### Navigation

The navigation function furnishes continuous, real-time, two dimensional solutions to the crew and provides the following navigational outputs:

* Estimated Aircraft Position (latitude, longitude)
* Aircraft Velocity
* Drift Angle (optional)
* Track Angle
* Magnetic Variation (optional)
* Wind Velocity and Direction
* Time
* Required Navigation Performance (RNP)
* Estimate of Position Uncertainty (EPU) or Actual Navigation Performance (ANP) or Estimate of Position Error (EPE)

COMMENTARY

For the purpose of this document, EPU, ANP, and EPE are synonymous and refer to the statistical indication of the system's current position estimation performance.

In system architectures utilizing IRS sensors, drift angle and magnetic variation may be provided directly by the IRS and are not required to be computed by the FMS.

For vertical aspects, the navigation function may provide altitude, vertical speed and flight path angle. Unless explicitly stated otherwise, altitude computations operate upon inputs of smoothed inertial altitude from the Inertial Reference Units (IRUs), Air Data/Inertial Reference Units (ADIRUs), or Attitude and Heading Reference System (AHRS), corrected by barometric (corrected or uncorrected) pressure altitude from the air data system. Flight path angle is derived from vertical speed and computed ground speed.

#### Multi-Sensor Navigation

The navigational output data is computed by using one or a combination of the following sensor inputs when available:

* GNSS Receiver
* DME Transponder
* VOR/LOC Receiver
* ILS/MLS Receiver(s)
* Inertial Reference Unit
	+ IRU or
	+ ADIRU or
	+ GPIRU
* AHRS
* Air Data Computer

The navigation function automatically selects the position sensor or combination of available sensors that provides the best solution for estimating the aircraft position and velocity. Using the sensor accuracy characteristics, sensor raw data, and information about the current conditions, the position sensor or best combination of position sensors (GNSS, IRU, DME, VOR, etc.) is selected to minimize the position determination error.

As a minimum, the navigation function must provide for GNSS data integrated with a heading/attitude sensor and air data system as some aircraft installations may not include other navigation radios. Adequate navigation availability must be a consideration in any implementation.

#### Navigation Modes

Available navigation sensor data is validated before it is used for updates to the aircraft position.

The primary mode of operation utilizes IRS heading, attitude, position, and velocity, with IRS position and velocity combined with GNSS or VHF radio data (e.g., DME, Tactical Air Navigation System (TACAN), VOR, and LOC/MLS). Optionally, the primary mode of operation utilizes position and velocity from the selected navigation sensor (GNSS, IRS, or VHF radio data) with heading and attitude being provided from an AHRS/IRS.

 The navigation function should provide for sensor error modeling such that the navigation solution accuracy can be maintained through short term unavailability of various sensors. The navigation function should behave smoothly regardless of sensor availability or sensor transitions.

COMMENTARY

With the transition to PBN, standardized navigation sensor selection logic is not required; however, in some implementations, a navigation mode sensor hierarchy such as the following may be utilized:

* + GNSS
	+ LOC(MLS) or LOC(MLS)/DME (approach only)
	+ DME/DME
	+ DME/VOR

It may be desirable for non-IRU aircraft to correct heading/attitude sensor data based on the other available sensors to provide for a more accurate coasting mode of operation.

#### RNP-Based Navigation

The navigation function should satisfy the accuracy, integrity, and availability criteria set forth for aircraft systems intended to operate in RNP airspace. The systems criteria are specified in the latest versions of RTCA DO-236 and RTCA DO-283.

The capabilities of the system should encompass position estimation, path definition, and path control and tracking, as well as computing position uncertainty. These capabilities, in addition to a means to evaluate and mitigate flight technical error, should form the basis for evaluating and determining total aircraft systems performance for RNP operations. The system should provide design, function, and operational integrity to ensure acceptable, repeatable, and error-free performance. The system should provide for clear and unambiguous indications of the navigation situation, including alerting to the flight crew when the navigation system does not comply with the requirements of the RNP airspace.

COMMENTARY

RNP is the required navigation performance necessary for operation within a defined airspace. RNP is specified in terms of accuracy, containment integrity, containment continuity, and availability of navigation signals and equipment for a particular airspace, route or operation.

The intent of the material in this section is to provide additional insight into RNP criteria, especially system and integration considerations.

##### RNP Determination

The system should provide the appropriate RNP selection and entry capabilities to support determination of the applicable RNP for a flight plan path terminator (leg), procedure, or environment based upon the following, in order of priority:

* Manual RNP entry by the crew Leg-Based RNP value from the navigation database or ATS datalink
* The default RNP value

COMMENTARY

RNP flight plans will consist of a limited subset of the path terminators defined in Section **Error! Reference source not found.**. These RNP routes and procedures will contain embedded information which establishes the RNP values which apply to the active or next path terminator; in the absence of the embedded RNP information, RNP may be determined or designated by default according to the airspace or environment. When the system is operated using the default RNP values, the system will require navigation environment (i.e., oceanic, enroute, terminal, approach) logic to ensure the proper transition from one RNP default value to another.

The system should output the current RNP and EPU values on the general-purpose output buses.

###### Manually Entered RNP Values

The system should support manual entry within a range of possible RNP values appropriate for the PBN operation to be flown.

A manually entered RNP value should supersede any pre-programmed RNP value associated with a route, procedure or leg, or any default value. The manually entered RNP value should be clearly distinguishable as a manually entered value. In the event of a manually entered value larger than the value being overridden, an advisory alert or annunciation, as appropriate, should be provided to the crew. When a manual entry is deleted, the system should return to the appropriate RNP value based upon its priority. Unless deleted by the crew, the manual entry should remain the active RNP value.

COMMENTARY

The annunciation and alerting requirement for manually entered RNP values which exceed the active RNP value may be applied in various ways. One instance is upon entry of the value; this assures pilot awareness of his action relative to overriding limits applicable to the route, procedure, leg, or airspace, and which form the basis for separation. However, conditions such as NOTAMs or diversions due to weather may be among the reasons why a manual entry is made. Once accepted, the system should also actively monitor the manual entry relative to the RNP for the procedure, route, leg or default, in the event they change to a smaller value. Advance annunciation or alerting would also be advisable in this case.

###### Preplanned RNP Values

When an RNP Authorization Required (AR) approach procedure offers multiple lines of minima, the system should allow the flight crew to specify or pre-select the desired RNP value for the final approach segment.

COMMENTARY

Some RNP-AR approaches are designed with multiple lines of minima corresponding to the respective RNP requirement. For these approaches, ARINC 424 specifies that the least restrictive “level of service” be coded in the primary record of the approach procedure. Additional lines of minima are contained in the approach continuation records. For RNP approaches designed with multiple RNP values associated with lines of minima, the flight crew may desire a more restrictive RNP value than the one coded in the NDB. The system should provide a means for the flight crew to specify or pre-select the RNP value to use on the final approach segment prior to reaching the initial approach fix.

###### Leg-Based RNP Values

The system should support the definition of an RNP on a leg-by-leg basis. The Leg-Based RNP value should be initialized to the navigation database value associated with the leg upon insertion of the navigation procedure into the flight plan. Uplink of a Leg-Based RNP Value via ATS datalink should be supported as part of dynamic RNP operations. Display of uplinked Leg-Based RNP values should be provided to allow crew review and acceptance of the uplinked values and provide situational awareness in lieu of a navigation chart.

COMMENTARY

The system designer may need to consider that although an RNP value may be specified for individual leg(s) of a procedure (SID, STAR, Airway, Approach, Transition, etc.), one is not required. The procedure designer may develop procedures where the RNP value is designated leg by leg, or possibly for only selected flight legs. In this case, where nothing is specified, the system default value would apply.

On some routes and terminal procedures, restrictions along the route (e.g., terrain, airspace, environmental) may require that RNP values be placed on individual legs. These values may be other than the default values (for the respective navigation environment), and the values may decrease as the aircraft proceeds along the arrival procedure. This RNP structure is referred to as the “Scalability” element of Advanced RNP. It is assumed that published procedures which employ the scalable RNP element will retrieve the respective RNP value for each leg from the NDB. In addition to the values coded in the NDB, RNP values may be transmitted via ATS datalink for dynamic operations.

When the RNP value is provided on downpath legs, the system should provide an indication to the flight crew when the RNP performance cannot be met at the next waypoint. The indication should be provided sufficiently early such that the flight crew can take action to resolve the situation.

###### Stored Default Values

The system should provide the capability for stored default RNP values for the various navigation environments (e.g., oceanic, enroute, terminal, approach). These values may be established as pre-programmed values and/or loadable into the system.

The stored default RNP value for each respective navigation environment should correlate to one of the Navigation Specification values as defined in **ICAO Doc 9613:** *Performance-Based Navigation Manual*.

COMMENTARY

The system design may establish the stored defaults with pre-programmed default values which can be overridden by loadable values via a separately loadable data file. As an alternative, the default values may be established by the loadable data file only. The approach taken will be influenced by the system built-in test design for faults and response, as well as the system design integrity.

##### Determination of Navigation System Performance

Navigation system performance should be evaluated considering position estimation error, path definition error, and flight technical error, which are the key elements of total system error. The total system error components in the cross-track and along track directions should be less than the RNPvalue 95% of the flying time.

COMMENTARY

The complete set of criteria for evaluating navigation system performance for RNPs ≥ 0.3 is provided in RTCA DO-283. It should be noted that while all system integrators will need to evaluate their systems using the same standards and criteria, the systems implementations will vary and will dictate the acceptable operating modes and systems configurations. In one method, the system operation will be predicated on a design which relies upon comparisons of the systems’ estimate of position uncertainty versus RNP, while at the same time evaluating integrity. However, this may carry with it restrictions on the mode of system operation (e.g., flight director mode or coupled with autopilot for RNP 1) necessary to achieve and assure consistent performance. In another method, the system operation will be predicated upon a real-time evaluation of all factors in total system error such that mode limitations or restrictions may not apply.

**COMMENTARY**

This section and DO-283 do not describe the criteria for evaluating navigation system performance for RNP <0.3 and LP/LPV approach as the implementation requires aircraft qualification and operational approval criteria that go beyond the minimum requirements established in RTCA DO-236. For navigation systems integrating these approach features, refer to the performance and functionality capability information as documented in the ICAO PBN Manual RNP AR APCH navigation specification, AC 20-138 Appendix 2 (RNP AR), and RTCA DO-229 (LP/LPV).

##### Navigation Alerting and Display

The system should provide for clear and unambiguous indications of the state of the aircraft navigation system, including situational awareness information and alerts.

COMMENTARY

The system should provide information which allows the determination that the equipment is functioning properly. In addition, indications should be provided which allow the operator to determine the navigation sensors in use and the actual level of navigation performance. The system should also provide annunciations and alerting of unacceptable degradation in navigation performance, including alerting to the flight crew when the navigation system does not comply with the requirements of the RNP airspace, routes, and procedures. Some solutions for this could include indications and alerts when the system estimate of position uncertainty exceeds the RNP value. In others, the estimate of position uncertainty and flight technical error may have correlated indications and alerts.

Additional display and alerting requirements relative to manually entered RNPs and determination of navigation system performance are described in Sections 1.1.1.3.1.1 and 1.1.1.3.2.

#### Navaid Data

In support of the navigation function, the system must contain an extensive navigation data base. This database typically includes the enroute, terminal, and approach procedures (including RNP values), the navigation aid ground station information, and the procedure recommended navaid information required for flight in the area in which the aircraft operates. See Section **Error! Reference source not found.** for additional details regarding the navigation database.

#### Crew Controlled Navigation Options

Some sensor inputs to the navigation function should be capable of being blocked by pilot action. LOC, DME, VOR, and GNSS updating may be stopped by manual selection on the MCDU. Additionally, DME and VOR navaids may be individually blocked from the navigation solution by entering their identifiers on the MCDU or by data link. This manual blockage of individual navaids should be cleared at flight completion.

Capability may also be provided for navigation override where the operator can force the navigation position to coincide with a selected navigation sensor or reference position (e.g., takeoff runway threshold or intersection point). This position shift action aligns the system position to the selected sensor. Override of the navigation position to a manual reference point (i.e., overfly fix) is inconsistent with RNP operation.

These options are intended as backup options for use in the event that a system generated message, such as verify position, alerts the crew to a problem in the navigation that the system cannot correct itself.

Facilities should be provided to accommodate manual tuning by the crew of the DME/VOR radios. If a receiver is being manually tuned, the navigation function should continue to auto tune any available channels with station selection as specified for auto tuning. If insufficient channels remain for satisfactory auto-tuning, then the navigation function may utilize the manually tuned stations if appropriate.

#### VHF Radio Tuning

##### Automatic Station Selection

When the navigation VHF radio receivers are available for automatic tuning, the navigation function should select and tune appropriate ground radio navigation facilities and use their position fixing data to refine the current navigation position. The navaids considered to be available for selection should be those contained within a usable distance from the estimated current aircraft position. This group of navaids, combined with any additional navaids defined by crew entry, should make up the set of navaids from which the best navigation aids can be drawn.

With scanning DME installations, up to five frequencies can be allocated to tune each interrogator and, depending upon the aircraft, may be designated for multiple DME range measurements, VOR/DME position fixing, ILS/DME or procedure-specified or pilot-selected navaids. If a procedure being flown has a specified navaid associated with it, then that navaid must be tuned and used for navigation purposes.

Station selection criteria should be designed to limit station switching activity to a minimum.

##### Navaid Reasonableness Determination

DME range measurements received by the navigation function should be compared with that of the expected radio range measurement as a reasonableness test. When the comparison is outside of a reasonable tolerance, the data should be rejected and should not be used in the position computations.

#### Real Time Clock

The system should receive real time (UTC) clock data from the GNSS. For back up purposes, the system should utilize a GNSS-updated (or manually synchronized) on-board clock (See Section **Error! Reference source not found.**), or provide an internal UTC time clock capability which is synchronized with the external input or may be manually initialized. In the event of loss of the external input, the internal time clock should maintain UTC within a ±1 second accuracy over the duration of the flight.