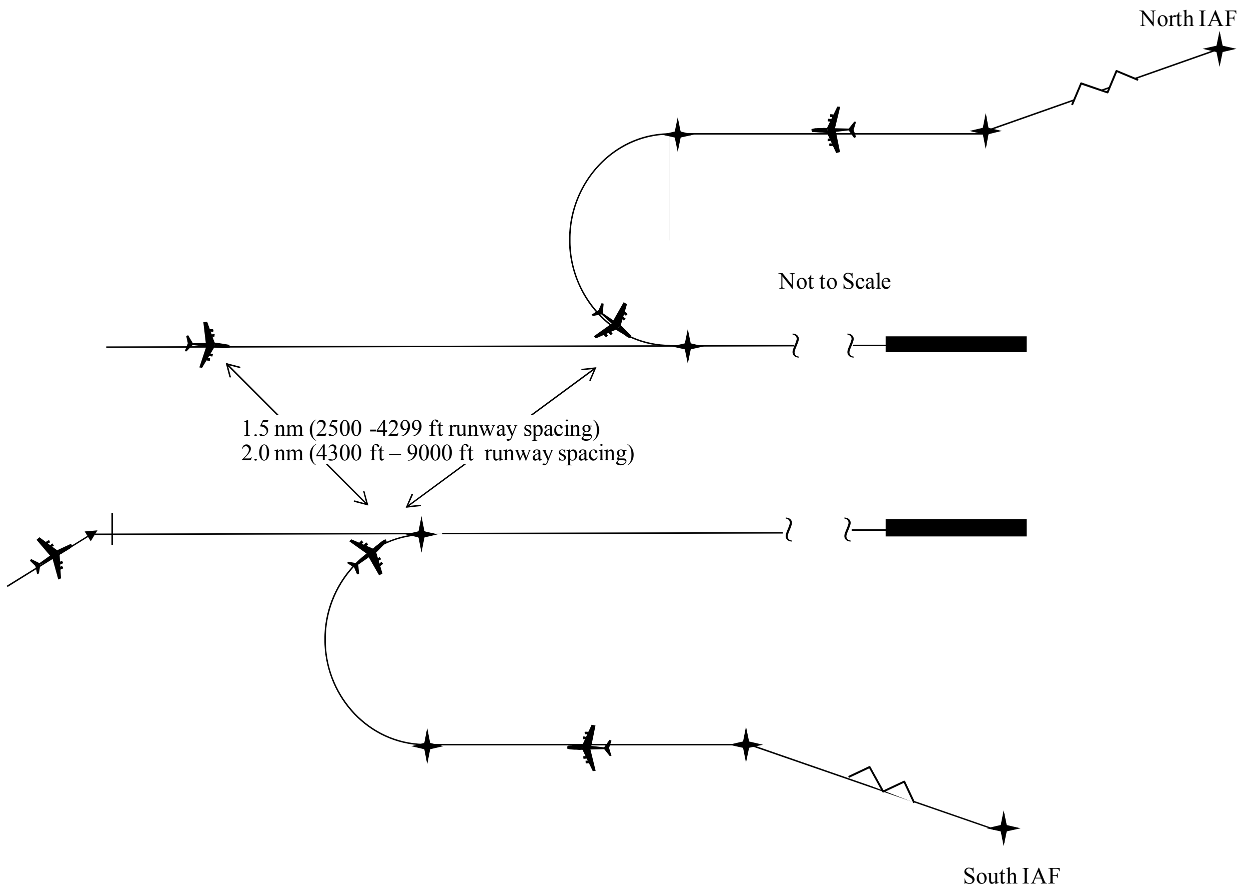

Figure 5 RF Turns onto Dependent Approaches

3.3 Recommended Operational and Design Parameters

Operational experience has shown that RNP procedures with RF turns have proven to be accurate and repeatable because the procedure design criteria ensures that the aircraft will remain on path throughout the turn, nearly eliminating the potential of the aircraft to overshoot the turn. In addition, should an extraneous condition arise that could cause an aircraft to deviate from the depicted path; RNP AR flight training requires that crews are trained in the procedures and importance of maintaining this path.

Accordingly, the following additional provisions are recommended to be incorporated into the procedure design and operation when implemented.

1. Each RNP Established procedure from a downwind will encompass an RF turn or a sequence of RF turns to final from the downwind or base segment, a straight final approach segment (appropriate for each potential transition/waypoint), and the missed

approach segment. The RNP Established procedure can begin in the base or downwind leg segment. The missed approach segment will be designed using existing criteria.

2. ATC should advise aircraft of RNP approach and runway assignment as soon as possible. If possible, approaches in use should be advertised on the ATIS. ATC should issue the approach clearance as soon as possible but NO LATER than 10nm (or distance determined by Safety Assessment) prior to IAF for the approach. It should be noted that this is a *minimum* distance, not an operational goal.
3. This assumes that:
    - As a Standard Operating Procedure (SOP), crews will brief possible approaches prior to approach assignment -- just as in multiple ILS operations.
    - Changing approach assignments requires the crew to reprogram the FMC. This involves selecting, reloading and executing the new approach and transition in the FMC.
    - Crews must review proper chart(s) and have them available.
    - Crews confirm that the proper RNP procedure has been selected in FMC and ensure that data (waypoints, sequence, speeds, altitudes, glide path) are correct and match the approach chart.
4. The point at which the clearance should be issued by ATC and acknowledged by the flight crew should be depicted on the controller's display and noted on the appropriate flight publications, and should be a minimum of 10 NM prior to the IAF. Once issued, the clearance cannot be amended by ATC after the aircraft has passed this point unless the controller opts to vector the aircraft for a straight in approach using appropriate non-RNP-capable procedures.
5. If ATC cannot issue the clearance, the flight crew cannot accept the clearance, or there is some difficulty that prevents the flight crew from accepting the clearance prior this point, ATC will issue approach control instructions to vector the aircraft onto the straight-in final with at least 1000 ft vertical separation or 3 NM lateral separation from aircraft on approaches to the other runways
6. ATC will only issue the RNP approach to appropriately equipped aircraft and RNP-capable flight crews. This may require a query by ATC or a pilot request for the procedure. Initially the process for identification of appropriately equipped aircraft will determined by the local ATC facility in coordination with users. Ultimately, ATC will know which aircraft are capable through automation.
7. The RNP procedures must be designed in accordance with FO 8260.54 or 8260.52.
8. The following design features should be considered if applicable:
    8.1. RF turn on waypoints must be spaced by an appropriate amount on opposite downwinds (e.g., the north and south downwinds in Figure 2)
    8.2. The turn-on segment may be a single or multiple sequential RF legs aligning the aircraft with the runway centerline
    8.3. The design and location of the RF should minimize the likelihood of a TCAS Resolution Advisory (RA) between RF-turn aircraft on opposite RF turns to final and between RF turn aircraft and straight-in aircraft
    8.4. The likelihood of a wake turbulence encounter is removed for turn onto final and during the final approach or missed approach
    8.5. Speed restrictions are included as appropriate for the turn-on segment

9. The aircraft operator must comply with AC 90-105 or 90- 101 (as deemed appropriate via the safety analysis).
10. Appropriate operating procedures are established for the procedures similar to those already contained in FAA Order 7110.65. such as precluding use of the procedures when convective or other weather could cause aircraft to deviate from assigned clearances to avoid weather.

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4 Safety Analysis

The overarching objective of the safety analysis is to determine the requirements for a safe operation to the largest number of users. The safety analyses, for both normal and non-normal conditions, should together determine:

- The minimum PBN criteria for aircraft equipment and crew requirements necessary for specific operations (e.g. AC 90-105 or AC 90-101)
- Required RNP value
- Ground surveillance requirements

A key factor in this recommended safety assessment strategy is that PBN operations (RNP and RNP AR) inherently mitigate many of the causal factors which have historically led to parallel runway operations developing a non-normal condition. Therefore, RNP capability should play into both analyses of normal and non-normal operations.

There is a common thread between both current parallel ILS and proposed RNP Established operations: airplanes are being cleared onto flight paths that are separated by less than terminal area standard radar separation minima, 3 miles lateral or 1000' vertical. Today's parallel ILS operations achieve the required level of safety through key elements of both executing normal operations and a safety net of non-normal mitigating factors:

- Normal parallel ILS operations safety elements
  - During the radar vectoring of aircraft to the ILS localizer, aircraft must be cleared to altitudes that provide vertical separation of at least 1,000 feet until both aircraft are established on their respective localizer courses
  - The combination of the ground based localizer transmitter's beam quality and the on-board aircraft receiver path compliance and deviation indications provide inherently high path tracking performance.
  - The flight crews have completed required training and have demonstrated currency for the parallel ILS approach procedures. The training includes elements that set procedures and performance limits for monitoring aircraft lateral and vertical path conformance while on the localizer and glide slope.
- Mitigating parallel ILS Non-normal factors
  - Crew are trained to recognize and mitigate system malfunctions and other non-normal operations
  - The air traffic controllers monitor the aircraft on parallel runways and if deviations are detected, deliver instructions either aircraft to break off the approach to ensure continuing levels of safety.

The safety assessment of the RNP Established operation should consider the safety contributions of new elements introduced with the RNP operations, both normal and non-normal. It should include the following foundational elements:

- Normal RNP Established operations safety elements
    - Prior to the aircraft to their respective operational "gates", RNP IAF/ILS localizer, aircraft must remain laterally or vertically separated until both aircraft are established on their respective published procedure.
    - The RNP and ILS "gate" geometry will be constructed to provide lateral path separation that ensures the RNP aircraft's path is a minimum of 3 miles laterally from the ILS path until established on the procedure.
    - The aircraft incorporates navigation system components with accuracy, integrity and redundancy, and RNP conformance monitoring and alerting capabilities that are certified to levels sufficient to guarantee path conformance to provide required levels of safety for normal operations and minimize the occurrence of non-normal events.
    - *In the case of RNP AR capable aircraft, avionics system design has documented hazard and failure assessments and error testing, including Monte Carlo testing of the autoflight system. (data collection)*
    - The flight crews are trained to configure, operate and monitor the RNP capable aircraft system elements to ensure airplane path conformance.
    - ILS aircraft will be established and stabilized on their guidance prior to the ILS gate once standard radar separation is lost.
- Mitigating RNP Established Non-normal elements
    - If ANP performance deteriorates beyond requirements, the crews are trained to break off the procedure. This should be a very rare event given the short "turn on" segment.
    - The remaining identified non-normal events will be shown to be very rare and involving 'set-up' related errors (for example crew/controller misunderstanding of clearance, crew FMC program error, etc), that will be bounded by agreed mitigations.
    - The guidance gate locations, designed for each airspace geometry, will afford sufficient lateral spacing that if guidance is not established by this point (e.g. ILS aircraft fails to capture the LOC), controller intervention (i.e. vectors) can effectively extract aircraft without loss of standard radar separation.

The sub-team postulated two methods for managing the risk: 1) reducing the risk through design and pilot/controller procedures (managing risk during Normal Operations and limiting the opportunity for non-normal conditions), and 2) establishing pilot and controller procedures to safely manage a deviation should it occur (during Non-normal conditions). The first category is referred to as Causal Mitigations/Design Considerations, and the second category is referred to as hazard condition mitigation or deviation resolution, as this was identified as the Prime Hazard.

4.1 Evaluation of Normal Operations

The sub-team discussed the need to explore requirements for NORMAL performance, such as required RNP value and ILS properties. Understanding normal operations, the range of built-in mitigations, path conformance, etc. that are provided by the variance of RNP operations and published ILS approaches designed for parallel operations, will be critical in determining the parameters for Normal Operations as well as the frequency and severity of non-normal events.

(a) RNP Value for the Approach – Normal Operations Considerations

Once the aircraft are established on their respective approach guidance, standard terminal separation (3NM lateral or 1000' vertical) is no longer required. Aircraft are then following their respective approach paths with specified precision and containment, minimizing the opportunity for traffic conflicts.

The RNP value specified for RNP/ILS parallel operations and its relation to RNP track and ILS/runway geometry is an important factor in building the safety case for these operations. Performance and safety requirements for normal performance will be a determining factor in selecting the necessary minimum RNP requirement for participating aircraft. The RNP value will be influenced by the inherent RNP containment bounds and both aircraft's navigation and guidance performance.

It is important to balance the specified RNP value to maximize the number of eligible participating aircraft with the required operational utility out of the procedure, i.e. as the specified RNP value goes down, the number of aircraft that can participate goes down. Also lower RNP values will increase the number of GPS RAIM holes, creating an complexity in the operation. With these counterbalancing forces in play, there are a number of factors to consider when determining an appropriate RNP value for these procedures:

- The RNP value should first be determined by needed approach minima

Additional factors that could be considered for RNP Established operations:

- Normal risk assessment should account for actual expected performance of the RNP aircraft during the "turn-on"
- RNP displays and alerting provides substantial crew situation awareness
- Off-nominal performance is monitored by crew and will invoke pilot action.

Because the principle means of separation for these procedures is aircraft RNP and ILS tracking capability, the appropriate RNP level must be specified to provide sufficient separation from any other participating traffic (e.g. on an ILS approach). RNP is fundamental to maintaining lateral separation during the "turn-on" as well as the following parallel approach segments. A study to look at normal performance, based on the aircraft's certified RNP performance and actual aircraft ILS navigation capability will be essential in selecting and demonstrating an RNP level that ensures separation in a normal operation.

When considering deviations, the Sub Group believes that there are two categories, normal and non-normal. The first is "Normal" deviations resulting from total system error (TSE) caused by flight technical and navigation systems error.

This normal performance should be assessed in a statistically rigorous manner, i.e. quantification of the collision risk of aircraft while on these procedures. One method, shown below, would be to use averaged actual performance data to describe tracking capability of aircraft on commensurate approaches. When operating normally, the ILS and RNP procedures associated with this concept provide repeatable, stabilized and *procedurally separated* paths. Although the RNP definition allocates 5% of errors greater than 1 x RNP, experience with GPS-based RNP operations shows that the aircraft tracks very close to the desired centerline, including during RF turns. The key to normal operational safety assessment is to exploit the well-understood tracking capability of ILS and RNP containment characteristics to model the system behavior resultant from procedurally separating streams of traffic on these guidance types. [see ILS: Thomas, J. et al., 1993, RNP: Williams 2009] . With such data, a Monte Carlo analysis of potential system interaction can be accomplished. Finally, from this analysis statistics on system separation performance can be attained. While this represents only one way to do so, it is important that any method selected to analyze normal operations fully characterize the normal performance of aircraft performing approaches with a specified RNP value and actual ILS.

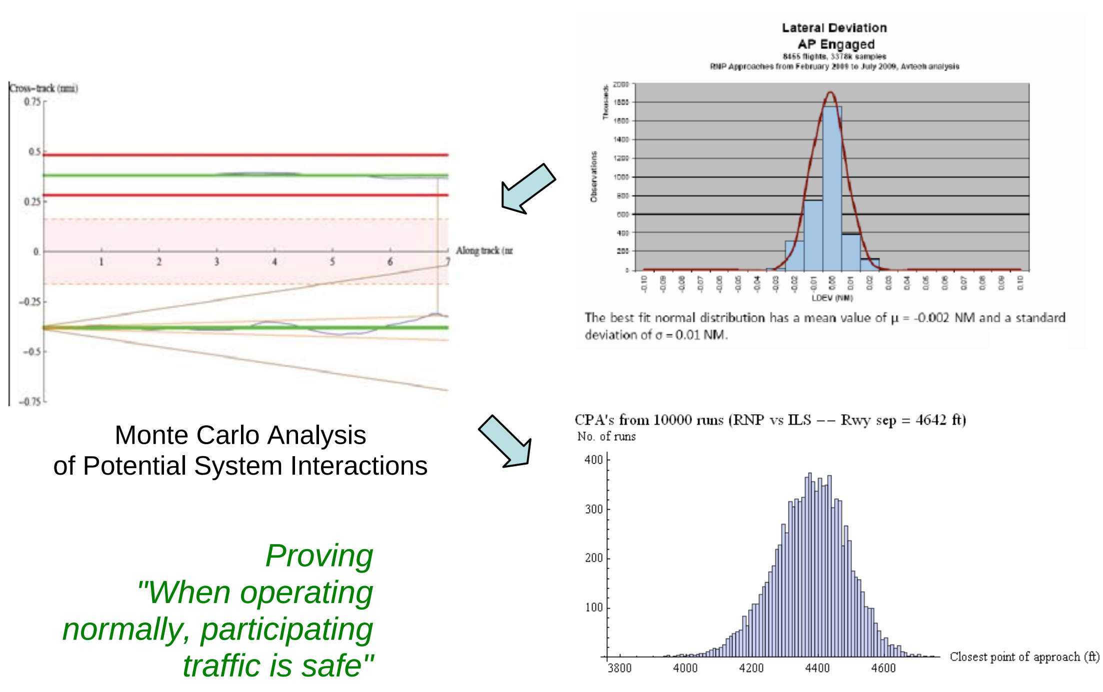

Figure 5. Tracking Capability of Aircraft on Approach

(b) Normal Operations – Frequency

Understanding normal operations will be critical in appropriately assessing frequency and severity of non-normal events. The built-in mitigation that will be provided by the use of RNP procedures and published ILS approaches designed for parallel operations should be demonstrable, and methods should be employed that will uncover the opportunity for non-normal events to occur relative to today's parallel approach operations.

4.2 Analysing Non-normal Conditions

The analysis of non-normal conditions requires quantifying both the severity of a condition and the expected likelihood or frequency of its occurrence. Introducing the RNP procedure to parallel runway operations should dramatically decrease the frequency of operational errors during the most safety-critical portions of the operation, namely as the aircraft are guided to their final guidance and pass within their respective gates. By this point in the operation, both aircraft are stabilized on guidance without a mode change, the guidance is driven from a high integrity navigation database, and specialized crew procedures and training minimize pilotage issues. Procedures are necessary to ensure errors, that might inhibit guidance capture and stabilization prior to the gates, are mitigated. It is expected that the procedures for the RNP aircraft will demonstrate a frequency of such events for the RNP aircraft that require no additional mitigation.

(a) RNP Value and Basic vs. AR – Non-normal considerations

Protecting against non-normal events must also be considered when specifying an RNP value. The RNP level will influence the frequency of events considered to be non-normal. While an approach at any value of RNP can be designated as RNP AR, specifying lower-level RNP values will dictate the use of RNP AR procedures and training: The more stringent training and operational requirements for RNP AR will influence the frequency of non-nominal behaviors, and also afford additional mitigating factors of off-nominal situations. RNP Basic/AR operations frequency, severity and recovery from non-nominal events should be considered.

Table 1 below summaries the RNP attributes of the three RNP capabilities, RNAV GPS, Basic RNP, and RNP-AR.

Table 1: RNP Attributes Comparison

<u>**RNAV GPS**</u>	<u>**RNP BASIC (90-105)**</u>	<u>**RNP AR (90-101)**</u>

• Database Management
• Lateral Accuracy
    • 95% 1NM, 0.3NM Final
• RAIM Alerting
	• Database Management
	• Guaranteed Lateral Accuracy
	    • 95% defined by RNP Value (as low as 0.3NM Final, 1 NM otherwise)
	    • RF optional - only available outside FAF
	    • AFM demonstrated value which addresses operations
	• Vertical Guidance
	    • Stabilized Approach
	    • Profile defined in database (VEB optional)
	• Integrity (Containment)
	    • 99.999% defined by 2X RNP Value
	    • Required multi-sensor
	• Alerting (accuracy only)
	• Minimal Additional Crew Training
		• Validated Database Integrity
		• Guaranteed Lateral Accuracy
		    • 95% defined by RNP Value (as low as 0.1NM)
		    • Unlimited use of RF leg for approach
		    • AFM demonstrated value which addresses operations
		• Vertical Guidance
		    • Stabilized Approach
		    • Defined in Database (VEB, Baro)
		• Integrity (Containment)
		    • 99.999% defined by 2X RNP Value
		    • Required multi-sensor
		    • Redundant FMS Hardware
		• Alerting (Comprehensive: accuracy & integrity)
		• Additional Crew Training and Procedures to Qualified Standards

(b) Causal Mitigations/Design Considerations

The PARC Sub-Action Team conducted its own Hazard Assessment of the RNP Established operation to focus the discussion of non-normal scenarios. The process used was based on the FAA's Safety Management System Safety Risk Management assessment. The primary hazard identified was a longitudinal, lateral, and/or vertical deviation of aircraft leading to conflict between the aircraft on adjacent approaches. As described above, the expected frequency of these events is greatly reduced due to the RNP procedure. Mitigating effects of RNP and the operational concept are reflected in the sub-team responses to the identified hazards. The list of potential hazard causes identified is below. The recommended mitigations were developed by the PARC Sub-Action Team, *and are shown in italics.*

1. Response to TCAS Alerts:

The TCAS system, designed to be a last line of defense against collision, is expected to remain active during parallel operations. It is therefore imperative that the relative closure rates and distances for aircraft following nominal published procedure in simultaneous operations be carefully considered: Paths must be constructed and conformed to such that TCAS RA alerting thresholds are not exceeded with nominal path conformance (i.e. within

RNP containment, normal ILS tracking, etc) to avoid nuisance alerting. Conversely, the effect of RAs (should a path deviation occur) must be assessed.

Through careful design, these concerns can be mitigated and validated prior to qualifying the operations. See (Tong et al2010).

2. Rare-normal atmospheric conditions, typically high winds or low atmospheric pressure, that exceed airplane capability to maintain the procedure track:

Operating weather limitations should be established that eliminate atmospheric conditions that would exceed the airplane's capability to maintain the procedure track.

3. Controller late or changed runway assignment leads to rushed flight crew, who in turn makes an error:

Establish a NO LATER point to change an aircraft from one approach to another based on the time required for the flight crew to modify the flight deck for the revised clearance. (See section 3.4.2) The point should be depicted on the controller's display and noted on the appropriate flight publications. Once issued, the clearance cannot be amended by ATC after the aircraft has passed this point unless the controller opts to vector the aircraft.

4. Inappropriate training and implementation of flight crew procedures for performing RNP operations. The flight crews fail to establish and conduct the appropriate RNP procedure

Require the appropriate level of flight crew performance via ops approval of AC 90-105 or AC 90- 101 as applicable.

As necessary, implement procedure design features, crew and/or ATC procedures that ensure that the correct approach is being executed.

5. Aircraft equipment failure during the approach that was not detected prior to the approach:

This is a highly unlikely scenario given how short these approaches are. The safety analysis should examine this possibility to determine if aircraft meeting AC90-105 performance levels are adequate, or if AC90-101 is required.

6. Controller is unable to identify if the aircraft has deviated from the nominal path:

Controllers will need to identify an aircraft that is not established on the correct procedure, or becomes a threat to proximate traffic.   Controller displays may need to be validated against these requirements.

7. Aircraft can not remain on path due to inappropriate procedure design:

Through careful design, these concerns can be mitigated and validated prior to qualifying the operations. RNP procedures will be designed within appropriate standards for the applicable approach: 8260.54 or, 8260.52. These criteria and the associated flight validation process address this issue.

The greatly reduced frequency of non-normal condition in RNP Established operations vs. traditional parallel runway operations is an expected result of such a safety analysis. The mitigating effects of the RNP procedure can be seen in the hazard assessment above.

(c) Non-normal Scenarios and Deviation Characterization

Primary Hazard- The primary hazard identified was a longitudinal, lateral, and/or vertical deviation of aircraft leading to conflict between the aircraft on adjacent approaches.

What has proven to be a safety concern with parallel ILS approaches, on rare occasion, are non-normal situations such as aircraft that are not able to acquire or maintain their paths (overshoots, equipment failures, poor pilotage, etc). There are many causes of such a deviation from normal operations, and they need to be addressed individually for mitigation. Many causes of such potential deviations can be mitigated before they are allowed to develop such outcomes, and therefore the system remains in a normal state. This type of causal mitigation analysis, complementary to hazard analysis associated with deviations (once they DO occur), is critical to the RNP Established procedure safety assessment.

In the past, "blunders", or deviations, have been known to occur during simultaneous approaches, but had not been rigorously characterized due to a lack of data. Rather, assumptions regarding deviations were developed and agreed upon by a consensus among the FAA, airlines, and general aviation, and pilot and controller unions. The major assumptions were

- A maximum of a 30 degree blunder would be protected against in the criteria
- Some blundering aircraft would not respond to controller instructions to return to course

Analysis determined that a maximum blunder rate of one blunder/2000 approaches could be tolerated and still meets safety criteria.

In recent years, improved access to radar data allowed for an extensive data collection of blunders. Over one million simultaneous approaches have been screened, and the data show that the severity and rate of blunders is much less than assumed during original analytical techniques. No non-responding blunders were observed in the data collection, and the overall rate of blunders was less than one blunder per 20,000 approaches. See [Massimini et al., 2008; Massimini et al., 2009] for additional detail.

Supporting the radar data, a scouring of the ASRS database for self-reported deviations from parallel approaches demonstrated few operational errors, and only two events traditionally described as "blunders". Most issues revolved around miscommunication/understanding between controller intention and pilot action, and were manifest in the guidance set-up on the flight deck. In turn, many of these instances were exacerbated by high workload events, such as late runway changes. The distinction between the majority events and the two "blunder" cases is establishment on guidance: in years of data, in only two cases were pilots reported to have suddenly deviated from established ILS guidance. In all the other cases, the cause of the non-normal scenario occurred prior to establishment and stabilization on final guidance. Therefore, mitigating these types of set-up errors, for/by both flight crews and controllers, is fundamental to the safety assessment of the RNP Established operation.

The following points are germane:

- Several features of the proposed RNP Established procedure will mitigate the occurrence of a blunder or a major path deviation
    - The flight crew is has established stable guidance from an RNP procedure before the loss of standard lateral radar separation (e.g. on downwind or base greater than 3nm from the opposing approach path)
    - Once established, the procedure is flown through touchdown. There is no change of navigation or guidance source, such as the shift from radar vectors to ILS that is present on a simultaneous ILS approach.
    - The aircraft systems are certified for reliability and integrity during approach procedures. They include redundant systems designed to maintain acceptable performance through out the procedure.
    - The flight crew is specially trained to monitor the flight performance and respond to performance anomalies or equipment issues.
    - Coded RNP turns to final are consistent, predicable and identifiable, unlike paths from vectors to intercept ILS procedures
    - In general, certified RNP approach performance has been shown to follow a more predictable ground-referenced path than ILS approaches, even in RF turns segments
    - Clearance for the RNP Established procedure will occur in sufficient time for the flight crew to brief and select the appropriate procedure. If ATC needs to change the procedure to be flown after this point, then the aircraft will not be assigned an RNP Established procedure, but will be vectored to the ILS final and separated from other aircraft by current rules.

(d) Mitigating Risk due to Deviations with Controller Intervention and Flight Crew Procedures

Notwithstanding the positive features noted above, it is difficult to conclusively prove that no aircraft will deviate from the RF turn on an RNP Established procedure to a level that results in an overall risk of an accident less than a level of 10^{-9} per hour or approach, which is the limiting FAA SMS requirement related to a catastrophic event mitigating the risk with controller intervention and flight crew procedures.

Controllers will serve as a layer of defense in collision avoidance during non-normal events using surveillance-driven, voice-commanded maneuvering. To provide useful threat mitigation, controllers must recognize a potential conflict, generate, and then transmit an escape maneuver with sufficient time remaining for the flight crew response to be effective. The controller must have a designated procedure to direct aircraft in the escape maneuver.

There is then a minimum time for which intervention can be expected to be effective. Both the controller and flight crew response times must be considered, as well as the stochastic variance in these times.

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5 Recommended Testing

(a) Normal Deviations (and Nuisance Breakouts)

ILS and RNP operations dictate aircraft systems, airline and aircrew minimum performance, and ground systems that together satisfy published, proven performance criteria. Within these criteria, the allowed deviation of an aircraft's position relative to a ground referenced nominal path is bounded and defined by the procedure. In the case of RNP procedures, the required navigation performance is determined by the declaration of a specific RNP value. Some deviations from path, those smaller than the maximum allowable under the navigation specification, can be considered NORMAL performance, as the system still meets the minimum navigation requirement for the procedure.

These normal deviations must be considered in the design of operations that utilize parallel ILS and RNP instrument approaches: The spacing of procedures must be set such that the normal performance expected during the operations maintains separation between the aircraft given the expected normal variation in path conformance.

There are a number of reasons these deviations exist between the ground-referenced approach path and the actual aircraft track. With ILS, normal variability of the ground-referenced path vs. the localizer signal can be substantial, especially for aircraft that are far from the runway, are operating at an airport with an inactive ILS critical area, are following very large aircraft closely in-trail, etc. These anomalies may or may not be detected by the flight crew. In these cases, the ILS Localizer is actually displaced relative to the ground-referenced path. The mitigations for such problems, however, are already in place, and controllers and pilots are familiar with the phenomena and their appearance.

Radar anomalies can also be substantial sources of apparent surveillance track "wander" from a controller's perspective (see Williams). Extensive data collections were accomplished by the FAA to characterize ILS path-following and signal errors during simultaneous independent approaches. See [Thomas, J. and D. Timoteo, 1989; Thomas, J. et al., 1993]. Subsequent testing used the errors measured in these studies to characterize aircraft path-following performance as measured by radar surveillance. The introduction of ADS-B to supplant radar surveillance should mitigate many of these anomalies.

During the RNP Established procedure, the Controller will need to be trained to recognize such *expected* path deviations and differentiate them from non-normal behavior.

For controller intervention to be a useful safety net for non-normal performance, the normal tracking behavior of the aircraft to their procedures needs to be sufficiently concise such that deviations outside those allowed by the performance specification can be appropriately detected. If an aircraft deviation that satisfies its' required navigation allows it to wander too near the No Transgression Zone (NTZ) or deviate too far from centerline in dependent approaches, then a controller may feel obliged to intervene. They may instruct the aircraft to return to course or "breakout" an aircraft on the parallel runway by vectoring them from the approach to ensure separation and then have to re-sequence the aircraft for approach at a later time. This breakout, though deemed necessary by the controller, is referred to as a nuisance breakout, as the participating aircraft were actually within their required navigation envelope on approach which in turn has been proven to provide separation.

Specific recommendations are to:

1. Using the minimum performance specifications for ILS and RNP procedures, develop realistic parametric models of normal path-following deviations. RNP models should reflect performance required for a specific RNP value.
2. Validate the parametric models using data from actual or simulated aircraft at the various RNP level specified in the procedures in both straight and turning segments. Validation data could be collected from procedures to single runways with similar flight path.
3. Perform a statistical analysis to verify that normal divergences from independent approaches using a specific RNP value do not penetrate the NTZ during the turn-on the straight RNP segment.
    a. Determine appropriate RNP value by selecting the RNP value that is operationally feasible and demonstrates no inappropriate interaction between normal path conformances on the approaches.
    b. Perform a statistical analysis to estimate the potential for collision during normal operations using the pair of parametric models developed above and verify the operation meets the desired TLS.
4. Perform a statistical analysis to verify that normal divergences from dependent approaches using a specific RNP value do not interfere with ILS traffic during the turn-on the straight RNP segment.
    a. Determine appropriate RNP value by selecting the RNP value that is operationally feasible and demonstrates no inappropriate interaction between normal path conformances on the approaches. Since there will be at least 1.5 NM diagonal separation between aircraft on the other parallel approach, the primary consideration would be to avoid a wake turbulence encounter between the RNP-established aircraft and an aircraft on the other final approach.
    b. Perform a statistical analysis to estimate the potential for collision during normal operations using the pair of parametric models developed above and verify the operation meets the desired TLS.

5. Using the above parametric models and models of surveillance errors, develop realistic parametric models of ATC surveillance target deviations during normal operations.
6. Trajectories should be created using the RNP levels determined above and evaluated to ensure that the rate of unnecessary TCAS alerts is minimal.
7. Perform a HITL simulation to verify the absence of nuisance controller alerting during normal operations.

(b) Non-Normal Deviations

The TLS is influenced by normal behavior path deviations as well as any incident of non-normal deviation. Ultimately, the RNP Established operations concept must satisfy SMS safety criteria. The expected frequency and severity of non-normal deviations must be assessed to determine if the system is expected to meet the TLS in light of rare, non-normal events. Mitigation, through controller intervention in such events, may be required or desired to further minimize risk.

However, mitigations as applied to the traditional 30 degree blunder in ILS/ILS parallel procedures do not readily apply to the RNP established curved procedure. A suggested generalized approach is to analyze the *time* is available for detection, action, and recovery whenever intervention might be necessary, and ensure it is comparable to time allotted in today's parallel procedure mitigation.

To provide useful threat mitigation, controllers must recognize a potential conflict, generate, and then transmit flight crew instructions to either or both with sufficient time remaining for the flight crew response to be effective. There is then a minimum time for which intervention can be expected to be effective. An assumed deviation from any point on either approach can define a direction and distance, and therefore the time, to threaten traffic on the opposing approach given specific approach speeds. The time to a potential hazardous state (i.e. time to maneuver to re-establish separation) caused by a deviation at any point in the operation can be quantified based on procedure design and operational parameters (see: Tong et al, 2010).

The recommendation for testing of deviations during the RNP Established procedure is to determine the likely frequency of such non-normal deviations, and to determine that the procedure design and operational limits afford at least as much time as is budgeted for the "30 deg blunder" before a non-normal condition becomes an actual safety threat. Time budgets from today's parallel ILS and historical intervention data may be useful, though controller and pilot response to an operational intervention should be considered and re-evaluated if there is SME consensus that it may be different than today's parallel procedures.

Today's non-normal events relate to radar vectors and ILS navigation. Since blunders have been shown to be rare events, it is unlikely that sufficient data could be gathered to objectively characterize the frequency of blunders from RNP procedures. Accordingly, some consensus should be developed to characterize the frequency of deviation to be tested for the RNP Established procedure.

Specific recommendations are to:

1. Characterize the frequency and causes of non-normal deviations.
2. For deviation causes with potential sufficient frequency, develop scenarios where the RNP aircraft deviate from the RF turn onto final and continue across to adjacent final approach course stemming from causes in 1.
3. Perform real-time simulation testing of these scenarios that would measure the time required for the controller to detect the deviation and the effectivety of the mitigation.
4. Validate against existing time budgets for the controller to issue an instruction to the pilot and for the pilot to respond to the instruction.
    a. The real-time simulation testing would use the RNP level determined in the previous subsection and incorporate the operational considerations presented in this paper.
    b. The real-time simulation should also be used to provide an operational evaluation by appropriate FAA, union, and industry experts.
5. Perform a statistical analysis to estimate the potential for collision during all operations which may include non-normal deviations [at the above-determined rate] from parametric models of normal operations [developed in above normal analyses] to verify that the operation meets the overall desired TLS.

6 RNP Established Operational Implementation

If the real-and fast-time simulations indicate that the RNP Established procedure will meet appropriate safety standards, an implementation plan should be developed that phases in the procedure. Such a plan should include

1. Development of procedures at specific airport(s)
2. Flying the RNP Established procedure during low-volume periods in visual conditions
3. Flying the RNP Established procedure during low-volume periods in instrument conditions
4. Flying the RNP Established procedure during high-volume periods in instrument conditions.

7 PARC RNP Sub Action Team Members

Airlines

Sarah Dalton-Lead

Grady Boyce
Ed Geiger
Perry Clausen
Gary McMullin
Brian Will
Ron Renk

OEM's

Sheila Conway
Dave Jones
Jerry Davis

FAA

John Dutton
Steve Karnes
John Swigart
Mark Steinbecker
Dan Gutwein
David Dodd
Brian Lentini
James Alerdice
Chuck Chamberlain

Mitre

Vince Massimini
Dennis Zondervan
Sam Miller
Tyler Smith

ALPA

Marc Henegar

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