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TÍTOL DEL TFG: RNP Approach Procedures in Málaga – Costa del Sol Airport

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Resum

L'augment de trànsit aeri arreu del món les últimes dècades ha donat peu a buscar nous sistemes de navegació més segurs, eficients, i sobretot que permetin un augment en la capacitat de l'espai aeri. La navegació per àrees ja és una realitat a tot el món i diversos aeroports han començat a implementar aquest mètode per a la realització d'aproximacions. Les aproximacions RNP tenen diversos beneficis sobre les aproximacions que utilitzen mètodes convencionals, com podrien ser una millora de la eficiència i estalvi de combustible.

A Espanya, aeroports com el de Madrid, Barcelona i Palma de Mallorca ja ofereixen la possibilitat de realitzar aproximacions RNP. L'aeroport de Màlaga és el quart d'Espanya per nombre de passatgers i es una proposta molt competitiva per ser la següent en la qual s'estudiï la seva implementació. El TFG es centra en estudiar la possibilitat d'establir aquest tipus d'aproximació per l'Aeroport.

Per la naturalesa del tipus d'aproximació que estem estudiant, els resultats d'implementació a l'Aeroport de Málaga són molt favorables, el qual obre la porta a que es pugui realitzar properament.

Title: RNP Approach Procedures in Málaga – Costa del Sol Airport

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Date: October 22nd, 2023

Overview

Air traffic growth worldwide in the last decades has encouraged the search of new navigation methods which rise the levels of safety, efficiency, and capacity of the airspace. Area navigation is already a reality around the world and some airports have started the implementation of this method to perform approach procedures. RNP approaches have several benefits when comparing with conventional approaches such as fuel savings and more efficient routes.

In Spain, Madrid, Barcelona, and Palma de Mallorca Airports already have the option of performing RNP approach procedures among its charts. Málaga – Costa del Sol Airport is the fourth largest airport in Spain in terms of passenger traffic and it is a very competitive proposal for its implementation. This final thesis is based in studying the possibility of establishing this type of approach procedure in this airport.

Because of the nature of the RNP systems, the results of the study are very favourable, which leaves open the possibility of implementation in the years to come.

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GLOSSARY

AAIM: Aircraft Autonomous Integrity Monitoring
ABAS: Aircraft-Based Augmentation Systems
AENA: Aeropuertos Españoles y Navegación Aérea
APCH: Approach
ATC: Air Traffic Control
Baro-VNAV: Barometric Vertical Navigation
CFIT: Controlled Flight Into Terrain
DME: Distance Measuring Equipment
DVOR: Doppler Very High Frequency Omnidirectional Range
EASA: European Union Aviation Safety Agency
EGNOS: European Geostationary Navigation Overlay Service
FAF: Final Approach Fix
FAP: Final Approach Point
FAS: Final Approach Segment
FDE: Fault Detection and Exclusion
FL: Flight Level
FTE: Flight Technical Error
GBAS: Ground-Based Augmentation Systems
GNSS: Global Navigation Satellite System
GP: Glide Path
HAT: Height Above Touchdown
IAF: Initial Approach Fix
IAP: Instrument Approach Procedure
IATA: International Air Transport Association
IF: Intermediate Fix
ILS: Instrument Landing System
INS: Inertial Navigation System
KIAS: Knot-Indicated Air Speed
LNAV: Lateral Navigation
LOC: Localizer
LP: Localizer Performance
LPV: Localizer Performance with Vertical Guidance
LRNS: Long-Range Navigation System
MEL: Minimum Equipment List
NAVAID: Navigation Aid
NDB: Non-Directional Beacon
NM: Nautical Miles
NOTAM: Notice to Air Missions
NSE: Navigation System Error
OBPMA: On-Board Performance and Monitoring
PA: Precision Approach
PBN: Performance-Based Navigation
RAIM: Receiver Autonomous Integrity Monitoring
RNAV: Area Navigation
RNP: Required Navigation Performance
RWY: Runway

SB: Service Bulletin
SBAS: Satellite-Based Augmentation System
TSE: Total System Error
VNAV: Vertical Navigation
VOR: Very-high Frequency Omnidirectional Range

INTRODUCTION

The aim of this project is to thoroughly explore the benefits of Performance-Based Navigation as well as theoretically study the possibility of implementation of these operational procedures in Málaga-Costa del Sol Airport, in the south of Spain.

Performance-Based Navigation (PBN from now on) is derived from area navigation, and it is being implemented around the world as a new navigation concept due to its efficiency and reduced operating costs. The air traffic growth around the world over the years has led to new use of technologies to accommodate for these demands. The aim of this project is also to demonstrate and prove if this navigation concept could benefit Málaga Airport and how.

The methodology to obtain the answers for our hypothesis will be the extensive research about this topic to fully comprehend how it operates and how can it be beneficial. The most reliable sources are official published manuals about PBN and area navigation which are published by international and regional organizations.

The first chapter introduces the concept of PBN including its benefits and the relationship it holds with the Global Navigation Satellite Systems (GNSS from now on). In addition, it also expounds on the origin and the context of PBN and focuses on the different specifications which derive from area navigation. These include RNAV specifications and RNP specifications whose implementation constraints are explored also in this chapter.

The aim of the second chapter is to study approach procedures using area navigation, specifically RNP specifications. This chapter aims to showcase the differences between the types of RNP approach specifications and explain its application requirements. The last part of this chapter exemplifies airports which have had RNP approach implementations.

The third and last chapter explores the possibility of implementation of RNP approaches in Málaga-Costa del Sol Airport. This chapter includes a feasibility study where infrastructure and economic requirements are studied. Furthermore, both possible RNP approach specifications are compared to explore these options and find the most suitable one to be implemented.

The last part of this project will be the discussion of the data and results obtained which will support our initial hypothesis or they will debunk our first impressions and thoughts about this concept.

CHAPTER 1. PERFORMANCE-BASED NAVIGATION

1.1. Performance-Based Navigation (PBN) Concept

1.1.1. Definition and Concept

The Performance-Based Navigation (PBN) concept is based on the usage of navigation systems and flight procedures for the precise guidance of aircraft through airspace. PBN is derived from area navigation (RNAV), which is defined as a navigation method that allows aircraft operations in any path chosen within the limits of navigation aids (ground or space). [1]
The International Civil Aviation Organization (ICAO from now on) defines the PBN concept as:

> ‹‹*The performance-based navigation (PBN) concept specifies that aircraft RNAV system performance requirements be defined in terms of accuracy, integrity, availability, continuity and functionality required for the proposed operations in the context of a particular airspace concept, when supported by the appropriate navigation structure.* ›› [2]

RNAV is based in GNSS to determine location and height of the aircraft. The position is determined by solving the triangulation between the signal of 4 satellites. The GNSS positioning alone is not enough to meet ICAO performance standards for navigation, so GNSS augmentation systems are used to check the integrity of the signal. The constant monitoring techniques check the quality of the GNSS signal and ensure its integrity. [3]

1.1.1.1. GNSS Augmentation Systems

GNSS Augmentation systems are used to correct and overcome the limitations of the GNSS systems to correctly meet the performance requirements in terms of accuracy, integrity, continuity, and availability. They are classified in three categories:

Aircraft-Based Augmentation Systems (ABAS): Receiver Autonomous Integrity Monitoring (RAIM) is an algorithm contained in the aircraft receiver and it is the most common form of integrity monitoring, also the most basic type of augmentation system. The computation of 3D positioning requires a minimum of 4 satellites in view, if a fifth satellite is in view, 5 independent computations of the position can be made. The higher the number of satellites is in view, the higher the number of independent positions that can be computed. The receiver then can detect the satellites transmitting locations outside a specific margin and exclude them from the positioning computation. This is called Fault Detection and Exclusion (FDE). [4]

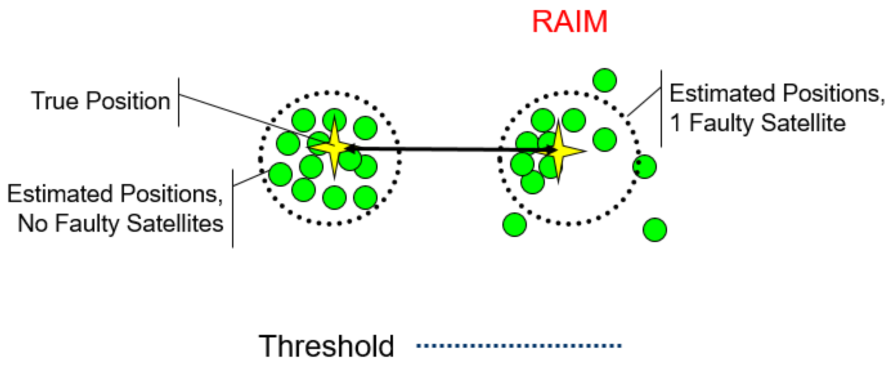

Fig. 1.1 Representation of the RAIM system functioning. [4]

Other augmentation systems can be found aboard which function in cases where there are not enough visible satellites. These can keep the integrity of the GNSS signal for short periods of time and are named Aircraft Autonomous Integrity Monitoring (AAIM).

Ground-Based Augmentation System (GBAS): Developed as a Precision Approach system, GBAS is a ground station which corrects the signal of the satellites that has in view. In case the correction is detected as unreliable of maintaining the standards, those specific satellites are pronounced as 'Do Not Use'.

The principle of the GBAS system in terms of operation is the measurement of satellite signals assuming the error of the ground station is the same as the aircraft. This makes this system have a limited range because the further away the aircraft is from the area, the more different both errors will be. [4]

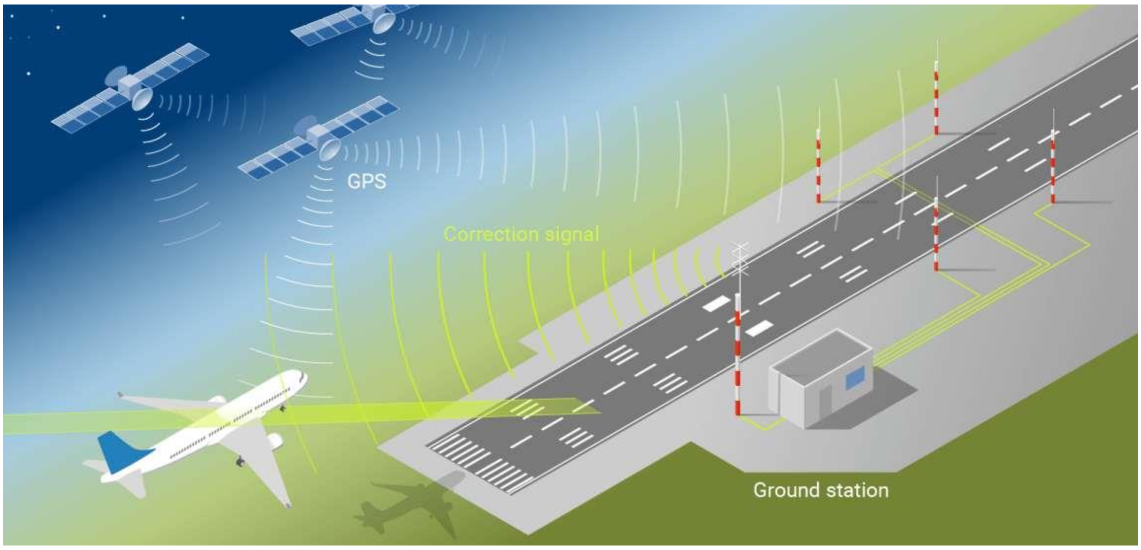

Fig. 1.2 Scheme depicting the functioning of GBAS: the GPS signal is received in different points, and it is processed in the ground station before being broadcasted and received by the aircraft. [5]

Satellite-Based Augmentation System (SBAS): To improve the GNSS signals, this system uses a geostationary satellite which covers the desired regional area where it is going to be used. Monitoring stations receive GNSS data and send them to a designated Master Control Centre (MCC) where corrections are computed for the satellites in view. In case those corrections are not reliable, the satellite will be declared as: 'Do Not Use' (Just like in the GBAS case). Then, the corrections are sent to the geostationary satellite to be broadcasted to the aircraft. The data sent by the geostationary satellite can be received by everyone, since it is sent in the L1 frequency (1575.42 Hz) but, to be able to read the encrypted information, a special SBAS receiver is required (ETSO 145C, ETSO 146C).

Aircraft with the appropriate SBAS receiver have an integrity of position estimation of 10^{-7} (or a 99,99999%) and greater level of accuracy (3m horizontally and 5m vertically for SBAS receivers).
Nowadays, several SBAS systems exist around the world which serve different areas of the world:

- European Geostationary Navigation Overlay Service (EGNOS) → Europe
- Wide Area Augmentation System (WAAS) → North America
- GPS Aided Geostationary Augmented Network (GAGAN) → India
- Multi-functional Transport Satellite Augmentation System (MSAS) → Japan
- System for Differential Corrections and Monitoring (SDCM) → Russia

All of them can provide corrections for GPS signals but, SDCM also monitors and offers corrections for GLONASS system. [4] All of the systems mentioned before are compatible and interoperable, meaning that they do not interfere with each other, and all users can benefit from the same level of service. [6]

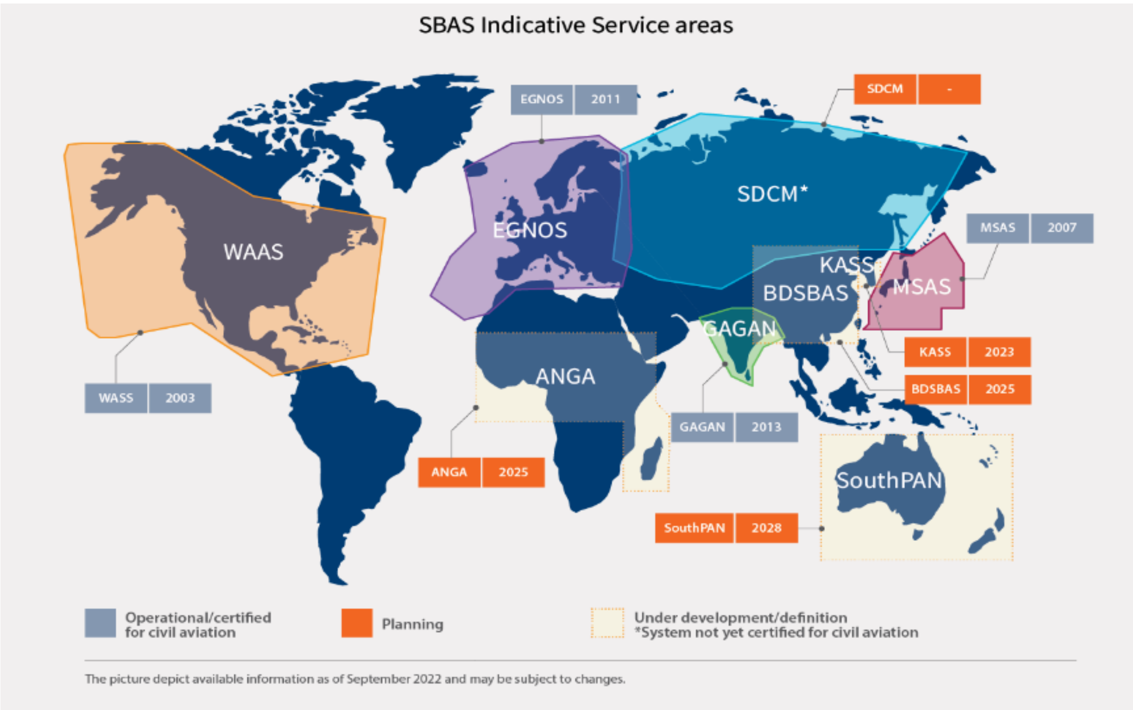

Fig. 1.3 Depiction of the current SBAS systems together with the future ones with their area of service. [6]

1.1.2. Benefits of PBN implementation

PBN offers several advantages over the sensor-specific method of developing airspace and obstacle clearance criteria, for example:

a. reduces the need to maintain sensor-specific routes and procedures, and their associated costs,
b. avoids the need for developing sensor-specific operations with each new evolution of navigation systems, which would be cost-prohibitive,
c. allows for more efficient use of airspace (route placement, fuel efficiency and noise abatement),
d. clarifies how RNAV systems are used,
e. facilitates the operational approval process for operators by providing a limited set of navigation specifications intended for global use.

These benefits result in the following:

- Enhanced safety: PBN allows for more precise navigation and flight path tracking, reducing the risk of accidents and improving situational awareness for pilots. It also enables the design of more efficient and safer airspace structures, reducing the risk of mid-air collisions.

- Increased efficiency: PBN enables more direct flight paths, reducing flight time and fuel consumption. It also allows for more efficient use of airspace, reducing congestion and delays.

- Reduced carbon footprint: PBN can significantly reduce the carbon footprint of aviation operations because of the implementation of more direct flights.

- Reduced costs: By reducing fuel consumption and flight time, PBN can significantly reduce the operating costs of aviation operators.

- Facilitated airspace design: PBN enables the design of more efficient and safer airspace structures, reducing the risks.

- Improved traffic flow: PBN enables more efficient use of airspace, reducing congestion and delays, and improving traffic flow.

- Improved access to runways: PBN enables the design of more efficient and safer approach and departure procedures, improving access to runways and reducing the risk of accidents.

- More accurate and reliable lateral and vertical track-keeping: PBN enables more precise navigation and flight path tracking, reducing the risk of accidents and improving situational awareness for pilots.

- Reduced flight crew's exposure to operational errors: PBN enables more precise navigation and flight path tracking, reducing the risk of operational errors and improving situational awareness for pilots. [2] [7]

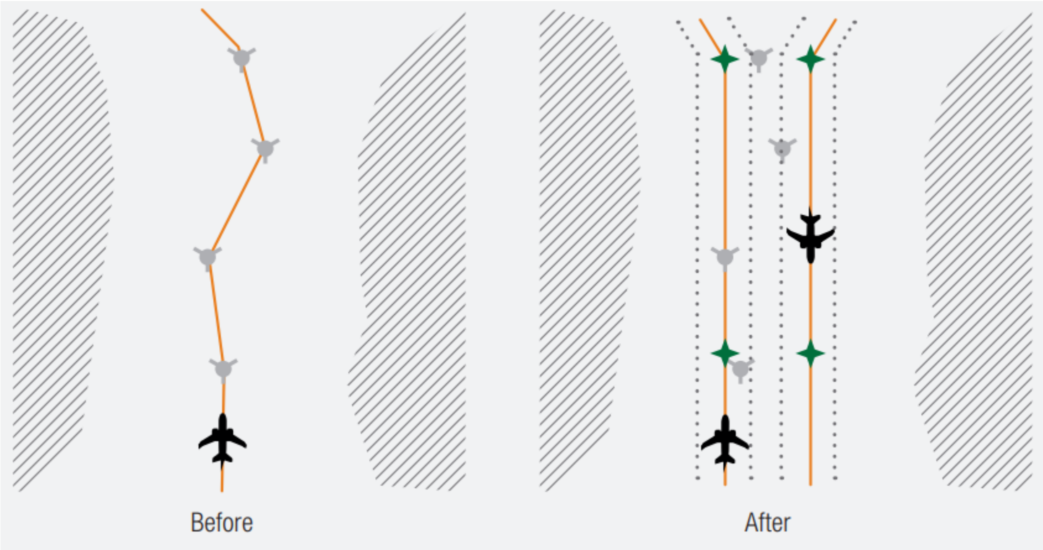

Fig. 1.4 Conventional routing (left) and PBN implementation (right) capacity comparison. [7]

1.2. Performance-Based Navigation (PBN) Context

The constant growth in air traffic in the last decades has required the development of methods for the efficient use of the airspace. The constant improvements in terms of surveillance, navigation and communication gave as a result the implementation of area navigation. PBN relies on the Navigation Aids (NAVAID from now on) structure and the navigation specification which gives as a result the navigation application.

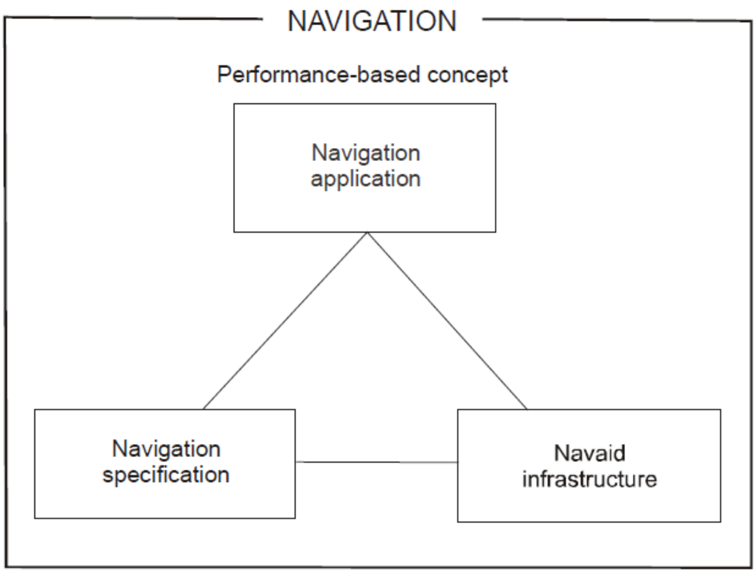

Fig. 1.5 Performance based navigation concept. [2]

The navigation application is achieved by combining the use of the NAVAID infrastructure and the associated navigation specification. NAVAID infrastructure refers to ground-based and space-based navigation aids, for example Distance measuring Equipment (DME) or Very-high frequency Omnidirectional Range (VOR). The navigation specification describes technically and operationally the functionality and performance requirements of area navigation, together with the identification of the necessary equipment to operate in the NAVAID infrastructure. [8] [9]

1.2.1. Navigation Specification

The main use of the navigation specification is the detailing of performance requirements of area navigation systems. It describes them in terms of accuracy, integrity, availability, and continuity, also in terms of functionalities, integration of sensors and requirements of the flight crew. A navigation specification can be a Required Navigation Performance (RNP) or a RNAV specification. The difference between both is that an RNP specification includes on-board performance and monitoring (OBPMA) and RNAV specifications do not. OBPMA determines whether the system accomplishes the safety level required by an RNP system, the capabilities to support lateral and longitudinal navigation, and whether it can detect if the system is not achieving the required performance.

Both specifications mentioned above (RNP and RNAV) have common navigation requirements for certain functionalities. These include continuous aircraft position monitoring; display of distance, bearing and speed to a waypoint; and failure indication among others.

1.2.1.1. Lateral accuracy

Designation of RNAV and RNP navigation specifications follow the lateral navigation accuracy of each one of them. They are expressed in the form of RNAV X and RNP X, where the “X” refers to the total system error expressed in nautical miles. Examples of this could include RNAV 5 or RNP 1, where their accuracies are 5 nautical miles and 1 nautical mile, respectively.

It must be considered that the approval of an aircraft for a specification does not mean that it qualifies for less strict specifications. This also means that aircraft approved for RNP do not automatically qualify for RNAV specifications.
In total, the PBN Manual contains 11 different navigation specifications:

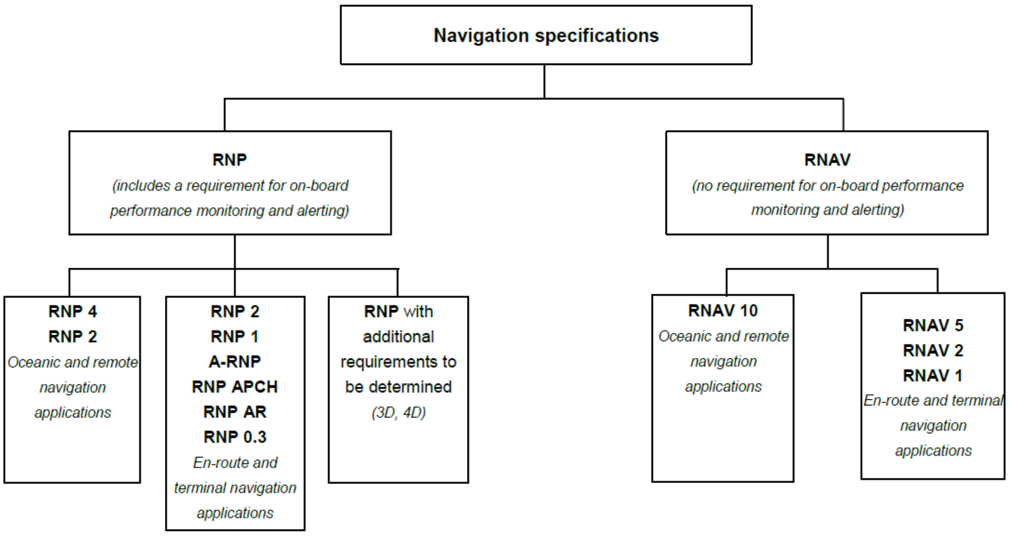

Fig 1.6 Navigation specifications. [8]

Airspace concepts are developed to satisfy strategic objectives and describe the intended operations within a specific airspace. These objectives may include safety improvements, increased air traffic capacity, and increased accuracy in flight paths, among others. The different airspace concepts support different navigation specifications.

Navigation Specification	Flight Phase								Additional Functionalities (Required or Optional)			
	En Route Oceanic Remote	En Route Continental	ARR	Approach				DEP	RF	FRT	TOAC	Baro VNAV
				Initial	Intermed	Final	Missed					
RNAV 10 (RNP 10)	10											
RNAV 5		5	5									
RNAV 2		2	2					2				
RNAV 1		1	1	1	1		1	1				O
RNP4	4									O		
RNP2	2	2								O		
RNP1			1	1	1		1	1	O			O
Advanced RNP	2	2 or 1	1	1	1	0.3	1	1	R	O	O	O
RNP APCH				1	1	0.3	1		O			O
RNP AR APCH				1-0.1	1-0.1	0.3-0.1	1-0.1		*Specific requirements for RF & VNAV*			
RNP 0.3		0.3	0.3	0.3	0.3	-	0.3	0.3	O			O

Fig. 1.7 Navigation specifications with each of their lateral accuracies and additional functionalities. [9]

1.3. Performance-Based Navigation (PBN) Procedures

This section aims to expand on the terminology used in PBN navigation and to compare and point out the differences between conventional navigation procedures and PBN.

1.3.1. PBN Terminology

For PBN procedures there is certain terminology and phraseology which is important to understand to thoroughly comprehend its use and application:

1.3.1.1. Waypoints

Waypoints are defined as specific geographical locations which are used to describe flight routes for aircraft performing area navigation procedures. We may distinguish two types of waypoints in aeronautical charts:

- **Fly-by Waypoints:** These waypoints represent a required turn anticipation to avoid overshooting the next route segment or for routing convenience to intercept tangentially the next segment of the procedure. It is represented in the map as a 4-point star with a circle in the middle. [10] [11]

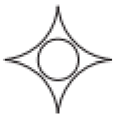

Fig. 1.8 Fly-by waypoint representation. [10]

- **Fly-over Waypoints:** These waypoints represent the requirement of overflying the waypoint before turning and manoeuvring before the interception of the following procedure segment. These are represented similarly to the fly-by waypoints but, fly-over waypoints are surrounded by a circle. [10] [11]

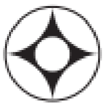

Fig. 1.9 Fly-over waypoint representation. [10]

The following figure (Figure 1.10) better represents and showcases how both waypoints must be flown in case of a 90-degree turn:

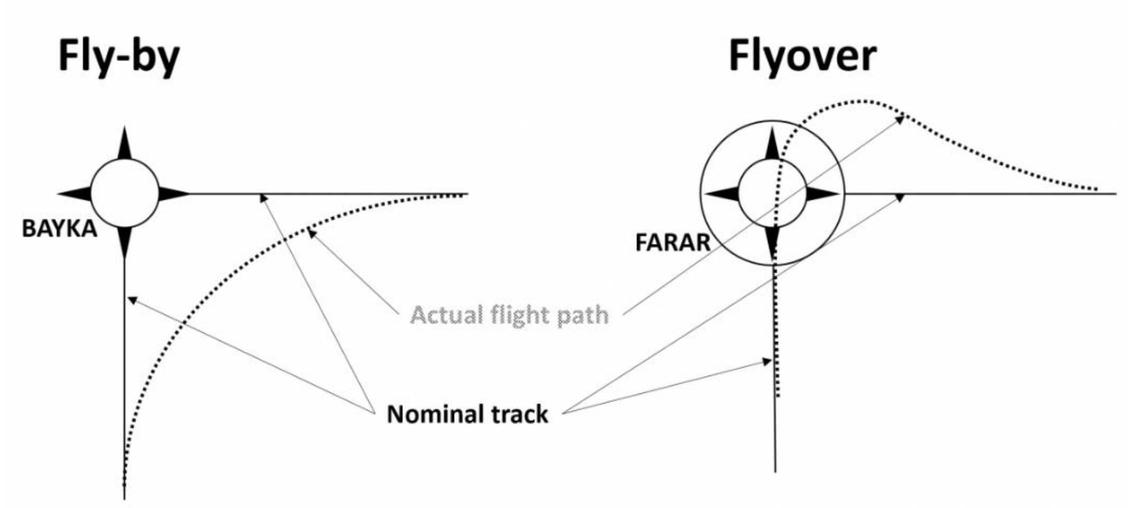

Fig 1.10 Representation of the comparison between the flight path performed on a fly-by waypoint and a fly-over waypoint. [11]

Some waypoints, depending on the position in the approach course, they take other more specific denominations:

- IAWP or IAF: These acronyms define Initial Approach Waypoint and Initial Approach Fix, respectfully. They define the beginning of the Initial Approach Segment.

- IWP or IF: These acronyms define Intermediate Waypoint and Intermediate Fix, respectively. They define the end of the Initial Approach Segment and the start of the Intermediate Approach Segment.

- FAF: The Final Approach Fix defines the end of the Intermediate Approach Segment and the start of the Final Approach Segment. [10] [12]

1.3.1.2. “Direct to” Procedure

The controller on duty shall use the “Direct to” command when they consider it safe and appropriate. This command consists of shortening the approach or departure procedure by skipping one or several constraints defined by the route waypoints. A visual example is provided below in Figure 1.11, where it may provide with better comprehension.

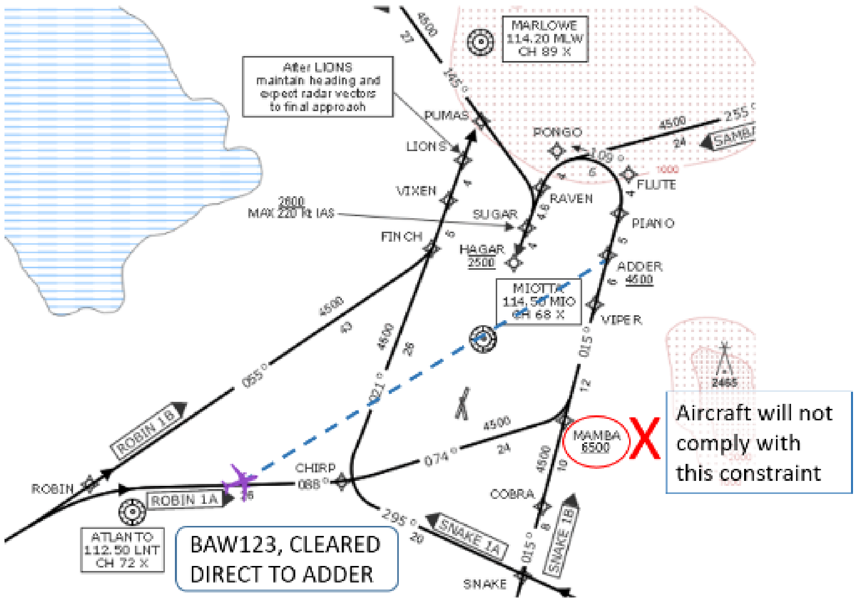

Fig. 1.11 Representation of a "Direct to" command by the duty controller from current position to ADDER waypoint. [13]

This procedure must only be carried out with waypoints which were considered in the flight plan. In case the controller on duty decides to use other waypoints from other approach procedures at the same airport, they shall use vectoring to direct the aircraft to the correct position. [13]

1.4. Implementation Process

1.4.1. RNAV Operations

The implementation process of RNAV specifications is based on a series of requirements for each of them. None of them have the requirement of monitoring and alerting systems, differentiating them from RNP specifications, as previously mentioned.

1.4.1.1. RNAV 10 (RNP 10)

The authorised name for this navigation specification is RNP 10 but, as it is mentioned in the PBN Manual by the ICAO, this specification does not include requirements for on-board performance monitoring and alerting. The name is recurrent throughout the different established routes, so the designation RNP 10 stays even though it is inside the RNAV category.

Regarding NAVAID infrastructure for the implementation of RNP 10, because it was developed to be used for oceanic and remote areas, it does not require any ground-based navigation infrastructure. One of the system requirements is having dual LRNSs (Long-Range Navigation System) to achieve the necessary continuity. The system performance requirements to be achieved in RNP 10 operations are:

- Accuracy: Operations using this specification must have a navigation system error (NSE) within ±10NM a minimum of 95% of the time.

- Integrity: Malfunction of the aircraft's LNRSs without any previous warning is considered major and should be below 1×10^{-5} per flight hour.

- Continuity: Dual independent LRNSs achieve the sufficient continuity requirements since the loss of function is considered a major failure for oceanic and remote navigation

Before obtaining authorization for operating any RNP 10 operations, some steps must be followed:

1. Aircraft eligibility must be determined and documented. This can be obtained by three different methods. The first one consists of using former certifications for RNP operations. This method is based on the use of the flight manual which addresses levels of operational performance obtained for RNP operations which may meet the criteria of RNP 10 operations to obtain authorisation. The second method is similar to the previous method but with systems whose performance can be equated to RNP 10 requirements. The last method is data collection, which requires operators to obtain RNP 10 authorisation by collecting data for a specific period time.

2. Documentation of operational procedures of navigation systems.

3. Pilots and ATC training documentation stating operational procedures. [14]

1.4.1.2. RNAV 5

In the case of RNAV 5 systems considerations, it is permitted for aircraft to fly any desired path within the coverage of station-referenced NAVAIDs, including ground-based systems and space-based systems. RNAV equipment uses input from VOR/DME, DME/DME, INS and GNSS, from one or a combination of them.

There are some specific demands when using each of these systems, for example, DME signals are sufficient to meet RNAV 5 standards, but it requires integrity checks to reassure the correct DME is being used, and it can only be used if the aircraft is between 3NM and 160NM. In the case of GNSS systems, integrity must be provided by SBAS or RAIM to meet the required performance requirements. In cases where GNSS alone is used, if RAIM loss of detection functions occurs, the position should be cross-checked with other sources of navigation information.

The system requirements for the operation of RNAV 5 operations are:

- Accuracy: The lateral NSE must be within ±5NM 95% of the flight time. In addition, cross-track deviation (difference between the RNAV system-computed path and the aircraft position) is limited to half the system accuracy, which in the RNAV 5 case is 2,5NM.

- Integrity: Just like in the case of RNP 10, malfunctions of the navigation equipment are considered major and must be kept below 1×10^{-5} per flight hour.

- Continuity: Loss of function considered minor just in the case that the pilot can revert to a different navigation system.

Regarding system required functions, these include the continuous indication of position relative to track displayed for the pilot on a display; display the distance and groundspeed as well as bearing to the active waypoint; failure indication and waypoint storage. [14]

1.4.1.3. RNAV 1 and RNAV 2

RNAV 1 and RNAV 2 have identical requirements in terms of NAVAID infrastructure and system performance. Regarding navigation aid criteria, to achieve the required performance Distance Measuring Equipment (DME) and GNSS are used.
Both have the requirement of maintaining the Flight Technical Error (FTE) under a value half of their accuracy (0.5 NM for RNAV 1 and 1 NM for RNAV 2) with values over 95%.

Regarding accuracy, integrity, and continuity values as a part of the system performance requirements, the following values are considered:

- Accuracy: During operations the NSE of RNAV 1 and RNAV 2 must stay within ±1NM and ±2NM, respectively, for at least 95% of the time.

- Integrity: Malfunction of the aircraft navigation equipment is considered major and should not exceed 1×10^{-5} per flight hour.

- Continuity: Because reversion to another system is possible, loss of function is considered minor.

In both RNAV 1 and RNAV 2 operations, pilots should use an autopilot in lateral navigation mode or an equivalent system. Additionally, pilots must notify to ATC any loss of RNAV capability. [14]

1.4.1.4. RNAV implementation summary

The table below (Table 1.1) summarizes the information stated above for better comprehension of the different system performance requirements.

Table 1.1 Summary of the RNAV system performance requirements. [14]

		RNAV 10	RNAV 5	RNAV 2	RNAV 1
Accuracy	**NSE**	10 NM	5 NM	2 NM	1 NM
	cross-track	-	2.5 NM	1 NM	0.5 NM
Integrity		1,00E-05			
Continuity		Dual LNRS	Loss of function is minor if reversion to another NAV system possible		
NAVAID	**GNSS**	YES	YES	YES	YES
	DME	NO	YES	YES	YES

In addition, all the RNAV specifications, as previously mentioned, require the pilots and ATC to receive specific training on each of them to be able to perform these navigation operations. [14]

1.4.2. RNP Operations

RNP specifications have common implementation requirements and considerations which only apply for each one of them. One of the common ones is the on-board monitoring and alerting system, which is also what differentiates RNP and RNAV operations when discussing area navigation specifications.
RNP 0.3 operations are not considered in this chapter because they are intended exclusively for helicopter and rotorcraft operations.

1.4.2.1. RNP 4

This RNP specification was intended for oceanic purposes or remote areas, which is one of the main reasons why it does not require any ground NAVAID infrastructure. RNP 4 relies on GNSS as a primary navigation sensor, or multi-sensor, system. For it to be authorised and ready for operation, the operator must elaborate a Minimum Equipment List (MEL) detailing the necessary equipment for using RNP 4.

Regarding system performance requirements, the following can be described:

- Accuracy: During operations using RNP 4, the total system error (TSE) and the along-track error must not exceed ±4NM for at least 95% of the flight time.

- Integrity: Navigation system malfunction is considered a major failure and must not exceed 1×10^{-5} per flight hour.

- Continuity: The loss of the navigation function is a major issue when operating oceanic or remote routes and the aircraft is required to be equipped with dual independent systems to operate RNP 4 routes.

- On-board performance monitoring and alerting: An alert must be provided in case of not meeting accuracy requirements, or if the probability of the lateral TSE exceeding 8NM is superior to 10^{-5}.

In addition to all the above, pilots are expected to follow centre lines throughout all the time of the operation, but slight deviations are permitted regarding cross-track deviation (which is limited to half of the specification accuracy). These deviations are allowed during or immediately after turns up to a maximum to the specification's accuracy (in this case 4NM). [15]

1.4.2.2. RNP 2

RNP 2 specification is intended for use in continental areas where there is little to no ground NAVAID infrastructure. It is based on GNSS infrastructure and requires ABAS systems (RAIM) to support its operation. Other requirements regarding system performance are the following:

- Accuracy: The total system error (TSE) and along-track error must not exceed ±2NM for at least 95% of the time. In addition, FTE must not exceed 1NM.

- Integrity: Navigation system malfunction is considered a major failure and must not exceed 1×10^{-5} per flight hour.

- Continuity: In the case of RNP 2 use for oceanic or remote area operation, the loss of GNSS navigation systems is considered a major failure. On the contrary, if the RNP 2 operation is over continental areas, the loss of function is considered a minor malfunction in the case that reversion to a different navigation system can be performed.

- On-board performance monitoring and alerting: An alert must be provided in case of not meeting accuracy requirements, or if the probability of the lateral TSE exceeding 4NM is superior to 10^{-5}.

Regarding ABAS availability throughout the entire RNP 2 operation can be verified through Notice to Air Missions (NOTAMs from now on), when available, or through GNSS prediction services. In addition, if a predicted event of continuous loss of error detection of over 5 minutes in any of the parts of the operation is detected, the flight plan should be revised and changed if necessary. [15]

1.4.2.3. RNP 1

RNP 1 specification was designed to offer GNSS operations between en-route services and the access to the terminal area, including departure and arrival procedures. It also may be used for certain continental operations and IAPs (Instrument Approach Procedure) up to the FAF (Final Approach Fix).

Regarding the system performance requirements, they have some similarities to the rest of RNP specifications:

- Accuracy: Lateral total system error (TSE) and along-track error must be within ±1NM for 95% of the time.

- Integrity: Just like other RNP specifications, malfunction of the equipment is considered major and must be below 1×10^{-5} per flight hour.
- Continuity: Because the system is designed to operate over continental areas, loss of function is considered a minor issue if reversion to another navigation system can be performed.

- On-board performance monitoring and alerting: An alert must be provided in case of accuracy requirement not met and in case the probability of TSE exceeding 2NM is over 10^{-5}. [15]

CHAPTER 2. RNP APPROACHES

2.1. General

RNP Approaches are described by a serious of waypoints, legs and speed and altitude requirements which are described by the constraints of each approach procedure. Just like the previously described RNP specifications, RNP approach procedures are enabled by GNSS systems. One of the benefits of this type of approaches is to provide with a lower minima and precision approaches to runways not equipped with ILS systems. Moreover, they reduce the risk of a controlled flight into terrain (CFIT) happening, which improves safety of the approach operations.
There are two different specifications for RNP approaches, which are RNP APCH and RNP AR APCH.

RNP APCH is designed to accommodate all aircraft certified for this specification and it is allowed to fly any RNP approach published. [16]

RNP AR APCH operations are not intended for their application at every airport. Instead, it is designed to be implemented in airports with challenging environment where no other instrument procedure can offer benefits. They require additional controls, authorizations and specific training for crews and ATC. This is not the case for Málaga-Costa del Sol Airport therefore, there will not be any further explanation. [8]

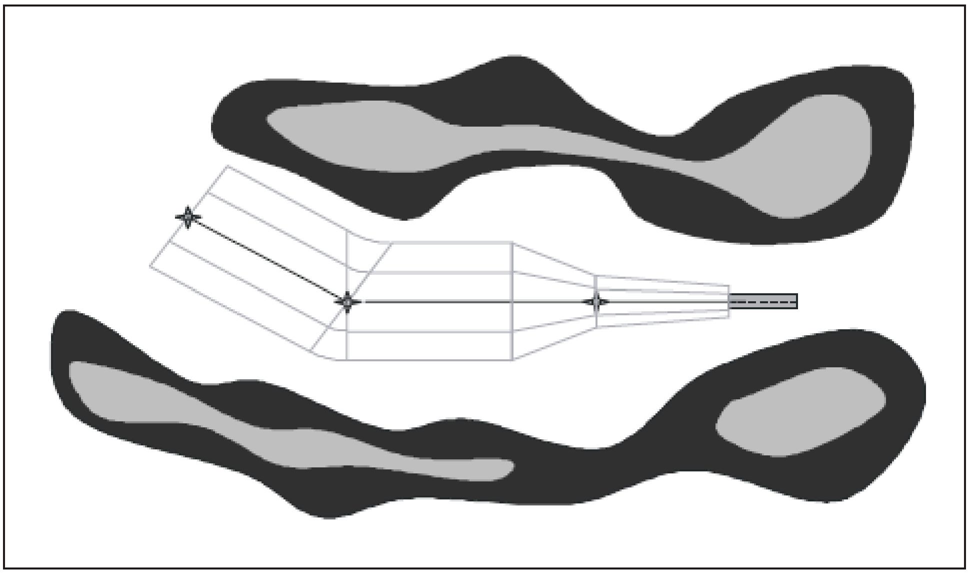

Fig 2.1 Example of an RNP APCH procedure. [2]

2.2. RNP APCH

RNP APCH utilizes certified Baro-VNAV systems or the SBAS geometric positioning, namely RNP APCH to LNAV/VNAV minima and to LPV respectively, introducing new types of 3D operations. The implementation of both of these types of operations require specific pilot and ATC training among other individual requirements.

2.2.1. RNP APCH operations down to LNAV and LNAV/VNAV minima

Regarding the NAVAID infrastructure needed for these types of operations, GNSS is required as previously mentioned. Operators must consider the acceptability of the risk of loss of approach capability due to interference on the GNSS signal or loss of on-board monitoring systems. In addition, operators also must have a minimum equipment list (MEL) detailing the required equipment for operation.

With reference to system performance:

- Accuracy: for initial and intermediate segments and for those missed approach procedures, the lateral total system error (TSE) and the along-track error must be within ±1NM 95% of the time.

  For the Final Approach Segment (FAS), these values are reduced to ±0.3NM 95% of the time for both TSE and along-track error. In addition, to satisfy the 95% flight technical error (FTE), the initial and intermediate segments should not exceed 0.5NM and for FAS it should not exceed 0.25NM.

- Integrity: Malfunction must not exceed 1×10^{-5} per flight hour.

- Continuity: Loss of function is considered minor if reversion to a different navigation system can be performed.

- On-board performance monitoring and alerting: The installed RNP system must alert the pilot if the accuracy constraints are not met or if the TSE exceeds 1NM with a probability greater than 1×10^{-5} per flight hour.

The ICAO also establishes minimum system functions and capabilities to operate this type of approaches. They include continuous displaying of the desired path, navigation databases and the ability to display RNP navigation functions. In addition, it also specifies the requirement of ATC and pilot training to operate this approach specification.

RAIM levels required for the correct operation of RNP APCH down to LNAV or LNAV/VNAV are verifiable through NOTAMs, RAIM functions or prediction services. In the case of any loss of the approach capabilities, ATS must be notified and react safely following previously developed contingency procedures. [15]

2.2.2. RNP APCH operations down to LP and LPV minima

As it was previously mentioned, this type of operation uses GNSS navigation systems combined with Satellite-Based Augmentation Systems to reach the required levels of accuracy.

This specification provides with the abilities to access to a different range of minima down to 60m. Which leads to these system performance requirements:

- Accuracy: The lateral and vertical total system error (TSE) depends on the navigation system error (NSE), path definition error (PDE) and the flight technical error (FTE), on the final approach segment up to the missed approach.

- Integrity: Failure in presenting accurate lateral and vertical in addition to distance data, simultaneously, during an RNP APCH down to LPV minima is extremely remote.

- Continuity: Loss of approach capability is considered a minor failure if reversion to another navigation system is possible.

- On board performance monitoring and alerting: During the FAS, the monitoring and alerting system provides with this service for the NSE and FTE as well as the navigation database. The following table (Table 2.1) showcases summarized information about the criteria in which an alarm is provided before the Final Approach Point (FAP) and after the FAP for NSE. For the vertical monitoring and alerting after the FAP, depending on which LPV minima of height above touchdown (HAT) is established, different values exist. [15]

Table 2.1 On-board performance alerting criteria for NSE.

NSE	2 NM before FAP - FAP	After FAP		
		Horizontal	Vertical	
			Down to 76m HAT	Down to 60m HAT
Alerting Time	10s	6s		
Max error	0.6 NM	40 m	50 m	35 m
Probability	1,00E-07	2,00E-07		

Regarding FTE monitoring, it is required the displaying of the course deviations and failure indications.

As the SBAS system is an essential element to perform RNP APCH down to LPV minima, its availability is an essential concept to considerate. The services required for its operation can be verified using prediction services or through

SBAS NOTAMs. In addition, if a continuous loss of service of more than 5 minutes is predicted in any of the segments of the RNP operation, the flight plan should be revised and resolve the issue applying any sort of delay or switch the approach procedure to another navigation system. [15]

2.3. RNP Approach application in current airports

The implementation of RNP APCH procedures has been very extensive all around the world and it provides airports and aircraft operators with other options to reach the desired destination. The application of RNP APCH in the following airports show two good examples of how using RNP has benefitted them.

- **Chicago Midway Airport (MDW)**

Chicago Midway airport is located south-west from downtown Chicago, in the United States of America. It carried about 10M passengers in 2019 [17] and together with Chicago O'Hare, they serve the city of Chicago and its surrounding areas.

The main goal of the implementation of the RNP APCH procedures in the airport was to reduce the interference with operations in O'Hare International Airport. [18] Another reason for its implementation was the interference of some of Chicago's skyscrapers with the radar signal which made the approaches more difficult.

The runways 22L and 22R were the most affected by conventional landing procedures, which are the ones whose approach paths interfered the most with O'Hare operations.

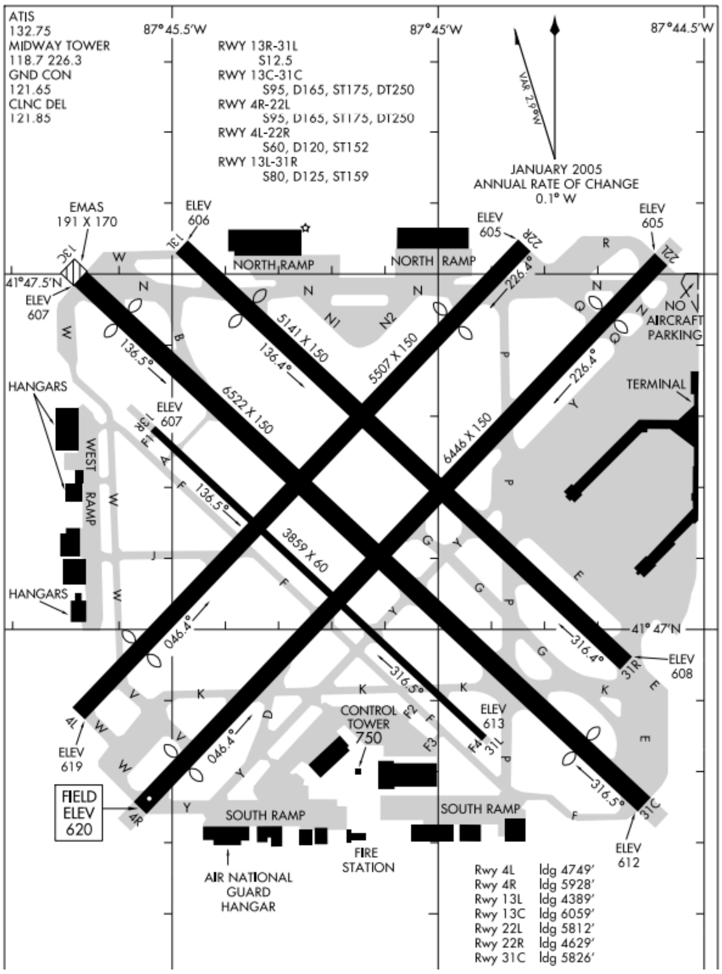

Fig 2.2 Section of Chicago Midway Airport diagram. [19]

The approach to these two runways was performed by following the ILS of runway 31C and then turning to perform a visual landing in runways 22L or 22R. The application of RNP APCH in the runways of Chicago Midway Airport supposes an average of $4.2 million dollars in fuel savings on the major carrier in MDW. [18]

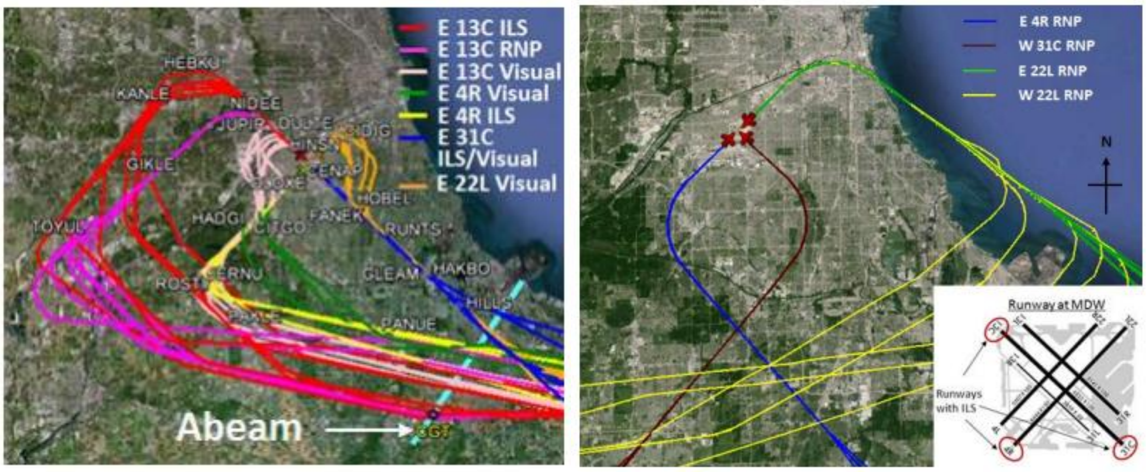

Fig. 2.3 Traffic flows using conventional approach systems (left) and RNP APCH procedures (right). [18]

- **Nice – Côte d’Azur Airport (NCE)**

Nice – Côte d'Azur Airport is located in the south-west from the city of Nice, in France. It serves the city of Nice and its surrounding areas. It is the second largest airport in France after Paris, in 2019 it served 14.5 million passengers. [20]

Due to the airport’s surrounding terrain, approach procedures to runways 22R and 22L can only be performed by using VOR or RNP. Because both approaches merge almost perpendicular when reaching the visual track, the sequencing of aircraft which are able to perform RNP procedures and the ones which are not was challenging to ensure, especially with adverse meteorological conditions. [21]

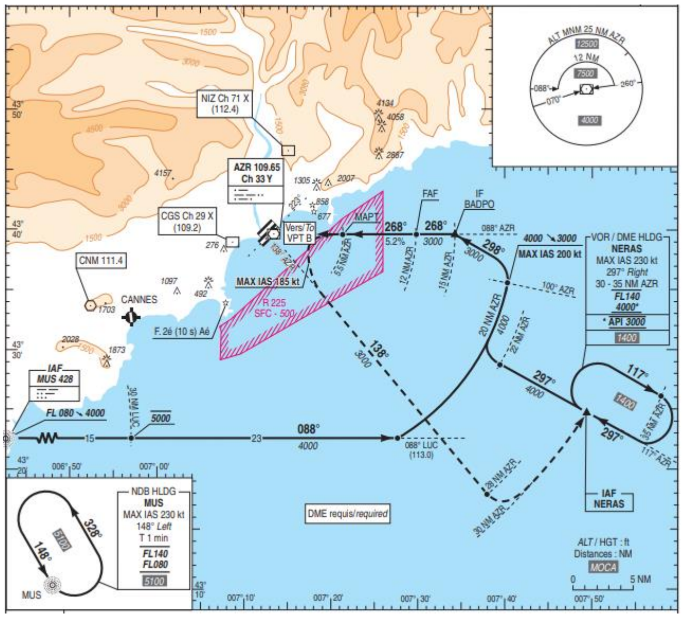

Fig. 2.4 VOR approach to RWY 22L/R in Nice Airport. [22]

The provisional decision was made to only accept VOR approaches for runways 22L/R until a better solution was found. As of January of 2019, it requires all aircraft operating in these runways to be approved for RNP APCH operations. These has eased the Air Traffic Management (ATM) workload specially in hazardous meteorological conditions and ensures a much better operating minima as well as a reduced number of delays in the airport. [21]

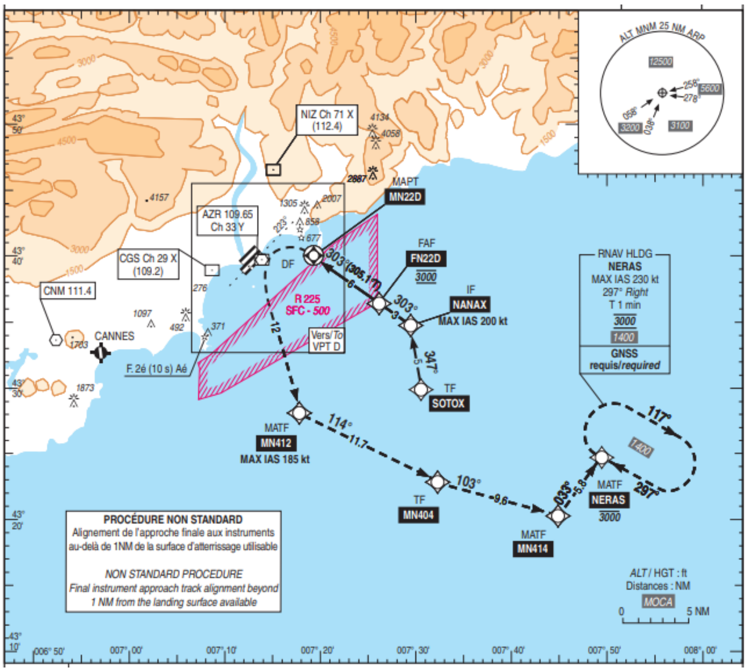

Fig. 2.5 RNP APCH to RWY 22L/R in Nice Airport. [22]

CHAPTER 3. THEORETICAL STUDY OF RNP APCH APPLICATION IN MÁLAGA-COSTA DEL SOL AIRPORT

3.1 General

This chapter aims to study the possibility of the implementation of area navigation approach operations (specifically RNP APCH) in Málaga-Costa del Sol Airport, located in the south of the Iberian Peninsula, in Spain.

Málaga – Costa del Sol Airport (IATA: AGP, ICAO: LEMG) is located at approximately 8km in the southwest of Málaga's city centre and it serves the city of Málaga as well as all its nearby towns. The airport had almost 18.5M passengers in 2022 which makes it the fourth busiest in Spain. The airport offers 148 destinations operated by 62 different airlines, with routes covering Europe and some intercontinental destinations. [23]

As showcased in the figure below (Figure 3.1), the passenger traffic was growing year after year, and has experimented a very good recovery after the global pandemic:

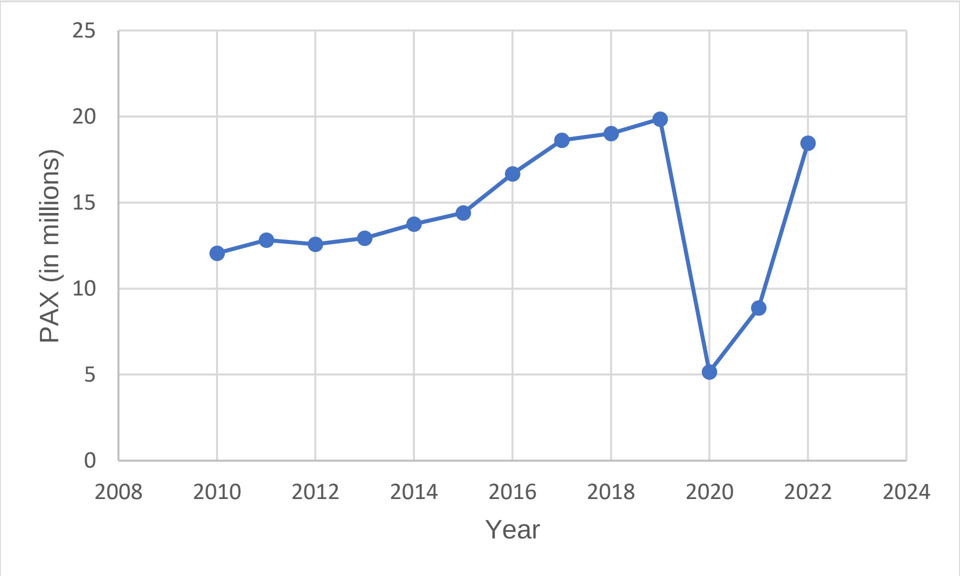

Fig. 3.1. Passenger traffic evolution in Málaga airport from 2010 to 2022. [23]

Málaga Airport is the busiest airport in Spain without an RNP APCH option for operators to make use. The three busiest in Spain, being Madrid, Barcelona, and Palma de Mallorca, all have implemented the RNP APCH options within its approach operation types. The rapid recovery from the pandemic and the historic data from its previous years demonstrates the potential of the airport to keep the growing tendency upwards, which makes it a very capable candidate for area navigation approaches implementation.

3.2 Feasibility Analysis

The aim of this section is to analyse the different aspects of the airport which could make this type of approaches implementable and beneficial for the Málaga – Costa del Sol Airport.

3.2.1. Infrastructure constraints

The airport is equipped with a very complete list of navigation aids, which allow approaches to up to CAT I of the Instrumental Landing System (ILS) in 3 of the 4 active runway headings. GBAS based approaches are also possible in 2 of the 4 active runway headings. The airport is also equipped with Doppler VHF (Very High Frequency) Omnidirectional Range (DVORs), DMEs, a Non-Directional Beacon (NDB) and various Localizers (LOC). [24]

The airport has two runways (12/30 and 13/31) which are currently used in four different configurations displayed in the following table (Table 3.1):

Table 3.1. Runway configurations in Málaga-Costa del Sol Airport. [24]

	North		South	
	1 RWY	2 RWY	1 RWY	2 RWY
Departures	RWY 31	RWY 30	RWY 13	RWY 13
Arrivals	RWY 31	RWY 31	RWY 13	RWY 12

As it might be observed, runway 30/12 only allows operations going in one direction, runway 12 can only operate approach procedures, and runway 30 can only operate departures. This is due to the location of a communications tower in the header of runway 30 which limits operations. In addition, runway 12/30 has been in multiples controversies for its low utilization since its inauguration. [25] [26] [27] The main runway is then 13/31, which is the one used all year round and for most operations. In addition, according to the Spanish navigation services provider Enaire, the preferred configuration is the South. [24]

Even with all the infrastructure and NAVAIDs available in Málaga Airport, for it to be able to provide support for RNP APCH procedures, there is no ground NAVAID requirements for these types of operations, since the main system to provide with guidance is GNSS combined with SBAS or Baro-VNAV systems. [15]

SBAS coverage is provided by EGNOS in Europe. The following picture (Figure 3.2) showcases the availability of this service and, as it may be observed, Málaga has perfect coverage to make use of all its capabilities:

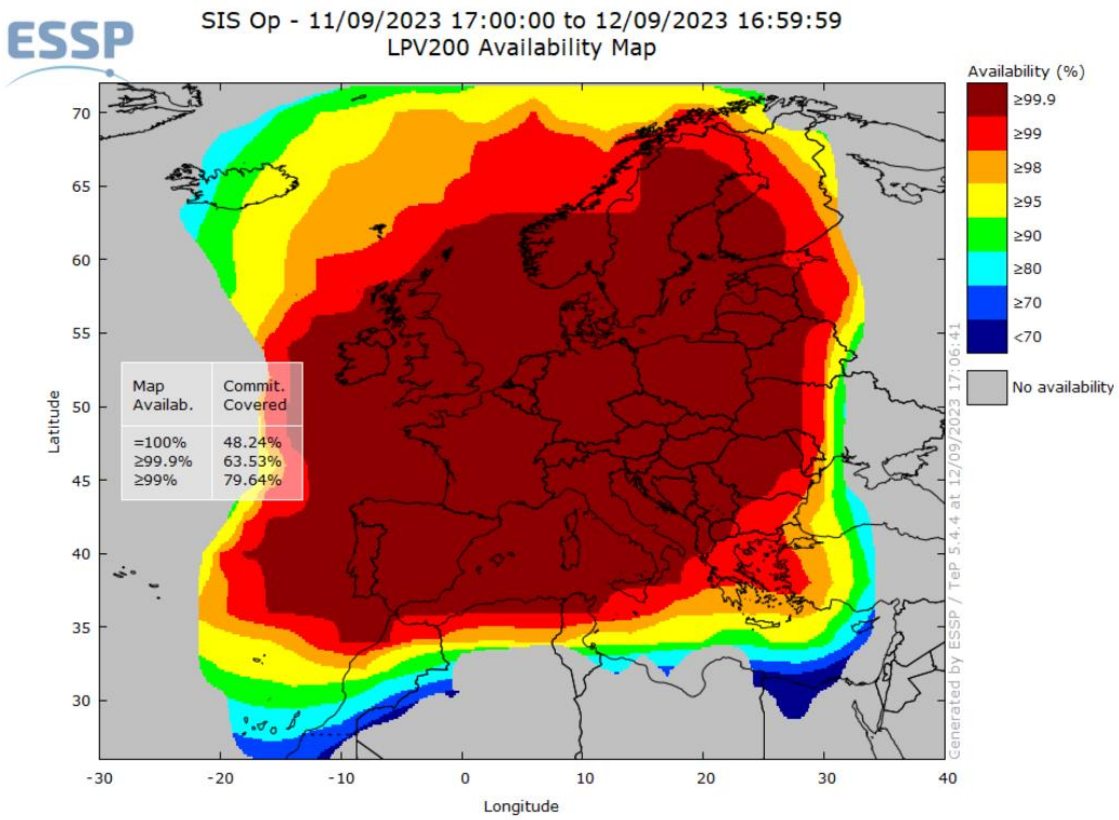

Fig. 3.2 EGNOS coverage in Europe. [28]

Figure 3.2 perfectly showcases the availability of the EGNOS services throughout Europe, where Málaga is included. Baro-VNAV systems use information provided by the pitot-static system and air data computer, so no ground-based NAVAIDs are necessary either. [29]

To summarize, Málaga – Costa del Sol Airport is perfectly capable to implement RNP Approaches in its operations.

3.2.2. Economic constraints

Since the implementation of RNP approaches is not conditioned by the installation of any new or the use of any ground-based NAVAIDs, its implementation does not require any new equipment purchasing and installation. This means RNP APCH procedures are much cheaper than conventional approaches to implement.

On the other hand, operators which want to operate these types of procedures, must invest in the proper equipment for their fleet, proper training in the use of RNP APCH for their pilots and, the establishment of normal, abnormal, and contingency procedures. [30]

3.3 Approach Type Selection

This chapter aims to justify and explain the decision of the implementation of either RNP APCH operations down to VNAV/LNAV minima or RNP APCH operations down to LP and LPV minima.

To decide which RNP approach would be more convenient for the airport and would get more use, we must analyse the main airlines providing the airport with passenger flow. According to statistic provided by AENA, the main operators in Málaga in 2022 were Ryanair, Vueling and easyJet, in which Ryanair carried more passengers than the two following combined. [31] It is showcased in the following graph (Figure 3.3):

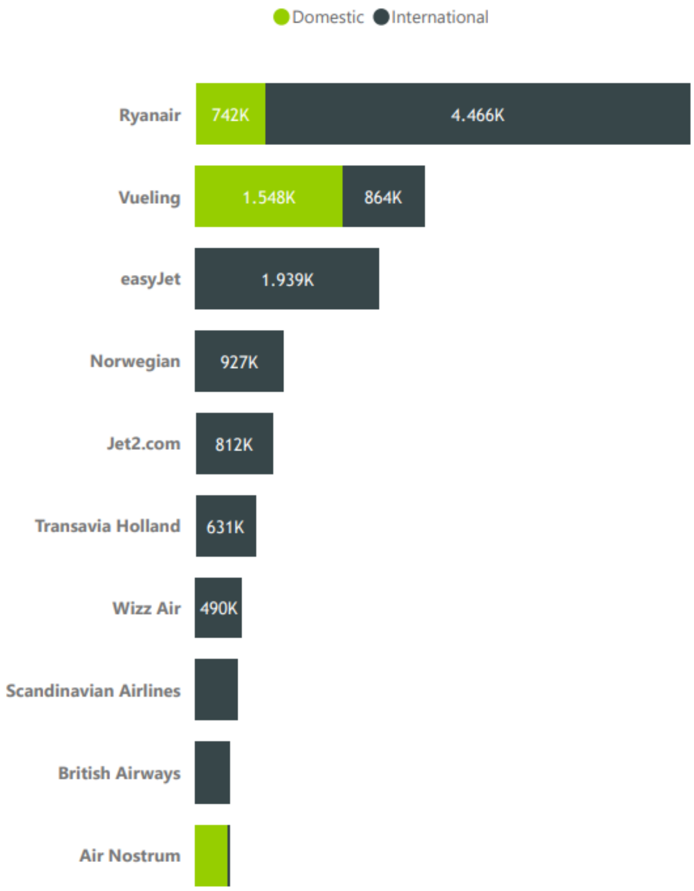

Fig. 3.3. Traffic flow distribution by airline in Málaga Airport in 2022. [31]

As it is showcased in Figure 3.3, the main operators in the airport are low-cost carriers. Ryanair's fleet consists of mainly Boeing 737 aircraft [32] and in the case of Vueling and easyJet, their fleet consists of the Airbus A320 family. [33]

All these aircraft are perfectly capable of operating both RNP APCH down to LPV minima and RNP APCH down to VNAV/LNAV. In the case of older planes in their fleets which were not designed with RNP operation capabilities in mind, operators must follow the airworthiness requirements and apply suitable EASA approved Service Bulletins (SB) for the appropriate in case they want to implement it in their whole fleet. [34]

So, once it is known that all the aircraft can support both operations, the decision of either one approach or the other cannot be based on the main Málaga aircraft operators' fleet. On the other hand, comparison between the level of safety of both of them can be provided.

As it has been mentioned before, RNP APCH operations down to VNAV minima use barometric altitudes to provide for vertical guidance. According to a ops bulletin published by the ICAO in July 2023 [35], the risk of an erroneous altitude setting when operating the final segment of the approach could have severe consequences. Altimeters on aircraft can have three different settings on the altimeter:

- QNH: indicates the altitude of the aircraft, sea level as a reference.

- 1013.2 hPa: indicates Flight Level of the aircraft.

- QFE: The altimeter indicates the height of the aircraft over a reference location, for example, an airport.

The incorrect setting of the barometric altimeter can lead to significant altimeter deviations. Each 1hPa error equates to 30ft height difference, wrongly setting the altimeter could have catastrophic consequences. [35]

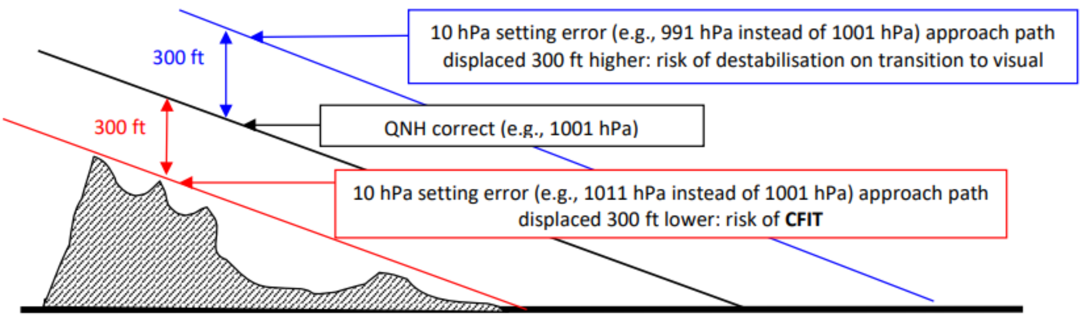

Fig. 3.4. Example of altitude deviation due to an incorrect altimeter setting. [35]

On the other hand, RNP APCH down to LPV minima does not use barometric altimeters to provide for vertical guidance. Instead, as previously mentioned, vertical guidance is provided by SBAS systems so issues with the altimeter settings do not affect the values.

In addition, regulation (EU) 2018/1048, establishes the requirement of operators of aerodromes and providers of air traffic management (ATM) to implement PBN routes and approach procedures following a series of deadlines to transition to

PBN procedures. In addition, this regulation requires the implementation of RNP APCH down to localiser performance with vertical guidance (LPV) minima. [36]

Provided with all the data above and looking towards the future development of the airport, the most practical RNP APCH type to be implemented would be RNP APCH down to LPV minima.

3.4 Approach trajectory

As it has been mentioned previously and according to the Spanish air navigation services provider, the preferred arrivals and departures configuration is the South configuration. The South configuration consists of both arrivals and departures using runway 13; or using runway 12 for arrivals and 13 for departures. Since runway 13 is the most used one, the approach trajectory to runway 13 is the one which will be studied. Before beginning with the trajectory for the RNP APCH procedure in Málaga Airport we can study how trajectories vary from conventional approach procedures to RNP APCH procedures in other airports:

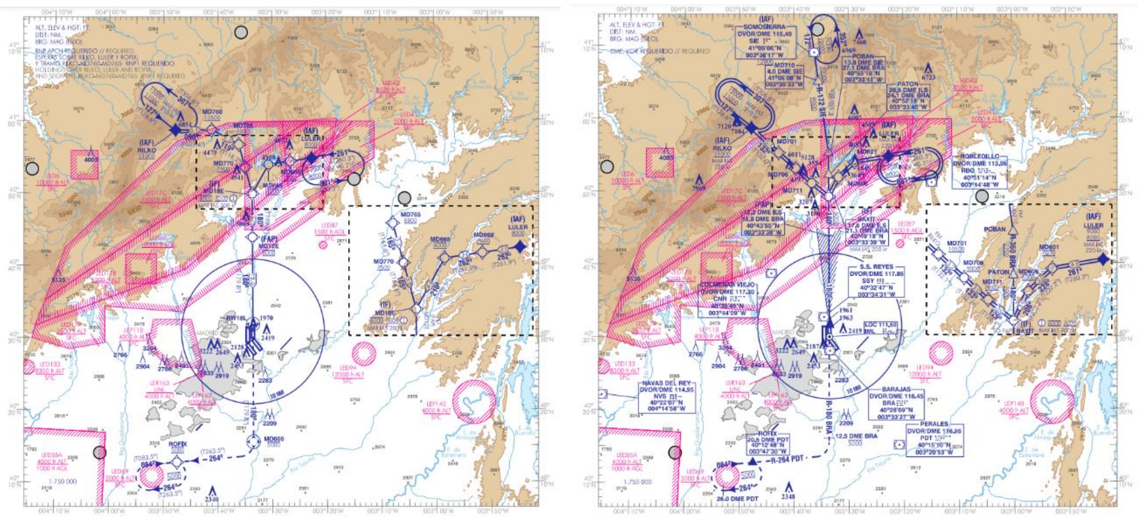

Fig. 3.5 Approach charts for runway 18L of Madrid-Barajas Airport. RNP APCH down to LPV minima (left) and ILS (right). [37]

The picture above (Figure 3.5) showcases an RNP APCH down to LPV minima on the left and a conventional precision approach (ILS) on the right. As it may be observed, both approach trajectories are very similar on the location of holding patterns and identical in the final approach segments. This also applies for the missed approach segments which also coincide with the same route and the holding pattern.

In the case of altitudes in all the approach segments follow the same pattern, but they are specified and performed according to the different navigation systems. In the case of ILS, DME and VOR are used, while RNP uses waypoints.

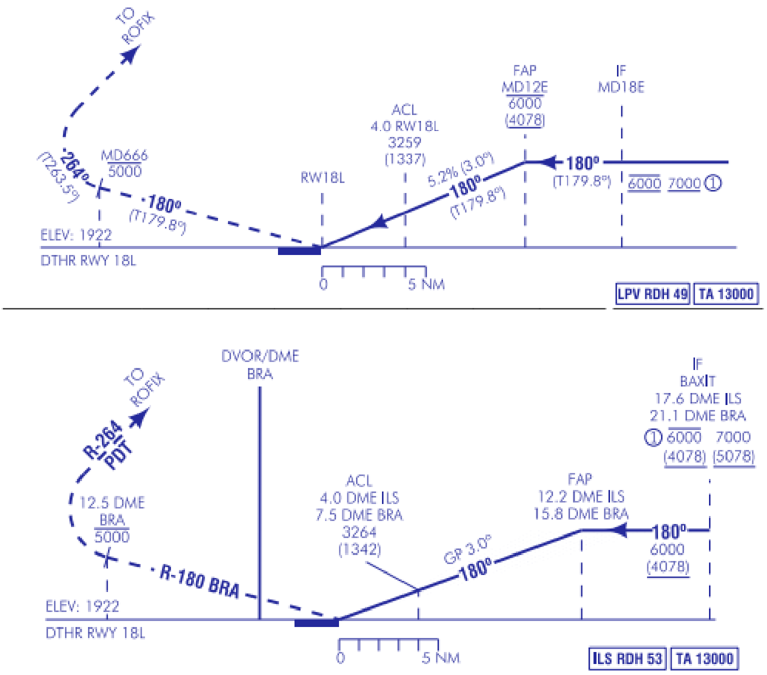

Fig 3.6 Altitudes for ILS approach and RNP APCH procedures on RWY 18L in LEMD. [37]

Another case where similitudes can be found is in Palma de Mallorca airport, in the Balearic Islands, also in Spain. The picture below (Figure 3.7) shows a side-by-side comparison between the RNP and ILS approach procedures in this airport.

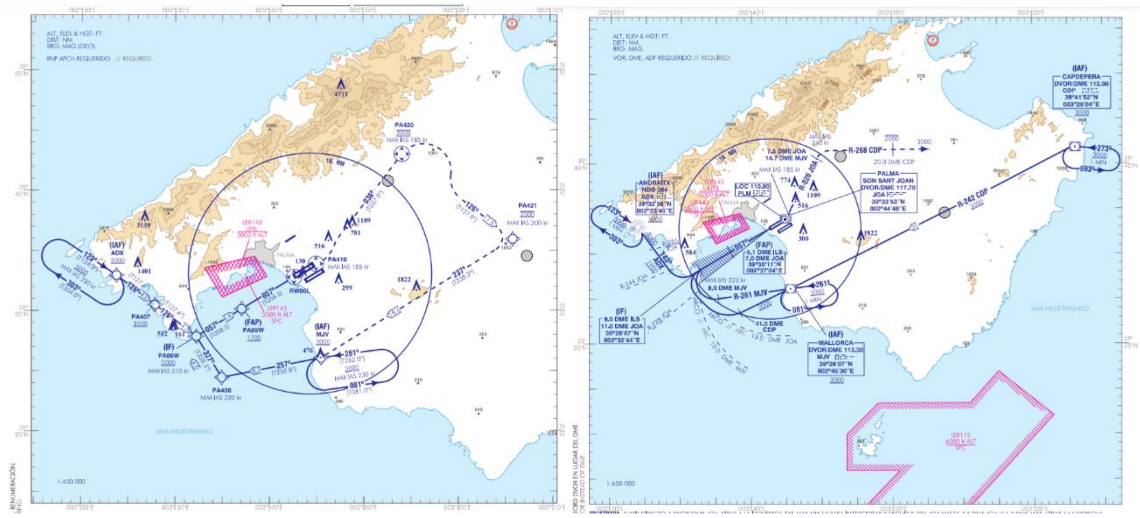

Fig. 3.7 Approach charts for runway 6L of Palma de Mallorca Airport. RNP APCH down to LPV minima (left) and ILS (right). [37]

Figure 3.7 showcases the approach trajectories followed by an RNP APCH and an ILS precision approach. As it is observed in both pictures, the approach trajectories are very similar, the only differences which can be distinguished are the Initial Approach Fix (IAF) named CAPDEPERA together with a holding pattern which does not appear on the RNP APCH. In addition, the segments can also be distinguished on the type of symbols used; in the case of RNP approach, fly-by and fly-over points are used, and in the case of ILS, DME arc and VOR radius are used for the navigation.

These two examples provide with guidance and expectations on which will be the route for the approach to runway 13 of LEMG. To provide with a similar approach to the one to be obtained, we can observe the approach to runway 13 using different navigation methods. The following figures show approach procedures using different navigation methods.

ANNEX 1 showcases the ILS procedure. As it may be observed, the IAF for this approach procedure are TOLSU, located in the north, and OMIGO, located in the north-west. From there, they both direct their routes towards NEPUR point, located approximately 310 degrees taking the airport DME as a reference. To reach the point, in the case of OMIGO IAF, it follows two MAR VOR radials, 010 and 148, respectively. In the case of TOLSU, the first step is to follow the radial 079 and then, when it intersects with DME arc at 3.3 NM, it goes to intersect radial 148. Then, at this point, it goes to intersect radial 132 from MLG to finally get the Localizer signal to perform the ILS landing. In the case of missed approach, when reaching 2.4 NM from MLG DVOR, radial 102 is intersected to reach the XILVI point to start the holding pattern until the landing can be performed again. [38]

ANNEX 2 showcases the VOR procedure. In this case, the same initial steps are followed, until NEPUR point is reached, which then radial 133 instead of radial 132 from MLG DVOR. The missed approach procedure is exactly the same as the one used in the ILS procedure, which finalizes in XILVI point with a holding pattern. [39]

ANNEX 3 showcases the case for GBAS. GBAS is a system based on GNSS signals using Ground-Based Augmentation systems [40]. This system also requires DME and VOR reception for guidance. This chart starts at IAF TOLSU and IAF OMIGO, just like the previous ones. From OMIGO a 190º course is followed to reach the MAR DVOR and then changing to course 148º to reach the IF before taking a course of 132º to reach the runway. The missed approach segment is also the same as the previous cases. [41]

According to the Aircraft Operations Manual from ICAO [42], there are some guidelines of the different tracks of the approach which must be followed. Before taking any of the approach charts above as a reference, these must be checked:

- For approach procedures with vertical guidance the intersection between the initial approach segment and the intermediate segment should not be exceeding 90º. As it is displayed in ILS and GBAS approach charts, the angle in the IF, the one made from the segment coming from DVOR MAR and the segment directed to the FAP, is over 90º.

- For basic GNSS, the minimum length of the initial segment preceded by an arrival route is 6NM. In the GBAS (this case only applies to procedure using GNSS) approach chart, the initial approach segment (from TOLSU or OMIGO up to the IF) is over 6NM.

- For approach procedures with vertical guidance the intermediate segment and the final approach segment must be aligned. On both the ILS and GBAS charts these segments are aligned.

All the constraints above are met for ILS and GBAS so RNP APCH down to LPV minima will follow the same trajectory as the other approaches to RWY 13. Because RNP APCH procedures do not rely on ground NAVAIDs, reference points must be chosen to create the trajectory on GNSS terms. To start defining our trajectory, INSIGNIA [43] software from the Spanish service provider ENAIRE will be very useful. INSIGNIA provides with reference points, ground NAVAIDs and an extensive list of layers to fully comprehend the airspace in Spain. The software also provides with the exact locations of all of them using cardinal coordinates and measurement of distances in Nautical Miles.

Some of the points chosen are used by GBAS and ILS approaches to RWY 13. The other points are created taking already existing points from conventional precision approaches. The difference between how these points are reached in these approaches from RNP APCH is their use. While GBAS and conventional approaches make use of the resources provided by DME and VOR like radials and arcs, RNP approach uses the coordinates directly to navigate through airspace. The points chosen for the approach to RWY 13 in a RNP APCH are showcased in the following table:

Table 3.2 Points to be used for the RNP APCH down to LPV minima in RWY 13. [38] [41] [43]

WAYPOINTS COORDINATES	
NAME	COORDINATES
TOLSU (IAF)	37º08’03.2”N 004º28’15.0”W
OMIGO (IAF)	37º13’12.9”N 004º54’26.0”W
MARTIN	37º03’18.8”N 004º56’23.2”W
NEPUR	36º55’45.6”N 004º50’16.8”W
MG402 (IF)	36º53’52.2”N 004º48’45.4”W
MG401 (FAP)	36º48’49.9”N 004º41’39.1”W
RWY13	36º41’04.3”N 004º30’45.3”W
MG13V	36º39'07.8''N 004º28'10.9''W
MG31N	36º39'35.8''N 004º22'18.9''W
XILVI	36º36’51.7”N 004º06’01.1”W

Most of them, are already in use for ILS and GBAS approaches (TOLSU, NEPUR, OMIGO, XILVI, MG402, MG401 and RWY13), the other waypoints were created in the map based in the following:

- **MARTIN:** This waypoint is based on the location of the DVOR with the same name, which services ILS and GBAS approaches. Its coordinates describe, therefore, the same location as the DVOR.

- **MG13V:** This point is located in the missed approach segment. This location is described in the previously mentioned approaches (ILS and GBAS) as 2.4 NM from MLG DVOR in the direction of the runway heading. To find the exact coordinates of this point, we make use of the INSIGNIA software:

1. To find the coordinates of the point to be used, INSIGNIA gives the option of drawing a line with the length and the bearing desired by giving the coordinates of the point where it originates, in this case, MLG DVOR:

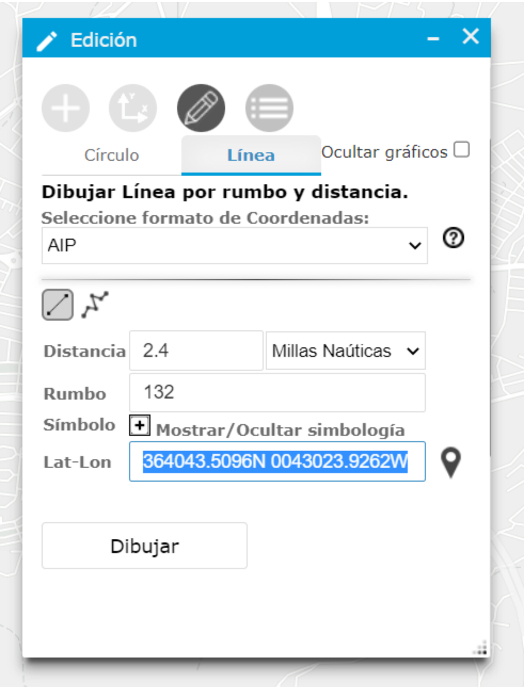

Fig 3.8 The Edit tab in INSIGNIA software used to draw in the map. [43]

As it may be observed in Figure 3.8, it is very easy to use and very self-explanatory.

2. Once you click on the “Dibujar” button, the line draws in the map this way:

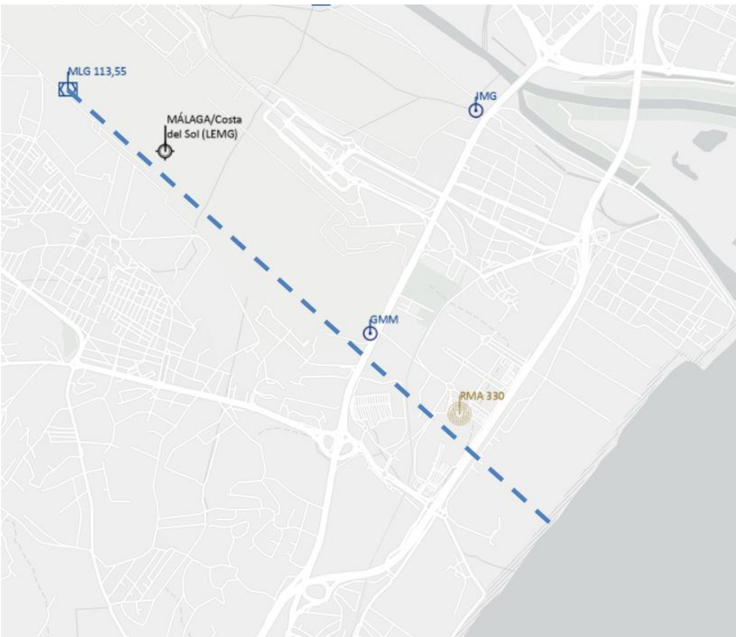

Fig. 3.9 Line of 2.4NM drawn in the INSIGNIA map. [43]

3. To know the coordinates of the desired point, the mouse pointer must be located at the end of the line and the coordinates appear on the down-right corner of the screen.

Fig. 3.10 Coordinates of point MG13V shown in the software. [43]

- **MG31N:** Both GBAS and ILS approaches describe the missed approach segment as following the runway heading until reaching 2.4 NM from MLG DVOR and then turning left to intersect radial 102 of mentioned DVOR. Because in RNP APCH no ground aids are used, MG31N point is created to solve this problem. The point is located in the intersection of the left turn and the DVOR radial 102. To find the exact coordinates of this point we can use INSIGNIA. First, following the previous steps, a line following radial 102 of DVOR MLG is drawn in the map. Then, the software has a layer which showcases all the approach procedures available in the airport, so, it is used to see where exactly the GBAS and ILS procedures intersect with the radial.

Fig. 3.11 INSIGNIA map showcasing approaches and radial 102 of MLG DVOR. [43]

Once the approach layer is activated, all the approaches are shown. It is easy to get confused on which are the exact ones which correspond to GBAS and ILS missed approach segments but, because the red line corresponding to radial R102 of MLG was drown, both are detected easily. The point MG31N is finally located approximately 4.7 NM away from MG13V and the coordinates are showcased in Table 3.2.

To visualize the location of the waypoints better, the following picture showcases all the locations in a Google Earth map:

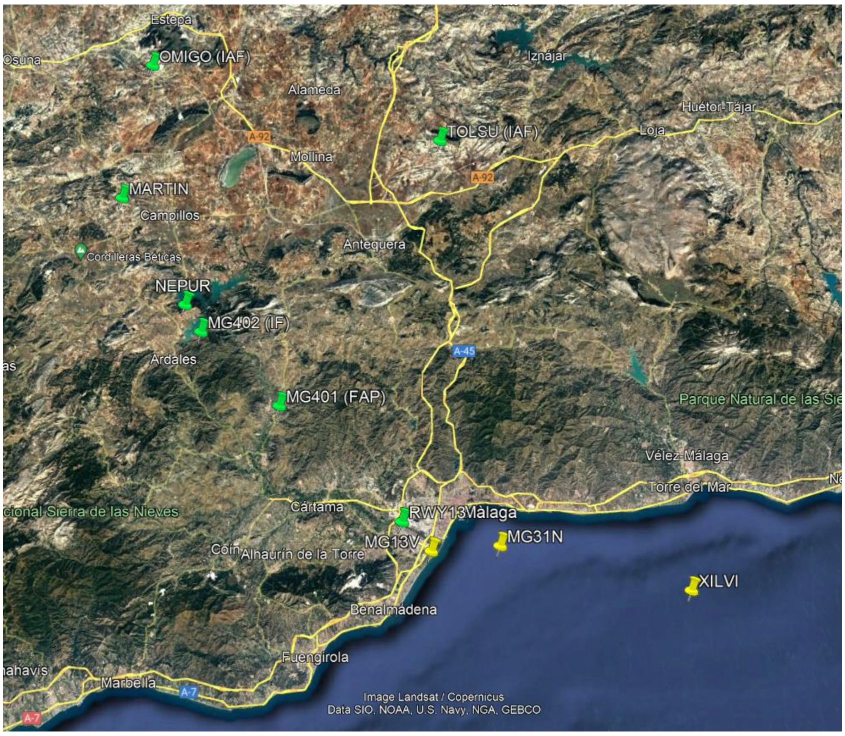

Fig. 3.12 Google Earth map showing the locations of the waypoints. In yellow, missed approach segment waypoints. [44]

The next step is using INSIGNIA to connect the waypoints. To do this task we shall use the same steps as it was done earlier. First, writing the origin waypoint coordinates, and then, indicating the coordinates of the point and second, stating the distance and heading. In addition, we must take into consideration which point is the one of origin to draw the line in the correct direction. Because many of the waypoints are known, the headings of the approach are the same as in ILS and GBAS. It will be easier then, to follow the trajectory of the approach. In case of doing some of the lines from a waypoint which is further ahead in the approach than the one which we are working on, we simply either subtract or add 180º to match the desired direction. The headings and distances of the trajectory (both in the direction of the approach and backwards) before the missing approach segment are showcased in the following table:

Table 3.3 Headings and distances of the trajectory. [43]

FROM	TO	ORIGIN WAYPOINT COORDINATES	DISTANCE (NM)	HEADING
TOLSU	MARTIN	37º08'03.2"N 004º28'15.0"W	23.0	259º
MARTIN	TOLSU	37º03'18.8"N 004º56'23.2"W		79º
OMIGO	MARTIN	37º13'12.9"N 004º54'26.0"W	10.0	190º
MARTIN	OMIGO	37º03'18.8"N 004º56'23.2"W		10º
MARTIN	NEPUR	37º03'18.8"N 004º56'23.2"W	9.0	148º
NEPUR	MARTIN	36º55'45.6"N 004º50'16.8"W		328º
NEPUR	MG402	36º55'45.6"N 004º50'16.8"W	2.2	148º
MG402	NEPUR	36º53'52.2"N 004º48'45.4"W		328º
MG402	MG401	36º53'52.2"N 004º48'45.4"W	7.6	132º
MG401	MG402	36º48'49.9"N 004º41'39.1"W		312º
MG401	RWY13	36º48'49.9"N 004º41'39.1"W	11.7	132º
RW13	MG401	36º41'04.3"N 004º30'45.3"W		312º

The missed approach trajectory had to be drawn in INSIGNIA as a guideline to later be polished, since two of the points which are used in this approach do not actually exist.

For the trajectory from waypoint RWY13 to waypoint MG13V, we shall follow the same guides as we did to find the mentioned waypoint, which will result in the drawing of the trajectory.

For trajectories between MG13V and MG31N, and MG31N and XILVI, the line which appears is a guideline to draw the approach correctly. To create this guideline, we shall take reference to the GBAS and ILS charts to find the course of the track and the distance.

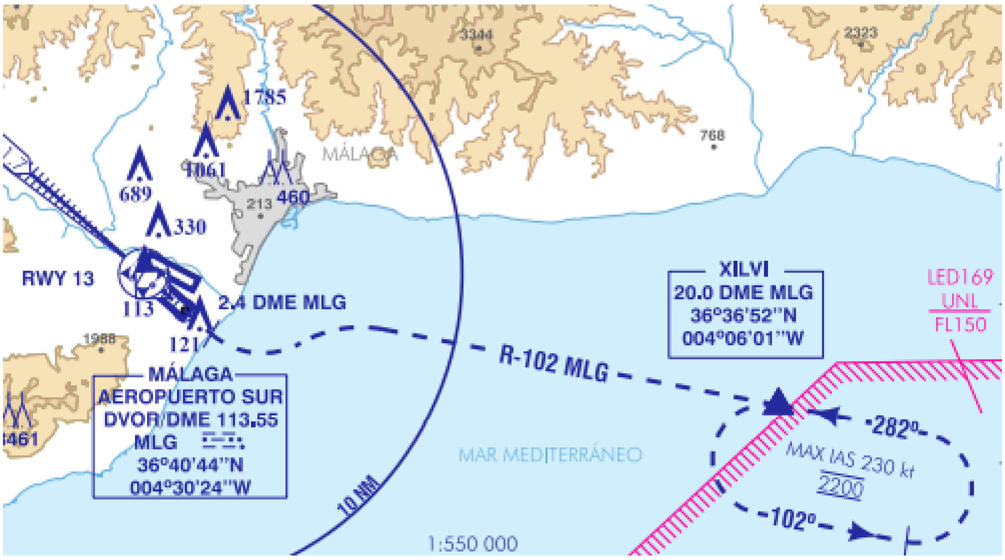

Fig. 3.13 Missed approach segment using GBAS on RWY 13. [41]

Figure 3.13 showcases the missing approach segment of the GBAS chart. As it is observed, XILVI point is situated 20NM from MALAGA DVOR following radial 102. Then, to draw our guideline, we can take the XILVI location coordinates and, following a heading of 282º (because 102º is considered taking MLG as reference) and 20NM, the desired result is obtained. All the courses and distances give as a result the following (Figure 3.14):

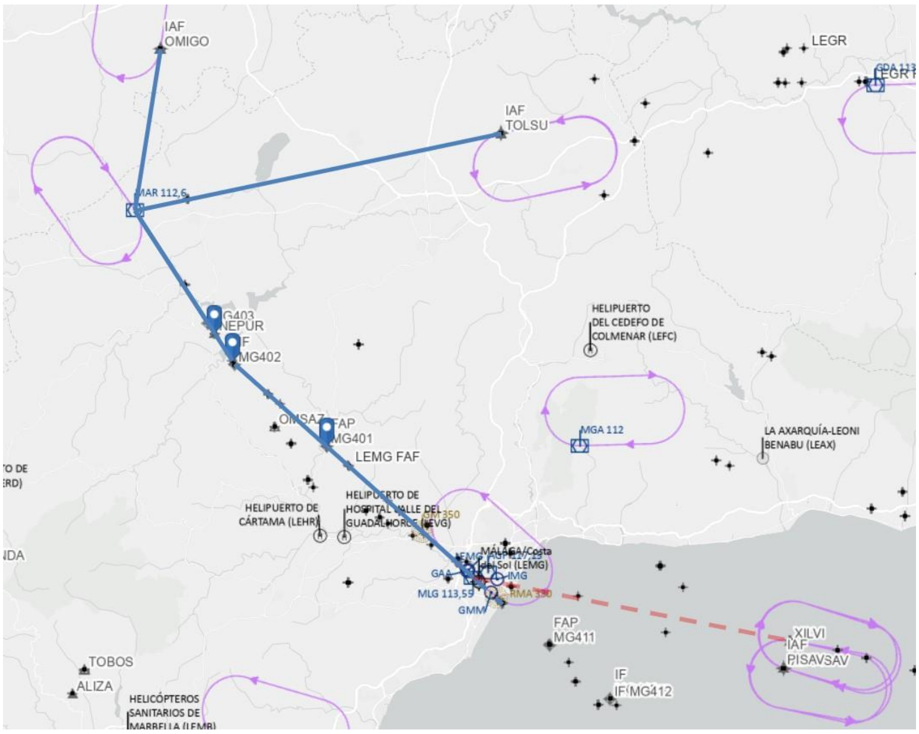

Fig. 3.14 Initial chart of the RNP APCH. [43]

The figure above represents the initial step to obtain the approach chart for RWY13 using RNP APCH down to LPV minima. The blue lines are representing actual trajectories which are part of the approach, and the red line represents the guideline to draw the missed approach segment.

The next step is to define the waypoints as fly-by or as fly-over. As it may be remembered, fly-by waypoints are the ones which require anticipation of a turn to perform the interception of the next segment tangentially. On the other hand, fly-over waypoints require the aircraft to fly over the waypoint before turning or continuing with the procedure. After drawing the points and the path of the approach, the trajectory has the following appearance (Figure 3.15):

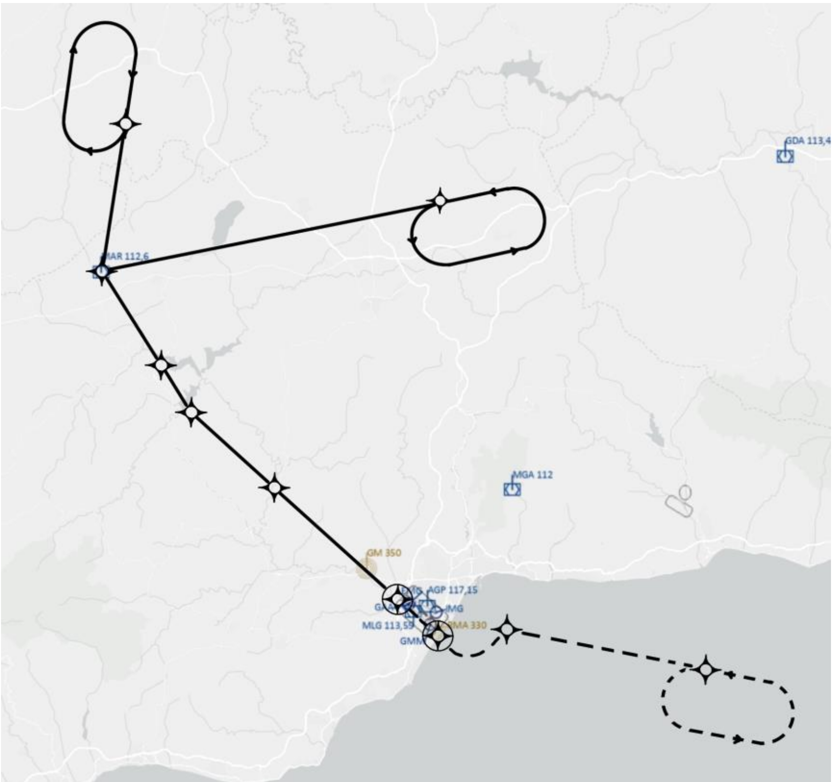

Fig. 3.15 Trajectory and waypoints of the RNP APCH procedure. [43]

The figure showcased above (Figure 3.15) is the sketch obtained taking the initial chart obtained from INSIGNIA. From TOLSU and OMIGO, the following points are MARTIN, NEPUR, MG402, MG401 and RWY13. This last one is the only classified on this list as a fly-over waypoint because it is the only which requires to be flown over by the aircraft since it is located in the threshold of the runway. The rest of the points are fly-by to avoid sharp edges and to allow for direct-to procedures.

The missed approach segment was drawn following the guidelines shown earlier. The first step was to allocate points MG13V, MG31N and XILVI. Because it is known that the missed approach segment starts with reaching point MG13V before taking a left turn in the direction of MG31N, MG13V is a fly-over waypoint (it must be flown over before continuing with the procedure). To provide with a smoother transition to course 102º to reach XILVI, a fly-by point was allocated in MG31N.

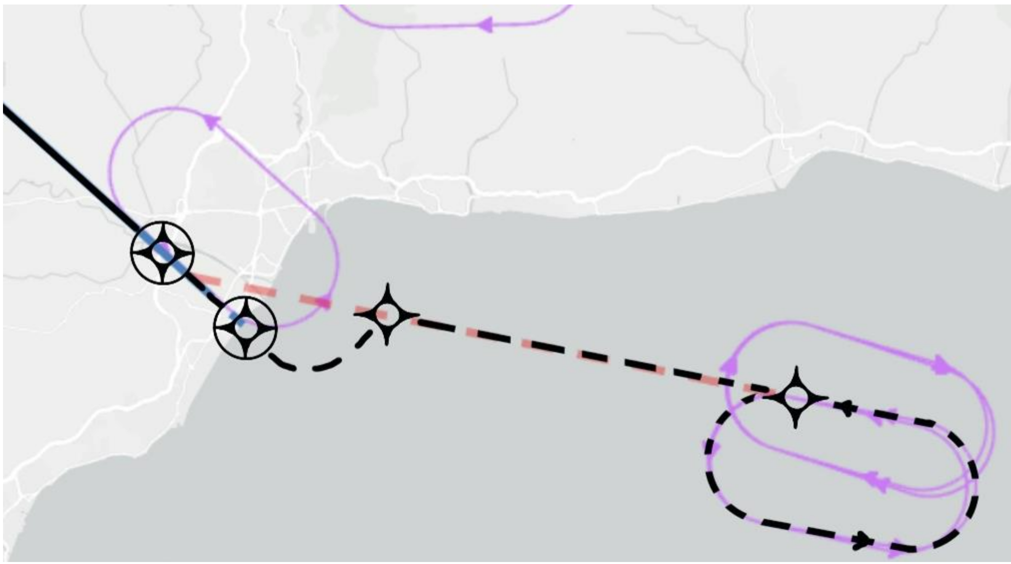

Fig. 3.16 Missed approach segment. [43]

XILVI, in this case, is also a fly-by point. This is due to the holding pattern rotating direction, which is counterclockwise. By making it a fly-by waypoint, it allows for a smoother transition to the holding pattern, if it were a fly-over waypoint, the aircraft should perform a much sharper turn to allocate itself correctly.

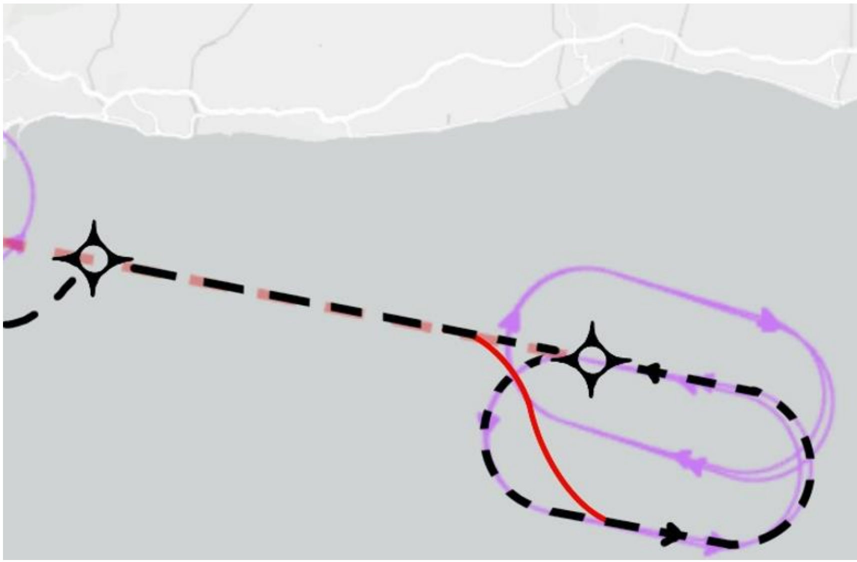

Fig. 3.17 Allocation to the missed approach holding pattern using fly-by waypoint XILVI. [43]

The next step for the completion of the approach chart is to determine the height restrictions of the route. To determine the entry point height for the IAF TOLSU and IAF OMIGO points, we can make use of what is stated in the STAR 1 chart for RWY 12/13. Málaga, as it has been discussed multiple times, does not have area navigation procedures established for neither its arrivals nor departures. The STAR chart is then provided for conventional instrumental approaches.

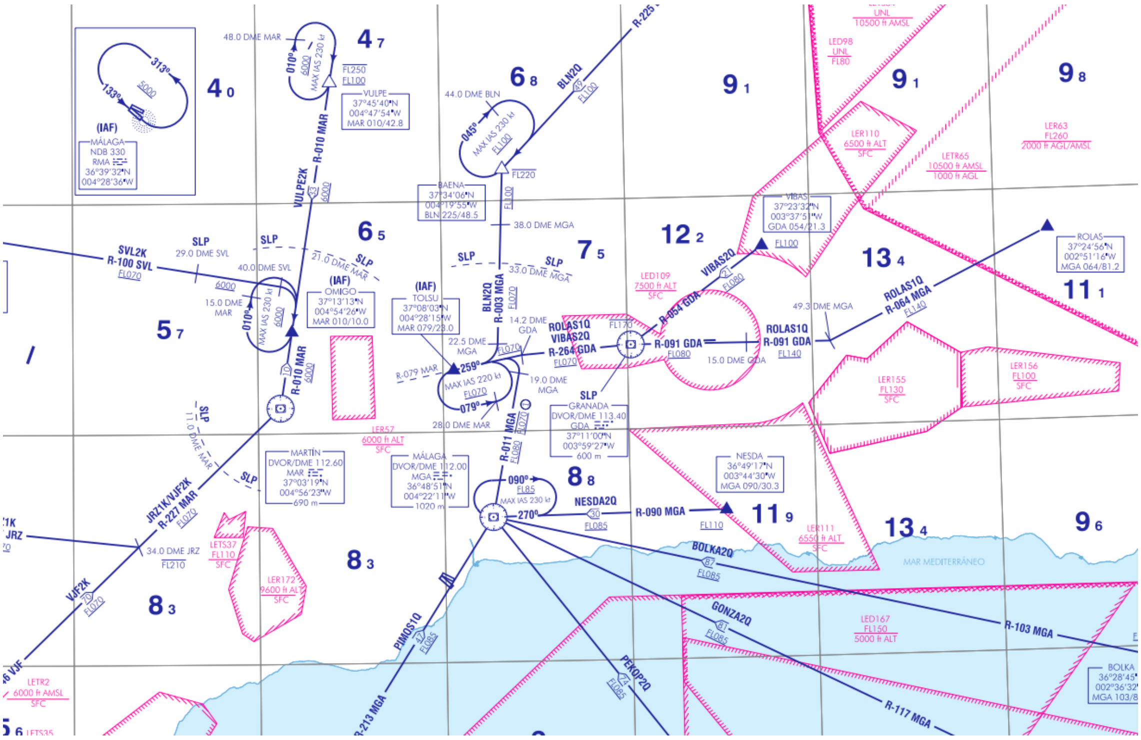

Fig. 3.18 Section of the STAR 1 RWY 12/13 of LEMG Airport instrumental arrival chart. [45]

Figure 3.18 depicts all of the previous navigation guidelines to reach IAF TOLSU and IAF OMIGO. The points are located in sections 7_5 and 6_5, respectively. It may be observed that TOLSU has a minimum height of 7000ft (FL070) and OMIGO has a minimum height of 6000ft. Comparing with the GBAS and ILS charts, ILS approach chart adjusts perfectly with these guidelines, since the minimum heights on both points are the same. In the GBAS approach chart, on the other hand, OMIGO has a minimum height of 7000ft as well.

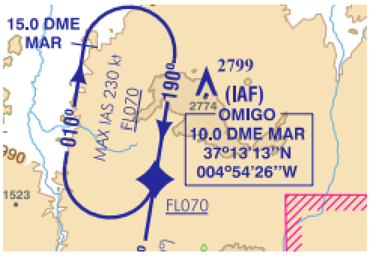

Fig. 3.19 Section of the GBAS approach chart which showcases OMIGO minimum altitude requirements. [41]

Considering that GBAS is also a GNSS based navigation system and that the height minima is more restrictive than the one stated in ILS, the height minimum for that particular point for our RNP APCH chart will be 7000ft (FL070).

Determination of the speed on the holding patterns depends specifically on the airport and on international constraints. According to the ICAO, holding patterns must follow these guidelines regarding maximum speeds (KIAS meaning Knot-Indicated Air Speed):

Table 3.4 Holding pattern speeds by holding altitude according to the ICAO. [46]

ALTITUDE	SPEED
14000ft or below	230 KIAS
above 14000ft to 20000ft	240 KIAS
above 20000ft to 34000ft	265 KIAS
above 34000ft	Mach 0.83

According to the data provided by the table above (Table 3.4), the maximum holding pattern speed for holdings performed at 7000ft will be 230kt. As it is seen in the GBAS, ILS and VOR approach charts, this is the case for both OMIGO and XILVI holding patterns, but not TOLSU holding pattern. TOLSU, as seen on the charts, is limited to 220kt when performing the holding pattern. This information is also provided in the GBAS chart when describing the procedure:

TOLSU (IAF) GBAS Z			
TOLSU a o por encima de FL070, velocidad máxima 220 kt. TOLSU at or above FL070, maximum speed 220 kt.	TOLSU[F070+;K220-]	IF	–
A MARTIN a o por encima de FL070, virar a la izquierda.	MARTIN[F070+;L]	TF	–

Fig 3.20 Section of the procedure description on GBAS approach chart. [41]

So, the TOLSU holding pattern will have a maximum speed of 220kt instead of the standard maximum provided by ICAO.

The last step before the approach chart is completed is the altitudes on the final segment of the approach. GBAS is also based on GNSS signals, as previously mentioned, we are taking the altitude chart on the GBAS approach to adapt it to fit in RNP APCH standards.

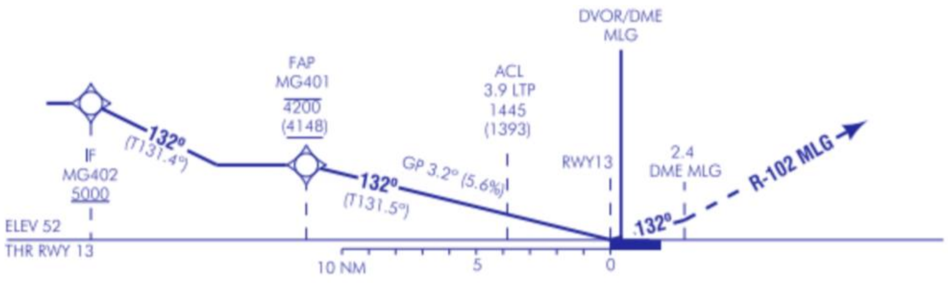

Fig. 3.21 Vertical altitude chart from GBAS approach chart. [41]

The Aircraft Operations Manual [42], by the ICAO, states some guidelines for SBAS approaches with vertical guidance (from now on, APV). Even though the approach charts are official approved documents, before making any modifications, requirements for APV shall be considered.

For the chart which is about to be produced, the most important data we have to take into account is the following:

- The FAP is not to be considered a descent waypoint, meaning that at the arrival of the FAP the altitude of the aircraft must be constant.

- The values which the glide path to the runway can take are from the minimum (optimum) 3.0º up to a maximum of 3.5º

Both conditions are met in the chart displayed above. The next step would be to adapt the above chart to the RNP waypoints created. The new points created (MG13V and MG31N) are drawn following the scale displayed under the chart.

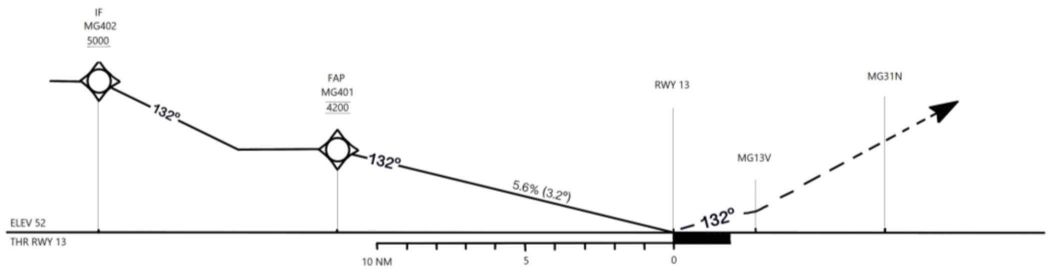

Fig. 3.22 Intermediate and final approach segment vertical chart. [41]

The last step is to finally write the names and altitude restrictions in the trajectory of the approach chart.

Fig. 3.23 Approach chart for the RNP APCH down to LPV minima in RWY13 of LEMG. [43]

Figure 3.22 is the resultant chart from the study made about the implementation of RNP APCH down to LPV minima in runway 13 of Málaga – Costa del Sol Airport. This implementation could bring a series of benefits for airlines operating in the airport and in general, for the environment. As it was previously mentioned, area navigation offers the possibility of shortening the distance travelled by performing “direct-to” procedures (if conditions are favourable, as per decision of ATC) which, in the long term, means less fuel burned and less air pollution for the area.

Furthermore, the results obtained, in addition to demonstrating the feasibility of the implementation of RNP APCH in the airport, it leaves room for further applications in LEMG airport such as runways 12 and 31.

While researching and producing the contents of this project, it was discovered that Málaga Airport is considered to acquire RNP APCH procedures inside the Transition plan to PBN which is being implemented in Spain. [47]

MAD	LEMD	MADRID/BARAJAS	PA	32R	PLANNED	2023	PLANNED	2023	PLANNED	2023
AGP	LEMG	MALAGA/COSTA DEL SOL	PA	12	PLANNED	2023	PLANNED	2023	PLANNED	2023
AGP	LEMG	MALAGA/COSTA DEL SOL	PA	13	PLANNED	2023	PLANNED	2023	PLANNED	2023
AGP	LEMG	MALAGA/COSTA DEL SOL	PA	31	PLANNED	2023	PLANNED	2023	PLANNED	2023

Fig. 3.24 Section of the list of airports inside the PBN Transition Plan in Spain. [47]

As we may see in Figure 3.24, Málaga Airport is planned to incorporate RNP approaches to all three (available for landing) runways. This means that we could be seeing RNP approaches being performed in Málaga Airport very soon.

CONCLUSIONS

This project has studied the possibility of the implementation of a RNP approach procedure in Málaga – Costa del Sol Airport.

The project introduces the concept of navigation based on performance and area navigation, including all its specifications. Later, benefits and implementation requirements of these specifications were discussed. Finally, a study of the characteristics of the Málaga Airport was conducted to determine the feasibility of its implementation.

The worldwide air traffic growth requires the seeking of newer and safer methods of aircraft operation. Málaga Airport is not exempt of the traffic growth, just before the global pandemic the airport traffic kept rising year after year until 2019 when it reached almost 20M passengers. These numbers provide with sense of what to expect in the coming years and to start searching for improvements to handle the future airport operations.

The study was conducted analysing the infrastructure of the airport and the type of airlines which transit it on a regular basis. Later, trajectory similarities between conventional approaches and RNP approaches on other airports were studied to find how the approach trajectory in Málaga would be.

The adaptation from the existing conventional approach charts to a RNP approach was performed following the current regulations and the corresponding nomenclature. The result from the adaptation gives an idea of how a RNP APCH down to LPV minima could look in runway 13 of LEMG.

From the infrastructure perspective, it was proved that Málaga Airport is perfectly capable of implementing RNP APCH. By implementing this system, airlines would be able to make use of the more efficient routes and shortcuts using area navigation, which at the same time would be beneficial in fuel costs and the environment. Furthermore, regulation (EU) 2018/1048 stablishes a series of measures to slowly transition to PBN which, in the future, might be the primary navigation system used by aviation.

This study leaves open the option of further studying implementations of RNP APCH in runways 12 and 31, as well as the full transition to area navigation of the airport in the future. In addition, while doing the research and making of this project, it was found that Málaga Airport is inside the transition to PBN plan and shall be seeing RNP approaches being performed very soon.

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Escola d'Enginyeria de Telecomunicació i Aeroespacial de Castelldefels
UNIVERSITAT POLITÈCNICA DE CATALUNYA

ANNEX

TÍTOL DEL TFG: RNP Approach Procedures in Málaga – Costa del Sol Airport

TITULACIÓ: Enginyeria de Sistemes Aeroespacials

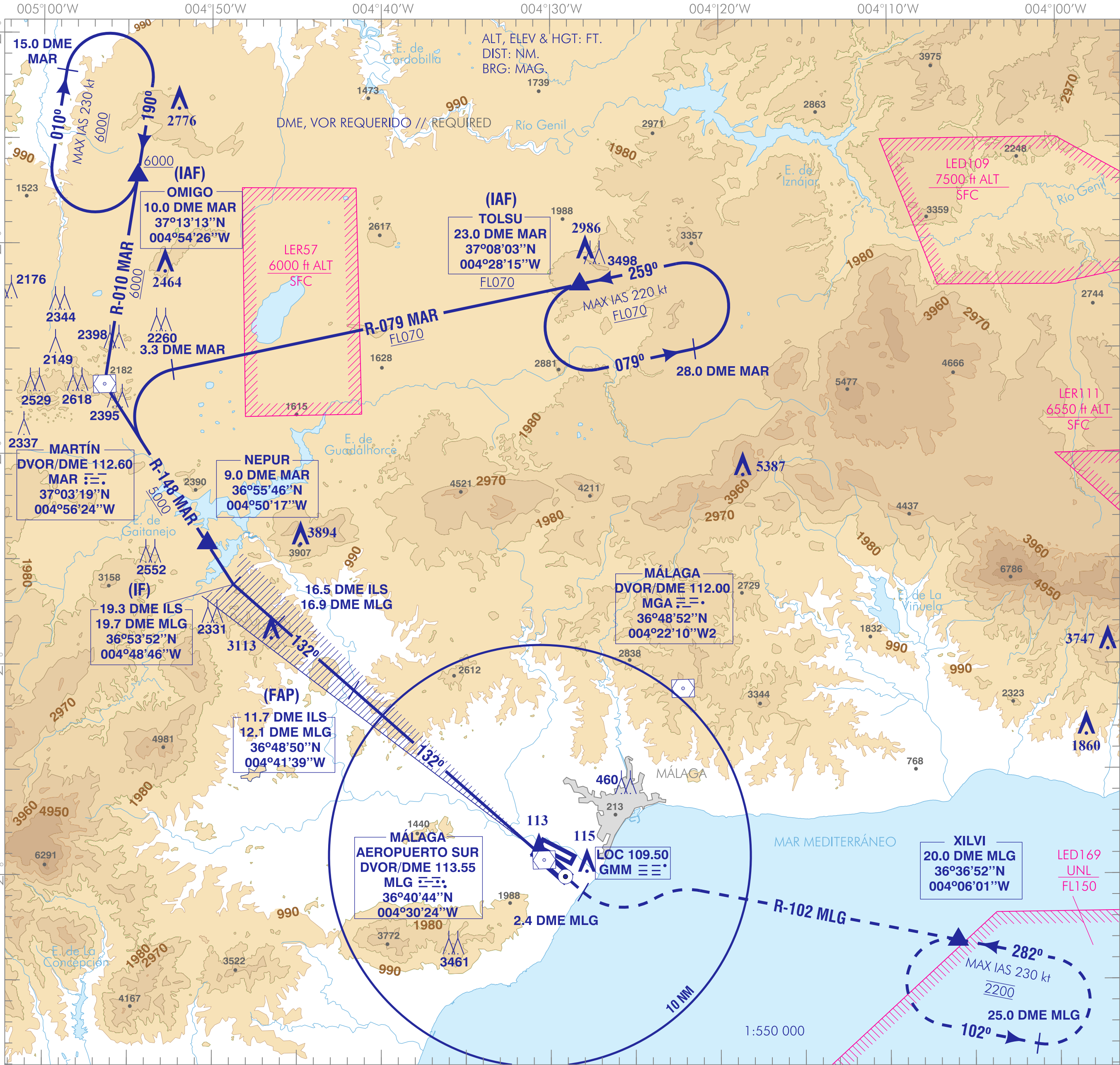
AUTOR: Mauro Sánchez Monclús

DIRECTOR: José Antonio Castan

DATA: 22 d'Octubre del 2023

ANNEX 1 – ILS RWY13 LEMG APPROACH CHART

CARTA DE APROXIMACIÓN POR INSTRUMENTOS-OACI	ELEV AD 52 VAR 1°W (2020)	ARR 123.855 TWR W 118.150 GMC E 121.955 GMC W 121.705 ATIS ARR 120.380	MÁLAGA/Costa del Sol ILS Z RWY 13



FRUSTRADA: SUBIR EN RUMBO DE PISTA HASTA ALCANZAR 2.4 DME MLG. VIRAR A LA IZQUIERDA PARA INTERCEPTAR Y SEGUIR R-102 MLG HASTA XILVI E INTEGRARSE A LA ESPERA A 2200. ALTITUD MÁXIMA 2200 DURANTE LA MANIOBRA DE FRUSTRADA. ESPERAR INSTRUCCIONES ATC.

FRUSTRADA FALLO DE COMUNICACIONES: SUBIR EN RUMBO DE PISTA HASTA ALCANZAR 2.4 DME MLG. VIRAR A LA IZQUIERDA PARA INTERCEPTAR Y SEGUIR R-102 MLG PARA SOBREVOLAR XILVI A 2200. SEGUIR R-102 MLG HASTA 23.0 DME MLG. VIRAR A LA IZQUIERDA PARA SEGUIR ARCO 25.0 DME MLG HASTA R-103 MGA. VIRAR A LA IZQUIERDA PARA SEGUIR R-103 MGA DIRECTO A DVOR/DME MGA A FL070 PARA INCORPORARSE A LA LLEGADA PEKOP2Q.

MISSED APCH: CLIMB ON RUNWAY HEADING TO REACH 2.4 DME MLG. TURN LEFT TO INTERCEPT AND FOLLOW R-102 MLG UP TO XILVI TO JOIN THE HOLDING AT 2200. MAXIMUM ALTITUDE 2200 DURING THE MISSED APPROACH MANOEUVRE. AWAIT ATC INSTRUCTIONS.

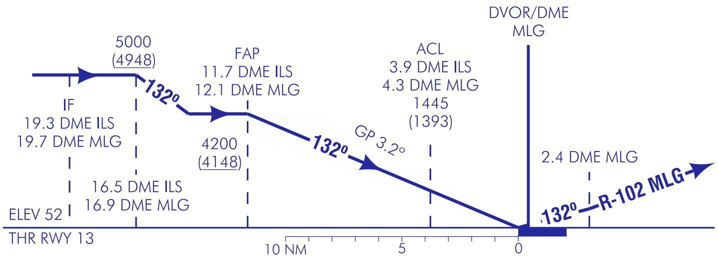
MISSED APCH COMMUNICATIONS FAILURE: CLIMB ON RUNWAY HEADING TO REACH 2.4 DME MLG. TURN LEFT TO INTERCEPT AND FOLLOW R-102 MLG UP TO OVERFLY XILVI AT 2200. FOLLOW R-102 MLG UP TO 23.0 DME MLG. TURN LEFT TO FOLLOW ARC 25.0 DME MLG UP TO R-103 MGA. TURN LEFT TO FOLLOW R-103 MGA DIRECT TO DVOR/DME MGA AT FL070 TO JOIN PEKOP2Q ARRIVAL.

NOTAS:
- VER OBST QUE VULNERAN LAS VSS.
- EN CASO DE QUE ATC PROPORCIONE GUÍA VECTORIAL RADAR, ESPERE REANUDAR PROPIA NAVEGACIÓN EN CURSO AL PUNTO NEPUR.
- CONTROL DE VELOCIDAD VER AD 2-LEMG IAC/6.2

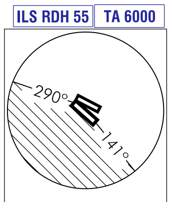
NOTES:
- SEE OBSTACLES THAT PENETRATE THE VSS.
- IF ATC PROVIDES VECTORIAL RADAR GUIDANCE, EXPECT TO RESUME OWN NAVIGATION ON TRACK TO POINT NEPUR.
- SPEED CONTROL SEE AD 2-LEMG IAC/6.2

NO OFZ RWY 13

HGT REF ELEV THR RWY 13



ILS RDH 55 | **TA 6000**



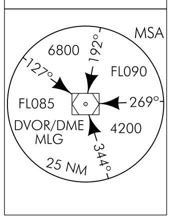
NO EN CIRCUITO
NO CIRCLING

OCA/H			A	B	C	D
STA	CAT I		275 (223)	285 (233)	295 (243)	305 (253)
En circuito (H) sobre / In circuit (H) over		52	650 (600)	1040 (990)	1470 (1420)	2200 (2150)

GS	kt	80	100	120	140	160	180
FAP-THR: 11.7 NM	min:s	8:46	7:01	5:51	5:01	4:23	3:54
FAF-MAPT:	min:s						
ROD: 5.6 %	ft/min	453	566	679	793	906	1019

ALT/HGT DME (ILS) FNA

13	12	11	10	9	8	7	6	5	4	3	2	1
		3960 (3900)	3600 (3550)	3240 (3190)	2890 (2830)	2530 (2480)	2180 (2130)	1830 (1780)	1480 (1430)	1140 (1090)	790 (740)	450 (400)



CAMBIOS: COORDENADAS DVOR/DME EN LUGAR DEL DME, OBST, CAMBIO EDITORIAL.
CHANGES: DVOR COORDINATES INSTEAD OF DME, OBST, EDITORIAL CHANGE.

MÁLAGA/Costa del Sol AD

CONTROL DE VELOCIDAD

– SI NO SE RECIBEN INSTRUCCIONES DIFERENTES DEL ATC, CRUZAR 16.0 DME ILS A IAS 200 kt O SUPERIOR, 8.0 DME ILS A IAS 180 kt y 4.0 DME ILS A IAS 160 kt.
– SI NO PUEDE CUMPLIR, NOTIFÍQUELO AL ATC EN PRIMERA COMUNICACIÓN.

SPEED CONTROL.

– UNLESS INSTRUCTED OTHERWISE BY ATC, CROSS 16.0 DME ILS AT IAS 200 kt OR HIGHER, 8.0 DME ILS AT IAS 180 kt AND 4.0 DME ILS AT IAS 160 kt.
– IF UNABLE TO COMPLY, NOTIFY ATC IN THE FIRST COMMUNICATION.

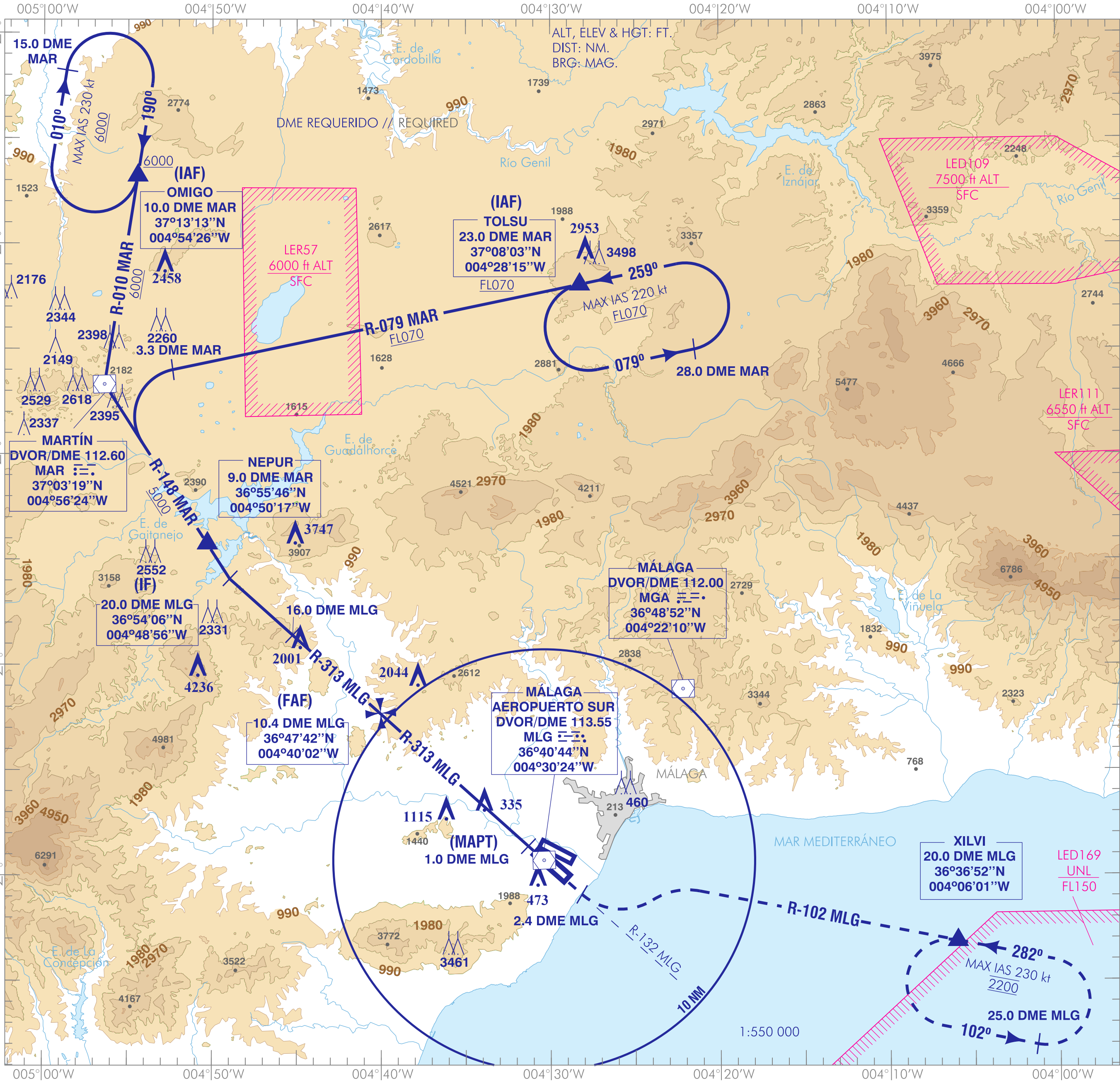
REQUISITOS DE LA BASE DE DATOS AERONÁUTICA
AERONAUTICAL DATABASE REQUIREMENTS

PROCEDIMIENTOS DE APROXIMACIÓN POR INSTRUMENTOS // INSTRUMENT APPROACH PROCEDURES

ILS Z RWY 13

PUNTO POINT	LAT	LONG	AZIMUT VERDADERO TRUE BEARING	DISTANCIA DME DME DISTANCE (NM)
NEPUR	36º55’45.6”N	004º50’16.8”W	146.99º (MAR)	8.99 DME MAR
OMIGO (IAF)	37º13’12.9”N	004º54’26.0”W	009.00º (MAR)	10.01 DME MAR
TOLSU (IAF)	37º08’03.2”N	004º28’15.0”W	078.00º (MAR)	23.00 DME MAR
IF	36º53’52.3”N	004º48’45.5”W	311.58º (LOC GMM)	19.30 DME ILS 19.74 DME MLG
FAP	36º48’49.9”N	004º41’39.1”W	311.58º (LOC GMM)	11.69 DME ILS 12.14 DME MLG
XILVI	36º36’51.7”N	004º06’01.1”W	101.00º (MLG)	20.00 DME MLG
Aproximación final de precisión - Pendiente (Ángulo de descenso) // Precision final approach - Slope (Descent angle)				5.59% (3.20º)

ANNEX 2 – VOR RWY13 LEMG APPROACH CHART



FRUSTRADA: SUBIR DIRECTO AL DVOR/DME MLG. PROCEDER POR R-132 MLG HASTA ALCANZAR 2.4 DME MLG. VIRAR A LA IZQUIERDA PARA INTERCEPTAR Y SEGUIR R-102 MLG HASTA XILVI E INTEGRARSE A LA ESPERA A 2200. ALTITUD MÁXIMA 2200 DURANTE LA MANIOBRA DE FRUSTRADA. ESPERAR INSTRUCCIONES ATC.

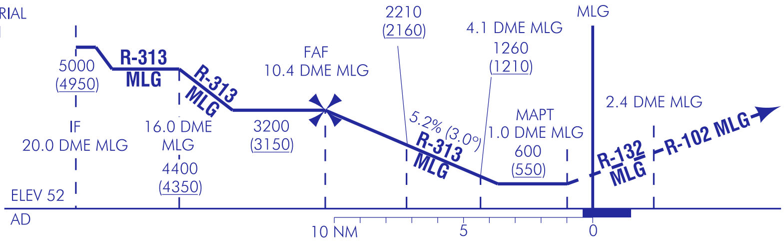
FRUSTRADA FALLO DE COMUNICACIONES: SUBIR DIRECTO AL DVOR/DME MLG. PROCEDER POR R-132 MLG HASTA ALCANZAR 2.4 DME MLG. VIRAR A LA IZQUIERDA PARA INTERCEPTAR Y SEGUIR R-102 MLG PARA SOBREVOLAR XILVI A 2200. SEGUIR R-102 MLG HASTA 23.0 DME MLG. VIRAR A LA IZQUIERDA PARA SEGUIR ARCO 25.0 DME MLG HASTA R-103 MGA. VIRAR A LA IZQUIERDA PARA SEGUIR R-103 MGA DIRECTO A DVOR/DME MGA A FL070 PARA INCORPORARSE A LA LLEGADA PEKOP2Q.

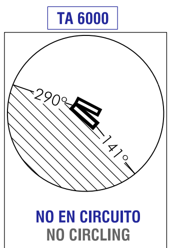
MISSED APCH: CLIMB DIRECT TO DVOR/DME MLG. PROCEED ON R-132 MLG UP TO 2.4 DME MLG. TURN LEFT TO INTERCEPT AND FOLLOW R-102 MLG UP TO XILVI TO JOIN THE HOLDING AT 2200. MAXIMUM ALTITUDE 2200 DURING THE MISSED APPROACH MANOEUVRE. AWAIT ATC INSTRUCTIONS.

MISSED APCH COMMUNICATIONS FAILURE: CLIMB DIRECT TO DVOR/DME MLG. PROCEED ON R-132 MLG UP TO 2.4 DME MLG. TURN LEFT TO INTERCEPT AND FOLLOW R-102 MLG TO OVERFLY XILVI AT 2200. FOLLOW R-102 MLG UP TO 23.0 DME MLG. TURN LEFT TO FOLLOW ARC 25.0 DME MLG UP TO R-103 MGA. TURN LEFT TO FOLLOW R-103 MGA DIRECT TO DVOR/DME MGA AT FL070 TO JOIN PEKOP2Q ARRIVAL.

NOTAS:
- EN CASO DE QUE ATC PROPORCIONE GUÍA VECTORIAL RADAR, ESPERE REANUDAR PROPIA NAVEGACIÓN EN CURSO AL PUNTO NEPUR.
- CONTROL DE VELOCIDAD VER AD 2-LEMG IAC/10.2

NOTES:
- IF ATC PROVIDES VECTORIAL RADAR GUIDANCE, EXPECT TO RESUME OWN NAVIGATION ON TRACK TO POINT NEPUR.
- SPEED CONTROL SEE AD 2-LEMG IAC/10.2





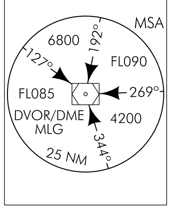
HGT REF ELEV AD

OCA/H		A	B	C	D
STA	2.5%	600 (550)			
En circuito (H) sobre / In circuit (H) over		790 (740)	1040 (990)	1470 (1420)	2200 (2150)

GS	kt	80	100	120	140	160	180
FAP-THR:	min:s						
FAF-MAPT:	min:s	NO AUTORIZADO EL CRONOMETRAJE // TIMING NOT AUTHORIZED					
ROD: 5.2 %	ft/min	421	526	631	737	842	948

ALT/HGT DME (MLG) FNA

13	12	11	10	9	8	7	6	5	4	3	2	1
			3130 (3070)	2810 (2760)	2490 (2440)	2180 (2130)	1860 (1810)	1550 (1490)	1230 (1180)	910 (860)		



CAMBIOS: COORDENADAS DVOR/DME EN LUGAR DEL DME, OBST, CAMBIO EDITORIAL.
CHANGES: DVOR COORDINATES INSTEAD OF DME, OBST, EDITORIAL CHANGE.

MÁLAGA/Costa del Sol AD

CONTROL DE VELOCIDAD

– SI NO SE RECIBEN INSTRUCCIONES DIFERENTES DEL ATC, CRUZAR 16.0 DME MLG A IAS 200 kt O SUPERIOR, 8.0 DME MLG A IAS 180 kt y 4.0 DME MLG A IAS 160 kt.
– SI NO PUEDE CUMPLIR, NOTIFÍQUELO AL ATC EN PRIMERA COMUNICACIÓN.

SPEED CONTROL.

– UNLESS INSTRUCTED OTHERWISE BY ATC, CROSS 16.0 DME MLG AT IAS 200 kt OR HIGHER, 8.0 DME MLG AT IAS 180 kt AND 4.0 DME MLG AT IAS 160 kt.
– IF UNABLE TO COMPLY, NOTIFY ATC IN THE FIRST COMMUNICATION.

REQUISITOS DE LA BASE DE DATOS AERONÁUTICA
AERONAUTICAL DATABASE REQUIREMENTS

PROCEDIMIENTOS DE APROXIMACIÓN POR INSTRUMENTOS // INSTRUMENT APPROACH PROCEDURES

VOR RWY 13

PUNTO POINT	LAT	LONG	AZIMUT VERDADERO TRUE BEARING	DISTANCIA DME DME DISTANCE (NM)
NEPUR	36º55’45.6”N	004º50’16.8”W	146.99º (MAR)	8.99 DME MAR
OMIGO (IAF)	37º13’12.9”N	004º54’26.0”W	009.00º (MAR)	10.01 DME MAR
TOLSU (IAF)	37º08’03.2”N	004º28’15.0”W	078.00º (MAR)	23.00 DME MAR
IF	36º54’06.0”N	004º48’55.8”W	312.00º (MLG)	20.00 DME MLG
FAF	36º47’41.6”N	004º40’01.9”W	312.00º (MLG)	10.41 DME MLG
MAPT	36º41’23.6”N	004º31’19.4”W	312.00º (MLG)	1.00 DME MLG
XILVI	36º36’51.7”N	004º06’01.1”W	101.00º (MLG)	20.00 DME MLG
Aproximación final de no precisión - Pendiente (Ángulo de descenso) // Non-precision final approach - Slope (Descent angle)				5.20% (2.98º)

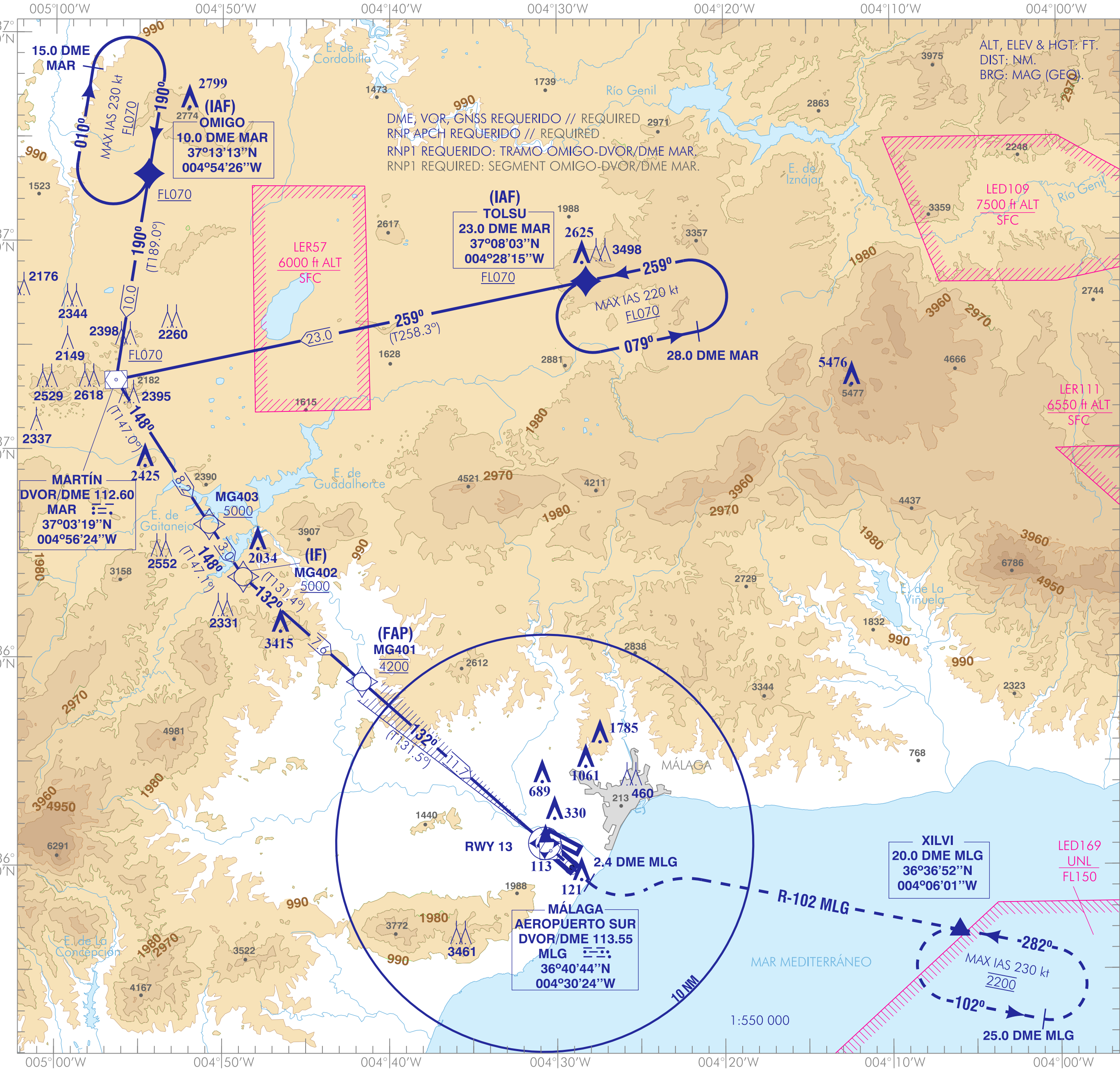
ANNEX 3 – GBAS RWY13 LEMG APPROACH CHART

ELEV AD
52
VAR 1°W (2020)

GBAS
CH 20697
G13A

ARR	123.855
TWR W	118.150
GMC E	121.955
GMC W	121.705
ATIS ARR	120.380

MÁLAGA/Costa del Sol
GBAS Z
RWY 13



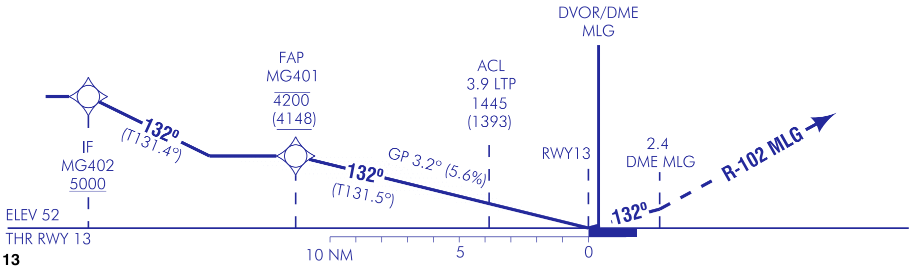
FRUSTRADA: SUBIR EN RUMBO DE PISTA HASTA ALCANZAR 2.4 DME MLG. VIRAR A LA IZQUIERDA PARA INTERCEPTAR Y SEGUIR R-102 MLG HASTA XILVI E INTEGRARSE A LA ESPERA A 2200. ALTITUD MÁXIMA 2200 DURANTE LA MANIOBRA DE FRUSTRADA. ESPERAR INSTRUCCIONES ATC.

FRUSTRADA FALLO DE COMUNICACIONES: SUBIR EN RUMBO DE PISTA HASTA ALCANZAR 2.4 DME MLG. VIRAR A LA IZQUIERDA PARA INTERCEPTAR Y SEGUIR R-102 MLG PARA SOBREVOLAR XILVI A 2200. SEGUIR R-102 MLG HASTA 23.0 DME MLG. VIRAR A LA IZQUIERDA PARA SEGUIR ARCO 25.0 DME MLG HASTA R-103 MGA. VIRAR A LA IZQUIERDA PARA SEGUIR R-103 MGA DIRECTO A DVOR/DME MGA A FL070 PARA INCORPORARSE A LA LLEGADA PEKOP2Q.

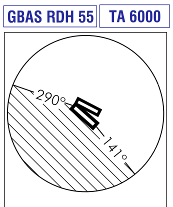
MISSED APCH: CLIMB ON RUNWAY HEADING TO REACH 2.4 DME MLG. TURN LEFT TO INTERCEPT AND FOLLOW R-102 MLG UP TO XILVI TO JOIN THE HOLDING AT 2200. MAXIMUM ALTITUDE 2200 DURING THE MISSED APPROACH MANOEUVRE. AWAIT ATC INSTRUCTIONS.

MISSED APCH COMMUNICATIONS FAILURE: CLIMB ON RUNWAY HEADING TO REACH 2.4 DME MLG. TURN LEFT TO INTERCEPT AND FOLLOW R-102 MLG UP TO OVERFLY XILVI AT 2200. FOLLOW R-102 MLG UP TO 23.0 DME MLG. TURN LEFT TO FOLLOW ARC 25.0 DME MLG UP TO R-103 MGA. TURN LEFT TO FOLLOW R-103 MGA DIRECT TO DVOR/DME MGA AT FL070 TO JOIN PEKOP2Q ARRIVAL.

CAMBIOS: COORDENADAS DVOR/DME EN LUGAR DEL DME, OBST, CAMBIO EDITORIAL.
CHANGES: DVOR COORDINATES INSTEAD OF DME, OBST, EDITORIAL CHANGE.



GBAS RDH 55 | TA 6000



NO EN CIRCUITO
NO CIRCLING

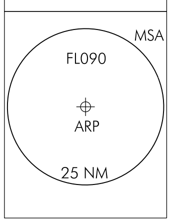
HGT REF ELEV THR RWY 13

OCA/H		A	B	C	D
STA	CAT I 2.5%	275 (223)	285 (233)	295 (243)	305 (253)
En circuito (H) sobre / Circling (H) over	52	650 (600)	1040 (990)	1470 (1420)	2200 (2150)

GS	kt	80	100	120	140	160	180
FAP-THR: 11.7 NM	min:s	8:46	7:01	5:51	5:01	4:23	3:54
FAF-MAPT:	min:s						
ROD: 5.6 %	ft/min	453	566	679	793	906	1019

ALT/HGT DME THR13

13	12	11	10	9	8	7	6	5	4	3	2	1
		3960 (3900)	3600 (3550)	3240 (3190)	2890 (2830)	2530 (2480)	2180 (2130)	1830 (1780)	1480 (1430)	1140 (1090)	790 (740)	450 (400)



MÁLAGA/Costa del Sol AD

REQUISITOS DE LA BASE DE DATOS AERONÁUTICA
AERONAUTICAL DATABASE REQUIREMENTS

PROCEDIMIENTOS DE APROXIMACIÓN POR INSTRUMENTOS // INSTRUMENT APPROACH PROCEDURES

GBAS Z RWY 13

PUNTO POINT	LAT	LONG	AZIMUT VERDADERO TRUE BEARING	DISTANCIA DME DME DISTANCE (NM)
TOLSU (IAF)	37º08'03.2"N	004º28'15.0"W	078.00º (VOR MAR)	23.00 DME MAR
OMIGO (IAF)	37º13'12.9"N	004º54'26.0"W	009.00º (VOR MAR)	10.01 DME MAR
XILVI	36º36'51.7"N	004º06'01.1"W	101.00º (VOR MLG)	20.00 DME MLG
Aproximación final de precisión - Pendiente (Ángulo de descenso) // Precision final approach - Slope (Descent angle)				5.59% (3.20º)

COORDENADAS WAYPOINTS // WAYPOINTS COORDINATES	
WPT	COORD
MAR DVOR/DME	37º03'18.8"N 004º56'23.2"W
MG401 (FAP)	36º48'49.9"N 004º41'39.1"W
MG402 (IF)	36º53'52.2"N 004º48'45.4"W
MG403	36º56'23.5"N 004º50'47.4"W
OMIGO (IAF)	37º13'12.9"N 004º54'26.0"W
RWY13 (LTP)	36º41'04.3"N 004º30'45.3"W
TOLSU (IAF)	37º08'03.2"N 004º28'15.0"W

DESCRIPCIÓN DEL PROCEDIMIENTO PROCEDURE DESCRIPTION			
DESCRIPCIÓN FORMAL FORMAL DESCRIPTION	DESCRIPCIÓN ABREVIADA ABBREVIATED DESCRIPTION	Código Path Terminator Previsto Expected Path Terminator Coding	Fly-Over Requerido Fly-Over Required
TOLSU (IAF) GBAS Z			
TOLSU a o por encima de FL070, velocidad máxima 220 kt. TOLSU at or above FL070, maximum speed 220 kt.	TOLSU[F070+;K220-]	IF	–
A MARTIN a o por encima de FL070, virar a la izquierda. To MARTIN at or above FL070, turn left.	MARTIN[F070+;L]	TF	–
A MG403 a o por encima de 5000 ft. To MG403 at or above 5000 ft.	MG403[A5000+]	TF	–
A MG402 a o por encima de 5000 ft, virar a la izquierda. To MG402 at or above 5000 ft, turn left.	MG402[A5000+;L]	TF	–
A MG401 a 4200 ft. To MG401 at 4200 ft.	MG401[A4200]	TF	–
A RWY13 a o por encima de 107 ft. To RWY13 at or above 107 ft.	RWY13[A107+]	TF	Y
APROXIMACIÓN FRUSTRADA CONVENCIONAL // CONVENTIONAL MISSED APPROACH PROCEDURE			
Subir en rumbo de pista hasta alcanzar 2.4 DME MLG. Virar a la izquierda para interceptar y seguir R-102 MLG hasta XILVI e integrarse a la espera a 2200 ft. Altitud máxima 2200 ft durante la maniobra de frustrada. Esperar instrucciones ATC. // Climb on runway heading to reach 2.4 DME MLG. Turn left to intercept and follow R-102 MLG to XILVI and integrate to holding pattern at 2200 ft. Maximum altitude 2200 ft during missed approach procedure. Wait for ATC instructions.			
APROXIMACIÓN FRUSTRADA FALLO DE COMUNICACIONES // COMMUNICATIONS FAILURE MISSED APPROACH PROCEDURE			
Subir en rumbo de pista hasta alcanzar 2.4 DME MLG. Virar a la izquierda para interceptar y seguir R-102 MLG para sobrevolar XILVI a 2200 ft. Seguir R-102 MLG hasta 23.0 DME MLG. Virar a la izquierda para seguir arco 25.0 DME MLG hasta R-103 MGA. Virar a la izquierda para seguir R-103 MGA directo a DVOR/DME MGA a FL070 para incorporarse a la llegada PEKOP2Q. // Climb on runway heading to reach 2.4 DME MLG. Turn left to intercept and follow R-102 MLG at fly over XILVI at 2200 ft. Follow R-102 MLG to 23.0 DME MLG. Turn left to follow arc 25.0 DME MLG to R-103 MGA. Turn left to follow R-103 MGA direct to DVOR/DME MGA at FL070 to incorporate to arrival PEKOP2Q.			

DESCRIPCIÓN DEL PROCEDIMIENTO PROCEDURE DESCRIPTION			
DESCRIPCIÓN FORMAL FORMAL DESCRIPTION	DESCRIPCIÓN ABREVIADA ABBREVIATED DESCRIPTION	Código Path Terminator Previsto Expected Path Terminator Coding	Fly-Over Requerido Fly-Over Required
OMIGO (IAF) GBAS Z			
OMIGO a o por encima de FL070, velocidad máxima 230 kt. OMIGO at or above FL070, maximum speed 230 kt.	OMIGO[F070+;K230-]	IF	–
A MARTIN a o por encima de FL070, virar a la izquierda. To MARTIN at or above FL070, turn left.	MARTIN[F070+;L]	TF	–
A MG403 a o por encima de 5000 ft. To MG403 at or above 5000 ft.	MG403[A5000+]	TF	–
A MG402 a o por encima de 5000 ft, virar a la izquierda. To MG402 at or above 5000 ft, turn left.	MG402[A5000+;L]	TF	–
A MG401 a 4200 ft. To MG401 at 4200 ft.	MG401[A4200]	TF	–
A RWY13 a o por encima de 107 ft. To RWY13 at or above 107 ft.	RWY13[A107+]	TF	Y
APROXIMACIÓN FRUSTRADA CONVENCIONAL // CONVENTIONAL MISSED APPROACH PROCEDURE			
Subir en rumbo de pista hasta alcanzar 2.4 DME MLG. Virar a la izquierda para interceptar y seguir R-102 MLG hasta XILVI e integrarse a la espera a 2200 ft. Altitud máxima 2200 ft durante la maniobra de frustrada. Esperar instrucciones ATC. // Climb on runway heading to reach 2.4 DME MLG. Turn left to intercept and follow R-102 MLG to XILVI and integrate to holding pattern at 2200 ft. Maximum altitude 2200 ft during missed approach procedure. Wait for ATC instructions.			
APROXIMACIÓN FRUSTRADA FALLO DE COMUNICACIONES // COMMUNICATIONS FAILURE MISSED APPROACH PROCEDURE			
Subir en rumbo de pista hasta alcanzar 2.4 DME MLG. Virar a la izquierda para interceptar y seguir R-102 MLG para sobrevolar XILVI a 2200 ft. Seguir R-102 MLG hasta 23.0 DME MLG. Virar a la izquierda para seguir arco 25.0 DME MLG hasta R-103 MGA. Virar a la izquierda para seguir R-103 MGA directo a DVOR/DME MGA a FL070 para incorporarse a la llegada PEKOP2Q. // Climb on runway heading to reach 2.4 DME MLG. Turn left to intercept and follow R-102 MLG at fly over XILVI at 2200 ft. Follow R-102 MLG to 23.0 DME MLG. Turn left to follow arc 25.0 DME MLG to R-103 MGA. Turn left to follow R-103 MGA direct to DVOR/DME MGA at FL070 to incorporate to arrival PEKOP2Q.			

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