AREA NAVIGATION SYSTEMS

1. Introduction

RNAV is defined as “a method of navigation which permits aircraft operation on any desired flight path within the coverage of station-referenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these.” This removes the restriction imposed on conventional routes and procedures where the aircraft must overfly referenced navigation aids, thereby permitting operational flexibility and efficiency.

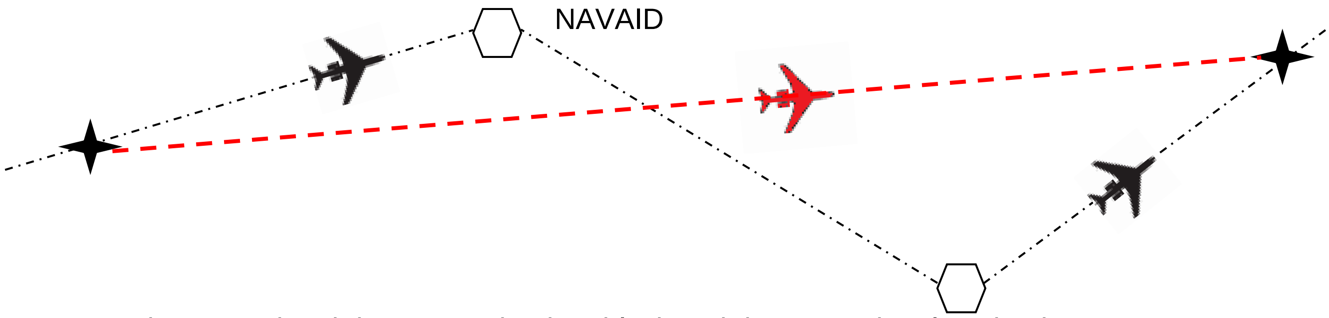


Figure: Red path is area navigation, black path is conventional navigation.

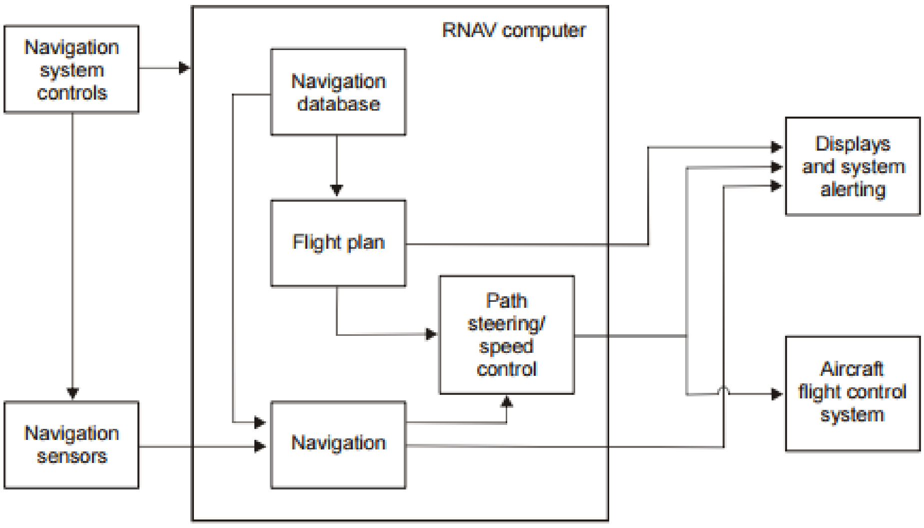
The position of the aircraft is known using various sensors that can compute its position. RNAV can then be summed up as the ability of an aircraft to navigate, computing change of tracks from one point to another, using only coordinates.

The RNAV system may also be connected with other systems, such as auto-throttle and autopilot/flight director, allowing more automated flight operation and performance management. Despite the differences in architecture and equipment, the basic types of functions contained in the RNAV equipment are common.

2. RNAV System architecture

RNAV systems are designed to provide a given level of accuracy, with repeatable and predictable path definition, appropriate to the application. The RNAV system typically integrates information from sensors, such as air data, inertial reference, radio navigation and satellite navigation, together with inputs from internal databases and data entered by the crew to perform the following functions:

- Navigation
- Flight plan management
- Guidance and control
- Display and system control



The navigation function computes data that can include aircraft position, velocity, track angle, vertical flight path angle, drift angle, magnetic variation, barometric-corrected altitude, and wind direction and magnitude.

The flight planning function creates and assembles the lateral and vertical flight plan used by the guidance function:

- More advanced RNAV systems include a capability for performance management where aerodynamic and propulsion models are used to compute vertical flight profiles matched to the aircraft and able to satisfy the constraints imposed by air traffic control.
- A performance management function can be complex, utilizing fuel flow, total fuel, flap position, engine data and limits, altitude, airspeed, Mach, temperature, vertical speed, progress along the flight plan and pilot inputs.

An RNAV system provides lateral guidance, and in many cases, vertical guidance as well.

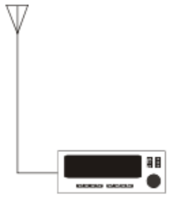
- The lateral guidance function compares the aircraft's position generated by the navigation function with the desired lateral flight path and then generates steering commands used to fly the aircraft along the desired path.
- The vertical guidance function, where included, is used to control the aircraft along the vertical profile within constraints imposed by the flight plan

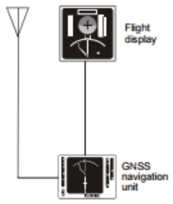
Display and system controls provide the means for system initialization, flight planning, path deviations, progress monitoring, active guidance control and presentation of navigation data for flight crew situational awareness.

The RNAV system is expected to access a navigation database, if available. The navigation database contains pre-stored information on navaid locations, waypoints, ATS routes and terminal procedures, and related information

RNAV systems range from single-sensor-based systems to systems with multiple types of navigation sensors:

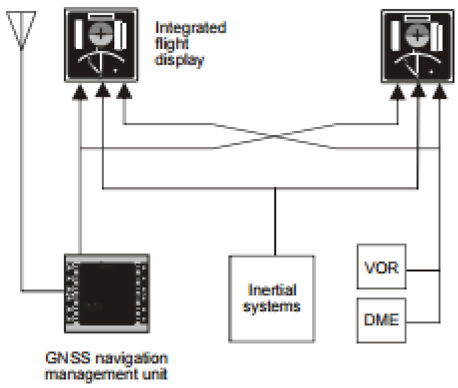
- Simple navigation can be based upon a single type of navigation sensor such as GNSS:





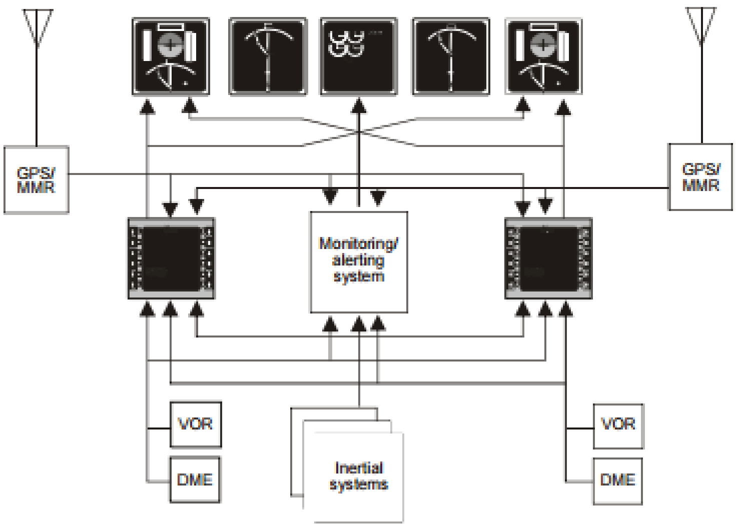
Basic RNAV system RNAV mapping system

- Advanced navigation can be based upon a variety of navigation sensors such as GNSS; Inertial system (IRS) and VOR/DME, but the management of navigation is only based on GNSS:



Simple multi-sensor avionic system

- Complex multi-sensor systems can use a variety of navigation sensors including GNSS, DME, VOR and IRS to compute the position and velocity of the aircraft:



Complex multi-sensor avionic system

3. Sensors

3.1. Presentation

There are actually 5 types of sensors:

- Satellite-based: Global Navigation Satellite System (GNSS)
- Ground-based: VOR / DME
- Ground-based: DME / DME
- Ground-based: LORAN (obsolete and not used on IVAO)
- Self-Contained Systems: Initial Reference Units (INS & IRS)

As the aircraft progresses along its flight path, if the RNAV system is using ground navaids, it uses its current estimate of the aircraft's position and its internal database to automatically tune the ground stations in order to obtain the most accurate radio position.

When a pilot is flying with RNAV-capable aircraft, he must indicate in his flight plan the aircraft's specification through what is called **Performance Based Navigation – PBN**. This information shall be then available in field 18 Remarks of the flight plan.

See below the table indicating all existing PBN designators:

		All permitted sensors	GNSS	DME/DME	VOR/DME	IRU	LORAN
Oceanic	RNAV 10	A1					
	RNP 4	L1					
En-Route	RNAV 5	B1	B2	B3	B4	B5	B6
	RNAV 2	C1	C2	C3		C4	
	RNAV 1	D1	D2	D3		D4	
Terminal	RNAV 1	D1	D2	D3		D4	
	RNP 1	O1	O2	O3		O4	
Final	RNP APCH	S1					
	RNP APCH with APV (Baro VNAV)	S2					
	RNP (AR) APCH with RF	T1					
	RNP (AR) APCH without RF	T2					

For example, a typical airliner pilot using complex FMC should include in his flight plan: **PBN/B1C1D1O1S2**
For example, a typical IFR general aviation pilot equipped with a simple GPS should include in his flight plan: **PBN/B2D2O2S1**

3.2. Global Navigation Satellite System (GNSS)

GNSS includes two different kinds of satellites meant for two different purposes:

- Positioning system: it allows positioning an object everywhere on earth in relation to its coordinates and its altitude.
- Augmentation system: it allows making sure the positioning system's integrity is reliable, thus there is no gap in positioning signal.

Examples of a few GNSS positioning systems:

- GPS (USA)
- GLONASS (Russia)
- Galileo (Europe)
- Compass (China)
- IRNSS (India)
- QZSS (Japan)

3.2.1. Positioning System

4 satellites are necessary to compute a 3-dimension position:

- Longitude,
- Latitude,
- Height and integrating dimension:
- Time.

The position is computed from the distances to the satellites. Aircraft can use up to 6 satellite signals:

- 4 signals is basic positioning
- 5 signals will allow detecting a faulty signal: **RAIM function**
- 6 signals will allow determining which satellite is faulty: **FDE function**

3.2.2. Accuracy and Integrity

GNSS must meet essential criteria to ensure flight safety:

- Accuracy: amount of errors between computed and true position
- Integrity: ability to alert the user when accuracy decreases
- Continuity: amount of time the system will operate without interruption
- Availability: amount of time the system is actually able to function

Receiver Autonomous Integrity Monitoring (RAIM) enables to achieve integrity when using GNSS.
It enables detecting a discrepancy in satellite signal, which leads to a decrease in position accuracy.
Since the monitoring is continuous, the pilot can be immediately alerted when inaccuracy hit a critical threshold, generally the required specification.

For ABAS-based approach (LNAV and LNAV/VNAV), RAIM must be operative to ensure Required Navigation Performance (RNP).
Some systems have RAIM built-in predictions, enabling to know whether RAIM function will be available or not in a specific location at a specific time.

The **Fault Detection and Exclusion (FDE)** function allows the user deselecting a faulty satellite to ensure continuity and availability of GNSS.

3.2.3. Augmentation Systems

For approach operation, a positioning system is basic, and computation needs strict accuracy monitoring.

That's why all approach operations are RNP specifications and not RNAV specifications.
In order to achieve this degree of precision, GNSS signals are correlated with augmentation systems.

There are three types of augmentation systems:

- Satellite-Based Augmentation System (SBAS)
- Ground-Based Augmentation System (GBAS)
- Autonomous/Aircraft-Based Augmentation System (ABAS)

Each of these systems is meant for a different use, and in particular, different kinds of RNAV approach, which we have already dealt with in this document.

As said, augmentation will magnify and enhance satellite signals and position computation to monitor its accuracy and thence the integrity of the system.

Examples of a few SBAS augmentation systems used for LPV & LNAV/VNAV approaches:

- WAAS (USA)
- EGNOS (Europe)
- MSAS (Japan)

Example of GBAS augmentation system used for GLS approaches:

- LAAS (USA)

Examples of ABAS augmentation systems used for LNAV & LNAV/VNAV approaches:

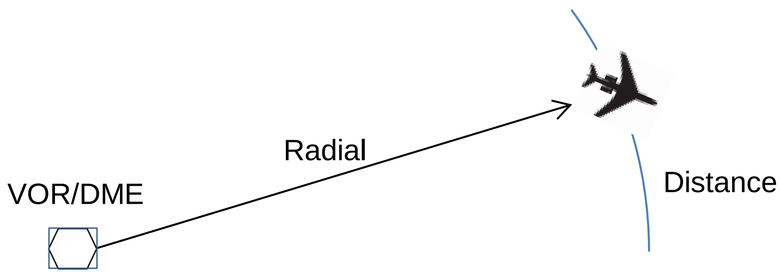
- Redundant position cross feeding comparison (GNSS & DME / DME for instance)
- RAIM / FDE

3.3. VOR / DME

Aircraft coordinates are computed from:

- VOR/DME coordinates
- aircraft actual radial from the station
- aircraft actual distance to this DME

It requires the coordinates of the selected VOR/DME.



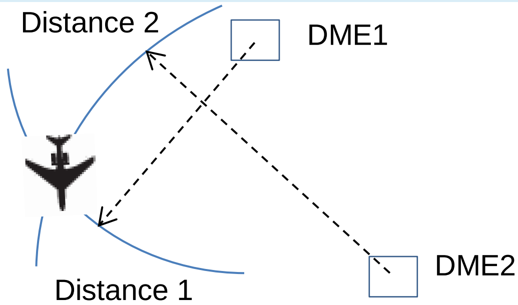
3.3.1. DME / DME

Aircraft coordinates are computed from:

- Both DMEs coordinates
- Aircraft actual distance to these DMEs

The closer two stations are to one line, the greater the error becomes, hence, selected DMEs are always angular apart between 30 and 150 degrees.

It requires DME coordinates (VOR part of the stations may be inoperative).



3.3.2. Long Range Navigation (LORAN)

LORAN is a radio transmission system developed during World War II.
The goal was to enhance long range navigation such as Atlantic crossing for ships and airplanes.
Basically, it is a super VOR which can be tracked up to 1,500 miles.

LORAN is completely deprecated and obsolete. LORAN is not implemented in our flight simulation software and it is considered as non-applicable for the IVAO network.

3.3.3. INS & IRS

Inertial Navigation/Reference Systems are precursors of today's Flight Management Systems.

After manual insert of the initial position, and a timed warm-up and computation (up to 20 minutes), the system was self-contained and autonomous to perform various calculations: wind aloft, track to coordinates, present position, ground speed, etc…

Coupled to a Flight Management Computer, it was able to store up to 9 waypoints defined by coordinates. Remaining in the cockpit of most airliners, it serves as backup in case of GNSS failure.

Some add-ons like the Delta Carousel Management Unit can be available in our simulators.

4. Database

CDUs as well as GNSs are relying on a **database** called AIRAC cycle to operate.

This database is.

- Each cycle is defined by the year on two digits followed by the number of the cycle in the year. At the time of the writing, cycle 1609 is effective (9^{th} cycle of 2016).
- An AIRAC cycle is valid only for 28 days.
- After 28 days, a new AIRAC cycle is published

AIRAC cycle contains pretty much the same elements of a country Aeronautical Information Publication (AIP):

- Airways
- Waypoints
- Airports
- Runways
- SID
- STAR
- Approaches
- Navaids

All RNAV procedures have coding tables, in order to ensure the coding of the procedure into the database.

Example: Jersey EGJJ – RNAV (GNSS) RUNWAY 08 via LAPLI IAF

Jersey RNAV (GNSS) RWY 08 - Instrument Approach Procedure via LAPLI

Designator	Sequence Number	Path Term-inator	Waypoint Name	Fly-over	Course/ Track °M (°T)	Turn Direction	Level Constraint	Speed Constraint	Co-ordinates	Remarks and Distance to MAPt
RW08L	001	IF	LAPLI	N	-	-	2000	210	491606.54N 0022827.89W	IAF JSY R282 / D17.1
RW08L	002	TF	GIPTA	N	174° (172.6°)	LEFT	2000	-	491109.26N 0022729.31W	IF / 10NM
RW08L	003	TF	JJ08F	N	084° (082.7°)	-	2000	-	491145.21N 0022020.93W	FAF / 5.3NM
RW08L	004	TF	RW08	Y	084° (082.7°)	-	-	-	491225.43N 0021221.95W	MAPt
RW08L	005	CF	JJM01	N	084° (082.8°)	RIGHT	-	185	491255.54N 0020618.83W	-
RW08L	006	TF	JJM02	N	174° (172.8°)	RIGHT	-	185	490758.14N 0020521.77W	-
RW08L	007	TF	GAMDU	N	264° (262.9°)	LEFT	3000	210	490735.73N 0020953.69W	HOLD

5. Procedure coding

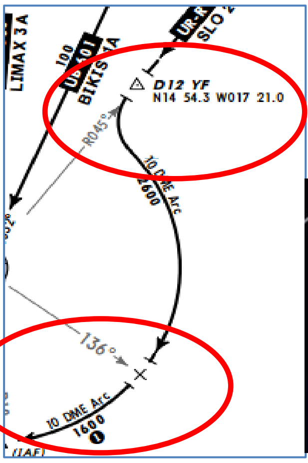
In relation to RNAV, database study is particularly important as it follows strict conventions.
There are two main coding particularities: waypoint naming and leg types.

5.1. Waypoint naming

Waypoints are named different ways:

- VOR/NDB or an airport: named using their identifier (i.e. **LND** VOR, **EGLL** airport)
- Waypoint when they are non-physical waypoint: defined by their coordinates and named using 5 or 6 letters (i.e. MERIT, ROMAM…)
- RNAV waypoint located in an RNAV approach route: waypoints are named such as the two last letters of the ICAO identifier of the airport plus 3 figures XXnnn (n=figure, X=letter) (i.e. RS604)
- Constructed waypoint for FMC: named using a defined radial and a distance DnnnX (n=figure, X=letter). The number 'nnn' represents the radial in degrees and the X the order of the letter inside the alphabet is the distance located at n NM. (i.e. D206J = Radial 206° 10NM)

Example: SLO2A arrival Dakar GOOY

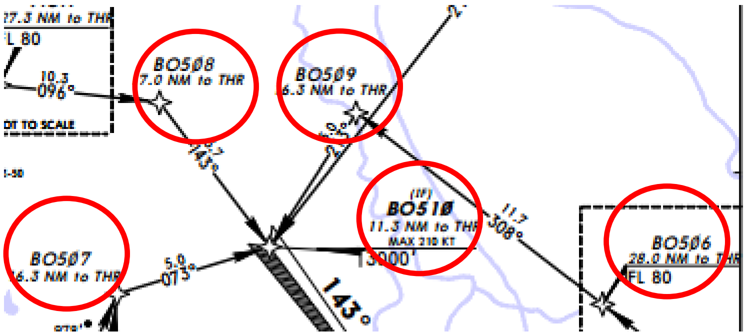


2 waypoints for example:

- Radial 045 ; 12NM
  Coded as D045L
- Radial 136 ; 10NM
  Coded as D136J

Depending on the FMC manufacturer, DME arcs are coded by adding a fictious waypoint each 10 or 15 degrees with the same coding (Boeing) or just by a radius-to-fix leg.

Example: Around Toulouse LF**BO** Airport, RNAV waypoints are named **BO**508, **BO**509, **BO**510…

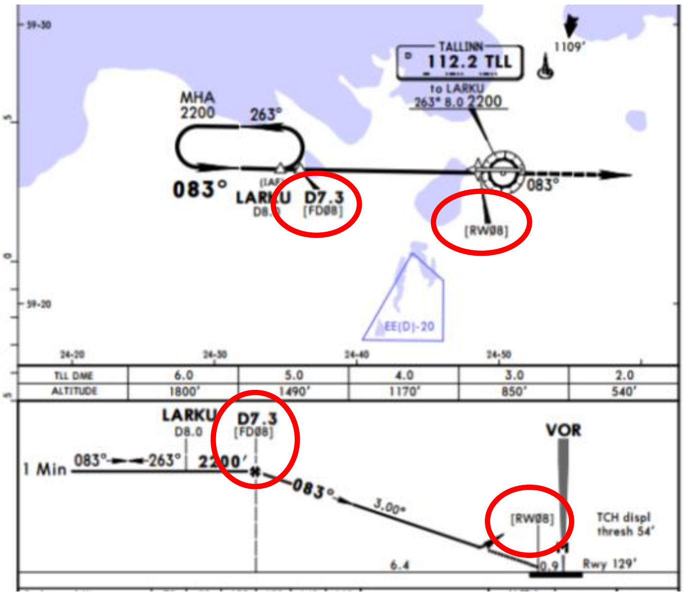


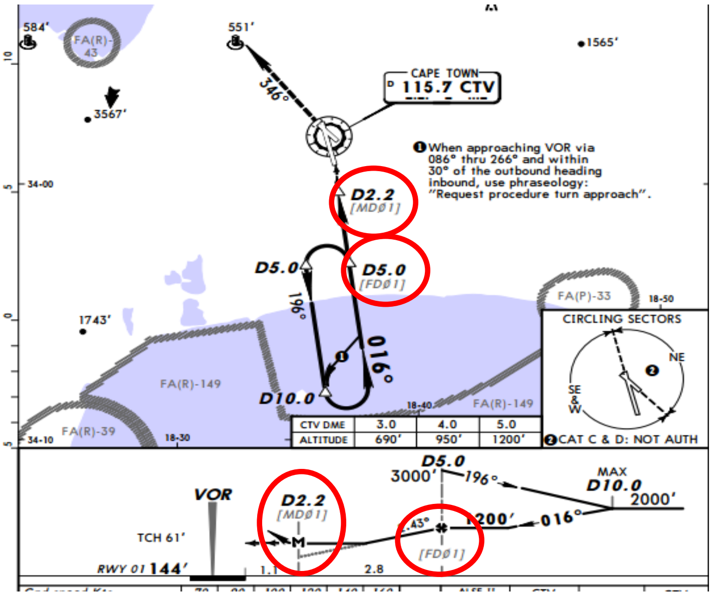
For approach procedures, waypoints generally follow these conventions, where xx is the runway identifier:

- CIxx/CSxx as a waypoint where the final course should be established, generally the IF
- FDxx/FIxx/FNxx/FSxx as where the final descent should be initiated, generally the FAF/FAP
- Maxx/MDxx as the missed approach point of a procedure
- RWxx as the runway threshold (often used for descent altitude-distance check).
- Any step down fix will have a proper waypoint

Example:

- Left: Tallinn EETN – VOR (Overlay) RUNWAY 08
- Right: Cape Town FACT – VOR Z RUNWAY 01





5.2. Leg types

A leg is the segment joining two points.
Depending on the intended flightpath, it is defined by a path type and a terminator.
It results in 14 different leg types.

Path		Terminator	
Constant DME arc	A	A	Altitude
Course to	C	C	Distance
Direct Track	D	D	DME Distance
Course from a fix to	F	F	Fix
Holding pattern	H	I	Next leg
Initial	I	M	Manual termination
Constant radius	R	R	Radial termination
Track between	T		
Heading to	V		

Leg types

Identifier	Description
CA	Course to an Altitude
CF	Course to a Fix
DF	Direct to a Fix
FA	Fix to an Altitude
FM	Fix to a Manual Termination
HA	Racetrack Course Reversal (Altitude Termination)
HF	Racetrack (Single Circuit – Fix Termination)
HM	Racetrack (Manual Termination)
IF	Initial Fix
TF	Track to a Fix
RF	Constant Radius Arc
VA	Heading to an Altitude
VI	Heading to an Intercept
VM	Heading to a Manual Termination

Example:

Jersey RNAV (GNSS) RWY 08 - Instrument Approach Procedure via LAPLI

Designator	Sequence Number	Path Term-inator	Waypoint Name	Fly-over	Course/ Track °M (°T)	Turn Direction	Level Constraint	Speed Constraint	Co-ordinates	Remarks and Distance to MAPt
RW08L	001	IF	LAPLI	N	-	-	2000	210	491606.54N 0022827.89W	IAF JSY R282 / D17.1
RW08L	002	TF	GIPTA	N	174° (172.6°)	LEFT	2000	-	491109.26N 0022729.31W	IF / 10NM
RW08L	003	TF	JJ08F	N	084° (082.7°)	-	2000	-	491145.21N 0022020.93W	FAF / 5.3NM
RW08L	004	TF	RW08	Y	084° (082.7°)	-	-	-	491225.43N 0021221.95W	MAPt
RW08L	005	CF	JJM01	N	084° (082.8°)	RIGHT	-	185	491255.54N 0020618.83W	-
RW08L	006	TF	JJM02	N	174° (172.8°)	RIGHT	-	185	490758.14N 0020521.77W	-
RW08L	007	TF	GAMDU	N	264° (262.9°)	LEFT	3000	210	490735.73N 0020953.69W	HOLD

5.3. Conventional Turns

Due to the nature of procedures based on conventional means, some coding will lead to discontinuities in particular when using less elaborate systems.

Under <u>no circumstances should a pilot rely on FMC/GPS rather than on published charts</u>.
If you notice a discontinuity or a difference with published flightpath, aircraft should be manned as to fly the right flightpath.

Special attention should be paied when flying procedures including:

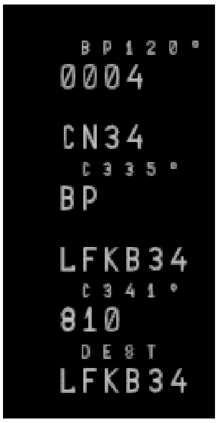
- Racetracks
- Track to intercept a fix radial
- Timed base turns
- Procedure 45/180 and 80/260 turns

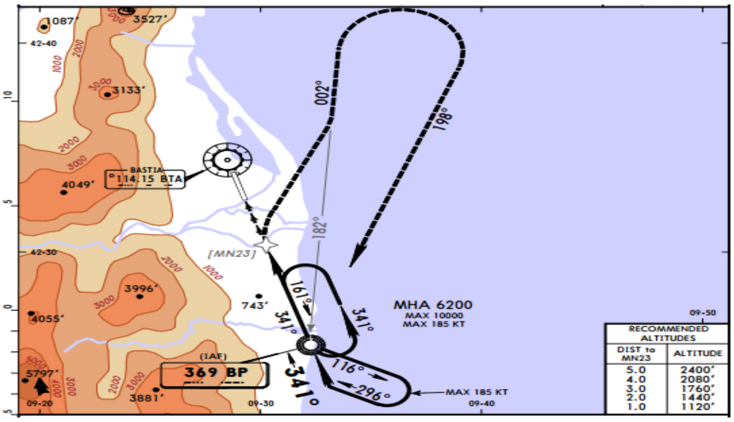
Study case: Bastia LFKB – NDB RUNWAY 34

<u>Description of the procedure:</u>

Given the MSA, the pilot should enter the racetrack at BP.
Then he should perform a procedure 45/180 turn before getting back onto the final axis course.
As shown on the ND, the Airbus MCDU is not able to transcript the approach and the pilot should make most of it manually.

Note that a waypoint is created to materialize the end of the procedure turn.





6. Conclusion

RNAV is a brilliant navigation method to optimize traffic flow using the power of GNSS even though it implies tons of new rules, standards and recommendations to implement for every actors of the aviation industry.

However the future is already marching on, as the evolution of RNAV is already being developed and enhanced: the Required Navigation Performance (RNP)