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ABSTRACT

This document states Future Air Navigation System 1 (FANS 1) navigation system capabilities for a757/767. It is intended to be used by the FMC Group, the Customer Airlines and the Operational Approval Regulatory Authorities to document the navigation capabilities of FANS 1 in order to facilitate the Customer Airlines in receiving operational approvals. This document describes definitions of terms used to define the FANS 1 capabilities, the interface of the FMC navigation function to the Flight Deck Crew, the specific navigation capabilities of the FANS 1 equipment, and potential application of the FANS 1 navigation system.

KEY WORDS

Navigation

Computer

Satellite

RNP

GPS

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL
A	Update section 1.2 to call out latest RNP documents for other airplane models. Update section 3 to include NDB specified RNP as a source of RNP. Update section 4.2 to include NDB specified RNP as a source of RNP. Update section 8.0 to include proposed RNP AFM updates for the 767-400 software update. Update section 10.1 and 10.2 for radio failure case. Does not affect top level AFM minimum RNP numbers.		T. E. Tarleton H. R. Shomber R. S. Leslie D. J. Murray

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL
B	Update abstract. Update section 4.0 to state display of sensor data on ND only applies to LFDS equipped airplanes Add section 4.7 to cover display of sensor data on the ND for LFDS equiped airplanes Update section 8.0 to include latest AFM. Update section 9.0 to include latest MMEL Update section 10.3 for each equivalent approach type to call out the appropriate DA(H)		T. E. Tarleton H. R. Shomber J. W. Van Horne

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ACRONYMS AND ABBREVIATIONS

ADS	Automatic Dependent Surveillance
AGL	Above Ground Level
ANP	Actual Navigation Performance
APF	Airline Policy File
ARINC	Aeronautical Radio, Inc.
ATS	Air Traffic Services
CDU	Control Display Unit
CMC	Central Maintenance Computer
CRT	Containment Radius Threshold
CT	Containment Threshold
EICAS	Engine Indicating & Crew Alerting System
EIU	EFIS/EICAS Interface Unit
EFIS	Electronic Flight Instrument System
FANS	Future Air Navigation System
FTE	Flight Technical Error
GMT	Greenwich Mean Time
GPS	Global Positioning System
GPSSU	Global Positioning System Sensor Unit
HFOM	Horizontal Figure Of Merit
HIL	Horizontal Integrity Limit
ICAO	International Civil Aviation Organization
IDS	Integrated Display System
IRU	Inertial Reference Unit
IRS	Inertial Reference System
LFDS	Large Format Display System
LRU	Line Replacement Unit
MAWEA	Modular Avionics Warning & Electronic Assembly
MCDU	Multipurpose Control Display Unit
MMEL	Master Minimum Equipment List
MOPS	Minimum Operational Performance Standards
NAIM	Non-Autonomous Integrity Monitor
ND	Navigation Display
NDB	Navigation DataBase
NM	Nautical Mile
PFD	Primary Flight Display
RAIM	Receiver Autonomous Integrity Monitor
RIP	Required Integrity Performance
RNP	Required Navigation Performance
RTCA	RTCA, Inc.
UTC	Universal Time Coordinated

1. Introduction

1.1. Purpose

The purpose of this document is to provide an overview of the navigation capabilities of a 757/767 upgraded with the addition of a MMR with the GPS function, an updated FANS 1 FMC and EICAS. The navigation capabilities described are expected to be FAA part 25 certified in the fourth quarter of 1997. This document will be used as a working paper to provide the regulatory authorities with the data they require to provide the airlines with part 121 flight operations approval to fly enroute, terminal and approach flight operations using RNP, in a timely fashion following the certification of FANS 1.

1.2. Scope

This document provides an overview of the RNP and GPS navigation capabilities provided by 757/767 FANS 1. This document does not provide an overview of all the existing navigation capabilities in the existing FMC, which is the baseline for FANS 1.

This document addresses the 757/767 FANS 1 configuration only, however discussions regarding ANP (section 2.0), RNP (Sections 3., 3.1, 3.2, 3.3 and 3.4) Applications of RNP (Section 10), and Proposed Operational Approval (section 11) contain concepts common to all Boeing models. Refer to the following documents for discussions applicable to the indicated models:

Model	Document Number
737	D6-39067-2
747-400	D240U126
777	D243W018-7

2. Actual Navigation Performance (ANP)

For FANS 1 Actual Navigation Performance (ANP) is defined as follows:

"Actual Navigation Performance (ANP) is the navigation system computed accuracy with associated integrity for the current FMC position."

Accuracy and integrity are expressed in terms of nautical miles and represent a containment radius of a circle centered around the computed FMC position where there is a defined containment probability level of the actual aircraft being inside the containment radius. For accuracy the containment probability level is 95%. For integrity the containment probability level is appropriate for route separation and obstacle clearance operations, and therefore much larger than 95%. The actual integrity containment probability levels are discussed in section 2.2 and 2.4.

The concept of ANP integrity is to ensure that the data being used to compute FMC position, and upon which ANP is based, has integrity. If the sensor data used to compute FMC position has integrity, then the FMC position and ANP have integrity.

The computed accuracy is displayed to the crew as ANP and annunciation is provided if ANP exceeds the selected RNP.

The FMC computation of ANP does not account for the following error sources:

1. Software errors in the FMC or Sensor.
2. Flight Technical Error. (This includes position errors induced by guidance systems ability to follow a track in various wind conditions or the ability of the pilot to manually keep the aircraft on track using LNAV and either the flight director or the Navigation Display map. The integrated cockpit design of the 757/767 with FANS 1 provides indications of FTE to the crew via the following: electronic map display; LNAV engage, disengage, and mode fail status; autopilot/flight director engage, disengage, and fail status.)
3. Errors in time source used when reporting the position.
4. Gross position errors in the navigation database data or resulting from incorrect manual waypoint entry.
5. Differences in local datum for the WGS-84 datum.

2.1 ANP Accuracy When GPS Updating

The FMC computed accuracy when GPS updating considers the following error sources:

1. Position errors induced by the satellite constellation (Reflected in HFOM or HIL).
2. Position errors induced in the navigation sensors on the airplane (GPS data latencies).
3. Position errors induced by the navigation system (Position Filter Latency).

There is conservatism in the displayed ANP for GPS updating in terms of cross track position error. The sources of the conservatism are as follows:

1. HFOM it is multiplied by 1.25.
2. Along track latency in the GPS position.

As a result of this conservatism the average ratio of r_{acc} to displayed ANP when HFOM is used to compute ANP for GPS updating is 0.59 for enroute/terminal operations, and 0.77 for approach. This conservatism in displayed ANP is used in sections 10.1 and 10.2 to account for FTE by defining minimum demonstrated RNP that are called out in the AFM.

2.2 ANP Integrity When GPS Updating

The GPS position integrity in the FMC is either provided by GPS Receiver Autonomous Integrity Monitor (RAIM) or FMC Non-Autonomous Integrity Monitor (NAIM). RAIM and NAIM have been designed to provide a containment probability level of 1E-7 per flight hour. RAIM and NAIM compute an actual containment radius. The RAIM containment radius is the largest of the worst case position error as a function of the satellite geometry or the position error as a function of the actual residual pseudo ranges. The NAIM containment radius is the magnitude of the difference between the GPS position and a reference position plus the error associated with the reference position. For GPS to be considered valid for position updating its actual containment radius must be less than the selected RNP containment radius threshold (Per section 3.2). This will assure that if the FMC is GPS updating, integrity for the selected RNP is provided to a containment probability level of 1E-7 per flight hour. Figure 2.2-1 contains examples of containment radius thresholds and containment probability level for various selected RNP:

	FMC/GPS/INERTIAL Integrity Versus Selected RNP						
	RNP 12.0	RNP 4.0	RNP 2.0	RNP 1.0	RNP 0.5	RNP 0.3	RNP 0.15
Position Fixing Containment Radius Threshold (2*RNP)	24.0 (NM)	8.0 (NM)	4.0 (NM)	2.0 (NM)	1.0 (NM)	0.6 (NM)	0.3 (NM)
Containment Probability Level	1E-7/FLT HR	1E-7/FLT HR	1E-7/FLT HR	1E-7/FLT HR	1E-7/FLT HR	1E-7/FLT HR	1E-7/FLT HR

Figure 2.2-1 FANS 1 Implemented GPS Integrity Versus Selected RNP

Figure 2.1-1 show that the containment probability level provided by the FANS 1 navigation design (i.e. 1E-7 per flight hour) exceeds the 1E-5 per flight hour containment probability level required for enroute and terminal area route separation flight operations, and the 1E-6 per flight hour containment probability level required for terminal and approach obstacle clearance flight operations per section 3.2. The 1E-6 per flight hour containment probability level is equivalent to 1E-7 per approach containment probability level for approach obstacle clearance, assuming the approach and missed approach exposure time is less than 6 minutes. Refer to section 10.2 for how approach exposure time is computed. The actual containment radius thresholds corresponding to 1E-5 and a 1E-6 per flight hour containment probability levels can be determined analytically. For the FANS 1 design NAIM is used to provide integrity whenever RAIM is not available, therefore NAIM is the limiting factor in determining the containment probability level. NAIM is defined as follows:

$$P([\text{GPS Pos} - \text{True Pos}] > C) = P(\text{Satellite Failure}) * P([\text{GPS Pos} - \text{True Pos}] > C \text{ during a satellite failure})$$

$$= (1E\text{-}4) * (1\text{-}.999)$$

$$= (1E\text{-}4) * (1E\text{-}3) = (1E\text{-}7)$$

Where:

C for NAIM is defined as the difference between the actual GPS position and a known position plus the 99.9 % error statistic associated with the know position. In this case the known position is either the inertial reference position with a retained GPS bias, or a Radio position, whichever provides the best integrity. The 99.9 % error statistic is associated with the inertial or Radio Position and is of Rayleigh distribution.

Based on the above definition of NAIM, the actual containment radius threshold can be computed for the 1E-6 and 1E-5 per flight hour containment probability levels. Given that the FMCF will drop GPS updating when NAIM exceeds two times, and assuming that the predominant error in computing C for NAIM is the error in the inertial position, not the difference between the GPS position and retained GPS bias position. The actual containment radius threshold for the 1E-6 and 1E-5 per flight hour containment probability levels are computed by scaling the 95.0% Rayleigh distributed error statistic when ANP exceeds RNP to 99% and 90% error statistics. The results of this scaling are given below as a function of ANP.

Containment Probability Level	Position Fixing Containment Radius Threshold
1E-7 per flight hour	2.00*ANP
1E-6 per flight hour	1.24*ANP (95% scaled to 99 % Rayleigh number)
1E-5 per flight hour	0.88*ANP (95% scaled to 90% Rayleigh number)

2.3 ANP Accuracy When Radio Updating and Inertial Only Mode

The FMC computed position accuracy when radio updating or inertial only mode considers the following error sources:

1. Position errors induced by the navigation aids. (Incorrect survey locations of the navaid in the NDB, ground based navaid signal in space errors, update navaids DME/DME geometry errors)
2. Position errors as the result of ADIRU drift in the inertial only mode.
3. Position errors induced in the navigation sensors on the airplane. (DME, VOR and ADIRU position errors and data latencies)
4. Position errors induced by the navigation system. (Position Filter Latency).

The displayed ANP (ACTUAL) is computed knowing the geometry relative to the navaids for radio updating and time since last radio update for inertial only mode. There is conservatism in the displayed ANP for radio updating in terms of cross track position error. The sources of the conservatism are as follows:

1. ANP does not accounting for baro altitude corrections in the terminal area for the DME slant to ground range conversions.
2. Along track latency in the navaid data due the average effect of the airplane track versus bearing to navaid.

As a result of this conservatism the average ratio of r_{acc} to displayed ANP for radio updating is 0.86 for enroute/terminal operations, and 0.89 for approach. This conservatism in displayed ANP is used in sections 10.1 and 10.2 to account for FTE by defining minimum demonstrated RNP that are called out in the AFM.

2.4 ANP Integrity When Radio Updating and Inertial Only Mode

The position certainty associated with the FMC position when radio updating or INERTIAL only has a Rayleigh distribution which can be characterized by the following equation.

$$P(R < r) = 1 - EXP(-(r^2/(2*(A^2))))$$

Where:

$P(R < r)$ is the probability that the actual position error (R) is less than the error threshold (r).
R is the actual position error.
r is the position error threshold of interest.
A is the peak of the Raleigh distribution.

and given the 95% radial containment (r_{acc}), the radial containment for 0.99999 and 0.999999 can be computed,

$r_{cs5} = 1.96 * r_{acc}$

$r_{cs6} = 2.15 * r_{acc}$

where r_{cs5} = 0.99999 containment radius (1E-5 loss of containment)
r_{cs6} = 0.999999 containment radius (1E-6 loss of containment)

As a result of the conservatism in the displayed ANP the following cross track containment thresholds apply:

Enroute/Terminal:	$r_{cs5} = 1.69 * ANP$	
Approach:	$r_{cs6} = 1.74 * ANP$	(With pilot check of navigation radio data as called out in AFM. Pilot check of navigation radio data provides integrity through an independent check that the FMC position and MAP display are correct. This check is assumed be 90% effective. This means a 0.999999 containment radius can be achieved using a 0.99999 containment threshold coupled with the check of navigation radio data.)
Approach:	$r_{cs6} = 1.91 * ANP$	(With out pilot check of radio navigation data.)

The containment requirements have been set at 2*RNP for enroute, terminal and approach operations. The pilot alerts are issued when the displayed ANP (ACTUAL) exceeds the RNP. Consequently, the difference between the required containment and the position fixing containment is available for other error sources (flight technical error).

3. Required Navigation Performance (RNP)

For FANS 1 Required Navigation Performance (RNP) is defined as follows:

"Required Navigation Performance (RNP) is a statement of the navigation performance necessary for operation within a defined airspace" (Adapted from accepted ICAO definition of RNP)

RNP specifies an accuracy, integrity, availability of navigation signals and availability of navigation equipment requirements for a particular area, airspace, route, procedure, or operation. For FANS 1 the initial implementation of RNP focus primarily on horizontal applications.

For the RNP function the Control Display Unit (CDU) displays of RNP, ANP and the associated scratch pad messages. The source of the displayed RNP is either a manual entry, a NDB specified RNP, or a default RNP based on navigation phase of flight.

The "UNABLE RNP" Engine Indication and Crew Alerting System (EICAS) annunciation is provided to the flight crew to indicate ANP exceeding RNP. "UNABLE RNP" is an advisory, level C, EICAS message resulting in an amber message displayed on the upper EICAS display, if ANP exceeds RNP while not on approach. "UNABLE RNP" is a caution, level B, EICAS message results in an amber message displayed on the upper EICAS display accompanied by the master caution light and an aural warning if ANP exceeds RNP while on approach.

Oceanic, Enroute, Terminal, Approach and Takeoff navigation flight phases are used to select the default RNP and times to alarm for issuing the "UNABLE RNP" messages. The default RNP and times to alarm are included in the software loadable Boeing type design controlled OPC. The initial certification values for these parameters are based on the existing operational requirements for existing airspace. As the operational requirements for a particular airline, area, airspace, route, procedure, or operation require different RNP the default values can be changed and implemented by an update to the OPC. The initial certification values for FANS 1 are as follows:

Phase of Flight	Default RNP	"UNABLE RNP" EICAS Message Level	Time To Issue "UNABLE RNP"
Oceanic/Remote	12.0	Advisory, level C	80 seconds
Enroute/Domestic	2.0	Advisory, level C	80 seconds
Terminal	1.0	Advisory, level C	60 seconds
Takeoff	1.0	Advisory, level C	10 seconds
Approach	0.5	Caution, level B	10 seconds

Figure 3.-1 Default RNP

Definition for each of the above flight phases are given below:

Oceanic/Remote - Radio updating is not viable due to either very limited navaid coverage or no navaid coverage.

Enroute/Domestic - Aircraft sequences above 15,500 feet while not actively flying a SID, or is above 15,500 and sequences the last waypoint of a SID, or the phase of flight is Oceanic and radio updating is viable.

Terminal - Aircraft sequences below 15,000 feet; or when the aircraft is in Approach and exceeds 3,000 feet above arrival airport elevation if there is no missed approach holding point, or the missed approach holding point is sequenced; or the aircraft is in Takeoff and exceeds 3,000 feet above departure airport elevation if no SID exist in active flight plan, or the last waypoint of the SID is sequenced below 15,500.

Takeoff - A flight plan or flight plan modification has been executed on the ground and at least one IRU is in Navigation mode.

Approach - The first waypoint on the active approach or approach transition is sequenced, or the aircraft sequences below 2,000 feet above arrival airport elevation. Approach flight phase will not be active when a VFR approach is in the active flight plan.

3.1 RNP - Accuracy

Accuracy is a 95% horizontal position certainty radius around the computed position. It will indicate the normal operating error characteristics of a navigation system.

RNP accuracy is assumed to consider the following error sources:

1. Position errors induced by the navigation aids or GPS satellite constellation.
2. Position errors induced by the navigation sensors on the airplane.
3. Position errors induced by the navigation system (FMC).
4. Path definition error.

RNP accuracy is assumed to not consider the following error sources:

1. Software errors in the FMC or Sensor.
2. Flight Technical Error.
3. Errors in time source used when reporting the position.
4. Gross position errors in the navigation database data or resulting from incorrect manual waypoint entry.
5. Differences in local datum other than WGS-84.

3.2 RNP - Integrity

Integrity is represented by a horizontal containment radius threshold around the computed FMC position, and a containment probability level that the actual position is outside the containment radius threshold. If the actual position falls outside the containment radius threshold it would result in an exceedance of RNP. The RNP integrity is assumed to consider the following error sources:

1. Position errors induced by the navigation aids or GPS satellite constellation.
2. Position errors induced by the navigation sensors on the airplane.
3. Position errors induced by the navigation system (FMC).
4. Path definition error.
5. Flight Technical Error.

The RNP integrity is assumed not to consider the following error sources:

1. Software errors in the FMC or Sensor.
2. Errors in time source used when reporting the position.
3. Gross position errors in the navigation database data or resulting from incorrect manual waypoint entry.
4. Differences in local datum other than WGS-84.

For a given RNP, the containment radius threshold is defined to be equal to RNP times two. This containment radius will be used in providing sufficient route separation and obstacle clearance.

For a given RNP the containment probability level will vary depending on the operational requirement. For enroute and terminal area operations route separation, the containment probability level requirement is 1E-5 per flight hour. For terminal area and approach procedures obstacle clearance, the containment probability level requirement is 1E-7 per procedure (i.e. approximately 1E-6 per flight hour assuming approximately a 6 minute exposure for the approach).

Flight Technical Error is accounted for in the RNP integrity by the FMC position integrity containment probability level for GPS and non-GPS updating being in excess of the stated requirements for enroute, terminal and approach

area operations as discussed in section 2.2 and 2.4. This allows some of the RNP containment threshold to be allocated for Flight Technical Error. Therefore, knowing the Flight Technical Error characteristics for various modes of flight, a minimum RNP can be computed and demonstrated for each mode of flight and documented in the Airplane Flight Manual (AFM). Sections 10.1 and 10.2 explain how this will work.

3.3 RNP - Availability of Navigation Signals

Availability of navigation signals is the probability that the required navigation signals external to the aircraft will be present during the planned flight operation to provide the required level of accuracy and integrity for the selected RNP.

Availability of navigation signals is based on the number of satellites in the GPS constellation and their ability to provide the required GPS signals to meet the required accuracy and integrity for the selected RNP.

Availability of navigation signals for radio updating is based on navaid coverage for the region of operation and their ability to provide the required radio signals to meet the required accuracy and integrity for the selected RNP.

3.4 RNP - Availability of Navigation Equipment

Availability of navigation equipment is specified by the probability that the required navigation equipment on the airplane will be operational during the planned flight operation to perform the required level navigation capability.

Availability of navigation equipment is achieved by providing redundancy of the navigation systems on the airplane along with considering the reliability of each component used to perform each navigation operation.

Availability of navigation equipment is measured by performing an analysis of the airplane architecture redundancy and the failure rates of equipment required for the various navigation operations.

4. Flight Crew Interface updates for RNP and GPS

Functional crew interface requirements for the GPS and RNP functions include MCDU pages for display of GPS/RNP information and to provide certain control features, the MCDU scratch pad which provides related annunciation), EICAS where GPS-related fault information and RNP alerts are displayed, and the Navigation Display (ND) where GPS position, ADIRU position's, VOR bearing, DME slant range and navigation update mode are displayed (on Large Format Disply System 'LFDS' equipped airplanes only).

4.1 Position Initialization Page 1/4

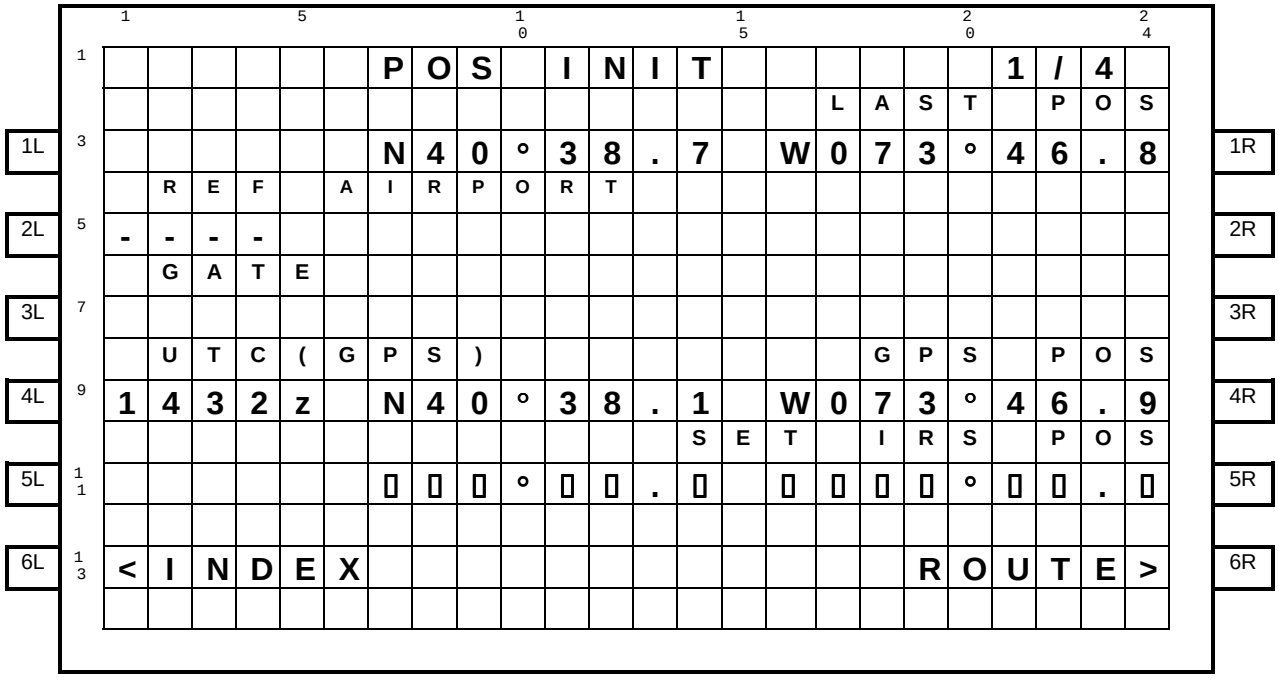

Figure 4.1-1 POS INIT 1/4 Page.

4L UTC

Displays UTC from either GPS or left clock or right clock, whichever is valid, in that order. If GPS is the source the header will display "UTC(GPS)", otherwise it will display "UTC(MAN)". GPS will only be used as a source of time if the GPS option has been selected.

4R GPS POS

Displays GPS position if GPS horizontal integrity limit is less than 0.5 NM., as an option for IRS alignment. Displays and header are blank if GPS option has not been selected.

4.2 Position Reference Page 2/4

Pos Ref 2/4 page with GPS updating active:

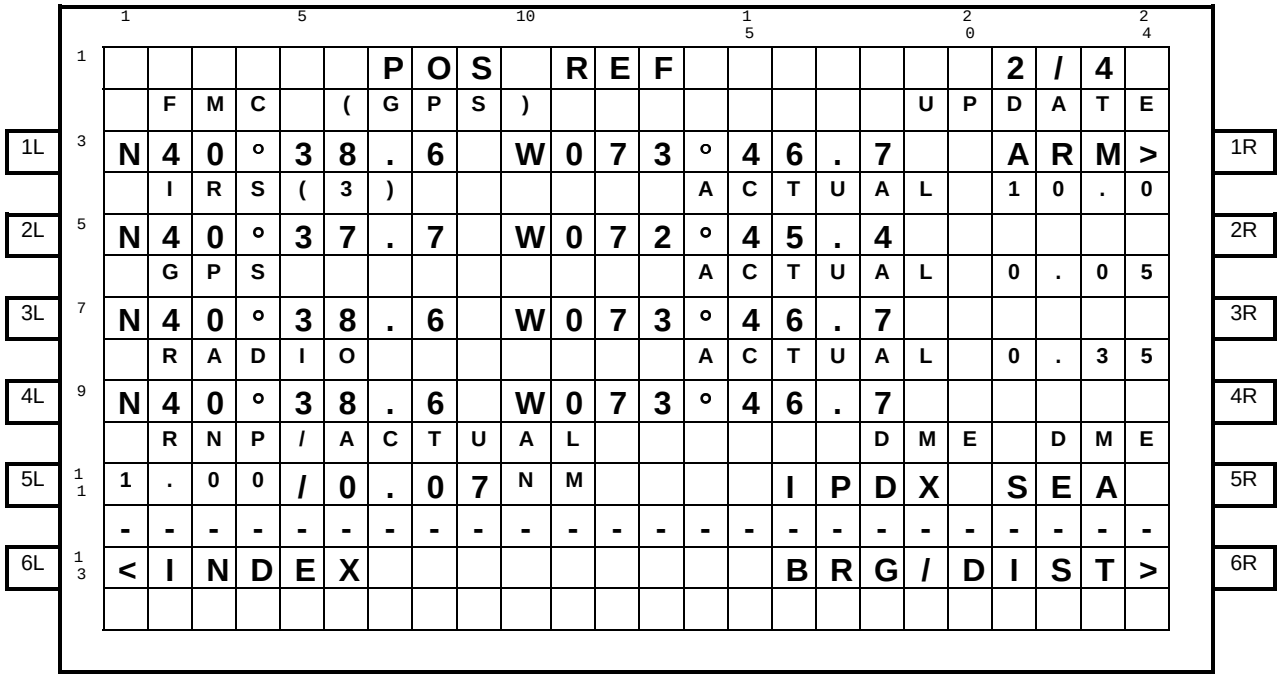

Figure 4.2-1 POS REF 2/4 Page GPS Updating, LAT/LON Format, With No Position Update Pending..

Pos Ref 2/4 page with radio updating active:

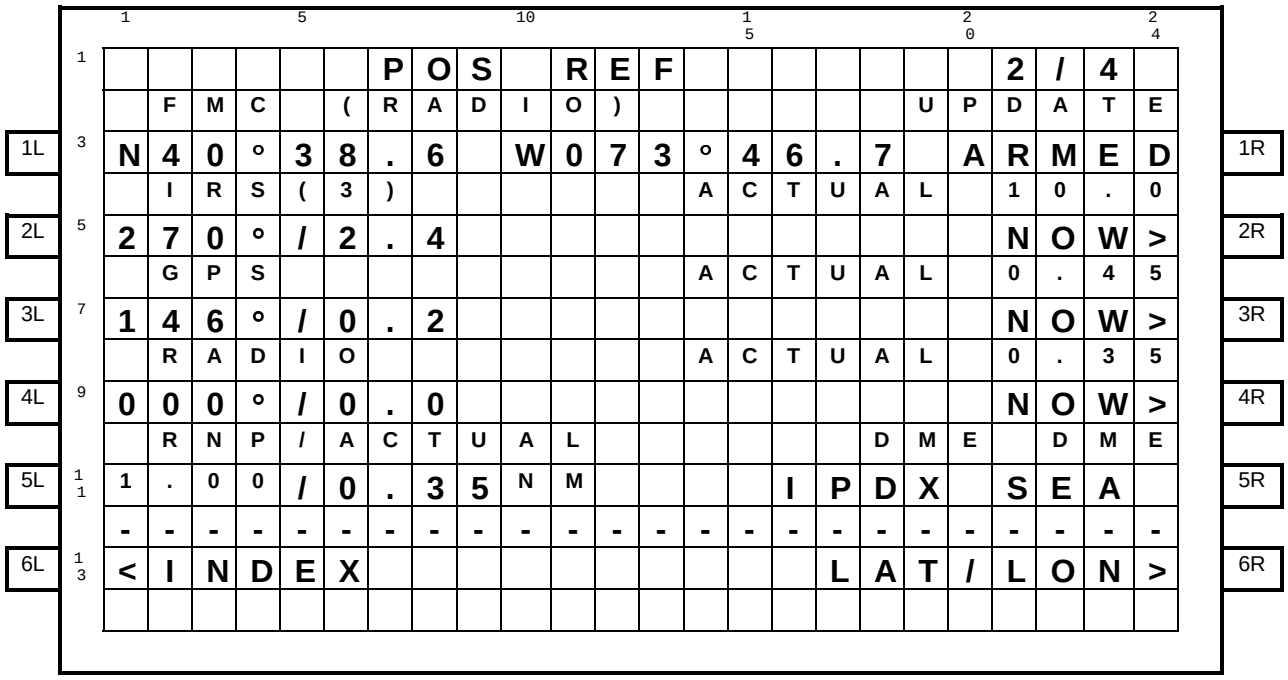

Figure 4.2-2 POS REF 2/4 Page Radio Updating, BRG/DIST Format, With Position Update Pending.

1L FMC POS

Displays FMC computed position based on the navigation source in parentheses. Possible navigation sources are LOC-GPS, LOC-RADIO, LOC, GPS, RADIO, or IRS. LAT/LON displays can be line selected to scratchpad.

2L INERTIAL

Displays the inertial reference position. Possible inertial reference position sources are IRS(3), IRS(L), IRS(C), IRS(R). LAT/LON displays can be line selected to scratchpad.

3L GPS

Displays the GPS position from the selected GPS position. LAT/LON displays can be line selected to scratchpad. Header and data line blank when the GPS option is not selected.

4L RADIO

Displays either a DME/DME or VOR/DME radio position computed from the navaids in 5R. Data field blank if no radio position computed. LAT/LON displays can be line selected to scratchpad.

5L RNP/ACTUAL

Displays the Required Navigation Performance (RNP) in columns 1-4. The source of the displayed RNP is either a manual entry, a NDB specified RNP, or a default RNP based on navigation phase of flight. Manual entry of RNP is displayed in large font. If there is no manual entry, RNP is displayed in small font. Display/entry range is 0.01 to 99.9.

Deletion of a manual entry will result in the display of first a NDB specified RNP if available or second a default RNP. Attempted deletion of RNP displayed in small font will result in the INVALID DELETE message.

Displays FMC computed Actual Navigation Performance (ACTUAL) for the FMC position displayed in 1L. ACTUAL is displayed in large font in columns 6-9. ACTUAL is displayed to tenths for values of 10 NM or larger, and to hundredths for values less than 10 NM. ACTUAL is the FMC computed 95% radial position certainty of the FMC position.

1R UPDATE/ARM>

Selection arms the position update function, causes the update NOW> prompts to appear adjacent to the inertial, GPS and radio positions, and causes the word ARMED to be displayed in placed of ARM. Subsequent selection of a NOW> updates the FMC position to the position corresponding to the NOW> prompt.

2R-4R ACTUAL/NOW>

Selection of NOW> updates the FMC position to the position corresponding to the NOW> prompt.

Displays the Actual Navigation Performance (ACTUAL) for each corresponding position in small font. ACTUAL is data is blank if no corresponding position is available for display.

5R NAV STA

Displays the identifier(s) of the navigation stations(s) currently being used to compute a radio position. Header displays the type of radio position (DME-DME or VOR-DME) currently being computed. NAV STA will be displayed in the header and the data line will be blank when no radio updating is occurring.

6R BRG/DIST

Initially displays BRG/DIST. Selection causes fields 2L through4L (and also fields 1L through 4L, when present, on the POS REF 3/4 page, and 1L through 3L on the POS REF 4/4 page) to be displayed in bearing/distance format, relative to the FMC position displayed in line 1L. If the distance is zero, the bearing will display 000 degrees. Selection also results in line 6R displaying the LAT/LON prompt. Selection of the LAT/LON prompt, or leaving the POS REF pages on both CDUs returns the position displays to latitude/longitude format and returns 6R to the initial display.

4.3 Position Reference Page 3/4

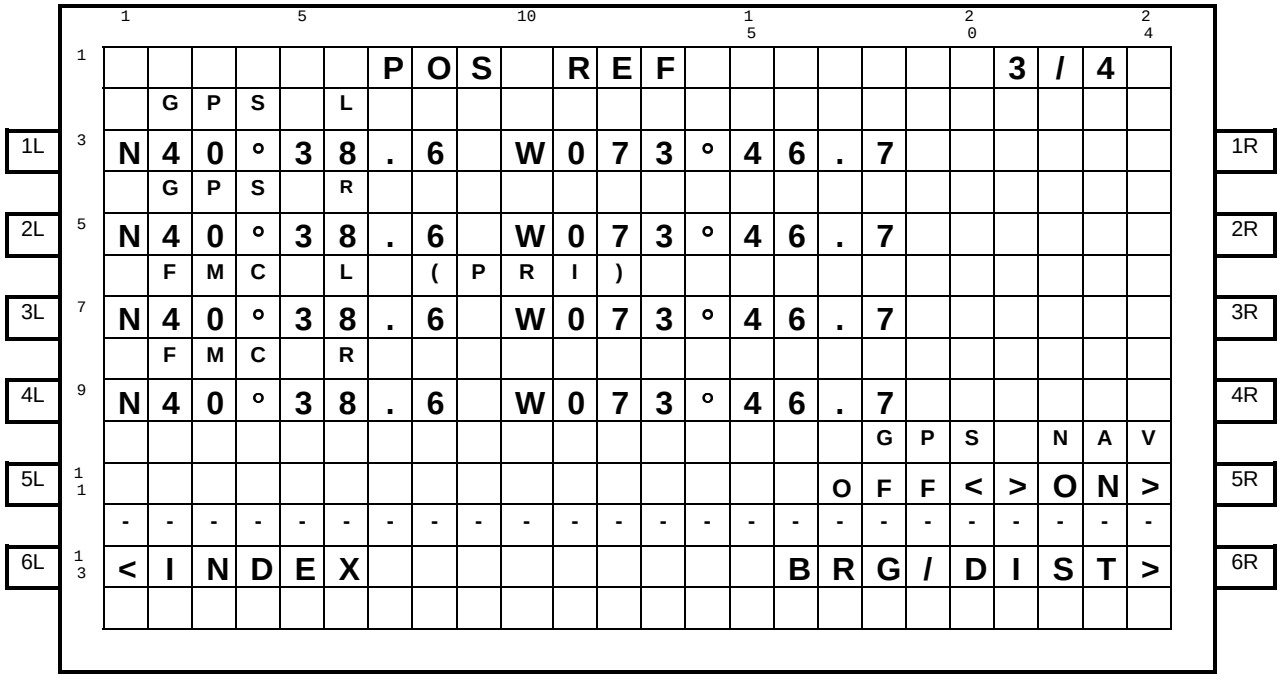

Figure 4.3-1 POS REF 3/4 Page.

1L-4L GPS AND FMC POSITION

Displays positions when computed by the indicated system. Display (PRI) next to the master FMC position which is currently providing navigation information to the guidance information for the autoflight system. LAT/LON displays can be line selected to scratchpad. 1L and 2L header and data line blank when the GPS option is not selected.

5R GPS NAV

Selection inhibits or enables the use of GPS data in the computation of the FMC position. The current state is displayed in large font green text. In the example, the GPS data is "ON" or enabled. "OFF" is displayed in small font text. If the line select key is depressed in the example "ON" will become small font text, "OFF" will become large font text. Header and data line blank when the GPS option is not selected.

4.4 Position Reference Page 4/4

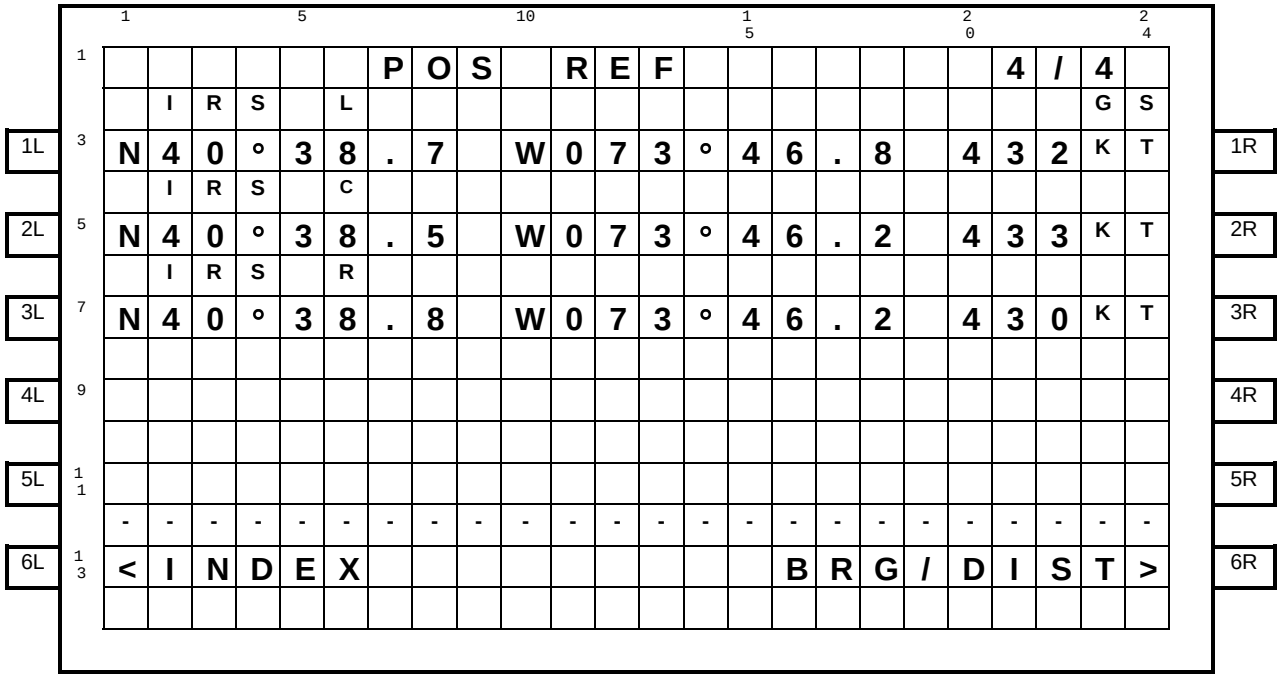

Figure 4.4-1 POS REF 4/4 Page.

1L-3L IRS POSITION

Displays positions when computed by the indicated system. LAT/LON displays can be line selected to scratchpad.

1R-3R GS

Ground speed associated with each of the indicated systems will be displayed. Displays of ground speed in 1R-3R will be frozen at flight completion and will be retained until power down, any IRU in ALIGN mode, or engine start.

4.5 MCDU Scratch Pad Messages

All of the following messages, with the exception of VERIFY RNP ENTRY message, when issued on the MCDU scratch pad, will be accompanied by the EICAS advisory message "FMC MESSAGE" which will be extinguished when the message is reset.

VERIFY POSITION

The onside and offside FMC position differ by more than greater of RNP or 0.4 NM for 5 seconds; or the difference between FMC position and the aiding sensor (GPS, Radio or Inertial) position is greater than 12 NM for 5 seconds.

VERIFY RNP - POS REF 2

The default RNP has changed, and the crew has previously entered a RNP value that exceeds the new default RNP value.

VERIFY RNP ENTRY

The crew has entered an RNP value on the POS REF 2/3 page, and the entered value is either greater than the default RNP value or less than the current Actual Navigation Performance value.

4.6 EICAS

EICAS advisory, level C, message "L GPS" or "R GPS" will be issued upon failure of the indicated GPS system. Failure of either a GPS sensor unit, antenna, or RF path between the antenna and SU will result in the message being issued.

The EICAS advisory, level C, message "GPS" will be issued upon loss of the GPS function. Appearance of this message indicates the total loss of GPS capability on the airplane and replace the EICAS advisory, level C, message "L GPS" or "R GPS ".

An EICAS advisory, level C, message "UNABLE RNP" will be issued when the ACTUAL navigation performance exceeds the RNP and the airplane is not in the approach.

An EICAS caution, level B, message "UNABLE RNP" will be issued when the ACTUAL navigation performance exceeds the RNP and the airplane is in the approach mode.

4.7 Navigation Display

The Navigation Display (ND) is where GPS position, ADIRU position's, VOR bearing's, DME slant range's and navigation update mode are displayed (on Large Format Display System 'LFDS' equipped airplanes only).

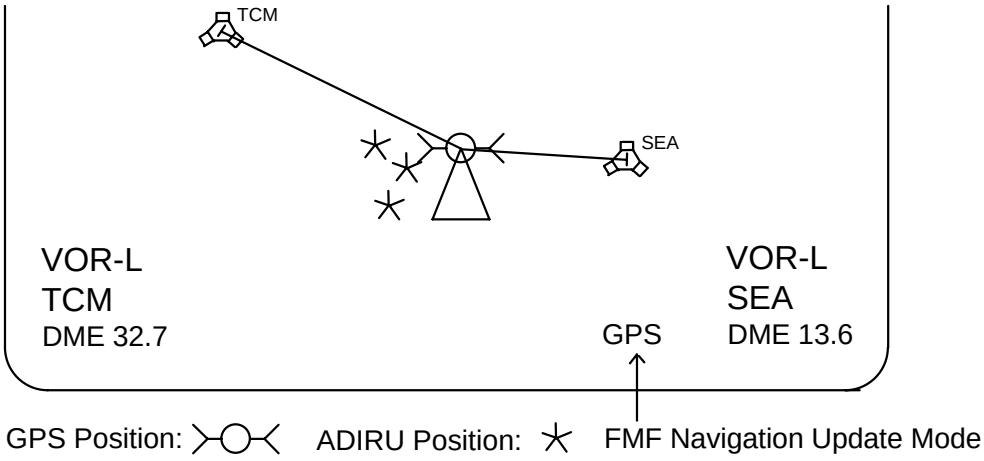

Figure 4.7-1 Navigation Display.

The symbols representing ADIRU positions, GPS left and right positions, VOR bearing and DME distance will be displayed on the ND when the POS switch has been selected on the EFIS control panel. When the GPS two symbols overlap due to close proximity of the two positions, only one symbol will be displayed.

The navigation mode annunciation and the corresponding data used to update the FMC position will be as follow:

Nav Mode on the ND	Type of position updating
LOC-GPS	Localizer and GPS position
LOC-DME-DME	Localizer and DME-DME position
LOC-VOR-DME	Localizer and VOR-DME position
LOC	Localizer
GPS	GPS position/GPS Only
DME-DME	DME-DME radio position
VOR-DME	VOR-DME radio position
INERTIAL	INERTIAL Only
Blank	No Position/Map Available

Figure 4.7-2 Navigation Mode Display.

5. Navigation System Capability Definitions

The definition of Primary, Enhanced Supplementary and Supplementary navigation systems in terms of RNP are provided.

5.1 Primary Means Navigation System

Primary Means - An integrated navigation system where greater than 99.999 % of the time, ANP is less than RNP. This includes loss of external navigation signals (i.e. not enough valid GPS satellites in view, or insufficient navaid coverage), and airplane navigation equipment availability (i.e. the failure rate of the navigation system to perform this function must be less than 1E-5 per flight hour). Failure of a "Primary Means" system may result in, or require reversion to a "non-normal" means of navigation or an alternate RNP.

This Primary Means definition is equivalent to the proposed ICAO Circular 267-AN/159 definition for a Sole-means navigation system. The proposed ICAO definition is stated as follows:

"Sole-means navigation system. A sole-means navigation system approved for a given operation or phase of flight must allow the aircraft to meet, for that operation or phase of flight, all four navigation system performance requirements: accuracy, integrity, availability and continuity of service.

Note: - This definition does not exclude the carriage of other navigation systems. Any sole-means navigation system could include one (stand-alone installation) or several sensors, possibly of different types (multi-sensor installation)."

5.2 Deleted

5.3 Supplementary Means Navigation System

Supplementary Means - An integrated navigation system where less than 99.999 % of the time, ANP is less than RNP. Failure of a "Supplementary Means" system may result in, or require reversion to, another RNP or alternate "normal" means of navigation for that area, airspace, route, procedure, or operation.

5.4 Primary Means RNP Example

The following is an example of what is defined by a Primary Means RNP 1.0. Primary Means RNP 1.0 defines an accuracy requirement of 1.0 NM, a containment radius requirement of 2.0 NM, an availability of navigation signals requirement to greater than 99.999 %, and an availability of navigation equipment requirement of greater than 1E-5 per flight hour for loss of function. The containment probability level requirement will be a function of the type of flight operation. For enroute and terminal area operations route separation, the containment probability level requirement is 1E-5 per flight hour. For terminal area and approach procedures obstacle clearance, the containment probability level requirement is 1E-7 per procedure.

6. Navigation Capability of the FMCS

The navigation capability of the airplane is defined by the navigation signals available at the current airplane location and the operational sensor on the airplane. The following sections define the airplanes navigation capabilities in

terms of GPS satellite signal availability to fly a selected RNP and the range and or typical values of ANP based on the position update mode.

6.1 GPS/IRS/FMC RNP Availability

The following table is a summary of FMC/GPS/IRS RNP availability from the Global Positioning System Performance Analysis, Document Number D244W018-3, Revision -, dated 11/10/94. The table is based on the following GPSSU and satellite configuration assumptions which apply to the FANS 1 system:

1) No Baro-Aiding (RAIM augmentation), no local area or wide area differential, or GIB (GPS Integrity Broadcast) in the GPSSU.
2) A 2.0 degree mask angle in the GPSSU.
3) FMC provides alternate GPS integrity. (NAIM).
4) FMC selects the update sensor set with the best accuracy.

	FMCS/GPS/IRS World-Wide Navigation Signal Availability for Selected RNP						
Number of Satellites In GPS Constellation	RNP 12.0	RNP 4.0	RNP 2.0	RNP 1.0	RNP 0.5	RNP 0.3	RNP 0.15
24 #	>99.999%	>99.999%	>99.999%	>99.999%	99.99%	99.98%	99.64%
23	>99.999%	>99.999%	99.99%	99.98%	99.89%	99.71%	97.83%
22	>99.999%	99.98%	99.94%	99.81%	99.48%	98.80%	94.50%
21	>99.999%	99.93%	99.77%	99.34%	98.45%	96.99%	89.42%

Figure 6.1-1 FMCS/GPS/IRS World-Wide Navigation Availability for Selected RNP.

Based on the above preliminary results FANS 1 is capable of provide the following levels of navigation with GPS:

	FMCS/GPS/IRS Navigation Performance Capability Versus Selected RNP						
Number of Satellites In GPS Constellation	RNP 12.0	RNP 4.0	RNP 2.0	RNP 1.0	RNP 0.5	RNP 0.3	RNP 0.15
24 #	PRIM	PRIM	PRIM	PRIM	SUPP*+	SUPP+	SUPP+
23	PRIM	PRIM	SUPP*+	SUPP*+	SUPP*+	SUPP+	SUPP+
22	PRIM	SUPP*+	SUPP*+	SUPP*+	SUPP*+	SUPP+	SUPP+
21	PRIM	SUPP*+	SUPP*+	SUPP*+	SUPP*+	SUPP+	SUPP+

Figure 6.1-2 FMCS/GPS/IRS Navigation Performance Capability Versus Selected RNP.

Key:

PRIM - Primary means of navigation per the definition in section 5.1.
SUPP - Supplementary means of navigation per the definition in section 5.3.
* - Indicates that the selected RNP is available as a primary means of navigation means if in a region of DME/DME navigation radio coverage.
+ - Indicates that the selected RNP may be available as a primary means of navigation if a prediction has been performed that shows there will be sufficient GPS accuracy and integrity during the time and place where the RNP flight operation is to be flown.
# - If there are more than 24 satellites available in the GPS constellation the actual Navigation Signal Availability and Performance Capability will be better than the values shown on this line.

6.2 Preliminary Method for Predicting GPS/IRS/FMC RNP Availability

The airlines may use off the shelf GPS prediction programs to determine the availability of GPS accuracy and RAIM provided integrity during the time and place where the RNP flight operation is to be flown. The off the shelf prediction program should allow for entry of specific satellites that have been identified by the Notam service, ADIS or other notification means as being not operational and should consider them in the predictions. This prediction may be done at the time of dispatch, and may also be available just prior to performing a specific flight operation via voice or datalink communications.

This prediction method may be used for the smaller RNPs in table 6.1-2 identified as Supplementary means of navigation. It will determine if the predicted GPS navigation signals at a particular time and location will support a Primary means of navigation flight operation.

6.3 FMC ANP Capability for Modes Other Than IRS/GPS

The following are the ANP capabilities of the FMCS for the position update modes other than IRS/GPS. These numbers are the result of an analysis that used existing accepted industry error characteristics of the VOR and DME and combined them based on the update mode. The IRS error mode for less than three hours following position updating was developed by Boeing to account for the schuler affect of the IRS better than the 2*T model accepted by the industry. Values for each mode are given as range of possible values or typical values.

NAVIGATION POSITION UPDATE MODE	RANGE OF ANP VALUES/ANP TYPICAL VALUES
IRS/LOC/(GPS)	This assumes a valid GPS position with an HFOM of 0.054 NM (100 meters), and the Range of ANP below starts at 20 NM from the Localizer and goes to the runway threshold assuming a ground speed of 200 knots. Typical ANP; 0.12 to 0.04 NM
IRS/LOC/(DME/DME)	This covers a DME/DME include angle range of 150 to 30 degrees, and the Range of ANP below starts at 20 NM from the Localizer and goes to the runway threshold assuming a ground speed of 200 knots. Range of ANP; 0.34 to 0.17 NM
IRS/LOC/(VOR/DME)	This covers the VOR/DME update navaid range of 40.0 to 0.6 NM, and the Range of ANP below starts at 20 NM from the Localizer and goes to the runway threshold assuming a ground speed of 200 knots. Range of ANP; 1.17 to 0.14 NM
IRS/LOC	This is a typical ANP assumes an initial ANP of 0.4 NM, and the Typical ANP below starts at 20 NM from the Localizer and goes to the runway threshold assuming a ground speed of 149 knots Typical ANP; 0.30 to 0.87 NM.
IRS/DME/DME	This covers a DME/DME include angle range of 150 to 30 degrees, and assumes a ground speed of 650 knots. Range of ANP; 1.00 to 0.54 NM This covers a DME/DME include angle range of 150 to 30 degrees, and the Range of ANP below starts at 20 NM from the runway threshold and goes to the runway threshold assuming a ground speed of 200 knots. Range of ANP; 0.48 to 0.24 NM
IRS/VOR/DME	This covers the VOR/DME update navaid range of 40.0 NM flying toward the navaid, 25 flying away from the navaid and excluding the inverted 60 degree zone of confusion. It also assumes a ground speed of 650 knots. Range of ANP; 1.65 to 0.60 NM This covers the VOR/DME update navaid range, and the Range of ANP below starts at 20 NM from the runway threshold and goes to the runway threshold assuming a ground speed of 200 knots. Range of ANP; 1.65 to 0.20 NM

Figure 6.3-1 FMC ANP Capability.

NAVIGATION POSITION UPDATE MODE	RANGE OF ANP VALUES/ANP TYPICAL VALUES
IRS	For IRS Only mode, ANP is the root sum square of the ANP that exists at the loss of position updating and the following 95% IRS drift characteristics: 0.0 to 0.5 hours; IRS 95% ERROR = 8.0* T NM 0.5 to 1.5 hours; IRS 95% ERROR = 4.0 NM 1.5 to 2.0 hours; IRS 95% ERROR = 4.0* (T - 1.5) + 4.0 NM 2.0 to 3.0 hours; IRS 95% ERROR = 6.0 NM 3.0 to 10.0 hours; IRS 95% ERROR = 2.0* (T - 3.0) + 6.0 NM 10.0 and on hours; IRS 95% ERROR = 20.0 NM Assuming an initial ANP of 0.40 NM, and a ground speed of 650 knots, typical ANP values range from 0.40 NM (at loss of updating) to 20.0 NM (after 10 hours of no updating). For a 20 NM approach scenario where the initial ANP is 0.40 NM, with a speed of 149 knots, and the entire approach is flown with no position updating. The ANP would range from 0.40 NM (at the beginning of the approach) to 1.21 NM (at the runway threshold).
TOGA position update	For TOGA takeoffs the FMC position is updated to the runway threshold plus pilot entered bias and ANP is initialized to 0.5 NM. Following TOGA while in IRS only the ANP will increase at the 8 knots for up to 30 minutes then remain constant for one hour. The following the range of ANP following a TOGA while in IRS only mode: Range ANP, 0.5 NM at TOGA, 0.83 NM at 5 minutes after TOGA, 1.42 NM at 10 minutes after TOGA, and 4.03 NM at 30 minutes after TOGA.

Figure 6.3-1 (Cont.) FMC ANP Capability.

7. Flight Technical Error (FTE)

Flight Technical Error FTE is defined as the ability of the pilot or the avionics to fly the airplane to the selected path. The industry standard lateral path FTE 95% values (per DO-208 appendix E) for each of mode of flight are given in the table below:

Mode Of Flight	Flight Technical Error (FTE) 1.96 Sigma (95%)	
	Enroute	Terminal/Approach
LNAV with the Autopilot Coupled	0.125 NM	0.125 NM
LNAV with the Flight Director Coupled	0.250 NM	0.250 NM
Manual Flight with the MAP on the ND	1.000 NM	0.500 NM

Note: Enroute FTE value of 1.00 NM, for manual flight with the MAP on the ND, is based on the 747-400 FTE study, since it is not provided in DO-208.

Figure 7.-1 Lateral Path FTE per DO-208 Appendix E

8. FANS 1 757/767 FMCS AFM Updates

Proposed AFM section 3.1 words for the FMCS in regards to RNP operations.

Section 3.1

NORMAL PROCEDURES

FLIGHT MANAGEMENT COMPUTER SYSTEM (FMCS)

The following FMCS demonstrations do not constitute operational approval.

The Flight Management Computer System (FMCS) has been shown to meet the requirements of FAA Advisory Circular (AC) 25-15 for long range navigation with the following equipment operational at departure:

One Flight Management Computer (FMC); two Hybrid Multipurpose Control Display Units (HMCDUs) or Multipurpose Control Display Units (MCDU); and two Inertial Reference Units (IRU) in NAV mode.

The FMCS has been shown to meet the requirements for RNAV operations (FAA AC 20-130A, JAA AMJ 20X2) the following equipment must be operational at departure (unless other appropriate procedures are used):

One FMC; one CDU, MCDU or HMCDU; one VHF Omni-directional Radio (VOR); one IRU in NAV mode; and either one Distance Measuring Equipment (DME) or Global Positioning System (GPS) (if installed).

The FMCS has been shown to meet the requirements of AC 20-130A for a multi-sensor area navigation system when operated with radio or GPS updating. When operated in this configuration, the FMCS may be used for enroute, terminal area operations and instrument approach navigation (excluding ILS, LOC, LOC-BC, LDA, SDF, and MLS). The FMCS will provide navigation, guidance, and map display between 87 degrees North and 87 degrees South latitude.

The FMCS has been shown to meet the requirements of AC 20-129 for vertical navigation (VNAV) for enroute, terminal area operations and instrument approaches (excluding ILS G/S).

GPS updating must be disabled for approach operations when operating outside the United States National Airspace, if the FMC database and charts are not referenced to WGS-84 reference datum, unless other appropriate procedures are used.

For flight operations without Required Navigational Performance (RNP), when using the FMCS to conduct terminal area procedures or instrument approaches, radio or GPS updating should be verified as appropriate to the procedure being flown.

For flight operations without RNP, the FMCS with the MAP display has been demonstrated for enroute and terminal area flight operations and instrument approach navigation (excluding ILS, LOC, LOC-BC, LDA, SDF, and MLS). In addition, the FMCS has been demonstrated with the MAP display as a supplement to other primary means navigation systems.

FLIGHT MANAGEMENT COMPUTER SYSTEM (FMCS) (CONTINUED)

Required Navigational Performance (RNP) Operations

For RNP operations, the demonstrated RNP capabilities are as follows:

Demonstrated RNP Flight Capability Versus Mode Of Flight		
Mode of Flight	FMC GPS Operational	FMC GPS Not Operational
LNAV with Autopilot Engaged	0.20 NM	0.26 NM
LNAV with Flight Director	0.39 NM	0.52 NM
Manual Control with MAP display only	0.92 NM	1.79 NM

The demonstrated RNP capabilities are predicated upon the assumptions, definitions, requirements and analysis in the FAA approved Boeing Document D926T0120, "RNP Capability of FANS 1 FMCS Equipped 757/767"

RNP flight operations are subject to assessment of GPS satellite availability and/or navaid coverage for the selected route.

The FMCS has been shown to meet the primary means RNP navigation with the following equipment operational at departure:

Two FMCs; two CDUs, HMCDUs, or MCDUs; two IRUs in NAV mode; and two sensors capable of complying with the RNP.

The FMCS has been shown to meet the requirements of AC 20-130A for multi-sensor instrument approach navigation, when operated with the following or smaller RNP values:

Approach Type	RNP
NDB, NDB/DME	0.6 NM
VOR, VOR/DME	0.5 NM
RNAV	0.5 NM
GPS	0.3 NM

8.1 Rationale for Proposed AFM Words

The minimum demonstrated RNP values for each mode of operation in the AFM were determined based on two factors. The first is the ability of the pilot to fly the airplane to the selected path (i.e. FTE). The second is when to provide the pilot with a warning that the ANP of the position being used to fly the airplane does not meet the RNP for the selected route. The minimum RNP value in the proposed AFM is the RNP that is entered on the POS REF 2/4 page. The minimum RNP values for each mode of flight are based on the tables in sections 10.1 and 10.2. By selecting theses minimum RNP values a RNP containment threshold of RNP times two will be protected such that

FTE and navigation position determination error will be included. Annunciation that ANP is greater than RNP, will indicate that the FMC position used as the reference for FTE indications is no longer adequate to ensure protection of the containment threshold for the selected RNP.

9. Propose FANS 1 MMEL

The following are the the proposed 757-200/-300 and 767-200/-300/-400 GPS, FMCS and IRS MMEL with the FANS 1 FMCS installed:

U.S. DEPARTMENT OF TRANSPORTATION				
			MASTER MINIMUM EQUIPMENT LIST	
FEDERAL AVIATION ADMINISTRATION				
AIRCRAFT:			REVISION NO:	PAGE:
BOEING 767			DATE:	
1. SYSTEM & SEQUENCE NUMBERS — ITEM	2. NUMBER INSTALLED	3. NUMBER REQUIRED FOR DISPATCH	4. REMARKS OR EXCEPTIONS	
-21-1 Inertial Reference Systems				
1) IRU (-200/-300)				
A) Without Hydraulic Motor Generator (HMG) Installed C	3	2	(M)(O)Either Center or Left may be inoperative unless approach minimums require its use.	
C	3	2	(M)(O)Right may be inoperative for day VMC flight.	
B) With HMG Installed C	3	2	(M)One may be inoperative provided: a) Approach minimums do not require its use, b) If Left or Right is inoperative, isolation is verified by an accepted maintenance procedure each flight day, and c) For ER operations, Left and Center must operate normally.	
2) ADIRU Inertial Function (-400) C	3	2	(M)One may be inoperative provided: a) Approach minimums do not require its use, b) If Left or Right is inoperative, isolation is verified by an accepted maintenance procedure each flight day.	

U.S. DEPARTMENT OF TRANSPORTATION

MASTER MINIMUM EQUIPMENT LIST

FEDERAL AVIATION ADMINISTRATION

AIRCRAFT:	REVISION NO:	PAGE:
BOEING 767	DATE:	

1. SYSTEM & SEQUENCE NUMBERS	ITEM	2. NUMBER INSTALLED	3. NUMBER REQUIRED FOR DISPATCH	4. REMARKS OR EXCEPTIONS
***	3) IRS Mode Selector Panel - Display and Keyboard Functions C	-	0	For ER operations, may be inoperative provided both FMCS CDU's operate normally.
	C	-	0	For Non-ER operations, may be inoperative provided one FMCS CDU operates normally.
60-3 ***	Global Positioning System (GPS) C	-	0	(O) May be inoperative provided alternate procedures are established and used.
	D	-	0	May be inoperative provided procedures do not require its use.

U.S. DEPARTMENT OF TRANSPORTATION

MASTER MINIMUM EQUIPMENT LIST

FEDERAL AVIATION ADMINISTRATION

AIRCRAFT:	REVISION NO:	PAGE:
BOEING 767	DATE:	

SYSTEM & SEQUENCE NUMBERS	ITEM	1.	2. NUMBER INSTALLED	3. NUMBER REQUIRED FOR DISPATCH	4. REMARKS OR EXCEPTIONS
61-1	Flight Management Computer System (FMCS)				
	1) FMC(Including CDU/HMCDU/MCDU) (-200/-300)	C	2	1	Except for ER operations, may be inoperative.
		C	2	0	(M)Except for ER operations, may be inoperative provided: a) Both Fuel Quantity Indicating System (FQIS) processor channels operate normally, and b) All flight deck fuel quantity indications operate normally, and c) Enroute Operations do not require its use
		C	2	1	For ER operations, may be inoperative provided other accepted means of navigation is available. NOTE: An associated HMCDU or MCDU, if operative, may be used to meet navigation requirements.
	2) FMC (-400)	C	2	1	One may be inoperative provided enroute operations do not require its use. NOTE: Left and right MCDU must be operative.

10. Possible Application of RNP

RNP will be an integral tool used in the planning of airspace, routes, procedures, operations or approaches. Following are two examples of how RNP might be applied to two different types of flight operations. Other applications for RNP will be devised in the future by PART 121 operations authorities and the airlines once RNP functionality is available.

For each of these examples the minimum demonstrated RNP shall be computed that accounts for FTE in the lateral containment threshold. This analysis will be used to determine the minimum demonstrated RNP for the AFM. The lateral containment threshold shall account for FTE, ANP, and path definition. The following assumption are made for this analysis:

1. FTE has a normal distribution.
2. ANP has a Rayleigh distribution.
3. FTE and ANP are independent.
4. Path definition error is zero relative to the minimum demonstrated RNP.

   [The basis for this assumption is that a reliable, repeatable, and predictable path is assured or mitigated by the following:

   Flight plans for RNP routes and procedures are comprised of specific, permissible leg types consistent with those being prescribed by industry groups such as SC 181. These leg types are direct to a fix (DF), course to a fix (CF), track to a fix (TF), initial fix (IF), and holding patterns (HX). Even in the case of these permissible leg types, the path definition error contribution may need further evaluation for the planned RNP operation considering the earth model, fix resolution, turn radius resolution, course resolution and/or magnetic variation that apply to each leg type.

   Surveys, fixes, procedure design, ATC coordination, testing/demonstration, crew qualification/training, crew procedures, obstacle assessments, and fly ability are evaluated for their acceptability for the planned RNP level and operation.]

Two cases must be considered when determining the minimum RNP. The first case is for no navigation data error or sensor input failures and an alert is issued when ANP exceeds RNP. The second case is when a navigation data error or sensor input failure has occurred and an alert is issued when ANP exceeds RNP. For the first case the minimum RNP is determined by solving the following equation for RNP with ANP equal to RNP:

$$2*RNP = ((ANP\ CT)^2+(FTE\ CT)^2)^0.5$$

Where:

ANP CT is the Rayleigh distributed ANP containment radius scaled to a normal distribution containment threshold.

FTE CT is the normal distributed FTE for an equivalent probability as ANP CT.

For the second case the minimum RNP is determined by solving the same equation for RNP with ANP equal to the nominal error for the selected update mode after a failure has occurred.

10.1 Enroute/Terminal Route Separation

Airplanes with RNP functionality will be able to fly routes with reduced lateral separation. The reduced separation will provide increased route capacity. This will provide the following benefits to the airlines:

1. Improve "on-time" performance through the use of more direct and optimal routing.
2. Increase number of available routes for crossing the Atlantic and Pacific.
3. Increase number of airplanes that can safely fly on a particular route, airway or airspace.

This will provide the following benefits to the ATC agencies:

1. Reduced route congestion on existing airway structure, by increasing the number of available routes.

2. Increased safety by providing better method for the flight crew to monitor compliance with route requirements.

The requirement for route separation is that aircraft not exceed lateral containment threshold of 2* RNP with a probability of 1E-5 per flight hour.

With GPS updating the following are used to solve for minimum RNP :

Case 1: GPS updating with no failure and alert issued.

ANP CT probability is 99.9%
ANP CT = (3.29/2.448) * (0.59) * ANP
ANP CT = 0.79 * ANP

[99.9% ANP CT is used instead of a 99.999% ANP CT due to the conditional probability that an EICAS advisory, level C, message "UNABLE RNP" will not be issued for an for RNP 1.0 with a 99% probability based on the worldwide availability of RNP with 21 satellites operational as shown in section 6.1. The (3.29/2.448) factor first scales the 95% Rayleigh distributed ANP to a one sigma number by dividing by 2.448, then scales it to a 99.9% normal distribution by multiplying by 3.29. This same scaling process is used throughout the section 10.1 and 10.2. 0.59 is the conservatism in displayed ANP per section 1.2]

FTE CT probability is 99.9%
FTE CT = (3.29/1.96) * FTE
FTE CT = 1.68 * FTE

Minimum RNP = 1.68 * FTE / SQRT (4 - 0.79^2)
Minimum RNP = 0.91 * FTE

Case 2: GPS updating with failure and alert issued.

ANP CT probability is 90.0%
ANP CT = (1.64/2.146) * (0.88*ANP)
ANP CT = 0.67 * ANP

[(0.88*ANP) is the 1E-5 per flight hour GPS containment radius from section 2.2. This is achieved based on the assumed satellite failure rate of 1E-4 per flight hour. There is no conservatism assumed in the displayed ANP, since latency would be insignificant HIL for these cases]

FTE CT probability is 90%
FTE CT = (1.64/1.96) * FTE
FTE CT = 0.88 * FTE

Minimum RNP = 0.88 * FTE / SQRT (4 - 0.67^2)
Minimum RNP = 0.44 * FTE

Mode of Flight	Case 1 Minimum RNP	Case 2 Minimum RNP	Minimum RNP
LNAV with Autopilot Engaged	0.11 NM	0.06 NM	0.12 NM
LNAV with Flight Director	0.23 NM	0.11 NM	0.25 NM
Manual Control with MAP display only	0.91 NM	0.44 NM	0.91 NM

Figure 10.1-1 Minimum RNP with GPS Operational for Route Separation (Enroute/Terminal) Operations.

For radio updating the following are used to solve for minimum RNP:

Case 1: Radio updating no failure and alert issued.

ANP CT probability is 99.999%
ANP CT = (4.42/4.798) * (1.69*ANP)
ANP CT = 1.56 * ANP

[(1.67*ANP) is the 1E-5 per event radio containment radius from section 2.4)]

FTE CT probability is 99.999%
FTE CT = (4.42/1.96) * FTE
FTE CT = 2.25 * FTE

Minimum RNP = 2.25 * FTE / SQRT (4 - 1.56^2)
Minimum RNP = 1.80 * FTE

Case 2: Radio updating with failure and alert issued.

ANP CT is 1.5*ANP — [Radio validation criteria will reject radio position data with errors in excess of 1.5*ANP from the current FMC position.]

FTE CT probability is 99%
FTE CT = (2.58/1.96) * FTE
FTE CT = 1.32 * FTE

[99% FTE CT is used instead of a 99.999% FTE CT due to the conditional probability that navigation data or a sensor has failed is assumed to be 1E-3 per flight hour.]

Minimum RNP = 1.32 * FTE / SQRT (4 - 1.50^2)
Minimum RNP = 1.00* FTE

Mode of Flight	Case 1 Minimum RNP	Case 2 Minimum RNP	Minimum RNP
LNAV with Autopilot Engaged	0.22 NM	0.13 NM	0.22 NM
LNAV with Flight Director	0.45 NM	0.25 NM	0.45 NM
Manual Control with MAP display only	1.79 NM	1.00 NM	1.79 NM

Figure 10.1-2 Minimum RNP with GPS not operational for Route Separation (Enroute/Terminal) Operations.

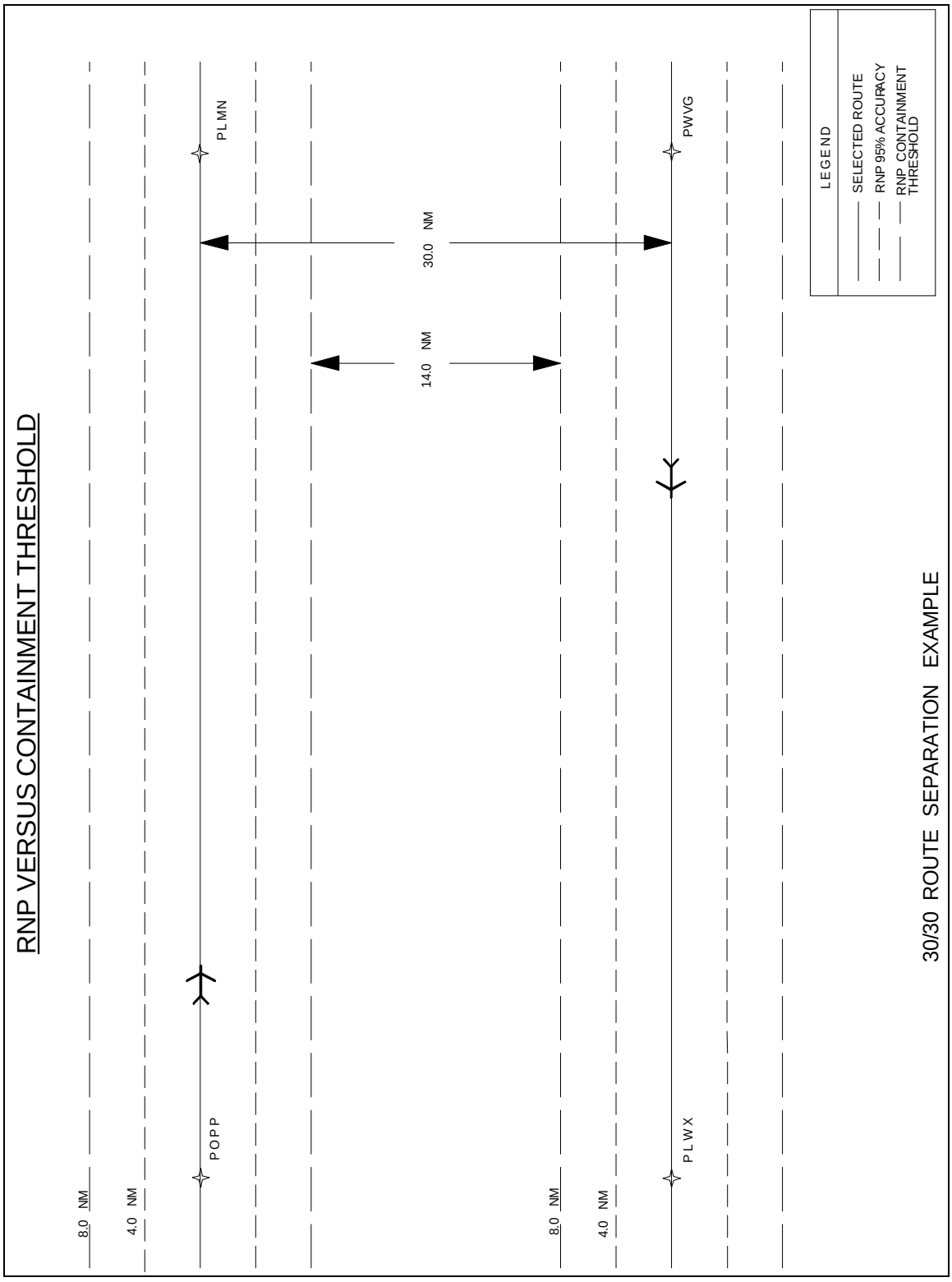

Figure 10.1-4: 30/30 Route Separation Example

10.2 Terminal/Approach Obstacle Clearance

RNP capable airplanes will be able to fly takeoff, terminal approach transition and approach procedures with reduced obstacle clearance requirements. The reduced obstacle clearance requirement will provide increased availability of these IFR procedures at the airports by reducing minima and visibility requirements. The reduced obstacle clearance requirements will provide benefits to the airlines and the ATC authorities. The airlines will reduce flight cancellations and improve "on-time" performance by having a higher availability of procedures to get in and out of airports. The ATC agencies will have an increased number of procedures available to them to spread the air traffic more evenly, reduce the amount of congestion in the terminal area, and a greater number of procedures for getting into and out of airports, thereby increasing safety in the terminal area.

The requirement for obstacle clearance spacing is that aircraft not exceed lateral containment threshold of 2* RNP with a probability of 1E-6 per flight hour. The minimum RNP can be computed using the same analysis as was done in section 10.1.

With GPS updating the following are used to solve for minimum RNP :

Case 1: GPS updating with no failure and alert issued.

ANP CT probability is 99.999%
ANP CT = (4.42/2.448) * (0.77) * ANP
ANP CT = 1.39 * ANP

[99.999% ANP CT is used instead of a 99.9999% ANP CT due to the conditional probability that an EICAS advisory, level C, "UNABLE RNP" alert will not be issued for an for RNP 0.15 with a 90% probability based on the worldwide availability of RNP with 21 satellites operational as shown in section 6.1. The 0.77 is the conservatism in displayed ANP per section 1.2]

FTE CT probability is 99.999%
FTE CT = (4.42/1.96) * FTE
FTE CT = 2.25 * FTE

Minimum RNP = 2.25 * FTE / SQRT (4 - 1.39^2)
Minimum RNP = 1.56 * FTE

Case 2: GPS updating with failure and alert issued.

ANP CT probability is 99%
ANP CT = (2.58/3.035) * (1.24*ANP)
ANP CT = 1.05 * ANP

[(1.24*ANP) is the 1E-6 per flight hour GPS containment radius from section 2.2. This is achieved based on the assumed satellite failure rate of 1E-4 per flight hour]

FTE CT probability is 99%
FTE CT = (2.58/1.96) * FTE
FTE CT = 1.32 * FTE

Minimum RNP = 1.32 * FTE / SQRT (4 - 1.05^2)
Minimum RNP = .78 * FTE

Mode of Flight	Case 1 Minimum RNP	Case 2 Minimum RNP	Minimum RNP
LNAV with Autopilot Engaged	0.20 NM	0.10 NM	0.20 NM
LNAV with Flight Director	0.39 NM	0.19 NM	0.39 NM
Manual Control with MAP display only	0.78 NM	0.39 NM	0.78 NM

Figure 10.2-1 Minimum RNP with GPS operational for Obstacle Clearance (Approach/Terminal) Operations.

For radio updating the following are used to solve for minimum RNP:

Case 1: Radio updating no failure and alert issued.

ANP CT probability is 99.9999%
ANP CT = (4.42/4.798) * (1.74*ANP)
ANP CT = 1.60 * ANP

[(1.73*ANP) is the 1E-5 per event radio containment radius from section 2.4 coupled with the required pilot monitoring of radio data as called out in the AFM gets to the 99.9999% ANP required for this computation]

FTE CT probability is 99.9999%
FTE CT = (4.89/1.96) * FTE
FTE CT = 2.49 * FTE

Minimum RNP = 2.49 * FTE / SQRT (4 - 1.60^2)
Minimum RNP = 2.08 * FTE

Case 2: Radio updating with failure and alert issued.

ANP CT is ANP * 1.5 [Radio validation criteria will reject radio position data with errors in excess of 1.5*ANP from the current FMC position.]

FTE CT probability is 99.9%
FTE CT = (3.29/1.96) * FTE
FTE CT = 1.68 * FTE

[99.9% FTE CT is used instead of a 99.9999% FTE CT due to the conditional probability that navigation data or a sensor has failed is assumed to be 1E-3 per flight hour.]

Minimum RNP = 1.68 * FTE / SQRT (4 - 1.50^2)
Minimum RNP = 1.27 * FTE

Mode of Flight	Case 1 Minimum RNP	Case 2 Minimum RNP	Minimum RNP
LNAV with Autopilot Engaged	0.26 NM	0.16 NM	0.26 NM
LNAV with Flight Director	0.52 NM	0.32 NM	0.52 NM
Manual Control with MAP display only	1.05 NM	0.63 NM	1.05 NM

Figure 10.2-2 Minimum RNP with GPS not operational for Obstacle Clearance (Approach/Terminal) Operations.

Figure 10.2-4 is an example of how obstacle clearance for approach procedures could be implemented. For this example a navigation system capable of RNP 0.3 is used. RNP 0.3 has a limiting containment threshold of 0.60 NM. This flight operation could be accomplished if an RNP of 0.3 is selected on the POS REF 2/3 page and the approach is flown LNAV coupled with the autopilot with GPS updating as required per the proposed AFM (Section 8.). This example has a buffer surface between the RNP containment radius threshold and any obstacles. The purpose of this buffer surface is to provide increased safety for initial implementations where ADS and ATS may not be implemented. Once operational experienced is gained to prove the system this buffer surface will be reduced. Once ADS and ATS are fully implemented the buffer surface an be completely eliminated and the obstacle clearance spacing can be the limiting containment threshold. This same concept could also be applied to procedures with RNPs of less than 0.3.

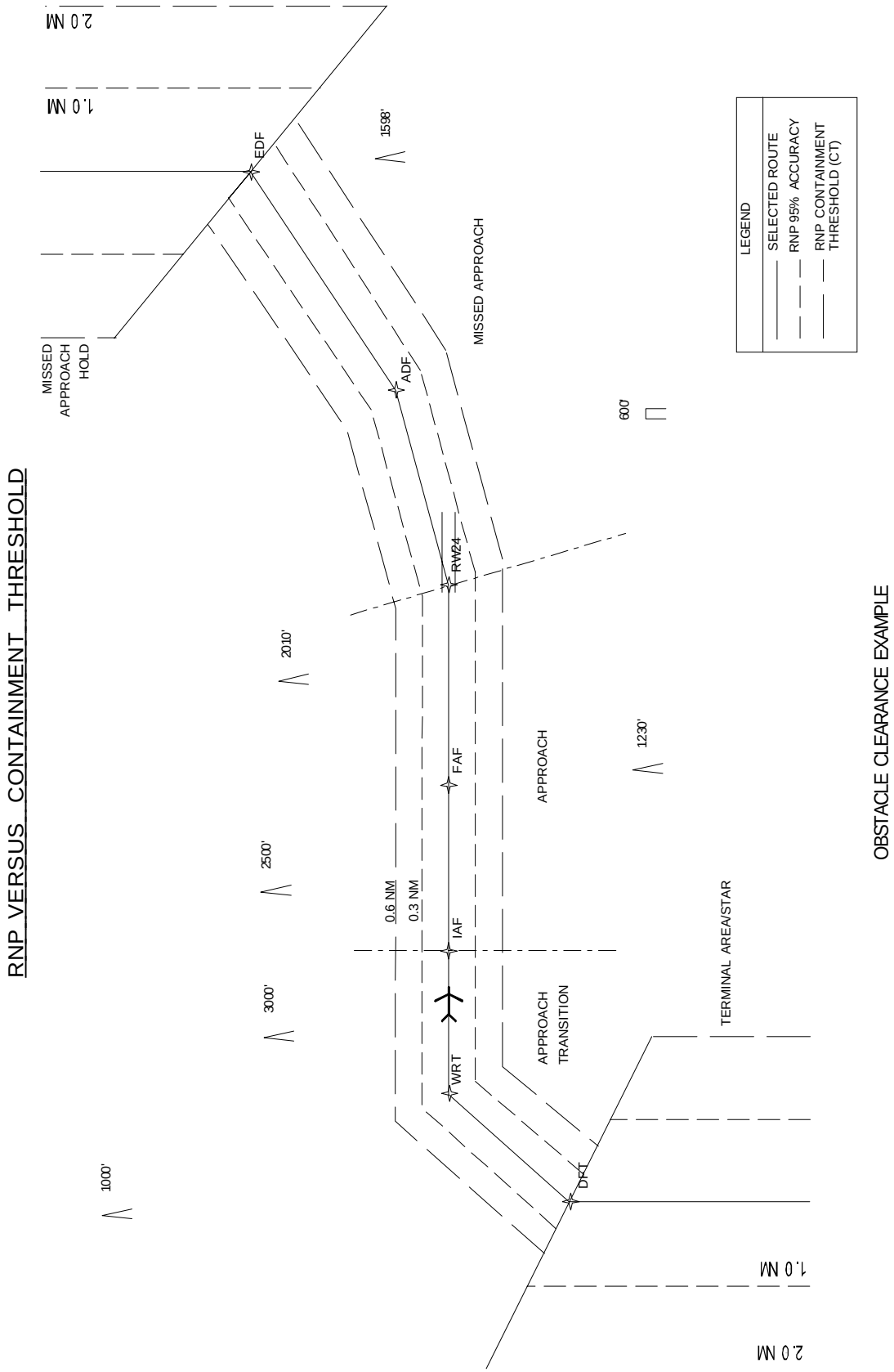

Figure 10.2-4: Obstacle Clearance Example

Further analysis of this method of obstacle clearance for the takeoff, terminal approach transition and approach operations, coupled with the definition for RNP result in a 1E-7 probability per operation of a catastrophic event (metal hitting an obstacle). These results are consistent with the FAR 25.1309 requirements.

The following analysis reduces the 1E-7 probability per operation to a 1E-6 probability per flight hour by determining a typical approach exposure time. The following are the assumptions made about the typical approach:

Approach Transition:

Typical Length 14 NM.
Typical Average Ground Speed 180 Knots.
Typical Exposure Time 4.7 Minutes.

Approach:

Typical Length 14 NM.
Typical Average Ground Speed 160 Knots.
Typical Exposure Time 5.3 Minutes.

Missed Approach:

Typical Length 6 NM.
Typical Average Ground Speed 180 Knots.
Typical Exposure Time 2.0 Minutes.

Total Exposure Time 12.0 Minutes

Therefore 10-7 events per approach is equivalent to 10-7/(12/60) = 5*10-7 events per hour which is approximately 10-6 events per hour. These are consistent with the FAR 25.1309 requirements.

10.3 RNP RNAV Instrument Approach Equivalent to Existing NDB, VOR, RNAV or GPS Non-Precision Approaches

This section defines the equivalent RNP RNAV instrument approach capability of the FANS 1 RNP airplane to fly existing NDB, VOR, or AC 20-130A RNAV or TSO C129a GPS non-precision approaches that comply with existing TERPS requirements. For each of these approach types the existing requirement will be stated and then the equivalent RNP RNAV instrument approach will be defined. By defining an equivalent RNP instrument approach the airlines and operational approval authorities will be able take advantage of any existing approaches.

1. NDB non-precision approach existing requirements:

   Accuracy to a 95% certainty level:

   Provided by monitoring ADF radial data on a RDMI or MAP.

   Integrity:

   Provided by monitoring ADF radial data on a RDMI or MAP.
   TERPS smallest protected containment threshold = 1.25 NM
   (This occurs when flying over the NDB. When not over the NDB the protected containment threshold increases as the distance to the NDB increases.)

   Availability of navigation signals:

   Limited by reliability of the NDB ground station.
   Limited by NDB coverage for the approach.

   Availability of navigation equipment:

   Provided by single ADF and display equipment operational at the start of the approach. MMEL covers requirements to have this equipment operational a time of dispatch.

   Annunciation of degraded navigation or loss of navigation:

   Display of ADF radial data on MAP and RDMI
   ADF fail flags on the RDMI

   Approach Minimums/Visibility:

   Terrain dependent, but with a MDA(H) of no less than 350.
   Dependent on multiple conditions approximate minimum visibility of 1.25 NM, RVR 6000 feet.

NDB non-precision approach equivalent FANS 1 RNP RNAV instrument approach would be an RNP of 0.60 as shown below:

Accuracy to a 95% certainty level:

Total System Error Threshold = 0.60 NM.

Integrity:

Provided by monitoring Flight Director deviation bars and MAP coupled with the “UNABLE RNP” alert provided by EICAS.
Provided by redundant FMC, IRU, GPS, VOR, DME, autopilot and display equipment on the airplane. MMEL covers requirements to have this equipment operational at time of dispatch.
Total System Containment Threshold = 1.20 NM

Availability of navigation signals:

GPS availability can be determined using ground based predictive RAIM, as an interim until satellite coverage or other GPS augmentations (WAAS, GIB, Local Differential etc.) are available such that predictions are no longer required for this RNP.
The current satellite constellation with FANS 1 does not support primary means RNP navigation operations less than 1.0 NM without a ground based predication.

Availability of navigation equipment:

Provided by redundant FMC, IRU, GPS, VOR, DME, autopilot and display equipment on the airplane. AFM and MMEL covers requirements to have this equipment operational at time of dispatch.

Annunciation of degraded navigation or loss of navigation:

Display of an EICAS caution, level B, message "UNABLE RNP" when the ACTUAL navigation position fixing performance degrades beyond selected RNP.
Display of deviation from the selected flight path on the ND MAP via the airplane triangle symbol and magenta line and by the Flight Director deviation bars on the PFD.
LNAV and/or VNAV mode fail annunciation via gold bar through the mode annunciation on the PFD.
MAP fail flag on the ND, when map lost due FMC failure, Symbol Generator failure or loss of all IRU's.
Display of an EICAS advisory, level C, message "L GPS", or "R GPS" for loss of either GPS.
Display of an EICAS advisory, level C, message "GPS" for loss of both GPS.
Issuance of the "VERIFY RNP ENTRY", "VERIFY RNP - POS REF 2", or "VERIFY POSITION" MCDU scratch pad messages.

Approach Minimums/Visibility:

Terrain dependent, but with a DA(H) of no less than 350.
Dependent on multiple conditions approximate minimum visibility of 1.25 NM, RVR 6000 feet.

2. VOR non-precision approach existing requirements:

Accuracy to a 95% certainty level:

Provided by monitoring VOR radial data on a RDMI or MAP.

Integrity:

Provided by monitoring VOR radial data on a RDMI or MAP.
TERPS smallest protected containment threshold = 1.00 NM
(This occurs when flying over the VOR. When not over the VOR the protected containment threshold increases as the distance to the VOR increases.)

Availability of navigation signals:

Limited by reliability of the VOR ground station.
Limited by VOR coverage for the approach.

Availability of navigation equipment:

Provided by single VOR and display equipment operational at the start of the approach. MMEL covers requirements to have this equipment operational a time of dispatch.

Annunciation of degraded navigation or loss of navigation:

Display of VOR radial data on MAP and RDMI
VOR fail flags on the RDMI

Approach Minimums/Visibility:

Terrain dependent, but with a MDA(H) of no less than 250.
Dependent on multiple conditions approximate minimum visibility of 1 NM, RVR 5000 feet.

VOR non-precision approach equivalent FANS 1 RNP RNAV instrument approach would be an RNP of 0.50 as shown below:

Accuracy to a 95% certainty level:

Total System Error Threshold = 0.50 NM.

Integrity:

Provided by monitoring Flight Director deviation bars and MAP coupled with the “UNABLE RNP” alert provided by EICAS.
Provided by redundant FMC, IRU, GPS, VOR, DME, autopilot and display equipment on the airplane. MMEL covers requirements to have this equipment operational at time of dispatch.
Total System Containment Threshold = 1.00 NM

Availability of navigation signals:

GPS availability can be determined using ground based predictive RAIM, as an interim until satellite coverage or other GPS augmentations (WAAS, GIB, Local Differential etc.) are available such that predictions are no longer required for this RNP.
The current satellite constellation with FANS 1 does not support primary means RNP navigation operations less than 1.0 NM without a ground based predication.

Availability of navigation equipment:

Provided by redundant FMC, IRU, GPS, VOR, DME, autopilot and display equipment on the airplane. AFM and MMEL covers requirements to have this equipment operational at time of dispatch.

Annunciation of degraded navigation or loss of navigation:

Display of an EICAS caution, level B, message "UNABLE RNP" when the ACTUAL navigation position fixing performance degrades beyond selected RNP.
Display of deviation from the selected flight path on the ND MAP via the airplane triangle symbol and magenta line and by the Flight Director deviation bars on the PFD.
LNAV and/or VNAV mode fail annunciation via gold bar through the mode annunciation on the PFD.
MAP fail flag on the ND, when map lost due FMC failure, Symbol Generator failure or loss of all IRU's.
Display of an EICAS advisory, level C, message "L GPS", or "R GPS" for loss of either GPS.
Display of an EICAS advisory, level C, message "GPS" for loss of both GPS.
Issuance of the "VERIFY RNP ENTRY", "VERIFY RNP - POS REF 2", or "VERIFY POSITION" MCDU scratch pad messages.

Approach Minimums/Visibility:

Terrain dependent, but with a DA(H) of no less than 250.
Dependent on multiple conditions approximate minimum visibility of 1 NM, RVR 5000 feet.

3. RNAV AC 20-130A non-precision approach existing requirements:

Accuracy to a 95% certainty level:

Position Fixing Error Threshold = 0.30 * (1.96/2.45) = 0.24 NM
Flight Technical Error Threshold = 0.50 NM. Assumes manual flight based on CDI
Total System Error Threshold = 0.55 NM. (RSS of above numbers)

Integrity:

Provided by monitoring raw DME distance and/or VOR radial data on a CDI or MAP.
Approx. protected containment radius to a 1E-6 per flight hour containment probability level:
Position Fixing Containment Threshold = 0.30 * (1.81) = 0.54 NM
Flight Technical Containment Threshold = 0.50* (2.25) = 1.13 NM
Total System Containment Threshold = 1.25 NM (RSS of above numbers)

Availability of navigation signals:

Limited by reliability of the VOR and DME ground station.
Limited by VOR and DME coverage for the approach.

Availability of navigation equipment:

Provided by redundant FMC, DME, VOR and display equipment on the airplane. MMEL covers requirements to have this equipment operational a time of dispatch.

Annunciation of degraded navigation or loss of navigation:

Display of raw DME slant range and VOR radial on the ND MAP.
Indication of the position update mode on the ND MAP.
MAP, VOR or DME fail flags on the ND.
Issuance of the "INERTIAL ONLY", "VERIFY POSITION", or "NAV INVALID TUNE XXX" MCDU scratch pad messages.

Approach Minimums/Visibility:

Terrain dependent, but with a MDA(H) of no less than 250.
Dependent on multiple conditions approximate minimum visibility of 1 NM, RVR 5000 feet.

RNAV AC 20-130A non-precision approach equivalent FANS 1 RNP RNAV instrument approach with GPS would be an RNP of 0.50 as shown below:

Accuracy to a 95% certainty level:

Total System Error Threshold = 0.50 NM.

Integrity:

Provided by monitoring Flight Director deviation bars and MAP coupled with the “UNABLE RNP” alert provided by EICAS.
Provided by redundant FMC, IRU, GPS, VOR, DME, autopilot and display equipment on the airplane. MMEL covers requirements to have this equipment operational at time of dispatch.
Total System Containment Threshold = 1.00 NM

Availability of navigation signals:

GPS availability can be determined using ground based predictive RAIM, as an interim until satellite coverage or other GPS augmentations (WAAS, GIB, Local Differential etc.) are available such that predictions are no longer required for this RNP.
The current satellite constellation with FANS 1 does not support primary means RNP navigation operations less than 1.0 NM without a ground based predication.

Availability of navigation equipment:

Provided by redundant FMC, IRU, GPS, VOR, DME, autopilot and display equipment on the airplane. AFM and MMEL covers requirements to have this equipment operational at time of dispatch.

Annunciation of degraded navigation or loss of navigation:

Display of an EICAS caution, level B, message "UNABLE RNP" when the ACTUAL navigation position fixing performance degrades beyond selected RNP.
Display of deviation from the selected flight path on the ND MAP via the airplane triangle symbol and magenta line and by the Flight Director deviation bars on the PFD.
LNAV and/or VNAV mode fail annunciation via gold bar through the mode annunciation on the PFD.
MAP fail flag on the ND, when map lost due FMC failure, Symbol Generator failure or loss of all IRU's.
Display of an EICAS advisory, level C, message "L GPS", or "R GPS" for loss of either GPS.
Display of an EICAS advisory, level C, message "GPS" for loss of both GPS.
Issuance of the "VERIFY RNP ENTRY", "VERIFY RNP - POS REF 2", or "VERIFY POSITION" MCDU scratch pad messages.

Approach Minimums/Visibility:

Terrain dependent, but with a DA(H) of no less than 250.
Dependent on multiple conditions approximate minimum visibility of 1 NM, RVR 5000 feet.

4. GPS TSO C129a non-precision approach existing requirements:

Accuracy to a 95% certainty level:

Position Fixing Error Threshold = 0.056 * (1.96/2.45) = 0.045 NM
Flight Technical Error Threshold = 0.25 NM. (Assumes Flight Director coupled with LNAV)
[Flight Technical Error Threshold = 0.125 NM. (Assumes Autopilot coupled with LNAV)]
Total System Error Threshold = 0.25 NM. [0.13 NM] (RSS of above numbers)

Integrity:

Provided by monitoring raw DME distance and/or VOR radial data on a CDI or MAP.
Approx. protected containment radius to a 1E-6 per flight hour containment probability level:
Position Fixing Containment Threshold = 0.3 NM
Flight Technical Error Threshold = 0.25 * (2.25) = 0.564 NM.
[Flight Technical Error Threshold = 0.125 * (2.25) = 0.282 NM]
Total System Containment Threshold = 0.64NM [0.41 NM] (RSS of above numbers)

Availability of navigation signals:

Predictive RAIM implemented in GPSSU and accessible on airplane.

Availability of navigation equipment:

Redundant FMC, GPS, autopilot and display equipment on the airplane.

Annunciation of degraded navigation or loss of navigation:

Annunciate in forward field of view if HIL or FOM exceed required threshold.
Annunciate with a fail flag in forward field of view if FMC, MAP or GPS fails.

Approach Minimums/Visibility:

Terrain dependent, but with a MDA(H) of no less than 250.
Dependent on multiple conditions approximate minimum visibility of 1 NM, RVR 5000 feet.

GPS TSO C129a non-precision approach equivalent FANS 1 RNP RNAV instrument approach with GPS would be an RNP of 0.30 as shown below:

Accuracy to a 95% certainty level:

Total System Error Threshold = 0.30 NM.

Integrity:

Provided by monitoring Flight Director deviation bars and MAP coupled with the “UNABLE RNP” alert provided by EICAS.
Provided by redundant FMC, IRU, GPS, VOR, DME, autopilot and display equipment on the airplane. MMEL covers requirements to have this equipment operational at time of dispatch.
Total System Containment Threshold = 0.60 NM

Availability of navigation signals:

GPS availability can be determined using ground based predictive RAIM, as an interim until satellite coverage or other GPS augmentations (WAAS, GIB, Local Differential etc.) are available such that predictions are no longer required for this RNP.
The current satellite constellation with FANS 1 does not support primary means RNP navigation operations less than 1.0 NM without a ground based predication.

Availability of navigation equipment:

Provided by redundant FMC, IRU, GPS, VOR, DME, autopilot and display equipment on the airplane. AFM and MMEL covers requirements to have this equipment operational at time of dispatch.

Annunciation of degraded navigation or loss of navigation:

Display of an EICAS caution, level B, message "UNABLE RNP" when the ACTUAL navigation position fixing performance degrades beyond selected RNP.
Display of deviation from the selected flight path on the ND MAP via the airplane triangle symbol and magenta line and by the Flight Director deviation bars on the PFD.
LNAV and/or VNAV mode fail annunciation via gold bar through the mode annunciation on the PFD.
MAP fail flag on the ND, when map lost due FMC failure, Symbol Generator failure or loss of all IRU's.
Display of an EICAS advisory, level C, message "L GPS", or "R GPS" for loss of either GPS.
Display of an EICAS advisory, level C, message "GPS" for loss of both GPS.
Issuance of the "VERIFY RNP ENTRY", "VERIFY RNP - POS REF 2", or "VERIFY POSITION" MCDU scratch pad messages.

Approach Minimums/Visibility:

Terrain dependent, but with a DA(H) of no less than 250.
Dependent on multiple conditions approximate minimum visibility of 1 NM, RVR 5000 feet.