RNP 10 Through Data Collection

Updated:
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Figures and Tables

CHAPTER 1. GENERAL

1.1 Purpose

This booklet provides guidance previously available in Order 8400.12C (Cancelled) and provides detailed instructions on data collection and statistical procedures to determine whether aircraft should be approved for flight in RNP 10 airspace. Guidance is provided for two types of data collection and analysis: sequential and periodic data collection methods. For the complete RNP 10 authorization guidance, refer to AC 90-105( ).

1.2 Specific Combination of Aircraft and Navigation System

RNP 10 approvals will be issued for specific combinations of aircraft and navigation systems. If the navigation system, which is a candidate for RNP 10 approval, is an inertial navigation system (INS), inertial reference system (IRS), or any other system whose accuracy decreases with increasing flight time, the approval must be limited to the number of hours during which the aircraft can be expected to satisfy both the lateral ("cross-track") and longitudinal ("along-track") accuracy criteria of RNP 10.

1.3 Applicability

This guidance applies to all operators conducting operations under 14 CFR parts 91, 121, 125, and 135.

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CHAPTER 2. SEQUENTIAL METHOD

2.1 Introduction

This method allows the operator to collect data and plot it against the pass-fail graphs to determine if the operator's system will meet RNP 10 requirements for the length of time needed by the operator.

2.2 Statistical Test

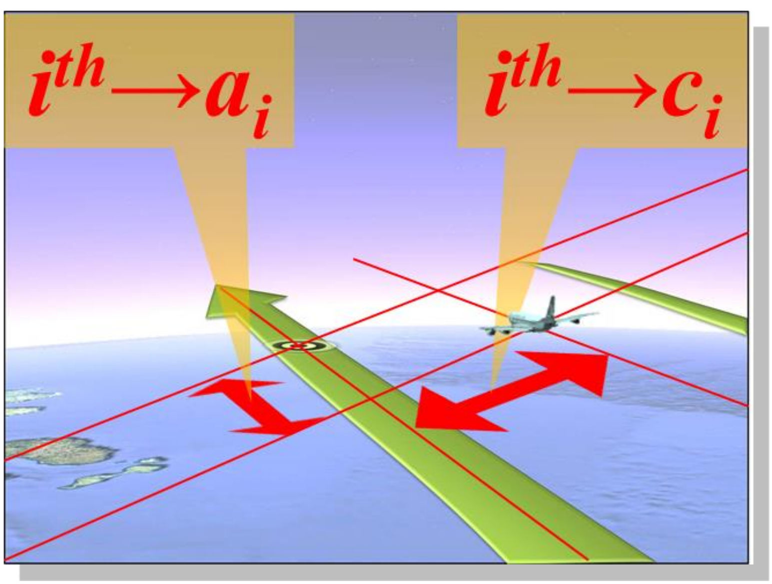
Statistical tests use data gathered from repeated flights. Invoking standard statistical terminology, this guidance refers to each such flight as an "independent trial." In each trial, the operator measures two errors:

1. The longitudinal position-determination error of the candidate navigation system, and
2. The lateral deviation of the candidate aircraft from its planned route centerline.

2.3 Longitudinal and Lateral Position-Determination Error

The longitudinal position-determination error measured in the "ith" trial is called "ai"; the lateral deviation measured in the "ith" trial is called ci. (See figure 1)

Figure 1: Longitudinal and Lateral Position-Determination Error



2.3.1 <u>Gathering Data</u>

In order for the statistical test to be valid, the data gathered in each trial must be independent of those gathered in any other trial. In other words, the outcome of each trial must not influence the outcome of any subsequent trial. Data is typically gathered after an aircraft has flown for at least as long as the time for which operational approval is being requested, while being guided solely by the navigation system, which is a candidate for RNP 10 approval.

2.4 Data Collection Requirements

An operator requesting RNP 10 approval for a candidate aircraft and navigation system must inform the FAA of the flights during which it plans to collect error data. The operator should collect data on every eligible flight until the statistical procedure described in this booklet indicates that the data collection should cease. The operator must use all valid data and, in particular, may not ignore data that shows large errors while submitting only data that shows small errors.

CHAPTER 3. DATA COLLECTION GUIDELINES

3.1 Time of Collection

Operators using the methods described in this booklet collect position estimates and use those estimates to compute the lateral and longitudinal errors of their aircraft. If a combination of aircraft and navigation system is a candidate for RNP 10 approval for a stated number of hours h, the data must be collected at least h hours after that navigation system was last updated or initialized. Furthermore, the data must be collected after the aircraft has been guided solely by that navigation system for a period long enough to eliminate the effects of prior guidance by any other navigation system that the aircraft may have used during its flight.

3.2 Position Estimates

In order to determine the lateral and longitudinal error data, the operator must simultaneously obtain position estimates from the navigation system, which is a candidate for RNP 10 approval (the candidate system), and a reference system, which must be highly accurate in the area where the position is estimated. (The estimate from the reference system is taken to represent the aircraft's actual position.)

3.2.1 Measuring Position

The candidate system position and the reference system position must be measured simultaneously, at a time when the aircraft has been flying along a straight segment of its planned route for several minutes, and is expected to continue flying along that segment for several more minutes.

3.2.2 Source of Measurement

The operator must ensure that the aircraft's position at the time of the measurement is due to guidance derived solely from the candidate system. In particular, the operator must ensure that no other navigation system (especially the reference system) contributed, to any significant extent, to the aircraft's position at the time of the measurement.

3.3 Accuracy

The operator is responsible for establishing that reference system positions are accurate. The operator may wish to consider the following in selecting reference systems:

- Distance measuring equipment (DME)/DME positions taken within 200 nautical miles (NM) of both DME stations, derived automatically and displayed on systems such as flight management computers (FMC),
- Global Positioning System (GPS)-derived positions, and
- Very high frequency (VHF) omnirange station (VOR)/DME positions taken within 25 NM of the Navigational Aid (NAVAID).

Note: Operators considering the use of these systems are reminded that many of them are installed so that their outputs are automatically used to guide the aircraft. If any system other than the candidate system has significant influence on the aircraft's position at the time when position estimates are obtained, the test of the candidate system will not be valid.

3.4 Coordinate System

The positions simultaneously reported by the candidate system and the reference system must both be expressed (or re-expressed) in terms of the same coordinate system.

3.4.1 Longitudinal Error

The longitudinal error *ai* is the distance between the position reported by the reference system and the position reported by the candidate system, measured along a line parallel to the planned route of flight. Thus, if the two reported positions are connected by a vector, and the vector is resolved into a component parallel to the route and a component perpendicular to the route, *ai* is the magnitude of the component parallel to the route.

3.4.2 Lateral Error

The lateral deviation *ci* is the distance between the planned route of flight and the position reported by the reference system. Note that the position reported by the candidate system has no role in determining the value of *ci*.

3.4.3 Longitudinal and Lateral Distances

The distances *ai* and *ci* must be absolute distances expressed in NM (i.e., expressed as non-negative numbers). In particular, longitudinal errors in opposite directions do not offset each other, nor do lateral deviations to the left and right offset each other.

3.5 Example

Suppose, for example, that an operator wishes to obtain RNP 10 approval of an airplane equipped with an INS, and that the RNP 10 time limit being sought for the INS is 6 hours. Suppose also that the airplane can very accurately determine its position when it is in airspace with multiple DME coverage and that it usually enters a large block of such airspace 5½ hours after the last use of another navigation system or signal to adjust its INS output.

3.5.1 On each occasion when:

1. The airplane is flying in an area of multiple DME coverage;
2. At least 6 hours have passed since the last adjustment of INS output; and
3. The airplane has been flying straight for several minutes, and is expected to continue flying straight for several more minutes,

3.6 The crew records:

1. The time,
2. The desired track (or just the “from” and “to” waypoints),
3. The position reported by the INS, and
4. The position reported by the multiple-DME system.

Note: The operator later computes the longitudinal error *ai* and the lateral deviation *ci*.

3.7 Non-Technical Summary

The following is a non-technical summary of the steps used in collecting, plotting, and analyzing data collected for the purpose of using the pass-fail graphs in this booklet. The data collected indicates the difference between the aircraft’s navigation system and a highly accurate reference system. The position determined from the reference system is the aircraft’s actual position. This data should be taken when first leaving oceanic and remote continental navigation at the designation end of the flight.

3.8 Collect Data

The operator collects the following independent data on each eligible flight:

1. On the desired flightpath, the last waypoint (last waypoint passed) and the “to” waypoint (these points should be taken from the flight plan),
2. The reference system (e.g., DME/DME) computed aircraft position, and
3. Aircraft guidance system (e.g., INS) computed aircraft position for each system.

Note: The subparagraph 3.8 (2) and (3) measurements should be taken simultaneously.

3.9 Collection Time

The data must be taken after the candidate navigation system has been operating without any external update for a time at least as long as the time limit being requested.

3.10 Analyze Data

The data gathered in subparagraph 3.8 is now used to calculate:

1. The cross-track error (XTK) (lateral deviation *ci*), and
2. The track error (longitudinal deviation *ai*).

Note: The element *ai* in subparagraph 3.10 (2) is considered to represent along-track error.

3.11 Cross Track (XTK) (*ci*)

Calculate the perpendicular distance from the reference-system-computed aircraft position to the desired flightpath. The desired flightpath is a great circle line between the last waypoint and the “to” waypoint.

3.12 Along-Track Error (*ai*)

Calculate the distance between the reference-system-computed aircraft position and the guidance-system (INS, etc.)-computed aircraft position along a line parallel to the desired flightpath.

3.13 Cross-Track Pass/Fail

Following the flights, errors are summed. For example, if the error was 2 NM on the first flight and 3 NM on the second flight, then the cumulative error would equal 5 NM.

3.13.1 Lateral Conformance

The cumulative error is the value of the ordinate (y coordinate in a Cartesian coordinate system) and the number of trials is the value of the abscissa (x coordinate in a Cartesian coordinate system). The intersection of these two is then plotted on Figure 2, Acceptance, Rejection, and Continuation Regions for Sequential Test of Lateral Conformance.

3.13.2 Plotting Cumulative Errors for Cross-Track

The cross-track RNP 10 requirements are passed when the plots of the cumulative errors fall below the lower pass line or fail if they go above the upper fail line.

3.14 Along-Track Pass/Fail

Following each flight, the errors are squared; following the flights, the errors squared are summed. For example, if the error was 2 NM on the first flight and 3 NM on the second flight, then the cumulative squared errors would be calculated as 4+9=13.

3.14.1 Longitudinal Accuracy

The cumulative error squared is the value of the ordinate (y coordinate in a Cartesian coordinate system) and the number of trials is the value of the abscissa (x coordinate in a Cartesian coordinate system). The intersection of these two values is then plotted on Figure 2, Acceptance, Rejection, and Continuation Regions for Sequential Test of Longitudinal Accuracy.

3.14.2 Plotting Cumulative Errors for Along-Track

The along-track RNP 10 requirements are passed when the plots of the cumulative errors squared fall below the lower pass line or fail if they pass above the upper fail line.

3.15 Planned Route System

3. Operators planning to use their aircraft in a particular route system (e.g., NOPAC, CEP) should gather error data from flights through that system. If operations are planned for an area other than the one in which data is collected, the operator should show that navigational performance will not be degraded there.

3.16 Standard Documentation Form

The operator should develop a standard form on which to document each flight. It should include:

1. Date,
2. Departure airport,
3. Destination airport.
4. Aircraft type, series, and registration number,
5. Make and model of the candidate navigation system,
6. Type of reference system used (e.g., VOR/DME, DME/DME),
7. Time at which the candidate system is updated while en route,
8. Times (if any) at which the candidate system is updated while en route,
9. Time at which positions are recorded from the candidate system and the reference system,
10. Reference system position coordinates,
11. Candidate system position coordinates, and
12. Desired track or waypoints passed immediately before and after the recorded positions.

3.17 Compute Lateral Deviation and Longitudinal Error

After the flight, the operator computes the lateral deviation *ci* and the longitudinal error *ai*, as indicated above

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CHAPTER 4. STATISTICAL PROCEDURES

4.1 Background

Sequential sampling procedures are used to determine whether a candidate aircraft and navigation system should receive RNP 10 approval. After each trial, the operator re-computes certain statistics and compares them to numbers indicated below. The comparison will yield one of three possible results:

1. The candidate aircraft and navigation system satisfy the RNP 10 performance requirements, and the statistical test is terminated;
2. The candidate aircraft and navigation system do not satisfy the RNP 10 performance requirements, and the statistical test is terminated; or
3. The operator needs to perform another trial (i.e., gather more data) and continue the statistical test, as it cannot yet reach a decision with the required level of confidence.

4.2 Number of Trials

A sequential sampling procedure typically requires fewer trials than does a statistical test that has a fixed number of trials and has the same probability of making the correct decision. In general, the better an aircraft navigates, the fewer trials it will need to pass the test (i.e., to demonstrate RNP 10 compliance). However, for the FAA to have sufficiently high confidence in the test results, even an aircraft that navigates perfectly will need to perform at least 13 trials in order to demonstrate that it meets the RNP 10 lateral containment criterion, and at least 19 trials to demonstrate that it meets the RNP 10 longitudinal accuracy criterion. An aircraft that navigates poorly will need relatively few trials before failing the test. The test has been designed so that the average number of trials needed for it to reach a decision is approximately 100.

4.3 Mathematical or Graph Method

To establish whether or not the navigation system meets the RNP 10 lateral containment criterion, the operator may use the mathematical process described in this paragraph, or use the graph shown in Figure 2 and described in subparagraph 4.5.

4.4 Mathematical Process

After conducting at least 13 trials, the operator should add together all of the lateral deviations obtained up to that point. Suppose, in particular, that n trials have been conducted.

4.4.1 Sum of Lateral Deviations does not exceed $2.968n - 37.853$

If the sum of lateral deviations does not exceed $2.968n - 37.853$, the candidate aircraft and navigation system have demonstrated compliance with the RNP 10 lateral containment criterion, and the operator should stop computing lateral deviation data.

4.4.2 Sum of the Lateral Deviations equals or exceeds 2.968n + 37.853

If the sum of the lateral deviations equals or exceeds 2.968n+37.853, the candidate aircraft and navigation system have demonstrated that they do not meet the RNP 10 lateral containment criterion, and the operator should stop computing lateral deviation data.

4.4.3 Sum of the Lateral Deviations is between 2.968n - 37.853 and 2.968n + 37.853

If the sum of the lateral deviations is between 2.968n - 37.853 and 2.968n + 37.853, the test cannot yet yield a decision. The operator must perform another trial to obtain an additional lateral deviation. This new lateral deviation is added to the sum obtained previously, and the new sum is then compared to 2.968(n + 1) - 37.853 and 2.968(n + 1)+37.853.

4.4.4 Lateral Deviations

In other words, let $S_{c,n}=c_1+c_2+...+c_n$ be the sum of (the absolute values of) the lateral deviations obtained in the first n trials.

1. If $S_{c,n} \leq 2.968n-37.853$, the aircraft and its navigation system pass the lateral conformance test.
2. If $S_{c,n} \geq 2.968n+37.853$, the aircraft and its navigation system fail the lateral conformance test.
3. If $2.968n - 37.853 < S_{c,n} < 2.968n + 37.853$, the operator must:
   - Perform another trial to obtain c_n+1,
   - Compute $S_{c,n}$ +1=c1 + c2 +...+ c_n + c_n +1(=$S_{c,n}$ + c_n +1),
   - Compare $S_{c,n}$ + 1 to 2.968(n + 1) - 37.853 and to 2.968(n + 1) + 37.853, and
   - Determine whether the candidate aircraft and navigation system pass the test or fail the test, or whether another trial (n + 2) is needed.

4.5 Graph Method

Figure 2 illustrates these rules for the lateral conformance test.

4.5.1 Plotting Points

The operator may wish to plot points on Figure 2 as lateral deviation data is collected. The abscissa (horizontal component) of each plotted point is n, the number of trials completed. The ordinate (vertical component) of each point is $S_{c,n}$, the sum of the (absolute values of the) lateral deviations observed in the n trials.

4.5.2 Determining RNP Lateral Containment Criterion

The test ends as soon as a point falls into the lower right region or the upper left region of the graph. If a point is plotted in the lower right region, the candidate aircraft and navigation system have shown that they satisfy the RNP 10 lateral containment criterion. If a point is plotted in the upper left region, the candidate aircraft and navigation system have demonstrated that they do not meet the criterion. Whenever a point is plotted in the middle region, the operator needs to accumulate more data.

4.5.3 After 200 Trials

In the event that the tests of $S_{c,n}$ do not yield a decision on the aircraft's lateral performance after 200 trials, the operator should perform the following computations:

1. Compute the quantity: $D_1 = c_1^2 + c_2^2 + \ldots + c_{200}^2$.
2. Compute the quantity: $D_2 = \frac{S_{c,200}^2}{200} = \frac{(c_1 + c_2 + \ldots + c_{200})^2}{200}$
3. Compute the quantity: $D_c^2 = \frac{D_1 - D_2}{200}$
4. If D^2_c does not exceed 18.649, the aircraft and navigation system satisfy the RNP 10 lateral containment criterion. If D^2_c does exceed 18.649, the aircraft and navigation system do not meet the criterion and do not qualify for RNP 10 approval.

4.6 Test of Longitudinal Accuracy

To establish whether or not the navigation system can meet the RNP 10 longitudinal accuracy criterion, the operator may use the mathematical process described in subparagraphs 4.4.1 and 4.4.2, or use the graph provided in Figure 3, as described in subparagraph 4.6.3.

4.6.1 After Trials

After conducting at least 19 trials, the operator should add together the squares of all the longitudinal errors obtained up to that point. Suppose, for example, that n trials have been conducted.

4.6.1.1 If the sum of the squares of the longitudinal errors does not exceed 22.018n-397.667, the aircraft and navigation system have demonstrated compliance with the RNP 10 longitudinal accuracy requirement, and the operator should stop computing longitudinal error data.

4.6.1.2 If the sum of the squares of the longitudinal errors exceeds 22.018n+397.667, the aircraft and navigation system have demonstrated that they do not meet the RNP 10 longitudinal accuracy requirement, and the operator should stop computing longitudinal error data.

4.6.1.3 If the sum of the squares of the longitudinal errors is between 22.018n - 397.667 and 22.018n + 397.667, the test cannot yield a decision. The operator must perform another trial to obtain an additional longitudinal error. The square of this new longitudinal error is added to the sum obtained previously, and the new sum is then compared to 22.018(n+1) - 397.667 and to 22.018(n+1) + 397.667.

4.6.2 Longitudinal Errors

4.6.2.1 In other words, let $S_{a,n}=a_1^2+ a_2^2+\ldots+ a_n^2$ be the sum of the squares of the longitudinal errors obtained in the first n trials.

4.6.2.2 If $S_{a,n} \leq 22.018n-397.667$, the aircraft and its navigation system pass the longitudinal accuracy test.

4.6.2.3 If $S_{a,n} \geq 22.018n+397.667$, the aircraft and its navigation system fail the longitudinal accuracy test.

4.6.2.4 If $22.018n-397.667< S_{a,n} <22.018n+397.667$, the operator must:

- Perform another trial to obtain another longitudinal error a_n+1,
- Compute $S_{a,n+1} = a_1^2+ a_2^2+\ldots+ a^2_{n+1}$ $(=S_{a,n} + a^2_{n+1})$,
- Compare $S_{a,n+1}$ to 22.018(n + 1)-397.667 and to 22.018(n + 1) + 397.667; and
- Determine whether the candidate aircraft and navigation system pass the test or fail the test, or whether another trial (n + 2) is needed.

4.6.3 Sequential Test of Longitudinal Accuracy

Figure 3 illustrates the rules for the sequential test of longitudinal accuracy.

4.6.3.1 The operator may wish to plot points on Figure 3 as longitudinal error data are collected. The abscissa (horizontal component) of a plotted point is n, the number of trials completed. The ordinate (vertical component) of a point is $S_{a,n}$, the sum of the squares of the longitudinal errors observed in the n trials.

4.6.3.2 The test ends as soon as a point falls into the lower right region or the upper left region of the graph. If a point is plotted in the lower right region, the candidate aircraft and navigation system have shown that they satisfy the RNP 10 longitudinal accuracy criterion. If a point is plotted in the upper left region, the aircraft and navigation system have demonstrated that they do not meet that criterion. Whenever a point is plotted in the middle region, the operator needs to accumulate more data.

4.6.3.3 In the event that the sequential sampling procedure described above does not yield a decision on the aircraft's longitudinal performance after 200 trials, the operator should perform the following computations:

1. Compute the quantity: $D_3= \dfrac{(a_1+a_2+\ldots+a_{200})^2}{200}$

2. Compute the quantity: $D_a^2 = \dfrac{S_{a,200} - D_3}{200}$

3. If D_a^2 does not exceed 21.784, the aircraft and navigation system satisfy the RNP 10 longitudinal accuracy criterion. If D_a^2 does exceed 21.784, the aircraft and navigation system do not meet the criterion, and do not qualify for RNP 10 approval.

Figure 2: Acceptance, Rejection, and Continuation Regions for Sequential Test of Lateral Conformance

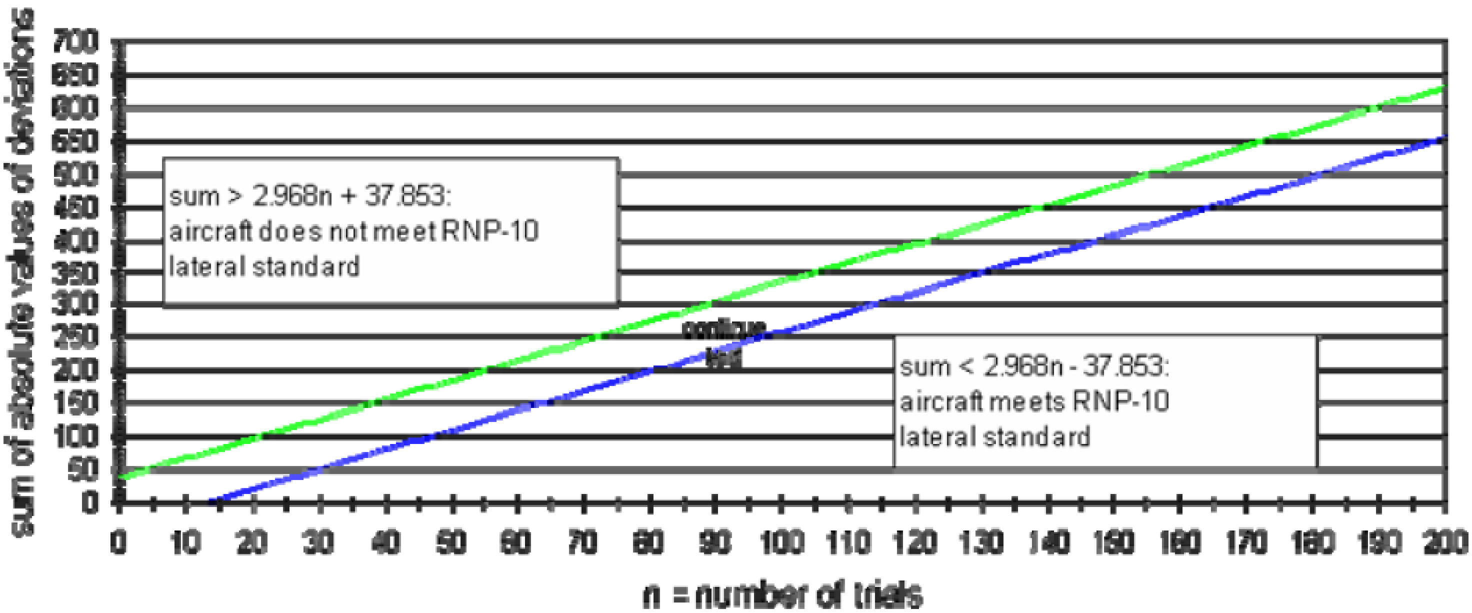
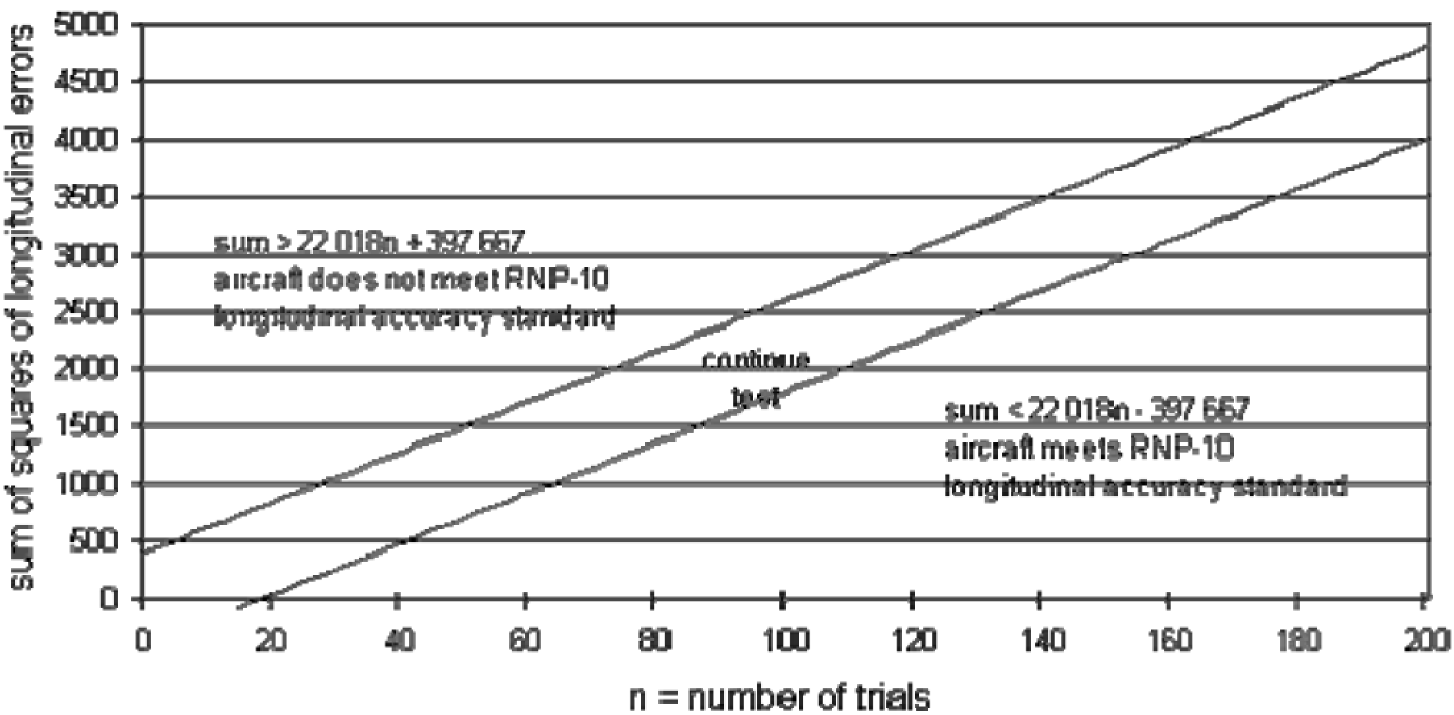


Figure 3: Acceptance, Rejection, and Continuation Regions for Sequential Test of Longitudinal Accuracy



CHAPTER 5. PERIODIC METHOD

5.1 Introduction

This method employs the use of a hand-held GPS receiver as a baseline for collected INS data. A description of this method may be obtained from the POI. These data collection procedures are approved by the Flight Technologies and Procedures Division (AFS-400) on the basis of analysis of the data and multiple validation flights. There are two methods in which data may be collected:

1. One procedure is based on the use of a hand-held Global Positioning System (GPS) as a baseline for the correct position determination. A nonessential flightcrew member takes the GPS readings and the data collection. Only authorized flightcrew members may operate the navigation system. Although no technical specifications are stated for the GPS unit used, it benefits operators to use the best quality unit that is practical. Poorer quality units might malfunction or provide erroneous data that will distort or negate the data collected and make the process excessively expensive.
2. The second method involves using a single, un-updated gate position as a data point and performing the calculations later in this section to determine a RNP 10 limit.

5.2 Triple-Mix and Individual Units

It is possible to evaluate triple-mix units, individual units, or both using this data collection procedure. The data collection forms are designed for this purpose.

5.3 Gate Position Only Data Page

Operators desiring to use gate position only do not need to use the data pages but can go directly to the destination data page and record the gate position data and time since last update.

5.4 Updating INS

Pilots are requested not to update the inertial navigation system (INS) to a GPS position. Doing so would invalidate the data collected.

5.5 Page Heading

Complete all sections of the heading on each page. This is important in the event that pages become separated and get mixed with data from other flights.

5.6 INS Initialization (Figure 4)

Include the following:

1. Record any unusual movement of the airplane during INS initialization before NAVIGATE (NAV) mode selected, such as wind gusts, an airplane service vehicle bumping the airplane, or settling during fueling,
2. If there was any unusual movement during INS alignment, record INS track (TK/GS) after NAV mode is selected,
3. Record the published gate coordinates and/or GPS position where the INS is initialized,
4. If there was any unusual movement during INS alignment, record INS track (TK/GS) after NAV mode is selected,
5. Record the published gate coordinates and/or GPS position where the INS is initialized,
6. Was triple-mix selected? Check yes or no, and
7. Check if updating is by radio navigation of position, yes or no.

5.7 Times (Figure 4)

Include the following:

1. Before departure, record the time the pilots are observed putting the INS NAV mode selectors in NAV,
2. Record "OFF" time,
3. Record the time leaving oceanic and remote continental navigation when radar contact is first established, and
4. Record "IN" (at the gate) time.

5.8 Destination Gate Positions (Figure 7 and Figure 8)

Include the following:

1. Request that pilots not remove INS updates until INS updated/triple-mix positions are recorded at the gate,
2. Record the destination gate number, published position, the number of GPS satellite vehicles ("SV" on the data pages) in view, GPS Dilution of Precision (DOP) and Estimated Position Error (EPE) values, and GPS position,
3. Record INS updated/triple-mix positions,
4. Remove INS updates,
5. Record INS un-updated positions and INS distances from the gate position, and
6. Record INS data in the maintenance log as usual.

5.9 Half-Hourly Position Readings (Figure 4, Data Page 2, and subsequent.)

Include the following:

1. Once every 30 minutes after takeoff (Aircraft Communications Addressing and Reporting System (ACARS) OFF time), plus or minus 5 minutes, record GPS and INS positions. Do not record data during climb or descent, during pilot INS Waypoint Change procedures or at other times when pilots obviously are busy with other tasks, such as air traffic control (ATC) or cabin communications.
2. Record the desired track (DSRTK/STS) of steering INS.
3. Record the last and next waypoints' latitude/longitude and name.
4. Freeze the GPS and INS positions simultaneously.
5. Record GPS position.
6. Record INS updated/triple-mix positions (HOLD and POS selected).
7. Record the INS un-updated (Inertial) positions. (HOLD and WAY PT, thumbwheel other than 0 selected.)
8. Release the frozen INS and GPS positions.

5.10 En Route INS Updates

Use this section only if manual updating is being evaluated. Include the following:

1. Record the identifier of the Navigational Aid (NAVAID) over which updating is accomplished and the NAVAID coordinates.
2. Record the number of GPS satellites in view and the GPS Position Dilution of Precision (PDOP) value.
3. Record the time when INS coordinates are frozen before the en route update is accomplished.
4. After INS positions are frozen and before an updated position is entered:
    (a) Record the INS updated/triple-mix positions and INS un-updated positions.

    (b) Record the GPS position.

5.11 Radio Navigation INS Updates

Use this section only if manual updating is being evaluated (e.g., ground-based radio navigation positions are used for INS updates). Record:

1. NAVAID identifiers.
2. Aircraft position derived from ground NAVAIDs (update position).
3. Time of update.
4. INS position before update.
5. GPS position.

Figure 4: Data Page 1

Flight No.:_________ UTC Departure Date:_________ Departure Airport: _________________

Aircraft Type: _______ Registration No. N ______ Arrival Airport: _______ Captain: _______

INS INITIALIZATION

Were there any unusual motion events during alignment? Yes: ______ No: ________
If yes, INS Track (TK/GS)

If yes, provide a brief description of the event(s):

____
____
____

INS initialization coordinates (published or GPS): N / S
E / W

Triple-mix selected? Yes _________ No __________

TIMES

	Z	OFF
	Z	Time NAV mode selected
hours	minutes	Time in NAV mode before takeoff
	Z	Time entering Class II navigation airspace
	Z	Approximate time leaving Class II navigation airspace
	Z	Time NAV mode selected
hours	minutes	Approximate time in NAV mode before leaving Class II airspace
	Z	IN
	Z	Time NAV mode selected
hours	minutes	Total time in NAV mode

Figure 5: Data Page 2

Flight No.:_________UTC Departure Date: _________Departure Airport:__________________

Aircraft Type: _______ Registration No. N_______Arrival Airport: ________Captain: ________

DATA POINT 1		**Z**		**Altitude**	
GPS	No. of SV	DOP		EPE	
GPS Position	N/S			E/W	
Triple-Mix Positions				Un-Updated Positions	
		INS 1			
		INS 2			
		INS 3			
LAST WAYPOINT		NAME		N/S E/W	
NEXT WAYPOINT		NAME		N/S E/W	

DATA POINT 2		**Z**		**Altitude**	
GPS	No. of SV	DOP		EPE	
GPS Position	N/S			E/W	
Triple-Mix Positions				Un-Updated Positions	
		INS 1			
		INS 2			
		INS 3			
LAST WAYPOINT		NAME		N/S E/W	
NEXT WAYPOINT		NAME		N/S E/W	

Figure 6: Data Page 3

Flight No.:_________UTC Departure Date: _________Departure Airport:__________________

Aircraft Type: _______ Registration No. N_______Arrival Airport: ________Captain: ________

DATA POINT 3		**Z**		**Altitude**
GPS	No. of SV	DOP	EPE	
GPS Position	N/S		E/W	
Triple-Mix Positions			Un-Updated Positions	
		INS 1		
		INS 2		
		INS 3		
LAST WAYPOINT		NAME		N/S E/W
NEXT WAYPOINT		NAME		N/S E/W

DATA POINT 4		**Z**		**Altitude**
GPS	No. of SV	DOP	EPE	
GPS Position	N/S		E/W	
Triple-Mix Positions			Un-Updated Positions	
		INS 1		
		INS 2		
		INS 3		
LAST WAYPOINT		NAME		N/S E/W
NEXT WAYPOINT		NAME		N/S E/W

Figure 7: Data Page 4

Flight No.:_________UTC Departure Date: _________Departure Airport:__________________

Aircraft Type: _______ Registration No. N_______Arrival Airport: ________Captain: ________

Note: Copy previous pages for use in collecting data points in excess of four as needed to collect data for the total flight hours. Use the procedures following the destination data pages to analyze the data.

COMPLETE DESTINATION DATA ON NEXT PAGE

Figure 8: Data Page 5

Flight No.:__________ UTC Departure Date:___________ Departure Airport: ___________________

Aircraft Type: _________Registration No. N ________ Arrival Airport: _________ Captain: ________

DESTINATION GPS/INS POSITIONS

Please do not remove INS updates until updated/triple-mix positions are recorded at the gate.
Destination Gate No.

PUBLISHED POSITION → N/S E/W

GPS	No. of SV	DOP	EPE
GPS Position	N/S	E/W	

Triple-Mix Position	Un-Updated Positions	Distance
[redacted]		

- Name of person recording data (Please print): ___________________________________
- Position: ____
- Company Location:____
- Telephone No. (Business and Home): ____

CHAPTER 6. RNP 10 DATA REDUCTION TECHNIQUES FOR PERIODIC, IN-FLIGHT METHOD OF DATA COLLECTION

6.1 Data Collection Period

Collect reference data (GPS) and INS/Inertial Reference Unit (IRU) data at least every 30 minutes after reaching initial cruise altitude and record latitude, longitude, height, and time at the same time for each system.

6.2 North-South and East-West Error

Determine North-South and East-West error in nautical miles (NM). This is the difference between GPS and INS/IRU position in NM.

6.3 Position Error

Graph position error (using GPS as reference) vs. time for each flight.

6.4 Equally Spaced Interval

Since the actual time of measurement and the test time interval will vary, establish on each flight chart (plot) an equally spaced interval.

6.5 Radial Position Error

At each time interval, calculate the radial position error for each flight. This requires interpolation of the North-South, East-West data from the graphs.

6.6 The 95th Percentile Level of Error

This radial error is the data used to determine the 95th percentile level of error. “The 95th-percentile error level of error” is used here to mean that it is 95-percent probable that the error in a given flight will fall below this level or that the level will be below this level in 95 percent of flights if the number of flights is very large.

6.7 Root Mean Square (RMS) and Geometric Mean (GM)

After collecting the data for all flights, calculate the RMS and GM of the radial errors for each elapsed time point. Also determine the ratio of GM/RMS for each elapsed time point. Use the formulas in Table1.

Table 1: Formulas for Calculating RMS and GM

Definitions	Formulas
r = Radial error at elapsed time point	$RMS = \left(\frac{1}{n} \sum_{i=1}^{i=n} r_i^2 \right)^{\frac{1}{2}}$
n = Number of observations of radial error at equally spaced time intervals	$GM = \left(\prod_{i=1}^{i=n} r_i \right)^{\frac{1}{n}}$

6.8 **$R_{(P)}$/RMS**

Using the P=95 curve from Figure 9, Most Probable 95th Percentile Level Distribution of Radial Error in a Sample, find the value of $r_{(P)}$/RMS for the calculated value of GM/RMS. Multiply this $r_{(P)}$/RMS factor by the value of RMS to determine an estimate of the 95th percentile value of radial error at this elapsed time point.

6.9 **Radial Error vs. Elapsed Time**

Repeat the above procedure for each elapsed time point. Graph $r_{(95)}$ values of radial error (in NM) vs. elapsed time since entering the NAVIGATE mode.

6.10 **Pass-Fail Criteria**

The elapsed time when radial error $r_{(95)}$ exceeds 10 NM defines maximum flight time wherein the navigation system meets RNP 10 criteria.

6.11 **Periodic Method Example**

As an example, Table 3, Table of Radial Errors "*r*" (Use for Airborne Data Collection), and Table 4, Table of Radial Errors (Use for Gate Position Data), show a six-flight data set (although in actual practice a much larger data set should be used to provide confidence). For simplicity of illustration, this example uses only the triple-mix positions after 10 hours in navigation (the time was an arbitrary selection to illustrate the means of calculation). Data for individual navigational units is not included in this example; if they had been used, they would be calculated in exactly the same manner that the triple-mix data is calculated in the example. If an operator decides to use gate position, only Table 4 should be used.

Table 2: Symbols Used In Examples and Formulas

Symbols	Definition
r	Radial error
r^2	Square of the radial error
$\prod r$	Product of the radial errors
$\sum$	Sum
$\sum r^2$	Sum of the squares of the radial errors

Figure 9: Most Probable 95th Percentile Level Distribution of Radial Error in a Sample

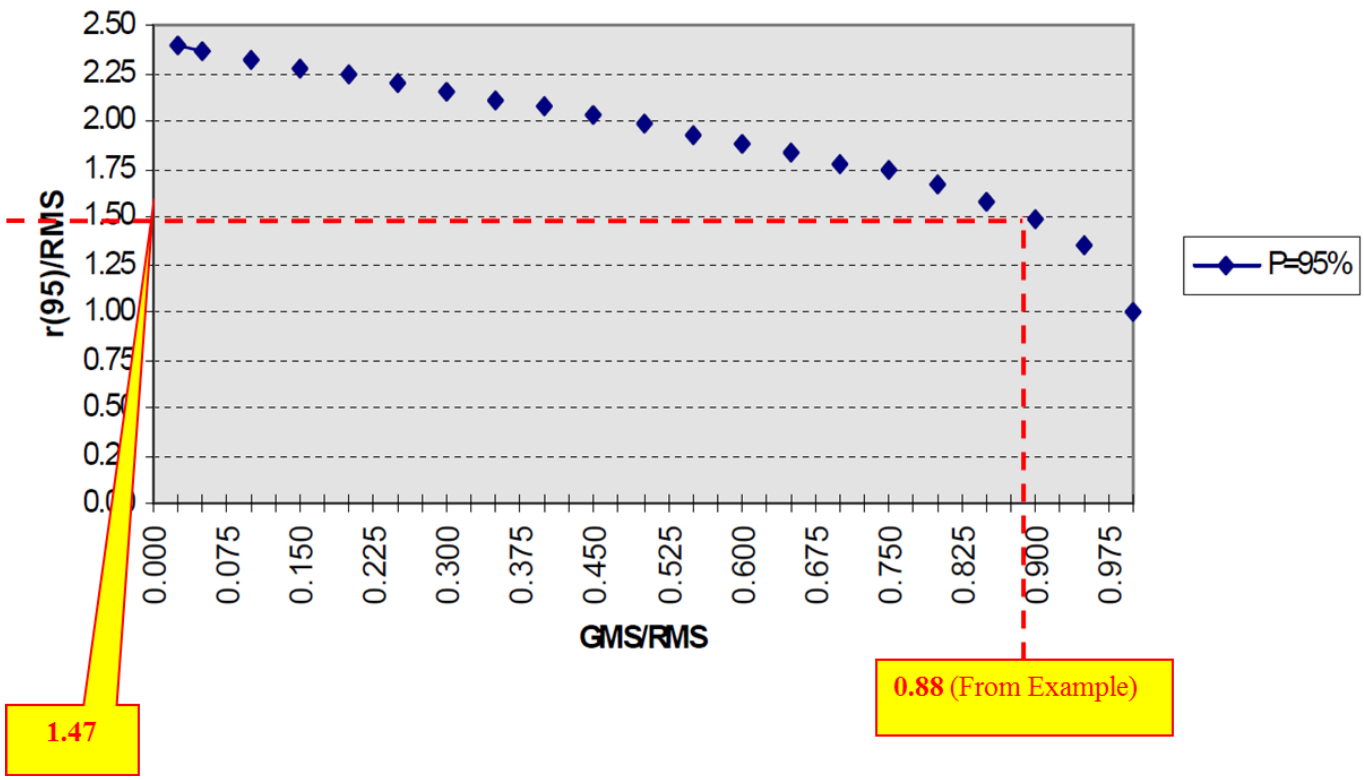


Table 3: Table of Radial Errors “r” (Use for Airborne Data Collection)

Flight	Radial Errors = r	R^2
1	6.5	42.25
2	5.5	30.25
3	12.7	161.22
4	14.0	196.00
5	7.2	51.84
6	7.0	49.00

6.12 **Example Solution**

The product (Π) of radial errors (column 2) =320,360. The sum of the radial errors squared (Σr2) (column 3) =530.63.

Figure 10: Calculations

$$RMS = \left(\frac{1}{n} \sum_{i=1}^{i=n} r_i^2 \right)^{\frac{1}{2}} = \left(\frac{1}{6} (530.63) \right)^{\frac{1}{2}} = 9.40$$

$$GM = \left(\prod_{i=1}^{i=n} r_i \right)^{\frac{1}{n}} = (320.36)^{\frac{1}{6}} = 8.27$$

$$RATIO = \frac{GM}{RMS} = \frac{8.27}{9.40} = 0.88$$

6.12.1 Find Value Example

Find this value (0.88) on the abscissa of the "Most Probable 95th Percentile Level Distribution of Radial Error in a Sample", Figure 9 and intersect it with the 95 percent curve to find $r_{(95)}$/RMS (on the ordinate of the graph). Thus, for this example: $r_{(95)}$/RMS=1.47.

6.12.2 Ordinate Value

The ordinate is defined as $r_{(95)}$/RMS, where $r_{(95)}$=95 percentile of error. Now $r_{(95)}$ for the data in the example is determined from the following: $r_{(95)}$= Ordinate value (for the data) x RMS=1.47x9.40=13.8 NM.

6.12.3 Example Results

These results indicate: The 95th percentile level of error at 10 hours is 13.8 NM, which is greater than the required 10 NM; the system would not qualify for RNP 10 for 10 hours based on the data presented.

6.13 Gate Position Data Collection

For guidance on gate position data collection, see Table 4, Table of Radial Errors (Use for Gate Position Data).

Note 1: No data is provided for this method. Calculations would be made identical to the procedure used in Table 3.

Note 2: Time is crucial with this set of data, and it should be noted that the credited time is that of the smallest time value in the data set.

Table 4: Table of Radial Errors (Use for Gate Position Data)

Flight	Times Since Last Update	Radial Error at Gate=r	R^2

1. The product (Π) of radial errors (column 3) =______________.
2. The n^{th} route of Π =____________= GM.
3. The sum of the radial errors squared (Σr^2) =______________=*RMS*.

4. The square root of $\left(\frac{1}{n}\sum r_i^2\right)$ =_______________=*RMS.*

Note: After calculating (2) and (4), use Figure 9 to determine $r_{(95)}$. Multiply this factor by the RMS to determine the drift in NM. If this value is less than 10 NM, then the navigation system can be approved for RNP 10 for the time in navigation of this flight. Note that this is the data for one flight only; data must be collected in the same manner and in an equal time length for a minimum of 20 flights.

CHAPTER 7. GUIDELINES AND ASSUMPTIONS

7.1 Inertial Reference Unit (IRU)

Inertial Reference Units (IRU) that meet the current requirements of 14 CFR part 121 appendix G meet all of the RNP 10 requirements for up to 6.2 hours of flight time without radio position updating. IRU accuracy, reliability, training, and maintenance issues required by part 121 appendix G are part of the aircraft certification. However, IRU manufacturers believe that the actual performance of some types of IRUs exceeds the current part 121 appendix G requirements. A methodology for analyzing IRU performance, combined with requirements to update IRU manufacturers' specification control drawings, acceptance test procedures, and airline IRU maintenance/removal criteria is described in the paragraph 2.

7.1.1 IRU Accuracy and Reliability

IRU accuracy and reliability must be analyzed in conjunction with the flight management system (FMS) interface. An analysis performed on a specific manufacturer's aircraft model is not necessarily applicable to other aircraft operating the same equipment. However, other aircraft may be analyzed using the same or equivalent methodology as proposed in this paragraph.

7.1.1.1 The radial navigation error distribution for IRUs is modeled by a Rayleigh distribution. The 95-percent statistic of radial position error will be used when demonstrating compliance. It is assumed that cross-track and along-track errors are Gaussian, independent, and have equal variances.

7.1.1.2 The radial position error will be evaluated for the range of the independent time variable (time in navigation), as certified for the IRU navigation maximum time (e.g., 18 hours).

7.1.1.3 Time-dependent position error data will be presented. Other non-inertial error sources will not be considered as part of the IRU certification (i.e., Flight Technical Error (FTE)). Therefore, the maximum time duration of flight operations in RNP 10 airspace will be evaluated and determined as part of the operational approval.

7.1.1.4 The assessment of navigation performance may employ system analysis, IRU error modeling (covariance analysis), and system simulation. Analytical findings may be validated with empirical data from laboratory testing and aircraft flight testing, as applicable.

7.1.2 Performance Superior to the Original Certification

When credit is required for IRU performance that is superior to the original certification, the existing IRU specification control drawings for the IRU type designs should be revised to account for the new tighter tolerance system error budgets.

7.1.2.1 If it has been determined that all IRUs for a given part number meet the minimum requirements of the new performance standard, then the IRU part number may remain the same.

7.1.2.2 When only some of the IRUs for a given part number meet the minimum requirements of the new performance standard, then screening is required and part number updates will be required to identify the IRUs that are compliant to the new performance standard.

7.1.3 Aircraft Flight Manual (AFM) or Aircraft Flight Manual Supplement (AFMS)

The AFM or AFMS must be modified to reflect the certification of IRUs to tighter accuracy requirements, consistent with the current edition of Advisory Circular (AC) 25-4, Inertial Navigation System (INS), subparagraph 5b(4). The AFM should provide sufficient time-dependent information so that the maximum time in RNP 10 airspace can be assessed as part of the operational approval.

7.1.4 Production and Field Acceptance Test Procedures

In addition, production and field acceptance test procedures will require an update by the supplier to ensure that the installed IRU meets the tighter accuracy tolerance required.

7.1.5 Operator Maintenance Procedures

Operator maintenance procedures will require updating to ensure appropriate monitoring of IRU performance to the new requirements contained in this order and replacement of IRUs on aircraft that do not meet the navigation performance of this new criterion.

7.1.6 Procedures for Flight Operations

Procedures for flight operations should be identified and applied to ensure IRU alignment before extended range flights and time in navigation for the intended time duration of flight in RNP 10 airspace.

CHAPTER 8. SAMPLE OPERATOR LETTER OF REQUEST TO OBTAIN RNP 10 OPERATIONAL APPROVAL LETTER OF REQUEST

8.1 Figure 10 Sample Letter of Request

Figure 11 below is a sample letter of request for an operator to request operational approval for RNP 11 operations in oceanic/remote areas of operation.

8.1.1 Letters of Authorization (LOA)

Aviation safety inspectors (ASI) can administratively issue an LOA to any General Aviation (GA) operator that meets the requirements of this order. LOAs should be issued through the Web-based Operations Safety System (WebOPSS).

Figure 11: Sample Letter of Request

SUBJECT: Request for Required Navigation Performance 10 (RNP 10) Approval

TO: Appropriate principal operations inspector (POI) or ASI

[Operator Name] is applying for Federal Aviation Administration (FAA) operations specifications (OpSpecs), management specifications (MSpecs), or letter of authorization (LOA), as appropriate, to conduct Required Navigation Performance 10 (RNP 10) operations in oceanic/remote areas of operation.

[Operator Name] plans to submit its application package showing its compliance with RNP 10 aircraft eligibility, operational and airworthiness requirements on _______. [Operator Name] plans to start RNP 10 operations on _______.

The following [Operator Name] aircraft will meet the requirements and capabilities as defined/specified in the current edition of FAA Order 8400.12, Required Navigation Performance 10 (RNP 10) Operational Authorization, dated [DATE], for an RNP 10 qualification.

Airplane M/M/S	**RNP 10 TIME LIMIT**	**S-LRNS NAVIGATION EQUIPMENT M/M**	**COMMUNICATIONS EQUIPMENT M/M**
X-XXX-XX	*	List navigation equipment by manufacturer/model	List communications equipment by manufacturer/model

[* See paragraph 13. If aircraft is equipped with Global Positioning System (GPS) approved for primary means of navigation in oceanic operations, incorporated into a multi-sensor system or installed with inertial navigation system (INS) or flight management computer (FMC)/Inertial Reference Unit (IRU), state: "Unlimited."]

Training of flightcrew members will be accomplished in accordance with applicable FAA regulations and guidance material.

Sincerely,

[typed name and signature]

[title]

Intentionally Blank

CHAPTER 9. AN APPROVED MANUAL UPDATING PROCEDURE FOR RNP 10 OPERATIONS

9.1 Introduction

In order to facilitate RNP 10 operations for airborne navigation systems that are unable to achieve RNP 10 performance for greater than 6.2 hours, the following methods of manual position updating are suggested as a means to extend the 6.2 hours.

9.2 Manual Position Updating

Manual position updating is defined to mean a technique where the crew uses one of the techniques described below to adjust their inertial navigation system (INS) output to compensate for the detected error. The detected error is the difference between the radio navigation position and the INS/Inertial Reference Unit (IRU) position with the radio navigation position being considered the correct position.

9.3 Means of Manual Updating

Two techniques using very high frequency (VHF) omnirange station (VOR)/distance measuring equipment (DME) or ultrahigh frequency (UHF) Tactical Air Navigational Aid (TACAN) and one technique using a Global Positioning System (GPS) are possible means of manual updating.

9.3.1 Position Update

The first is a position update based on crossing a fix along a route defined by a bearing and distance from/to a VOR/DME or TACAN facility. The second is based on a route that flies over a VOR/DME or TACAN facility. The third is similar to the first, but uses a Technical Standard Order (TSO)-C129/C129a/C196 GPS receiver with an approved installation for the update in place of a Navigational Aid (NAVAID).

9.3.2 Plotting Chart or Log

In each of the three methods, the time that the system was updated should be annotated on the plotting chart or a log that will be retained by the operator for a period of 30 days.

9.3.3 Conditions for Updating

The conditions under which any of these methods may be used are as follows:

1. For the first and second methods, the minimum distance from the reference VOR/DME facility must be at least 50 nautical miles (NM).
2. Both the VOR and DME functions of the reference facility must be operational prior to dispatch release and during the intended updating operation unless the GPS procedure is used as a reference.
3. The flightcrew member must have a plotting chart in his or her possession.

4. The GPS or GPS/wide area augmentation system (WAAS) receiver must not indicate an integrity alarm or other fault condition.

9.4 Training

9.4.1 Commercial Operators

Commercial operators intending to use manual updating procedures must ensure that every flightcrew member using the procedures is trained in the updating procedures. The operator should be able to demonstrate that it has a reliable method of having its crews perform the update, and can be approved by the operator's principal operations inspector (POI) to determine if the method is acceptable. Training manuals must be updated to include the procedures and will be evaluated by the POI as a part of the approval process.

9.4.2 General Aviation (GA) Operators

GA operators intending to use manual updating procedures must provide evidence to the responsible office that crews using the procedures are capable of maintaining the same standards as commercial operators.

9.5 Method 1: Manual Updating Based on Crossing a Fix Along a Route

9.5.1 Timing and Distance

Using Method 1, the update is performed when crossing over a fix that is defined by a crossing radial and distance from a VOR/DME or TACAN facility. To accomplish this update, the crossing radial must be at or near perpendicular to the route. The minimum DME/TACAN distance used to define the fix location will be at least 50 NM.

9.5.2 Updating the Inertial Position

The flightcrew member should tune in the reference VOR/DME or TACAN facility and preselect the appropriate bearing on one course deviation indicator (CDI). As the CDI centers, the flightcrew member will note the distance from the VOR/DME or TACAN facility and mark it on the plotting chart. The flightcrew member will also note the inertial positions of each of the operating INS. The crew will then compare the inertial position against the derived position. The crew then may use the derived position (expressed in latitude/longitude) to update the inertial position. If interpolation is necessary, round up. This procedure would provide a means to restart the RNP 10 clock for an additional, predetermined time.

9.5.3 Plotting Chart

To accomplish this manual update, the flightcrew member should have a plotting chart that displays the route fix and DME fixes of 1-mile increments located along a line that is perpendicular or near perpendicular to the route along the axis of the VOR/TACAN radial used to define the fix. Each fix should be displayed in both DME distance and latitude/longitude coordinates.

9.5.4 Verifying the Position Update

Put two fixes along the route, one on either side of the "update" fix, and note the coordinates on the plotting chart. The flightcrew member should then use these fixes to validate the position update. This is similar to the method used for updating when flying on a route that passes over a VOR/DME or TACAN facility. It is imperative for flightcrew members to remember that these additional fixes are to be used for verification only, not as an update fix. They do, however, provide a means of verification of the update.

9.6 Method 2: Manual Updating when Flying a Route that is Defined by a VOR/DME or TACAN Facility

9.6.1 Accuracy

The accuracy of a manual update when overflying a VOR/DME or TACAN facility is questionable, due to the "cone of confusion" that exists overhead the facility and that varies as a function of the altitude of the aircraft. To increase the accuracy of a manual update in this situation, it is recommended that a plotting chart be created that has fixes depicted along the route at a minimum distance of 50 NM, but not more than 60 NM from the VOR/DME or TACAN. These fixes should display the bearing and distance and the latitude/longitude coordinates expressed to a tenth of a degree. The specified distances will account for slant range error and radial width.

9.6.2 Procedure

In this situation, the suggested procedure would be for the flightcrew member to discontinue INS navigation when receiving the VOR/DME or TACAN signal and attempt to align the aircraft exactly on the desired radial to or from the station. When passing over the specified fix, the flightcrew member will compare each of the INS positions with the reference latitude/longitude position of the fix. The flightcrew member should attempt the manual update if the along-track position error is greater than 1 NM. After the manual update is completed, the flightcrew member should continue to navigate by the VOR radial to the next designated fix and compare the coordinates to verify that the update was successful.

9.6.3 Minimum Requirements

As minimum requirements for use of these procedures, the flightcrew member must have onboard the appropriate plotting charts with the specified information, and the operator must demonstrate that its flightcrews know how to use the charts and procedures.

9.6.4 Conditions

These procedures should be based on the assumption that triple-mix position fixing is not used, and each inertial must be updated accordingly. The crew must notify air traffic control (ATC) any time it becomes aware that the aircraft can no longer maintain RNP 10 performance based on evaluation of the position checks.

9.7 Method 3: Using an Instrument Flight Rules (IFR) Approved GPS Installation as an Updating Reference

9.7.1 Overview.

Using method 3, the update is performed by comparing the INS position to the GPS position at a chosen waypoint.

9.7.2 Updating.

Accomplish the following:

1. Record the time when INS coordinates are frozen before the en route update is accomplished and the flight level.
2. Record the number of GPS satellite vehicles locked on and the GPS Dilution of Precision (DOP) and Estimated Position Error (EPE) values.
3. Record the desired track (DSRTK/STS) of the steering INS.
4. Freeze the GPS and INS positions simultaneously.
5. From the data, determine the approximate amount of drift per hour flown, make appropriate corrections, and continue to navigate.
6. If data indicates that RNP 10 capability is impossible to maintain, ATC must be notified as soon as flight conditions will permit.

9.7.3 Completion of Oceanic and Remote Continental Navigation and Post Flight

This step is important in that it verifies the accuracy of the updating process and will warn operators if there is an equipment or procedural problem that might affect future flights. Additionally, this information can be used in a response to an Oceanic Navigational Error Report (ONER). Accomplish the following:

1. Record the time leaving oceanic and remote continental navigation when radar contact is first established or when first within 150 NM of a VOR NAVAID, record IN time.
2. For destination gate positions, do not remove INS updates until updated INS is recorded at the gate.
3. Record the destination gate number, the number of GPS satellite vehicles in view, and the GPS DOP and EPE values.
4. Record updated INS position.
5. Remove INS updates.
6. Record INS un-updated positions and INS distances from the gate position.
7. Record GPS position. If GPS position is unavailable, record the gate position (Flight Operations Manual (FOM) airport page 10-7 or airport plan view).
8. INS data should be recorded in the maintenance log as usual.
9. Release the frozen INS positions.