

March 28, 2010

Ms. Margaret Gilligan
Associate Administrator for Aviation Safety
Federal Aviation Administration
800 Independence Avenue
Washington, DC 20591

Dear Peggy:

In early 2009 the PARC was asked to form a team to gather information from aircraft manufacturers regarding their autoflight systems ILS capture designs for the purpose of evaluating the possibility of using RNP transitions (LNAV / VNAV) to position aircraft to capture an ILS final approach. The PARC formed a new action team to develop an engineering survey that would gather the necessary information from manufacturers, and to collect the results and relate the findings to procedure design constraints that would allow the operation to succeed over varying temperatures and conditions for all the aircraft surveyed.

The team contacted Boeing, Airbus, Embraer, Bombardier, Gulfstream and Cessna, receiving data from each by September of 2009. After evaluating all of the differing conditions for each of the aircraft, relative to procedure design constraints and operations, the conclusion is that it is possible to design and implement operations for an RNP transition to an ILS final approach.

The detailed recommendations are attached in two parts. The first part contains a detailed explanation of the findings and recommendations; the second part contains the de-identified details of the OEM responses to the questionnaire. PARC has retained a history of meetings and backup substantiation of conclusions on the PARC website.

These recommendations represent a significant milestone in implementation of a Performance based NAS. The ability to implement operations with RNP transitions to an ILS final approach is another step in improved safety in operations, as well as enabling other NextGen benefits such as improved airspace management and leveraging existing aircraft capability. The ability to proceed in achieving these results is due to the efforts of Mike Cramer and the RNP to ILS Action Team.

PARC appreciates your continued support of our activities and invites you to join us in a discussion of these recommendations at your convenience. Please call me if you have any questions or would like to set up a discussion.

Sincerely,



Dave Nakamura
Chairman, PARC

cc: J. Hickey
J. McGraw
J. McCarthy
M. Cramer

RNP to ILS Action Team Report

Introduction

PARC was asked by FAA to form an action team to gather and interpret the avionics equipment aspects of flying an RNP (or RNAV) path to intercept an ILS final approach, to identify what constraints the avionics might place on the procedure design. All present day equipment was to be considered so that the action team could assess the operation from an avionics perspective to produce a design (constraints) that would assure localizer and glideslope capture could occur, whether manually or automatically, from the RNP part of the procedure.

This paper summarizes the team tasking, then follows with the findings and recommendations. The final part of the paper is a recap of the questionnaires that were sent to the OEMs and vendors to obtain the data from which to produce the findings. The responses will all be available to the whole team once they are de-identified.

Tasking

The team terms of reference stated the following as objectives and considerations:

The ability to use the methods available for RNP AR procedures to connect to an ILS (or LPV or GLS) to the landing runway could be useful in solving complex approach problems that could benefit from combining the linear containment and the obstacle avoidance maneuvering (RF) of RNP with the lower DA of ILS. There may be operational and procedure design limitations required to ensure successful automatic or crew managed transition from RNP to ILS within current aircraft architectures and autopilot designs depending upon the ILS capture criteria used and the method by which the FMS RNP navigation is taken out of the loop. This work is intended to obtain an understanding of what those operational and procedures design limitations might be across the fleet of aircraft that can do both types of operation.

The scope of this activity will span all aircraft and avionics combinations currently in service that can perform both RNP AR and ILS operations (any category).

Maintain a focused scope involving only current generation aircraft and their avionics configurations and operation to enable near term implementation where it would be beneficial, while capturing improvements that could be made to avionics in the future.

Findings & Recommendations

Initial review by a smaller team of the Action Team and subsequent analysis seems to indicate that it is possible to design an RNP to ILS path that will allow each of the OEMs aircraft to capture the ILS from the RNP path. What follows in this section is a review of the design constraints that will apply to building an appropriate path on the RNP part of the descent to compensate for up to 95% navigation errors and non-standard temperature effects on the VNAV path. There is also a spreadsheet that performs many of the necessary computations, at

least enough of them to have a reasonable assurance that the recommended practices will form a good basis for FAA to further define the procedure design criteria.

To a large degree, the lateral and vertical captures can be considered independently, with the exception that some of the systems will not capture glideslope prior to localizer capture, so the paths will need to be designed such that the lateral capture criteria are generally satisfied first. The analysis of the various systems shows that a path can be designed that will place each system in a configuration to achieve capture at some point along the path, depending upon the individual system's characteristics. Temperature is the most constraining element, since the baro-VNAV path of the RNP transition varies widely with ISA deviation.

The basic lateral path design is an RF turn to align the RNP path with the ILS final course, starting from as much as 180 degrees from the final course. In this case, the minimum distance from the runway where the lateral intercept can be designed can be calculated from the localizer width and the RNP value assuming that the maximum lateral error could be $1 \times \text{RNP}$ (95% navigation error). It is $1 \times \text{RNP}$ further from the runway than the point at which the localizer half-width is $1 \times \text{RNP}$. Variations of the lateral path could be defined by introducing a straight segment to intercept the localizer from the RF; the RF could be terminated at any point after its course is within 45 degrees of the final approach course.

Lateral Path Design Conditions

To assure all systems will be in a position to complete a lateral capture, the path must ultimately reach a point where three conditions are met:

1. RNP course is less than 45 degrees from the final approach course, AND
2. Localizer deviation is less than 2 dots (full scale) AND
3. Deviation is decreasing (converging on the localizer null)

Given these three avionics driven conditions, assuring that the true aircraft path takes the aircraft into compliance requires two further conditions,

1. The minimum distance from the design path intercept to the runway as a function of RNP and localizer scaling; see Figure 1 & Figure 2 below.
 - a. $\text{Min distance} = \text{RNP} * (1 + 1/\tan \theta) + D_{\text{VERT}}$ where θ = localizer half angle and D_{VERT} is defined by vertical constraint item 3a. For anchoring at ILS TCH, $D_{\text{VERT}} = 0$.
 - b. Localizer half angle is derived from the distance from the antenna to the threshold and a threshold half width of 350 feet
2. The minimum radius of the RF turn as a function of RNP, see Figure 3 & Figure 4 below
 - a. $\text{RF} > 3.414 * (\text{RNP} + \text{Margin})$

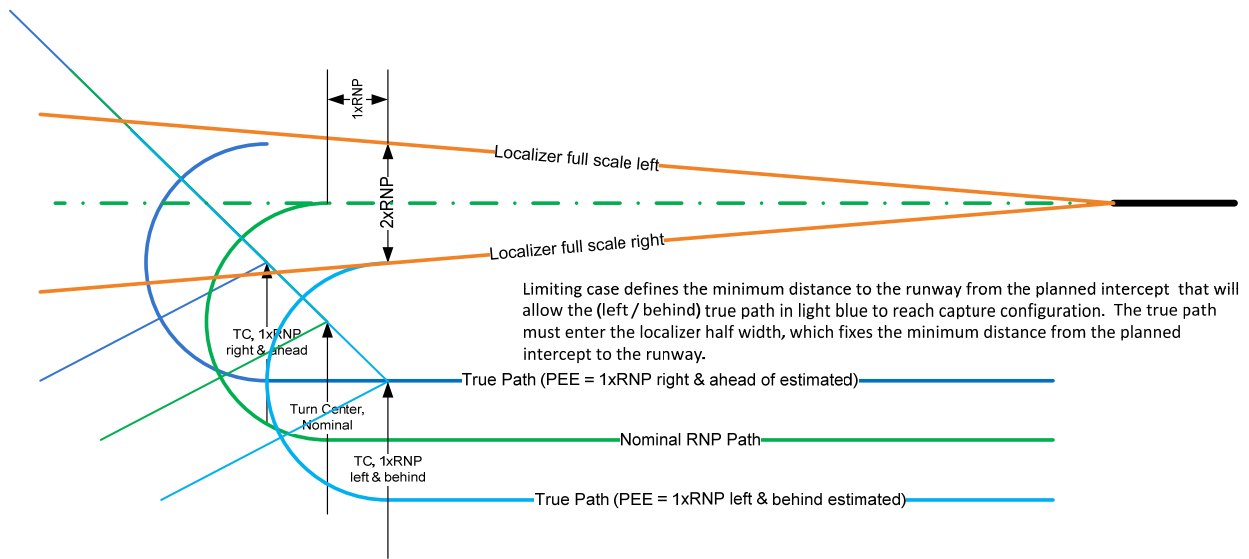


Figure 1 Geometry of limiting case for minimum intercept distance to runway

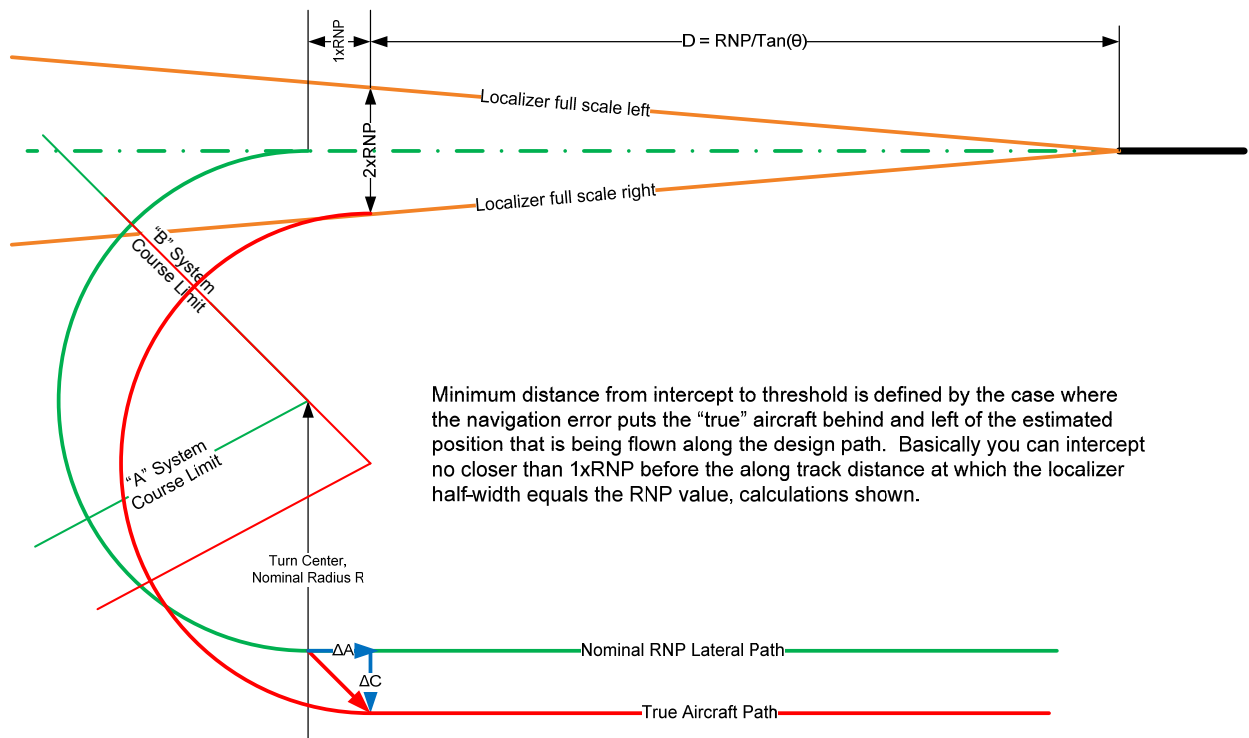


Figure 2 Minimum Distance Calculations Defined

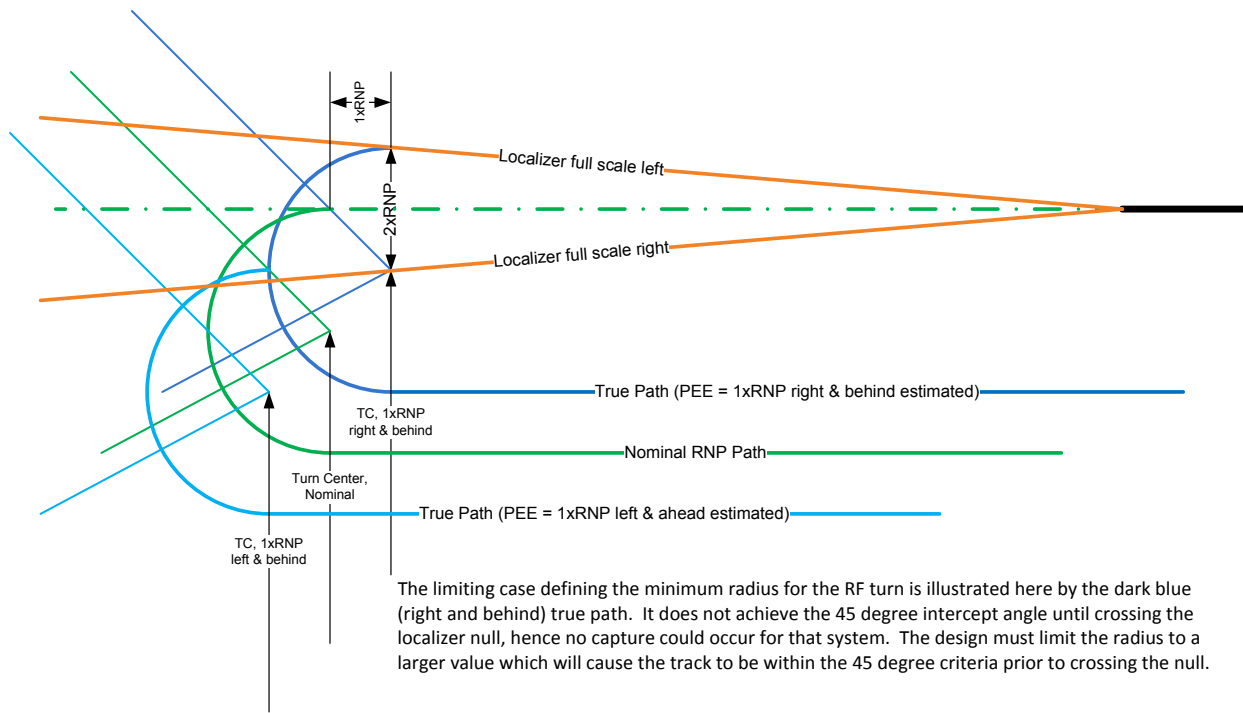


Figure 3 Limiting Cases Defining Minimum RF Radius

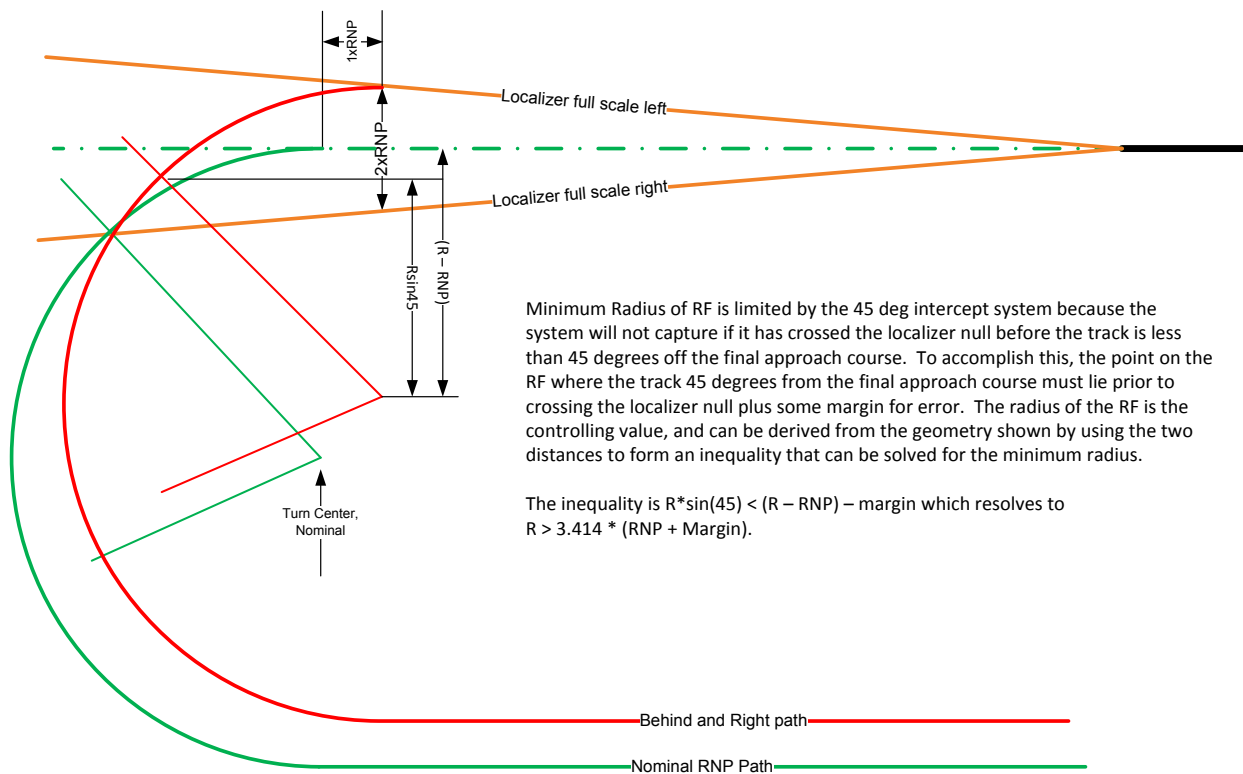


Figure 4 Minimum RF Radius Calculations Defined

In summary, there are five conditions that will assure lateral capture given limiting conditions derived from navigation error (95%) assumed to occur in a worst configuration for each. Figure 5 below shows the relationship of the minimum RF radius and the closest lateral intercept distance from threshold to the RNP value used for the procedure for a 10,000 foot distance from localizer antenna to the threshold (which gives a 2 degree splay to the localizer full scale). This data does not apply to other localizer to threshold distances, but is used here to illustrate the relationship of RNP to the minimum distances.

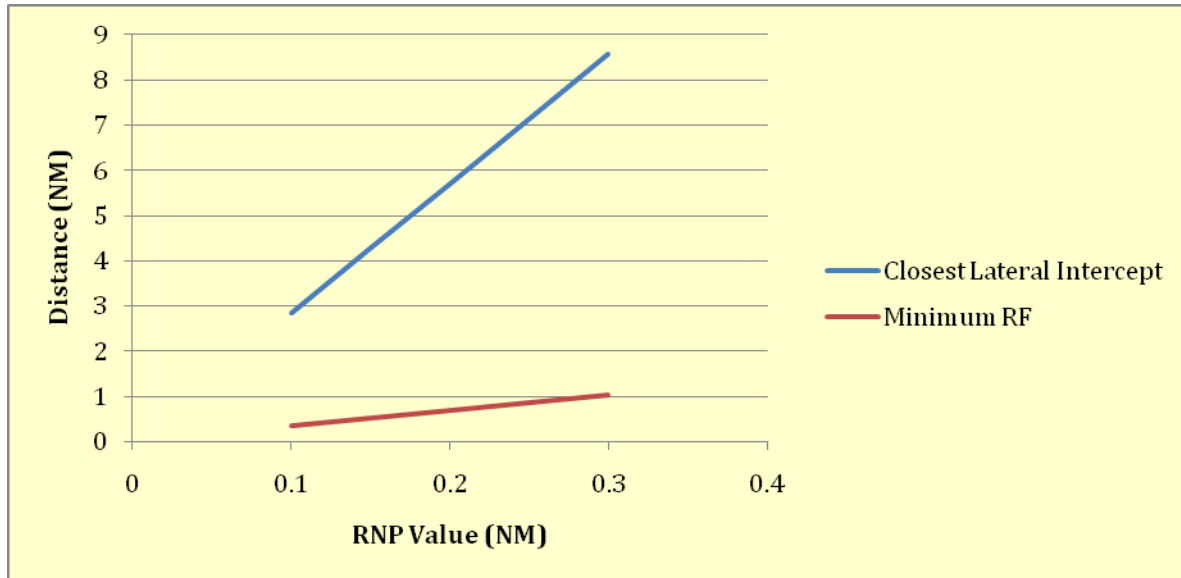


Figure 5 Minimum Lateral Design Values

Vertical Path Design Conditions

To assure all systems will be in a position to complete a glideslope capture, the path must ultimately reach a point where four conditions are met:

- 1) The aircraft (lateral path) track must be within 80 degrees of the approach course AND
- 2) The aircraft (lateral path) must be within the coverage width of the glideslope (8 degrees of localizer centerline) AND
- 3) The glideslope deviation must be within 2 dots converging to 0.5 dot AND
 - a. Some systems will capture within 2 dots
 - b. Some will not capture until 0.5 dots, hence the converging requirement
- 4) Glideslope deviation must be decreasing (converging on the null)

Given these four system conditions, assuring that the true aircraft path takes the aircraft into compliance defines one further condition,

- 1) The baro-VNAV path must be designed such that the aircraft actual path on the hottest day the procedure is to be flown must intercept the glideslope from below with sufficient distance to its crossing through the null that capture can occur.

The figure below notionally shows the conditions that must be met,

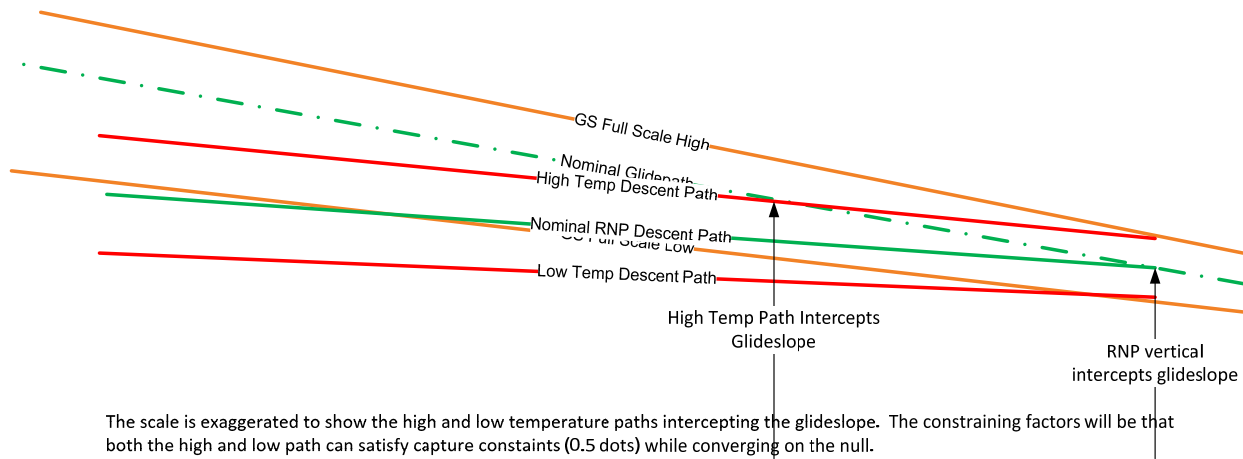


Figure 6 Vertical Capture Geometry

Preliminary computations seem to show that three constraining design conditions will allow one to meet the capture criteria and meet the additional constraints of the high and low temperature paths shown above in Figure 6. These are:

- 1) The RNP vertical path should be anchored at the runway threshold crossing height (if necessary to anchor it higher, see 3 below) AND
- 2) The baro-VNAV path descent angle (for a 3 degree glideslope) should be 2.5 degrees for an RNP of 0.3 NM and a maximum ISA deviation of plus 40°C.
- 3) If the RNP vertical path is anchored to an elevation higher than the ILS threshold crossing height, the minimum distance from the threshold that the lateral path can join the localizer centerline must be moved out a distance equal to the distance from the threshold to the point where the RNP vertical path intersects the glideslope.

a. Additional distance $D = (RNP_{TCH} - GS_{TCH}) / (\tan\theta_{GS} - \tan\theta_{RNP})$

The relationship of the maximum VNAV glidepath angle (GPA) to the non-standard temperature is also a function of RNP value for the procedure (since that controls the closest point to the threshold that the lateral intercept can be placed). The relationship is illustrated below in Figure 7 for a standard 3 degree glideslope angle and three common RNP values.

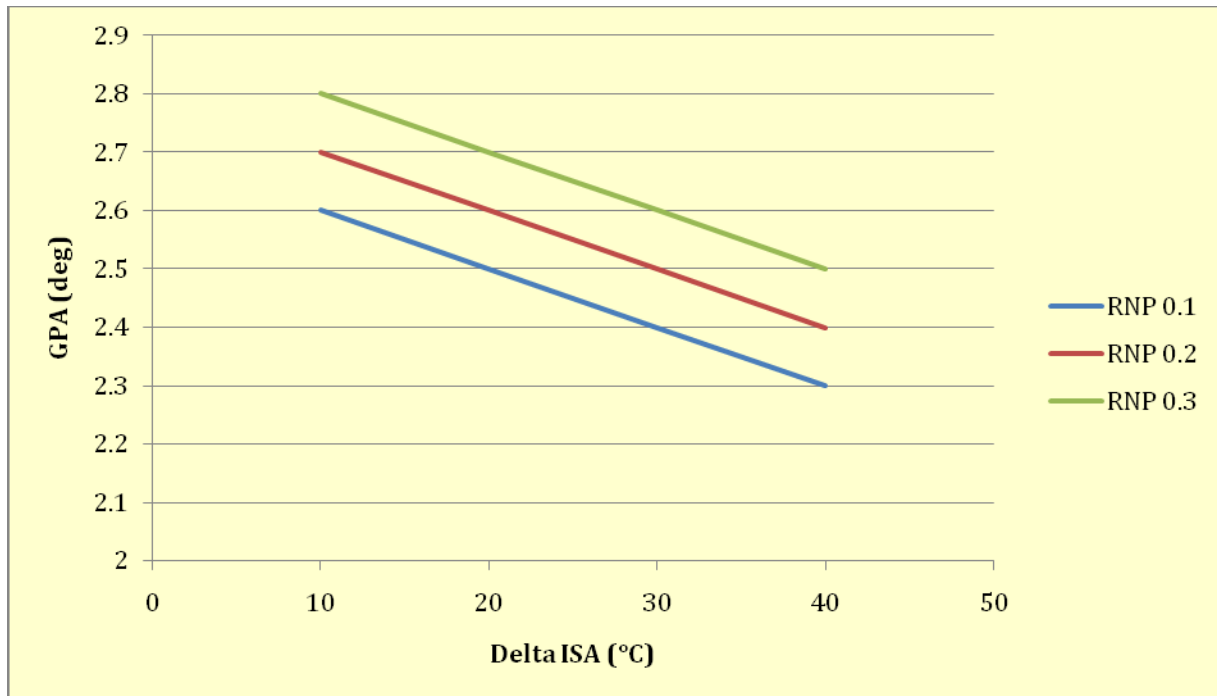


Figure 7 Maximum VNAV GPA vs Δ ISA

Post-Capture Maneuvers

Responses from the two major OEMs have been received and are being reviewed.

Methodology

The team decided that to gather the information necessary, a request for information needed to go out to all manufacturers of currently flying aircraft. A very structured set of questions was devised in early 2009, and sent to Airbus, Boeing, Embraer, Bombardier, Gulfstream, Cessna, Honeywell and Rockwell Collins. The latter two avionics manufacturers helped cover the Gulfstream, Cessna and Bombardier aircraft avionics.

Responses were received from all by late summer, and initial work was begun to compare the systems and derive any limiting factors that would affect procedure design. During the analysis, it was found that further questions needed to be asked, so a second questionnaire was devised and sent to all in October, with responses received later in the fall. A preliminary procedure design was built that would allow all aircraft to effect a capture.

Initial Questionnaire (Completed by all manufacturers by date of this report)

The questions for which we have complete answers from all manufacturers were the following:

1. Aircraft & avionics identification
 - a. Aircraft type, e.g. A319, B737-600

- b. Avionics identification – relevant software/hardware part numbers of flight control computer, flight management computer, mode control panel, etc.
- 2. Avionics ILS (LOC, G/S) capture criteria: what are the design parameters?
 - a. Preconditions to capture (vertical and lateral)
 - b. Avionics internal checks that enable (or prevent) capture – sequence and timing
 - c. Lateral proximity to final course (track and lateral offset left or right for capture)
 - d. Vertical proximity to glideslope (angle, proximity high or low for capture)
 - e. LNAV / VNAV disengagement criteria when ILS capture occurs
 - f. Lateral steering maneuver response to LOC capture
 - g. Vertical steering maneuver response to G/S capture
 - h. Flight control computer limitations on transition to multi-channel for autoland
 - i. Other?
- 3. Crew / Pilot Preparation for ILS approach capture: what is required?
 - a. Sequence of required actions to enable avionics to capture ILS
 - b. Timing or location (position/altitude) constraints on actions (a) enabling capture
 - c. Differences between Category I, II and III approach operations for crew enabling the avionics properly
 - d. Operationally, should there be a “capture no later than point” which defines a crew initiated go-around if LOC or G/S is not captured?
 - e. Other?
- 4. Path Constraints and Considerations: what might be done?
 - a. Non Standard temperatures result in aircraft being off the planned VNAV path on the RNP portion of the procedure, what might be done to facilitate capture from below or above, or can we design to prevent this?
 - b. At what latest (nearest the runway threshold) point must the lateral paths become coincident?
 - c. Other?

Follow-up Questionnaire (Open item, to be used for operational considerations)

In addition, after the analysis of responses to this first set of questions, a second set was distributed to further understand the potential aircraft maneuvers following localizer and glideslope capture while flying a curved path. The nominal path design was provided and the scenario as the path is expected to be flown was also provided.

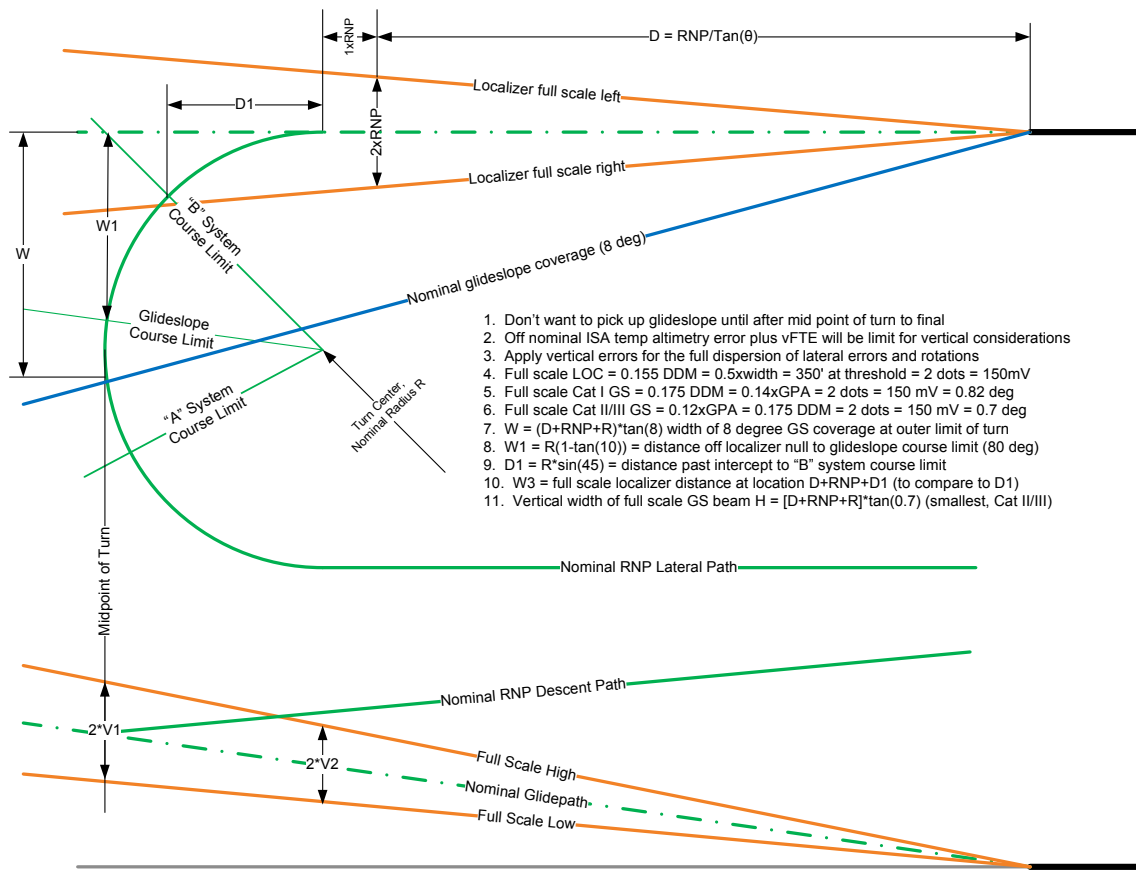


Figure 8 Nominal Path and Constraint diagram

Operation Description

The aircraft will be transiting from right to left on the "nominal" path line, vertical and lateral. After crossing each of the "course limit" lines and coverage lines, captures will be possible, and we are trying to understand what maneuvering might occur once a capture is possible and the FMS is disconnected so the autopilot or FCC is doing the steering in LOC or GS modes. It is important for us to understand more detail of how the steering is accomplished once a capture (LOC or GS) happens, which will be the focus of the questions following a more detailed explanation of how we see the initial conditions, below, recognizing that aircraft will satisfy their "conditions" for capture at different points on the path based on the limits depicted in the path diagram above.

Conditions:

1. Aircraft established on a minimum radius RF leg (approximately 2 NM radius) that intercepts the localizer centerline no nearer than 3 NM from threshold (955 feet HAT)
2. RF requires a nominal 25 degree bank at Category approach speed (C=140, D=165 KT) and
3. Path is descending at 3 degrees; then
4. The aircraft track, while converging on the final approach course because of being on the RF leg, meets the track capture limits for both localizer and glideslope; then

5. The glideslope deviation capture limit is satisfied so capture should occur; then
6. The localizer deviation capture limit is satisfied so capture should occur.

Questions:

1. If glideslope limits are satisfied before localizer limits are satisfied, will glideslope capture occur before localizer?
 - a. Does the glideslope deviation rate of change have to be negative to allow capture? That is, does the deviation need to be decreasing?
 - b. When capture occurs, how are deviation and deviation rate used to modify pitch and thrust commands to close on and follow the glideslope?
 - c. Explain the effect of changing scaling as a function of distance from threshold, how is that effect handled?
 - d. What effect will the intercept location relative to the runway threshold have on the above responses?
2. Repeat preceding questions for localizer capture.
 - a. Given that the aircraft is established on the RF with a bank angle that is allowing the track to converge on the approach course, is it possible that the bank will be reduced when lateral capture occurs? How much and at what rate?

The complete responses to all of the first and second questionnaire items have been compiled into a matrix in full detail, available for review once they are de-identified (they are not at this time) should the PARC or FAA require the detailed data once the findings are reviewed.