AFI Flight Operations Safety Awareness Seminar (FOSAS)

Performance-Based Navigation
PBN

ICAO/Airbus
Nairobi, 19-21 Sep. 2017

AIRBUS

History


Aircraft Navigation
From Conventional to PBN
1920
1930
1970‘s
1980‘s
1990‘s
2000‘s
Now

1920- First Step toward Instrumental flight

1923
Aeronautical lighthouse

First NAVAID at night!

1920 - 1930 The pioneers of instrumental flight

1929 First instrumental flight

+ **1929**

  First Instrumental flight by Jimmy Doolittle

+ **1930's**

  ILS, gonio, NDB, VOR...

+ **1938**

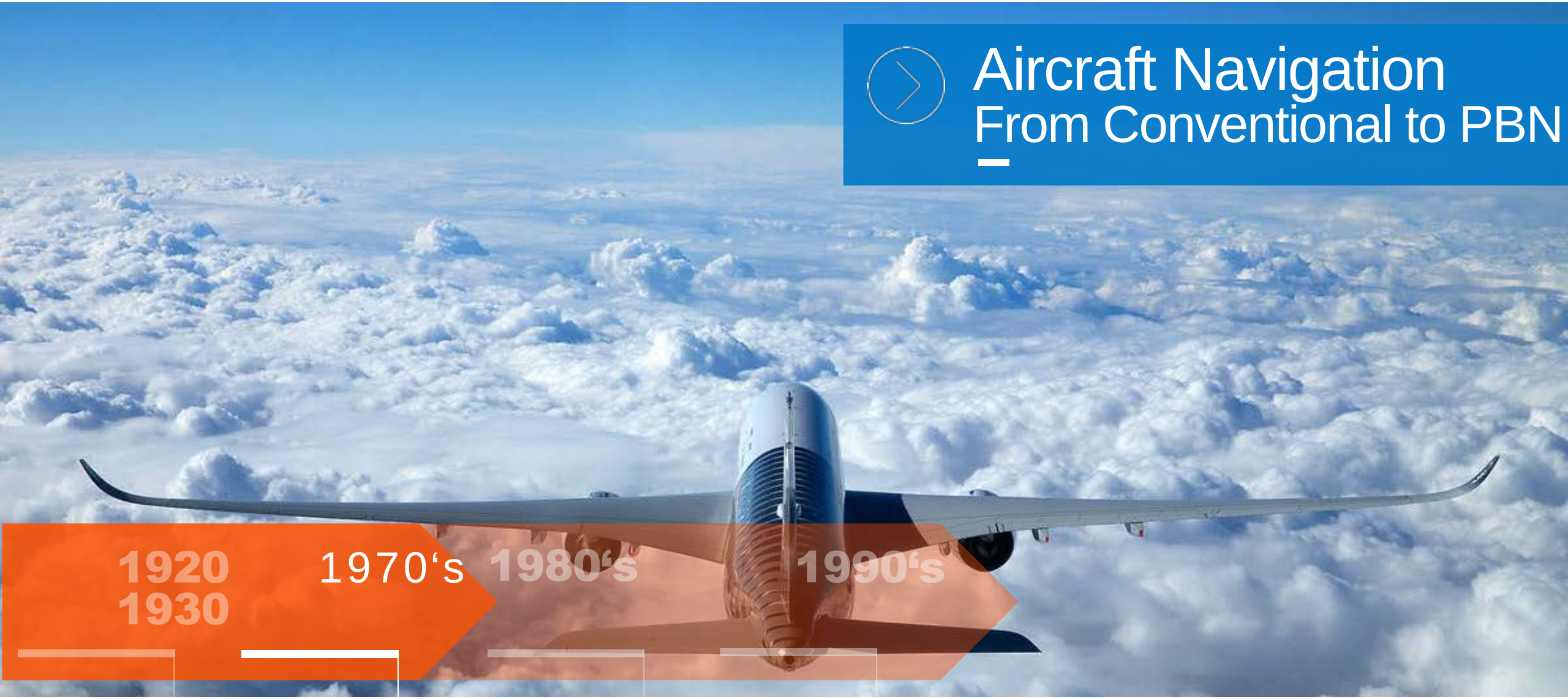
  First ILS approach

First ILS

ILS: Instrument Landing System VOR: VHF Omni Range
NDB: Non Directional Beacon

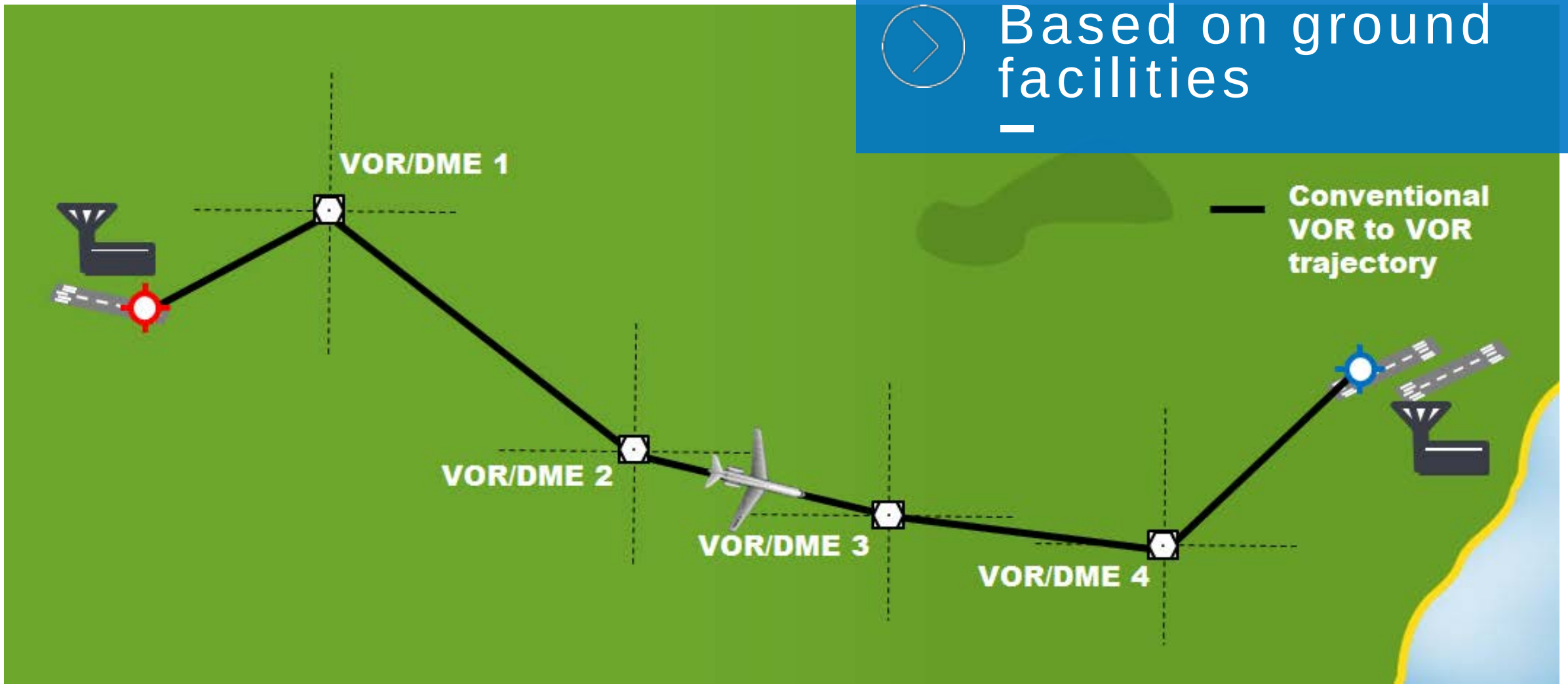
AIRBUS

History


Aircraft Navigation
From Conventional to PBN
1920
1930
1970‘s
1980‘s
1990‘s

Up to 1970's- ILS and NAVAIDs era

Based on ground facilities



DME: Distance Measurement Equipment
VOR: VHF Omni Range

AIRBUS

Up to 1970's- ILS and NAVAIDs era

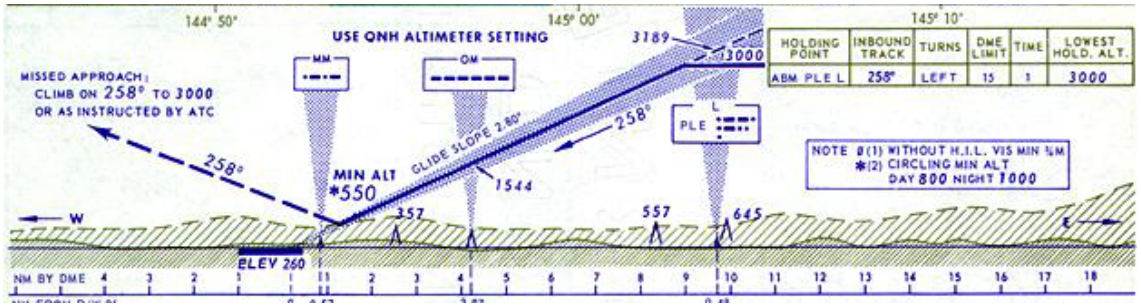
Based on ground facilities

+ **Precision Approach**

  ILS with vertical guidance

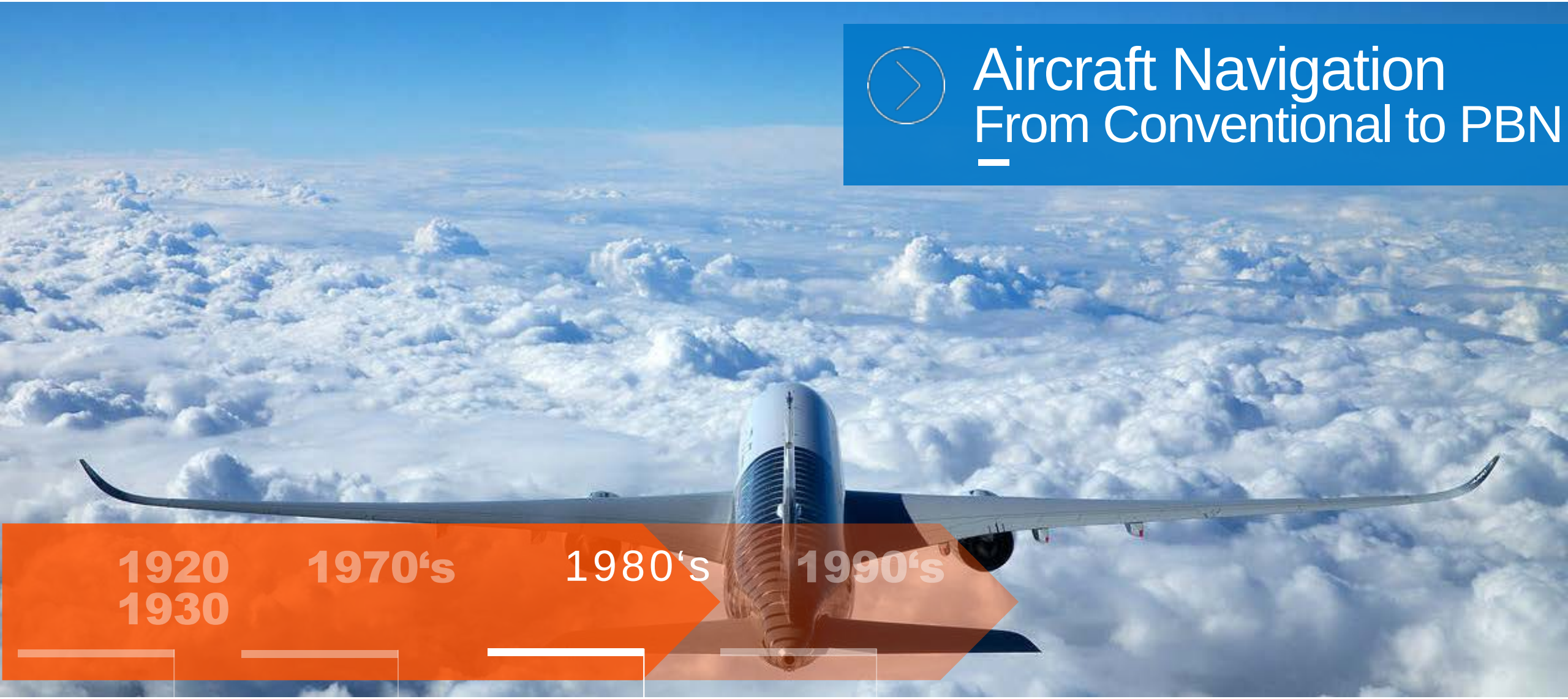
+ **Non Precision Approach**

  Navaids (VOR DME)



AIRBUS

History



AIRBUS

1980’s - The Flight Management System and Inertial Reference System

FMS+IRS: revolution in the cockpit

+**A/C position and Navigation Display**

Map with Flight Plan and A/C symbol

+**Distance to threshold**

Altitude distance checks

+**RNAV (area navigation) concept**

Waypoints in coordinate

AIRBUS

1980’s - The Flight Management System and Inertial Reference System

FMS+IRS: revolution in the cockpit

AIRBUS

1980’s - The Flight Management System and Inertial Reference System

FMS+IRS: revolution in the cockpit

+**A/C position and Navigation Display**

Map with Flight Plan and A/C symbol

+**Distance to threshold**

Altitude distance checks

+**RNAV (area navigation) concept**

Waypoints in coordinate

+**Lateral guidance on FPLN**

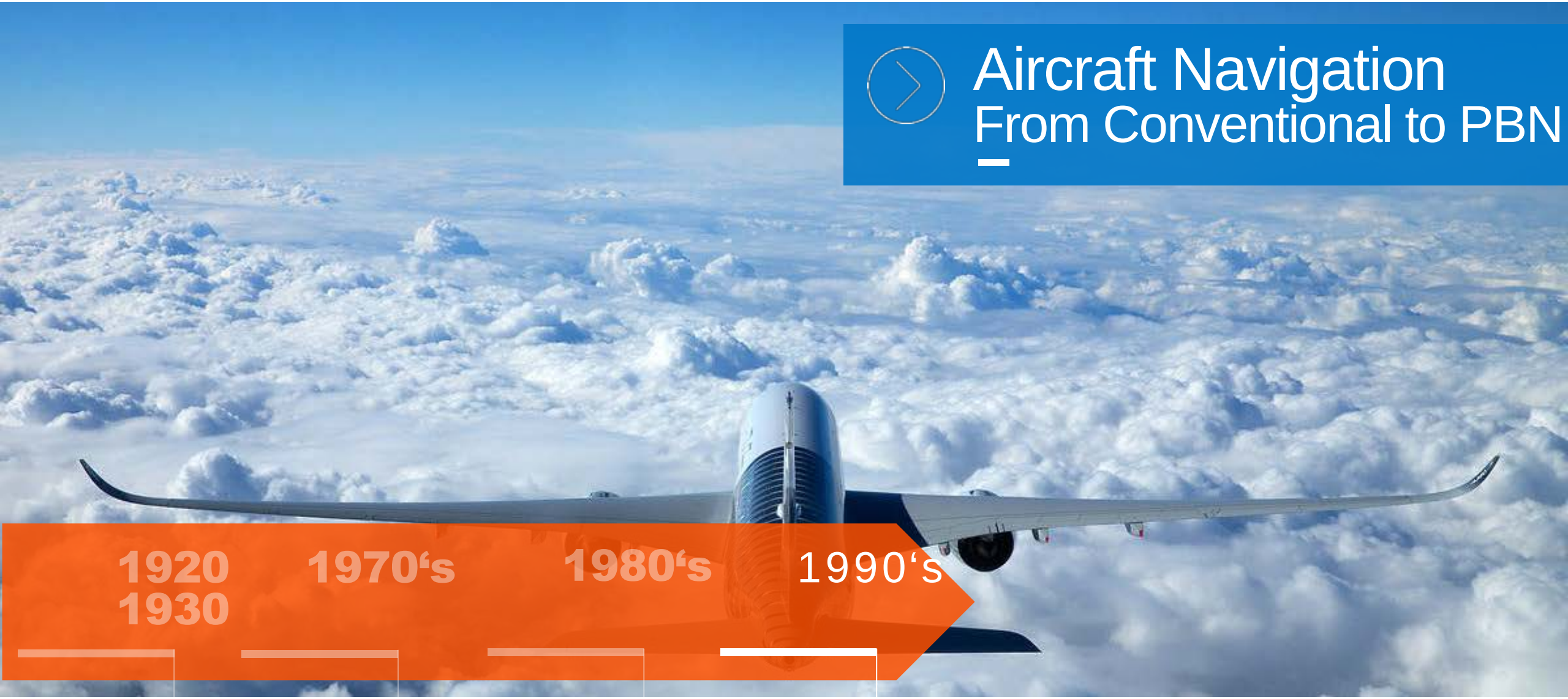
Approach coded in Nav DataBase, selection

+**Vertical Guidance** in Barometric

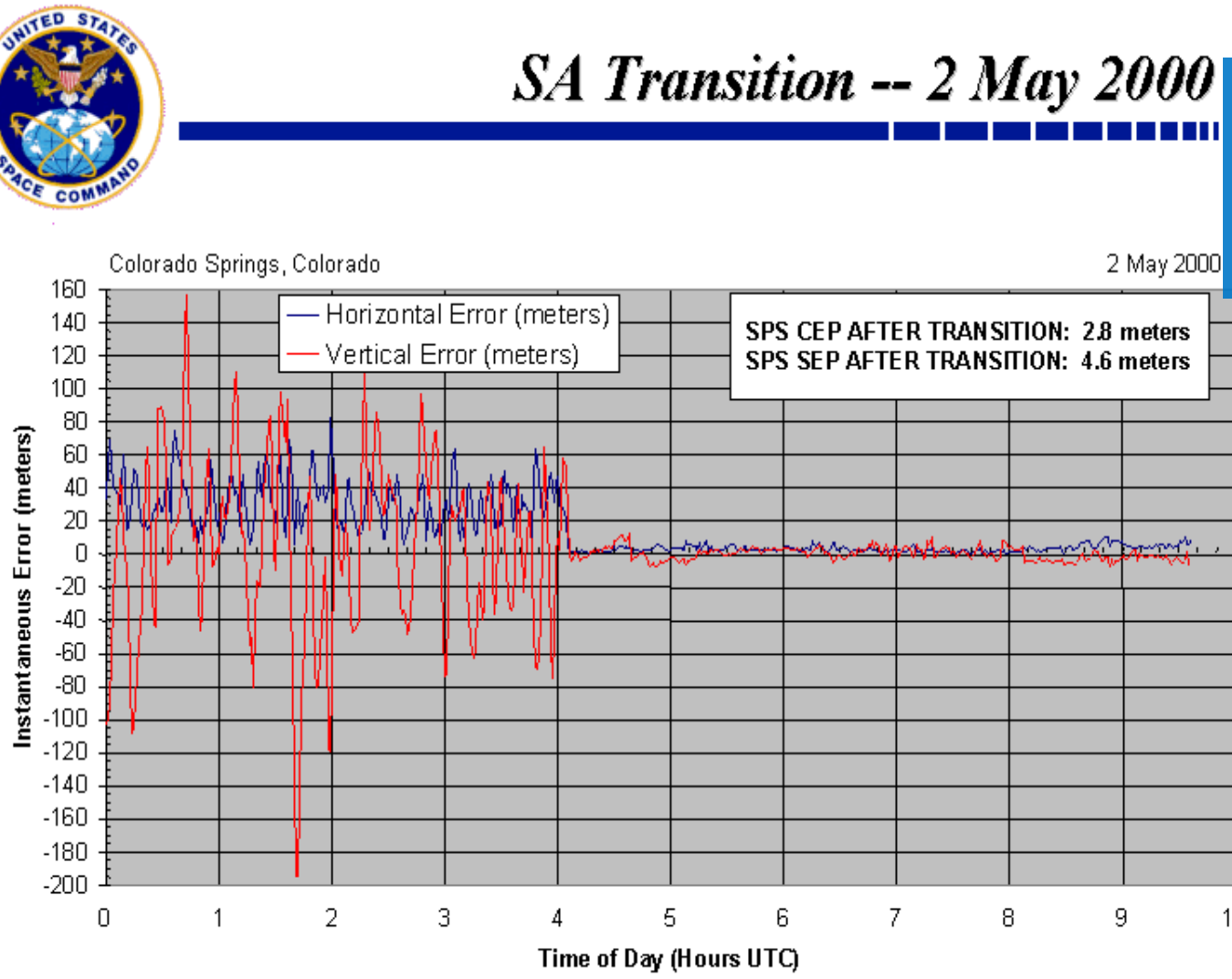
RNAV: aRea NAVigation

AIRBUS

History


Aircraft Navigation
From Conventional to PBN
1920
1930
1970‘s
1980‘s
1990‘s

1990's - The GNSS – Global Navigation Satellite System



Bring accuracy and integrity on position

+ **PBN concept**

the Navigation Performance

PBN: Performance Based Navigation

RNP AR: required Navigation Performance with Authorization required

AIRBUS

Agenda

PBN

PBN Concept

GNSS augmentation

Aircraft Design

Next Step

AIRBUS

Agenda

PBN

PBN Concept

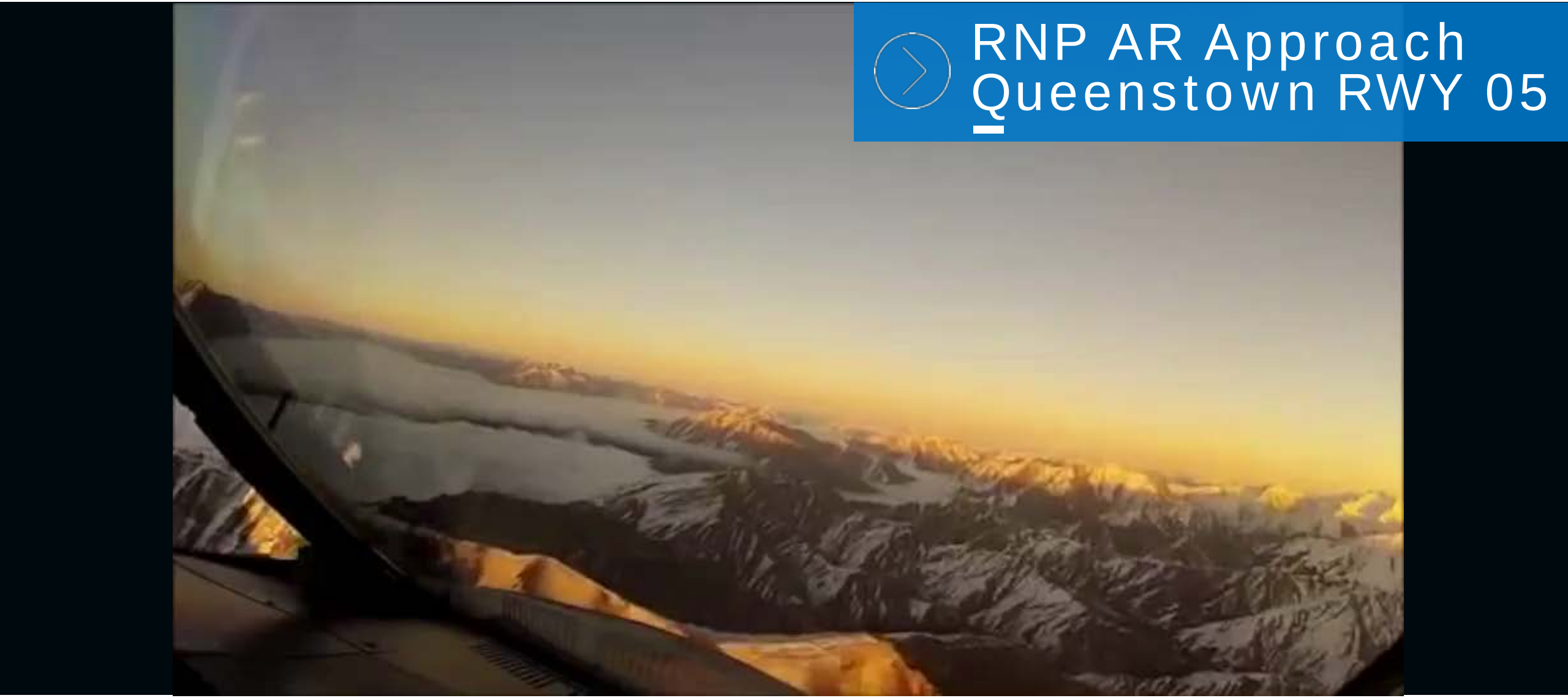
GNSS augmentation

Aircraft Design

Next Step

AIRBUS

RNP objectives



AIRBUS

RNP objectives

Give access to remote areas

AIRBUS

PBN in terminal Area to face congested airspace

AIRBUS

Advantages of PBN for ANSP

+**Independent routes**

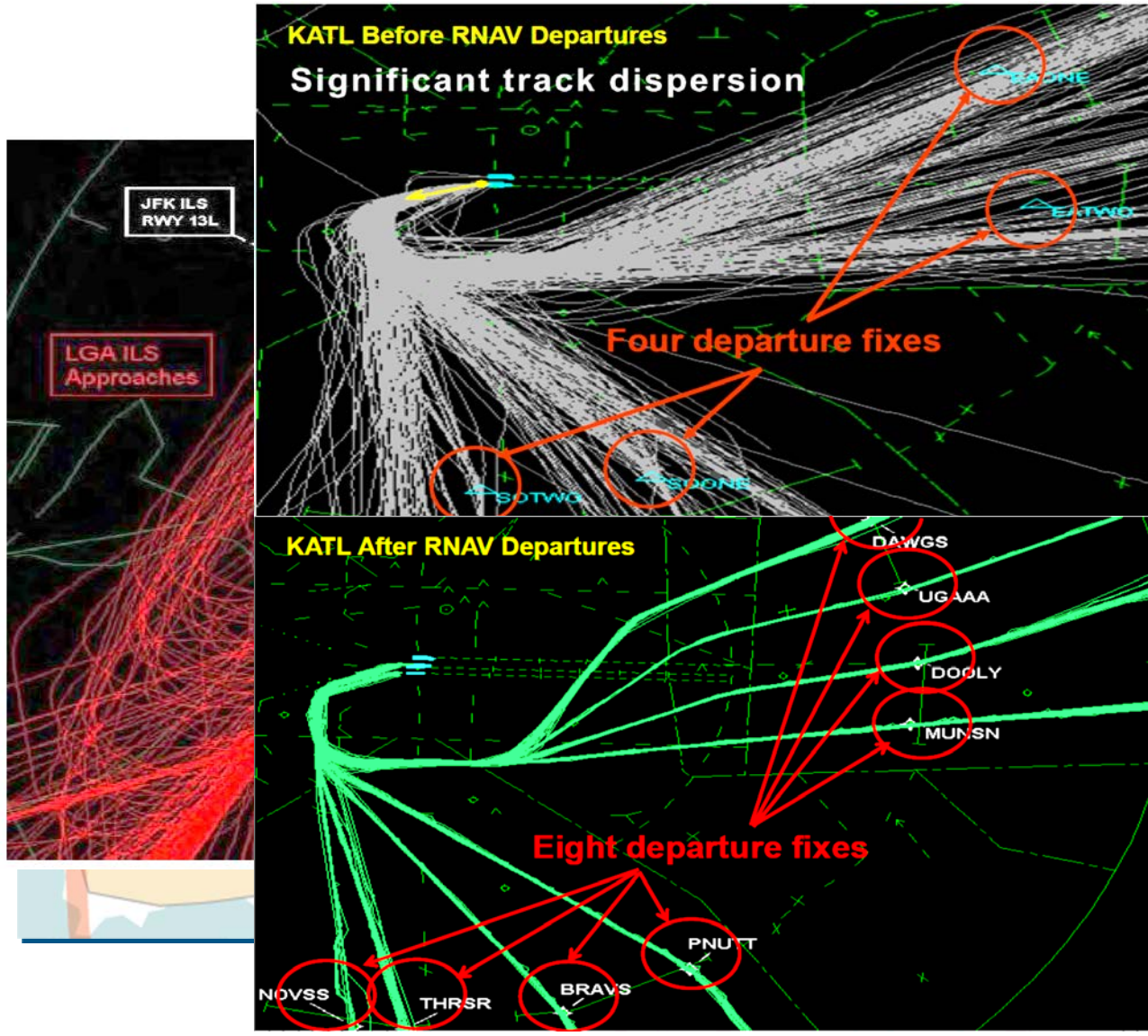
Not based from NAVAIDs location

+**Fully coded route**

NDB

+**Lateral & Vertical "containment"**

- Reduction of the separations
- Solution for traffic segregations between 2 airports
- Noise sensitive area avoidance

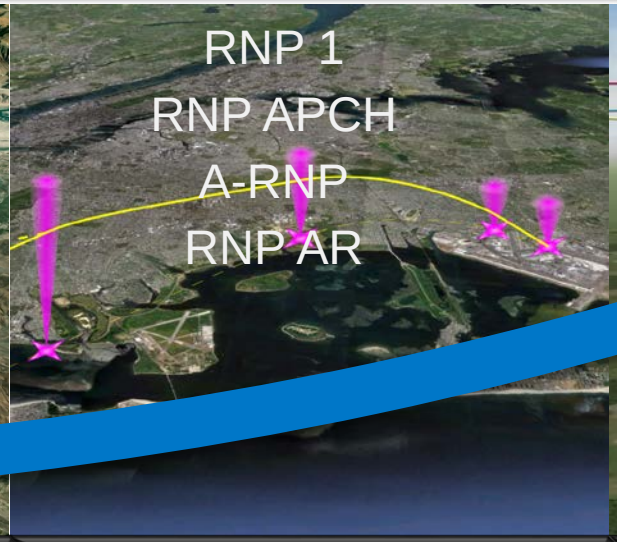


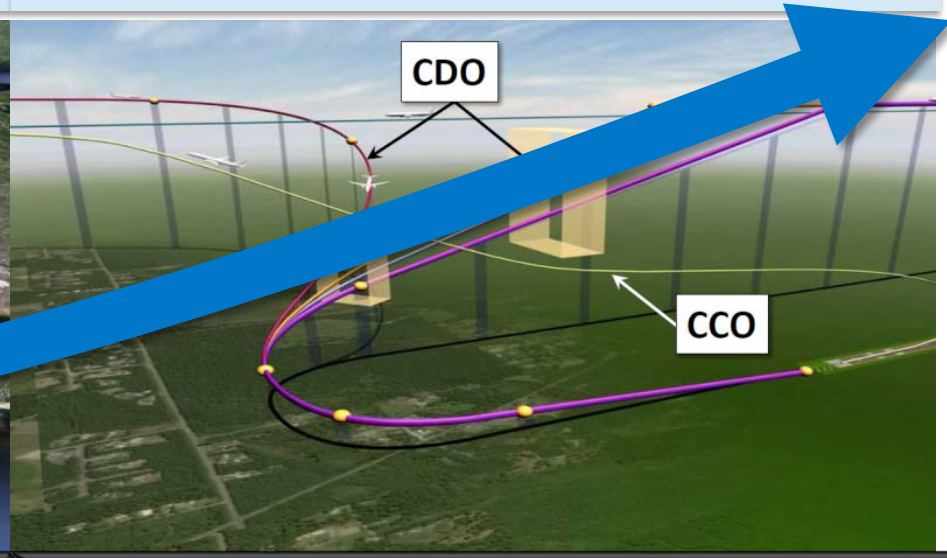
AIRBUS

From a specific to a wide use of RNP

Increasing number of RNP applications

Specific: Few Airlines, few procedures	More and more users	Wide Use of RNP





90's

First RNP Approach → **Now** → **The future** 4D trajectory SESAR

+ Giving access to remote areas + Improving Airport capacity

+ Increasing efficiency fuel and time saving

AIRBUS

PBN Concept: Positioning

Total System Error

Path Definition Error

~~NDB~~

+

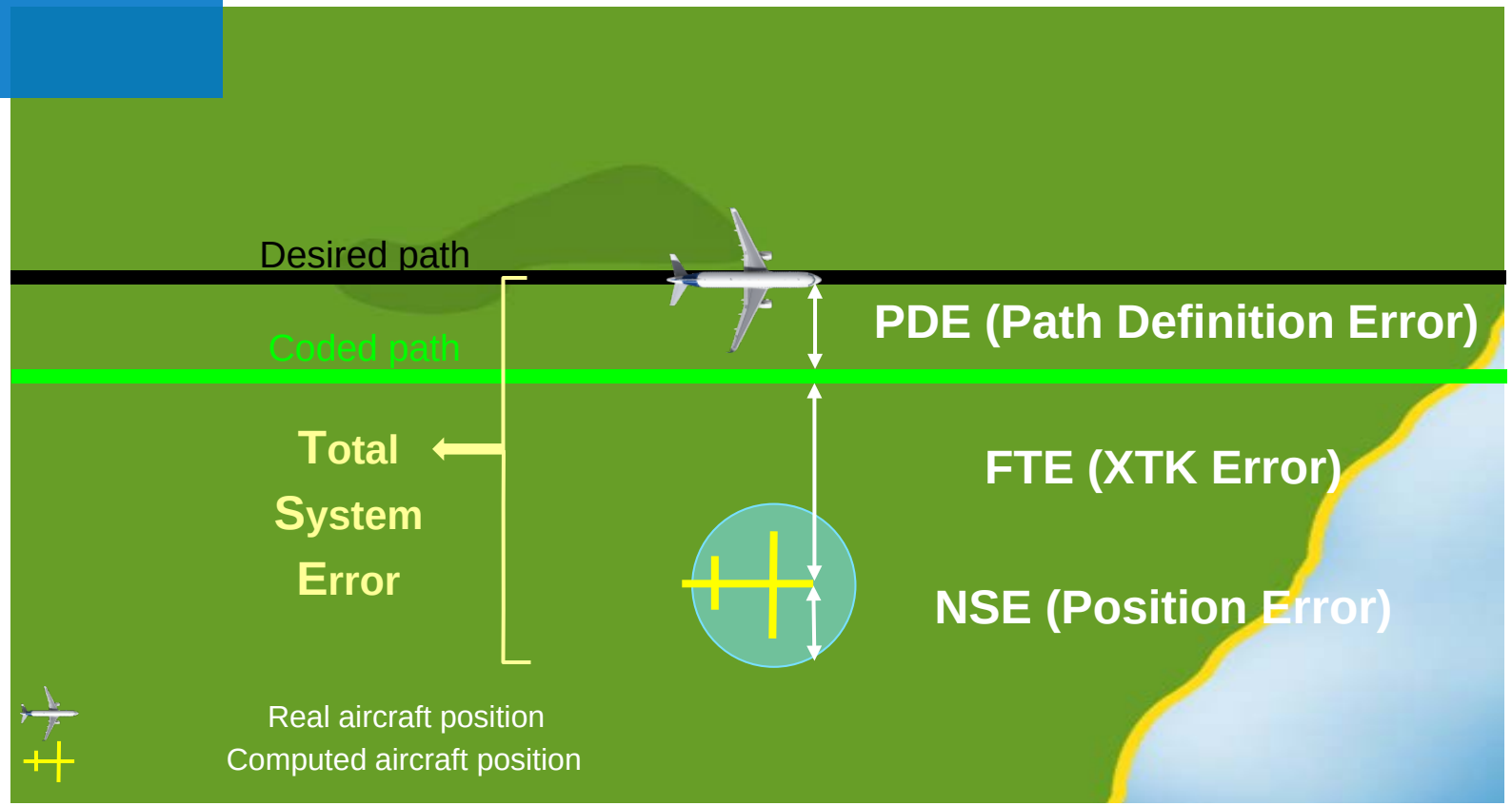
Guidance Error (FTE)

XTK

+

Position Error (NSE)

computation



AIRBUS

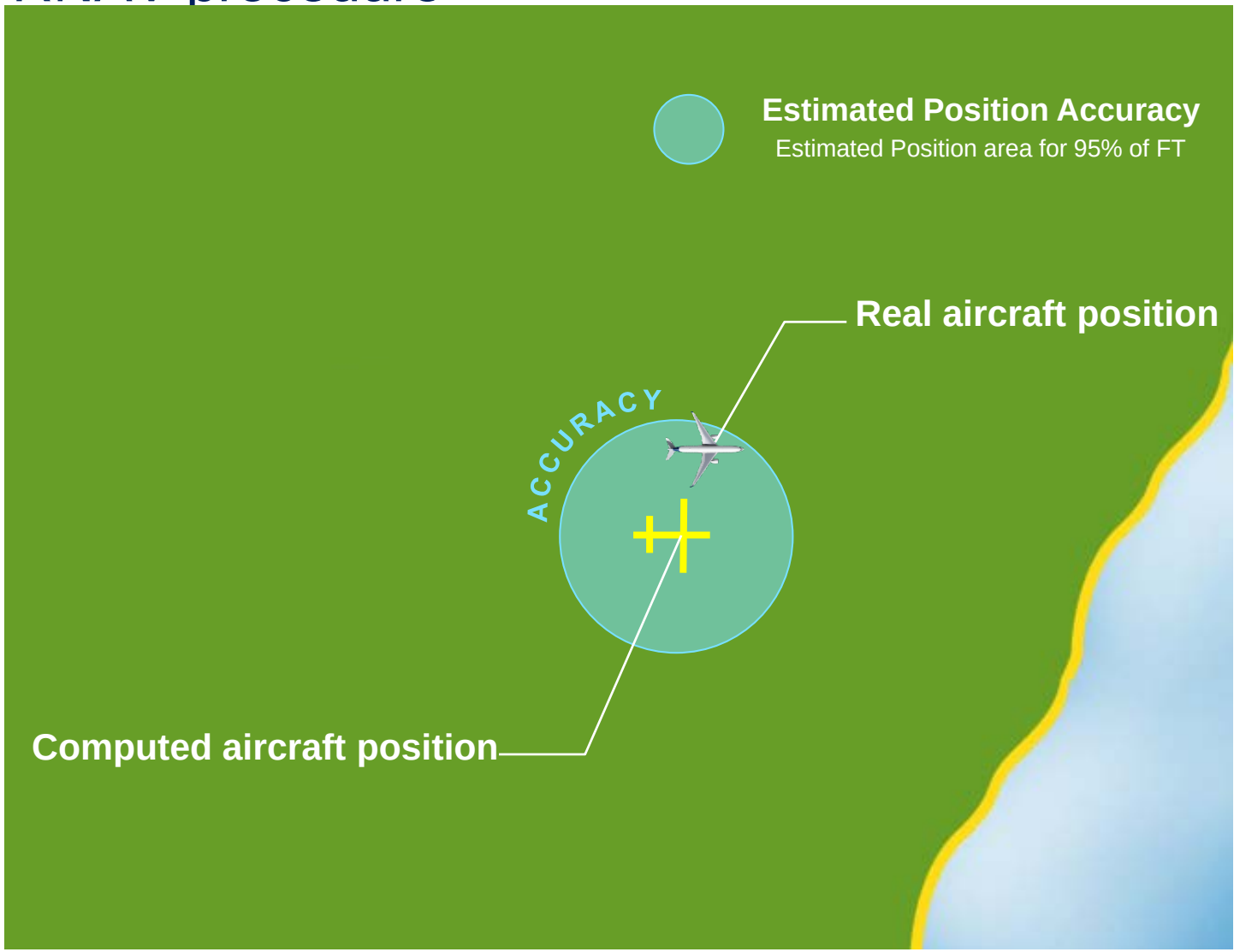
The GNSS – Global Navigation Satellite System

AIRBUS

PBN Concept: Design of a RNP or RNAV procedure

+**On-board position error estimated**

Accuracy



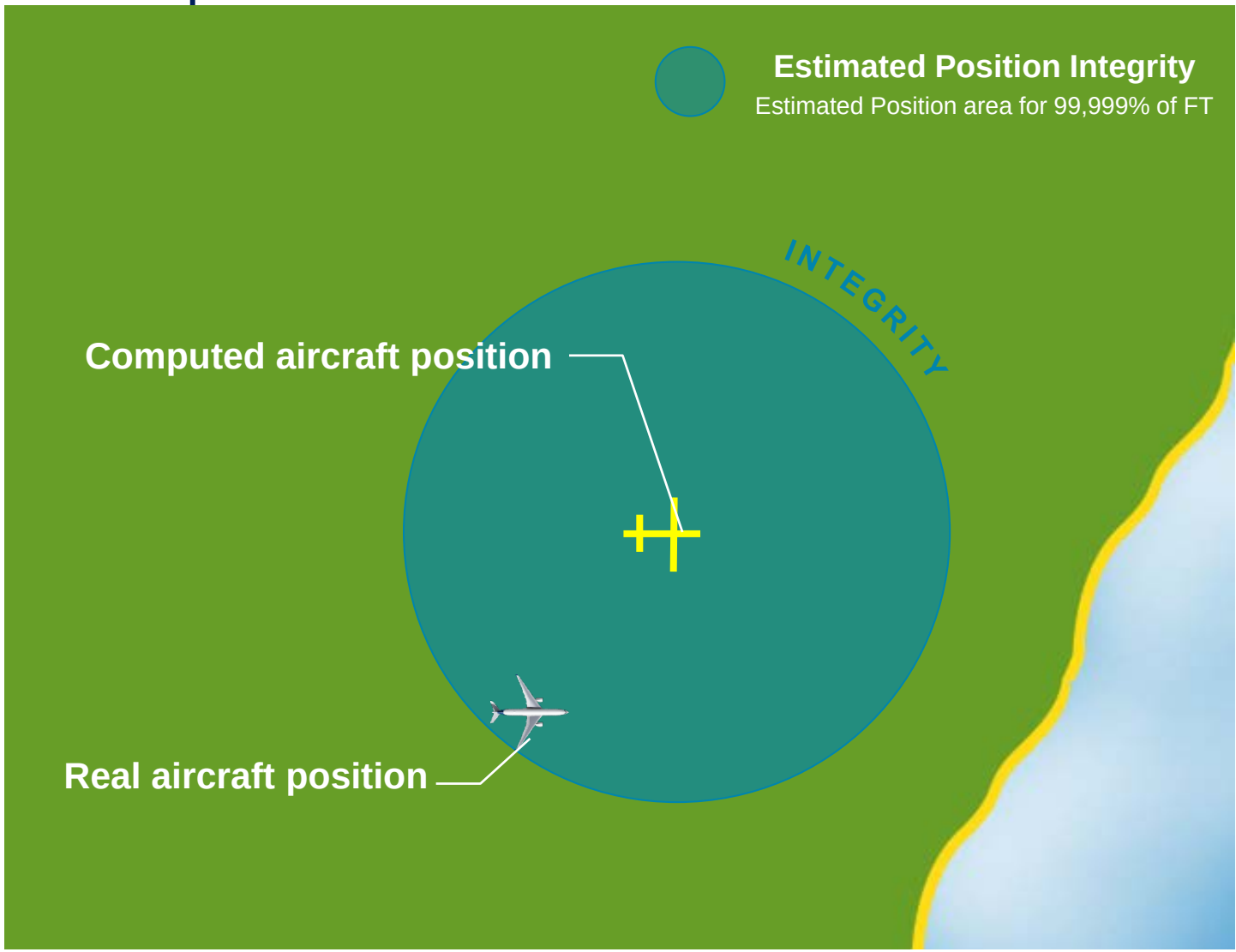
AIRBUS

PBN Concept: Design of a RNP or RNAV procedure

+**On-board position error estimated**

Accuracy

Integrity



AIRBUS

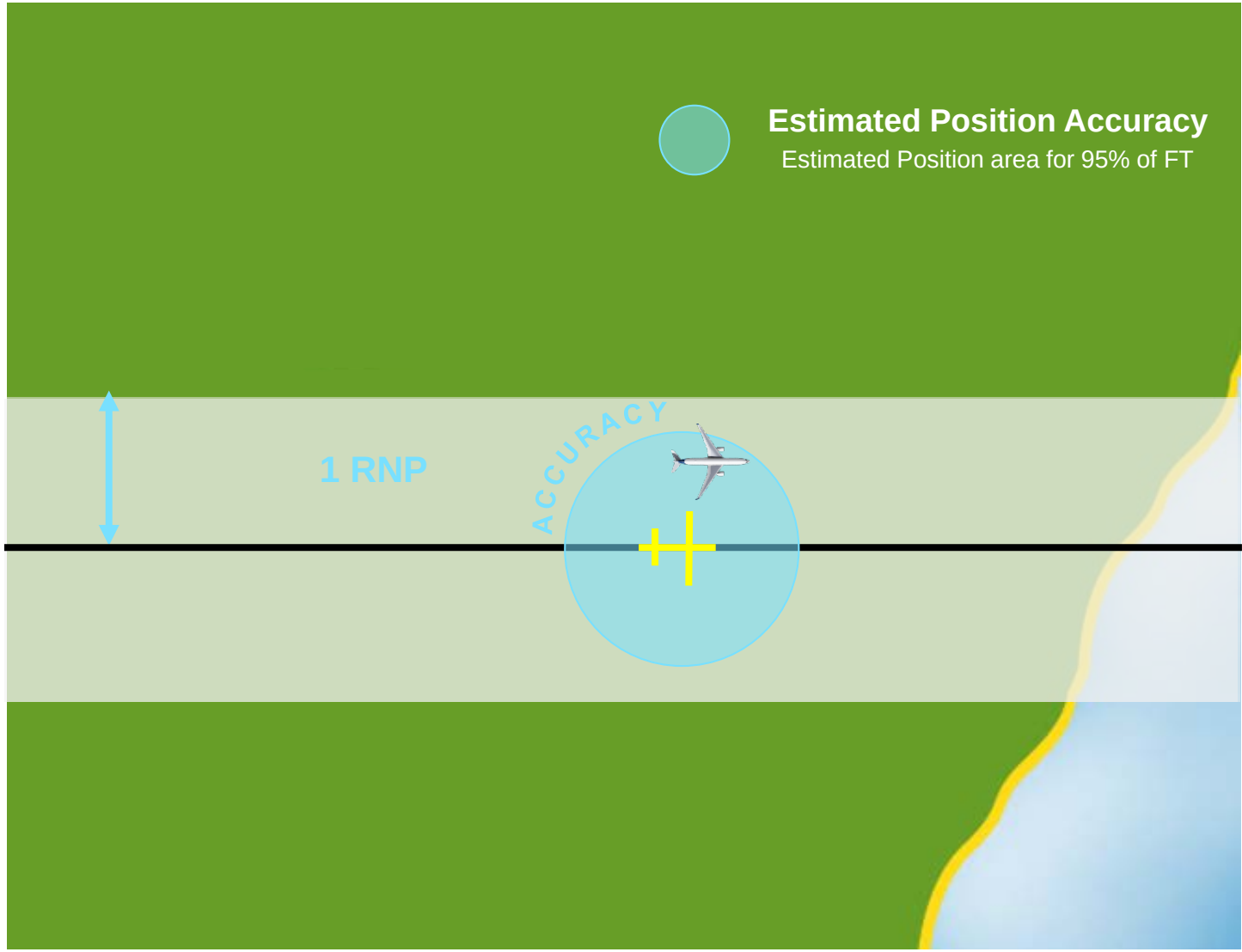
PBN Concept

+Accuracy criteria

TSE 95 % < 1 RNP

Under normal condition

A/C position inside 2 RNP corridor 95% of flight time



AIRBUS

PBN Concept

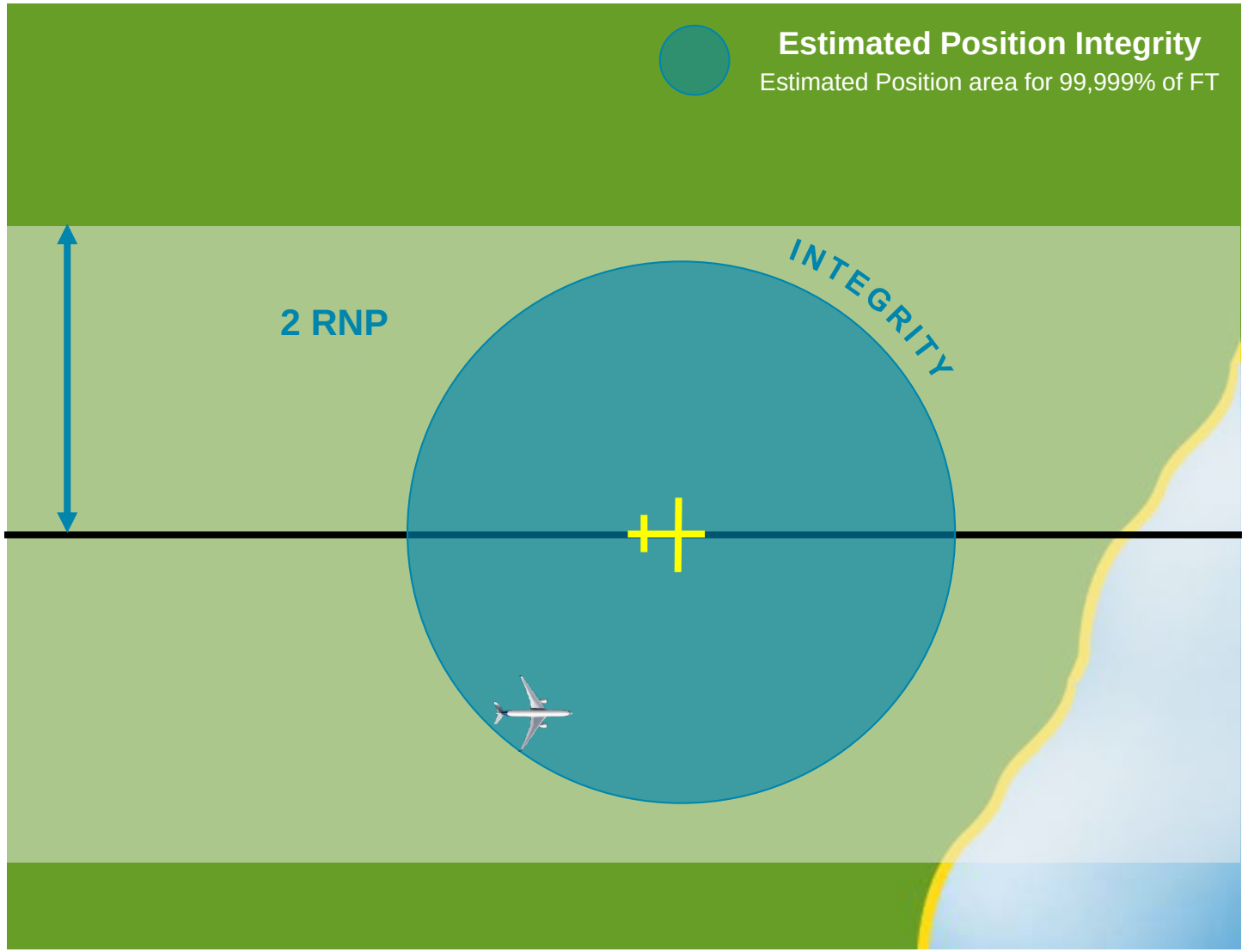
+Integrity criteria

TSE 99.999% < 2 RNP

A/C position inside 4 RNP corridor 99.999% of flight time

Demonstration considering probable failure

- Guidance failures → impact on FTE
- Navigation failures→ impact on NSE



AIRBUS

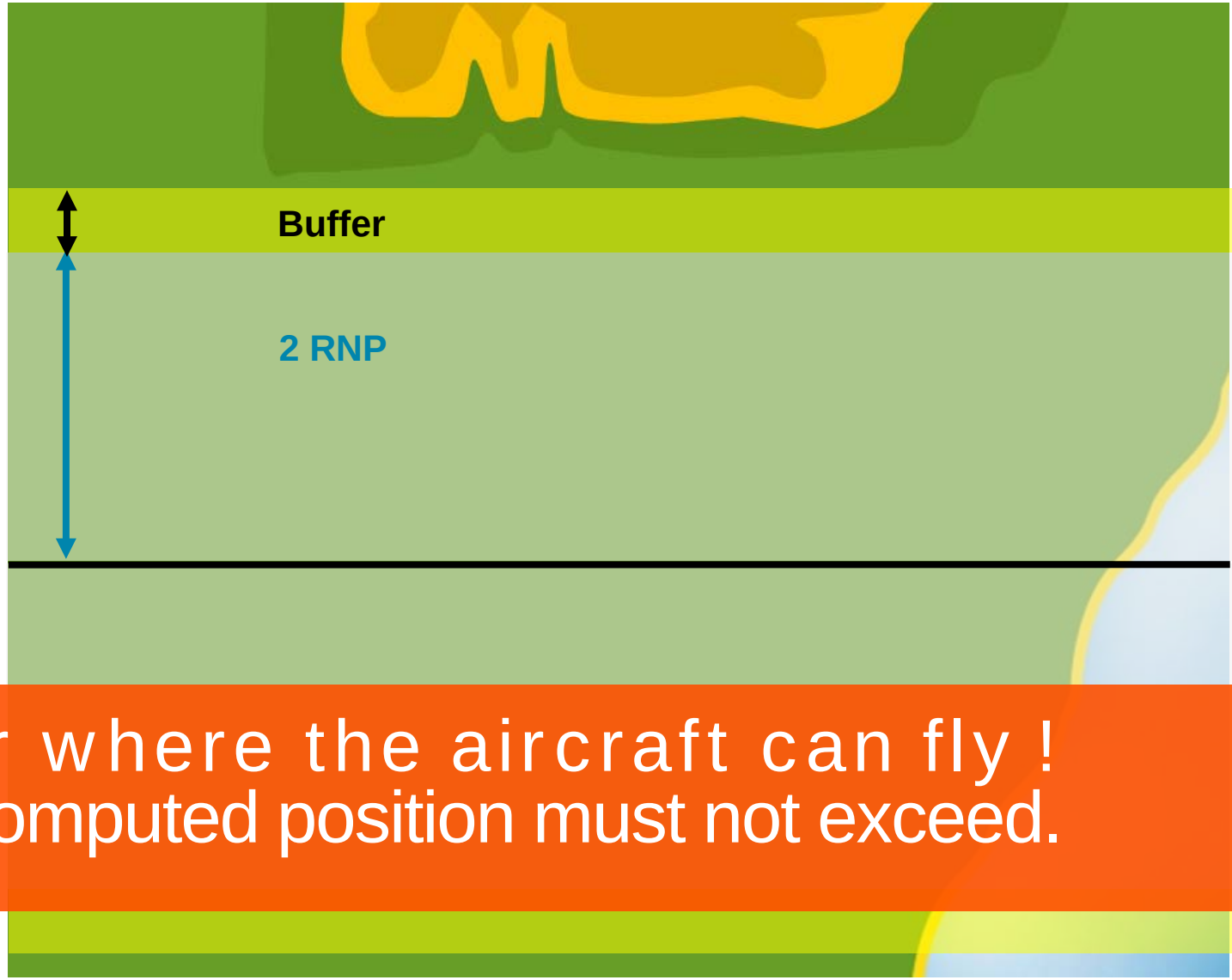
PBN Concept

+ Procedure Design

Corridor 2 RNP each side of the A/C

Buffers

Obstacle or other airspace outside



NOT a corridor where the aircraft can fly !
But limit that a/c computed position must not exceed.

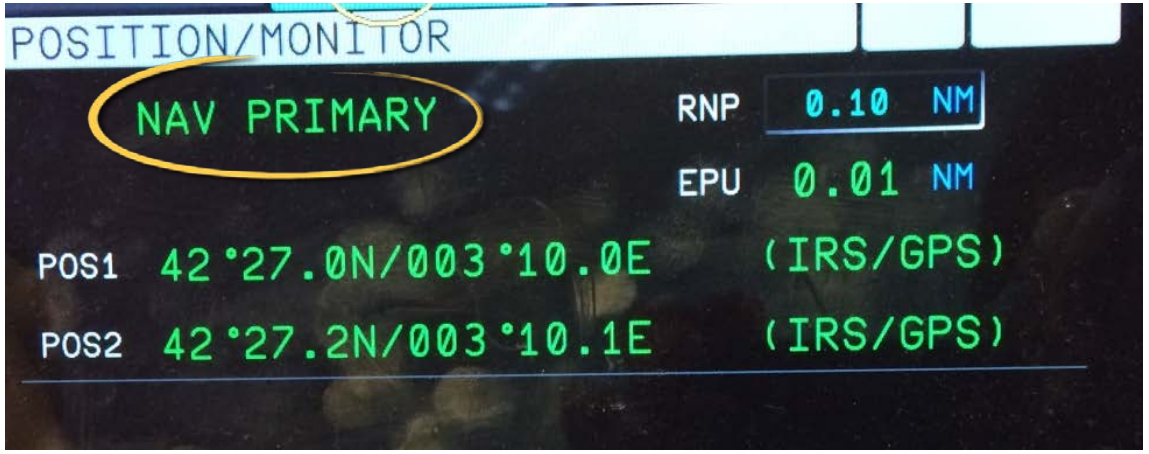
AIRBUS

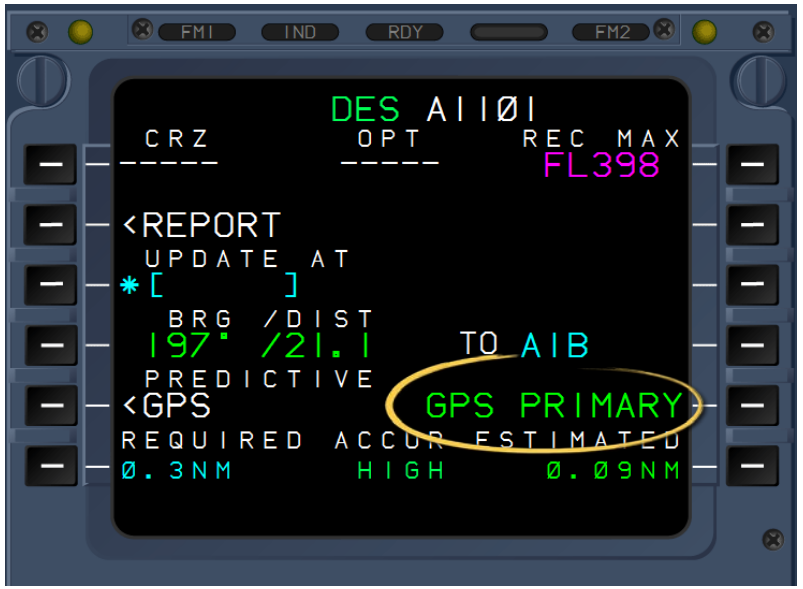
PBN Concept: RNP

- To be RNP capable, the aircraft (FMS) must monitor its navigation performance regarding the RNP value.

- It requests an On-Board Performance Monitoring and Alerting (OBPMA) System.

- All Airbus A/C have an OBPMA



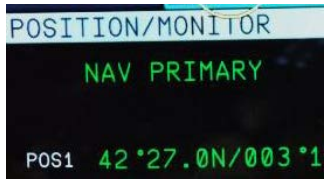


PBN Concept: Airbus A/C performances

- **PDE**: considered null (NDB well coded and verified)

- **XTK:** MONITORED BY THE CREW
upon AP less than 0.1NM most of the time

- **EPU:** MONITORED BY THE SYSTEM (OBPMA)
less than 0.08NM most of the time

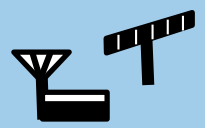


4 RNP corridor to cover major critical failures

AIRBUS

External Monitoring

ATC (mode S, ADS-B, ….)



RNAV

On-Board Monitoring

TSE

NSE

Accuracy

Integrity

NAV ACCURACY

GPS PRIMARY

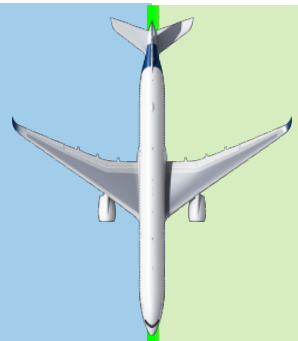
FTE

XTK

OBPMA

RNP

AIRBUS



External Monitoring

ATC (mode S, ADS-B, ….)

On-Board Monitoring

TSE

NSE

Accuracy

Integrity

NAV ACCURACY

GPS PRIMARY

FTE

XTK

OBPMA

On-Board Monitoring

OBPMA

RNAV

RNP

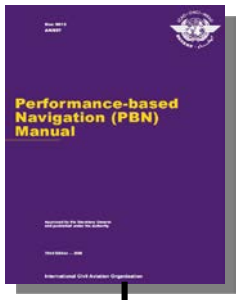
ICAO
PBN MANUAL
(Doc 9613)
PANS-OPS
(Doc 8168)

Navigation Specification	Navigation Accuracy (NM) per flight phase						
	En-route		Terminal	Approach			Departure
	Oceanic Remote	Continental		Initial Interm.	Final	Missed	
RNAV 10 (RNP 10)	10						
RNAV 5		5	5				
RNAV 2		2	2				2
RNAV 1		1	1	1		1	1
RNP 4	4						
RNP 2	2	2					
RNP 1			1	1		1	1
RNP APCH				1	0.3 or angular	1	
RNP AR APCH				1-0.1	0.3-0.1	1-0.1	

PBN Standard

AIRBUS

PBN Manual: Standardization



RNAV

On Board Perf. Monitoring and Alerting system not mandatory

RNP

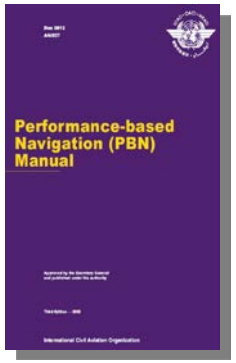
On Board Perf. Monitoring and Alerting system mandatory

RNAV		RNP			
EN-ROUTE	TERMINAL	EN-ROUTE	TERMINAL	APPROACH	
RNAV 10	RNAV 5	RNAV 1 RNAV 2	RNP 4	RNP 2	RNP1	RNP APCH	RNP AR APCH

ADVANCED RNP (Advanced features: RF, FRT, …)

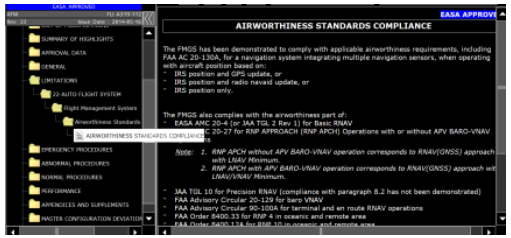
AIRBUS

PBN Manual and Airbus documentation



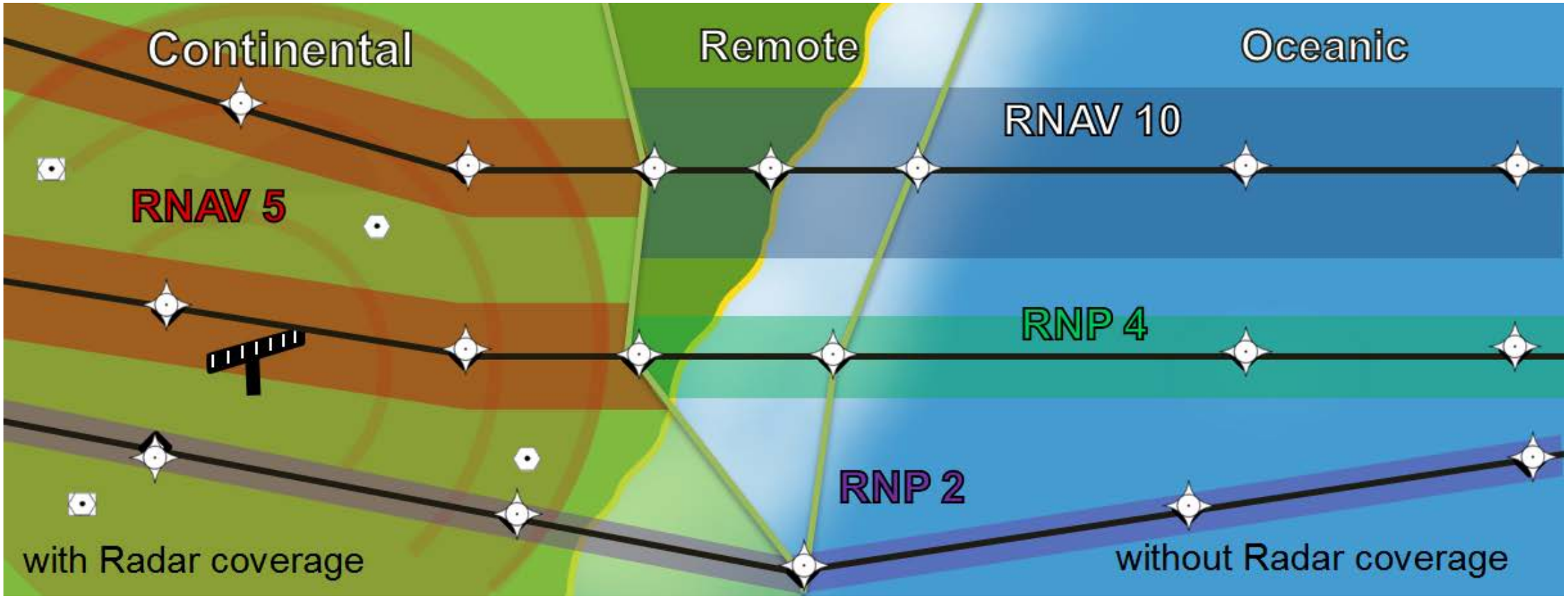
NOT a regulatory guidance
Standard and recommended practices

A/C compliant to FAA or EASA regulations



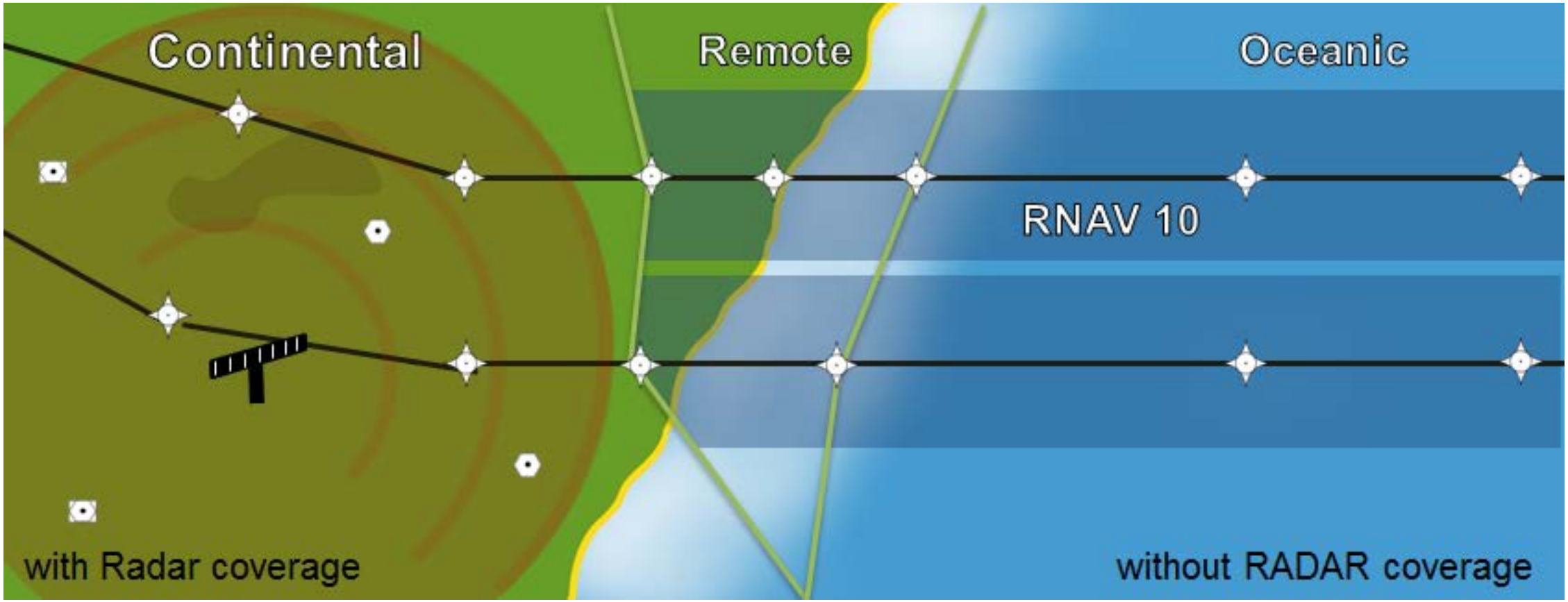
Operational documentation (AFM/FCOM)
Statement of compliance with EASA or FAA regulation

En Route Operations



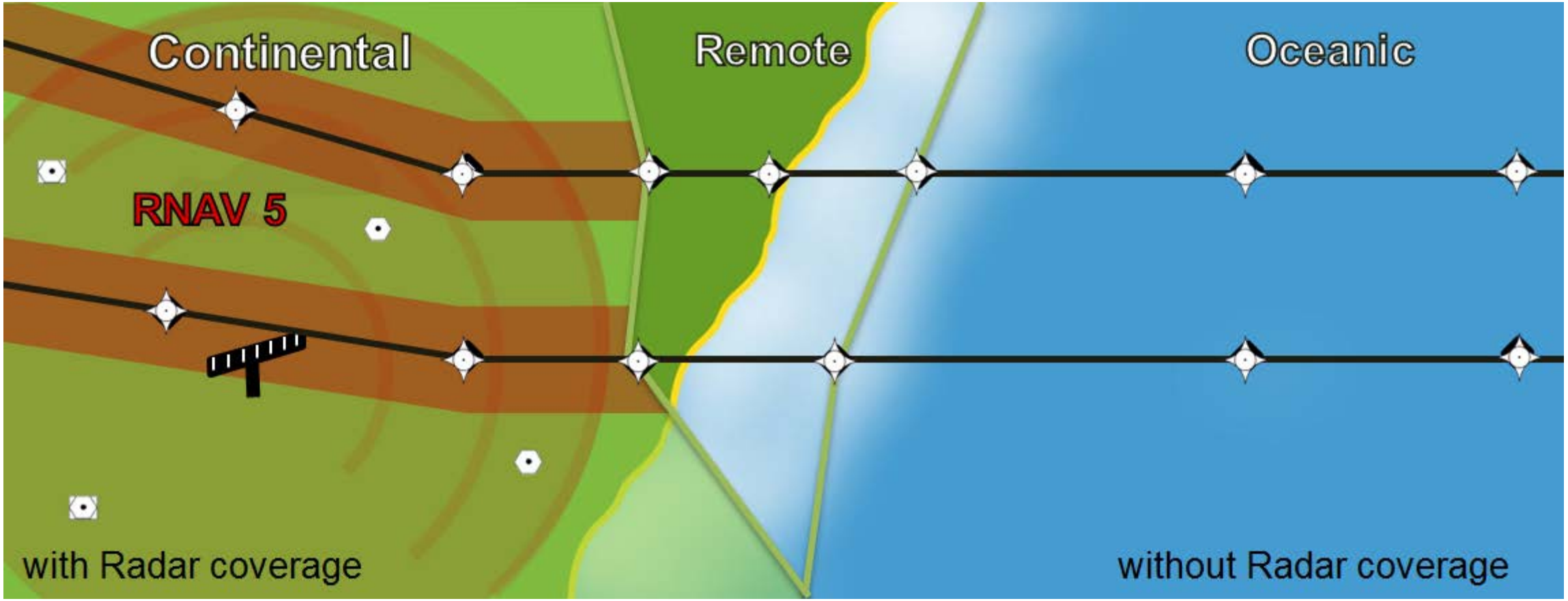
AIRBUS

En Route Operations: RNAV 10 (RNP 10)



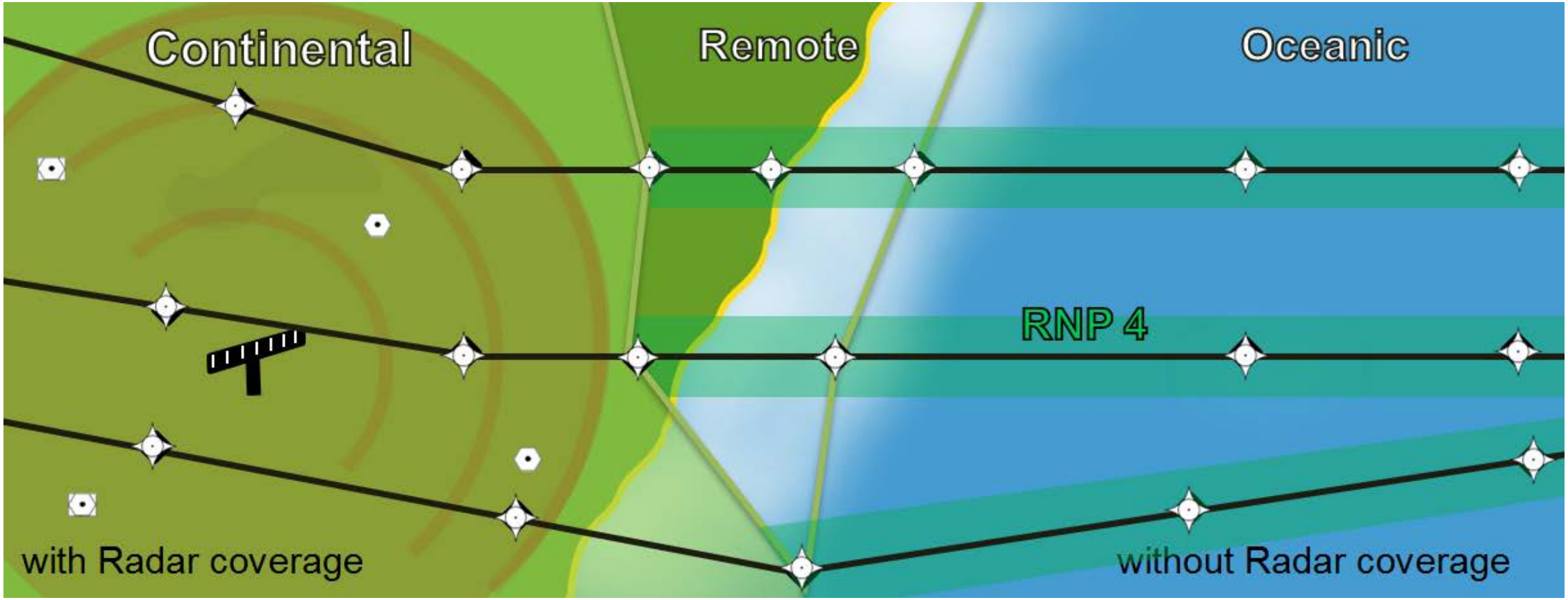
- Compliance: All Airbus aircraft (but A300)
- Airspace example: MNPS

En Route Operations: RNAV 5 (B-RNAV, Basic RNAV or RNP5)



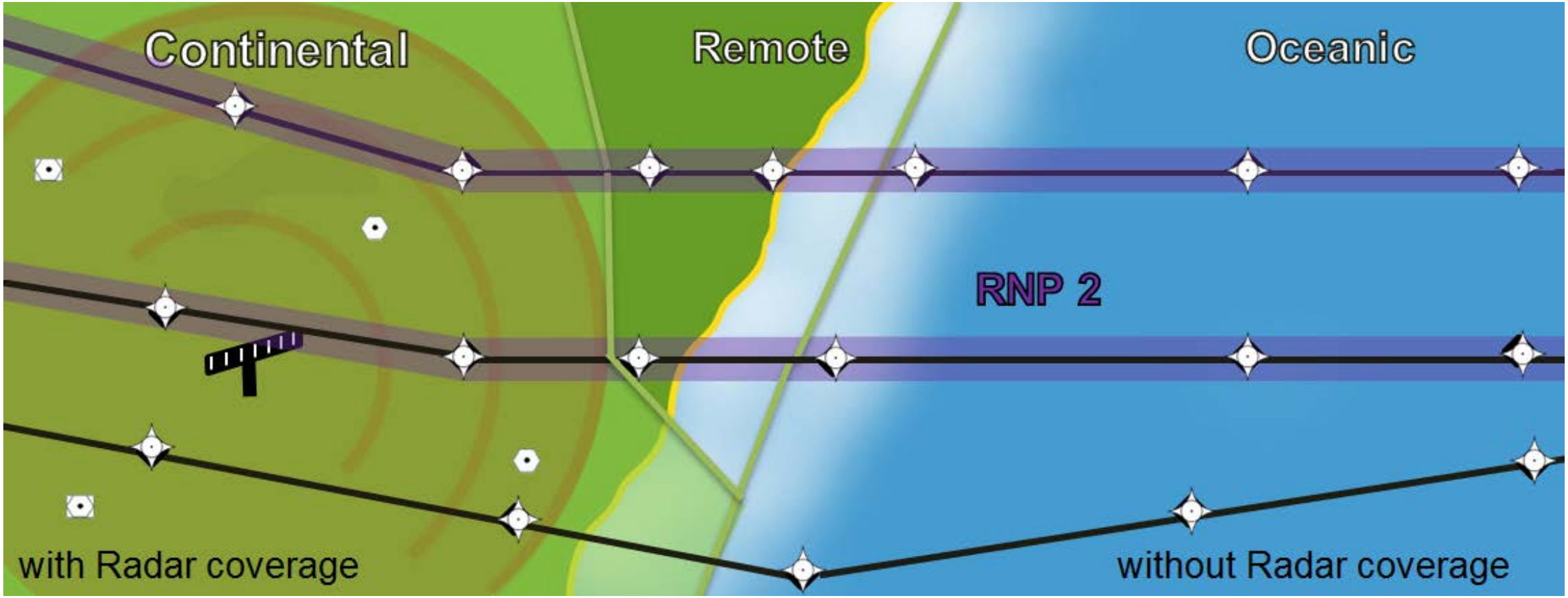
- Compliance: All Airbus aircraft
- Airspace example: Europe

En Route Operations: RNP 4



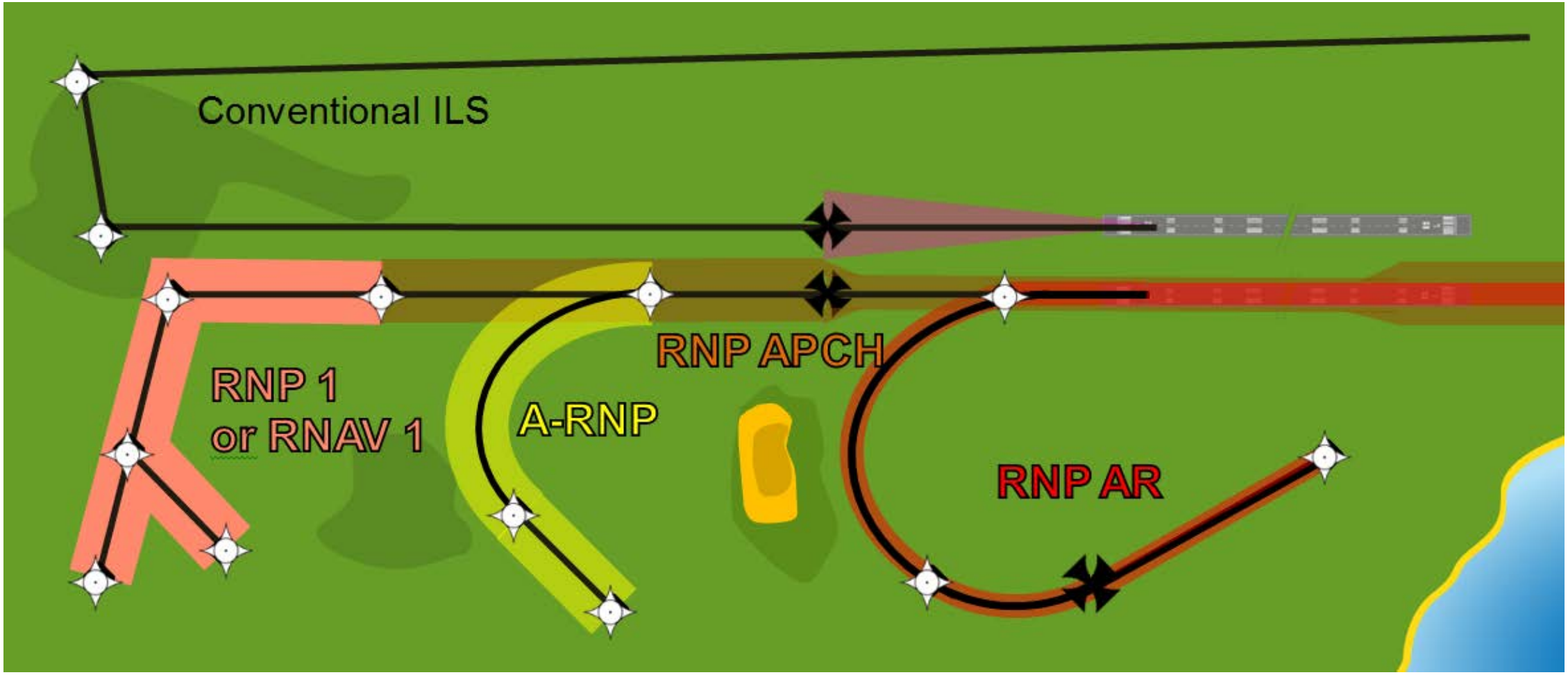
- Compliance: All Airbus aircraft with GPS (but A300)
- Airspace example: Golf of Mexico

En Route Operations: RNP 2



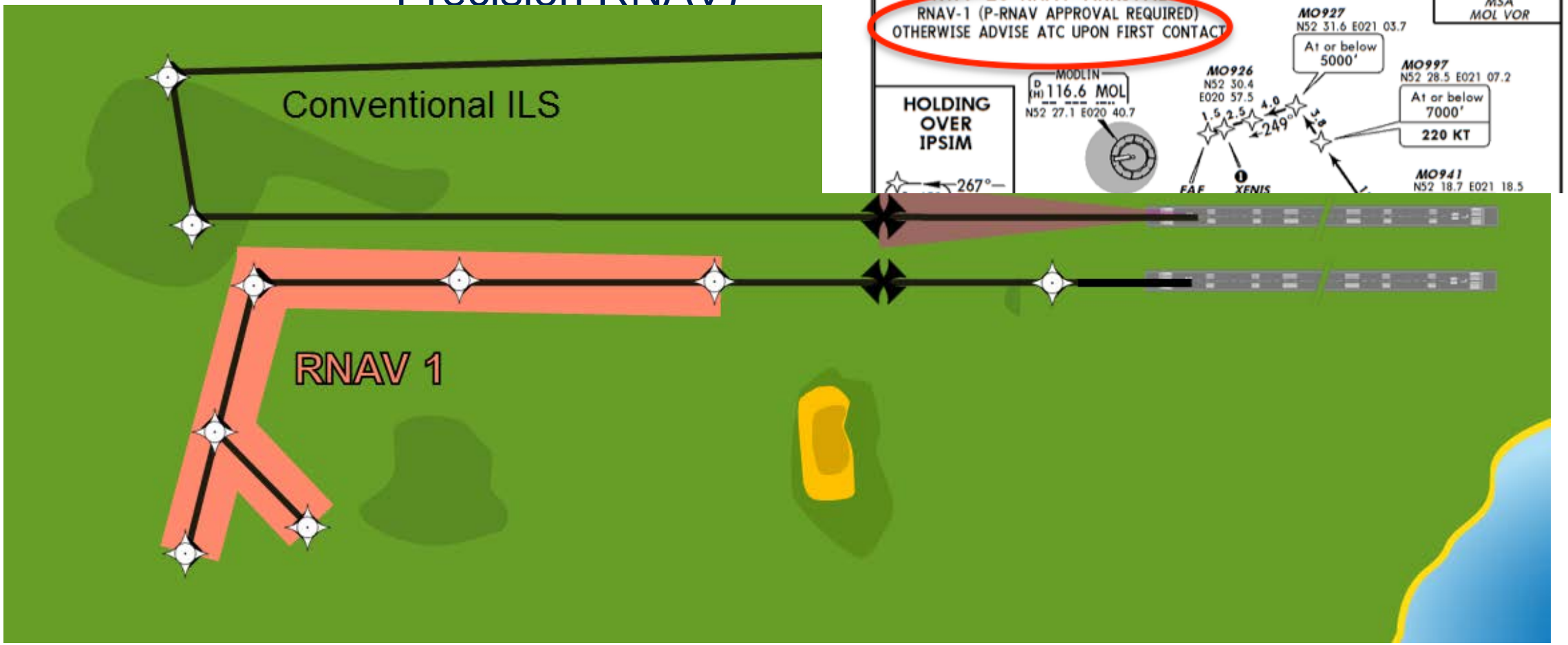
- Compliance: A380, A350 (Q3 2017) and A320/A330/A340 with FMS 2 and GPS.
- Airspace example: Australia (since 2013) and now India.

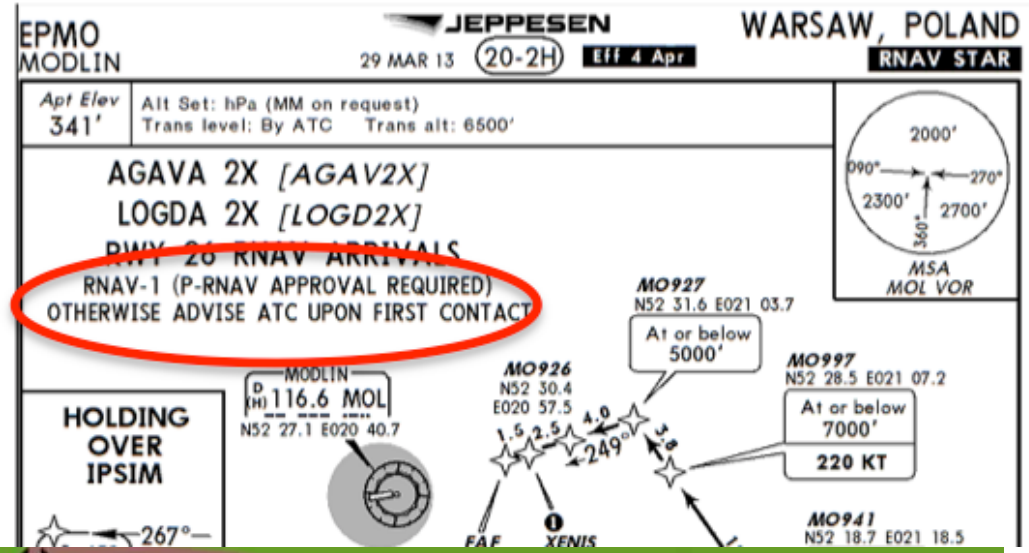
RNP in terminal area



AIRBUS

RNAV 1 or RNAV 2 (Terminal RNAV or Precision RNAV)

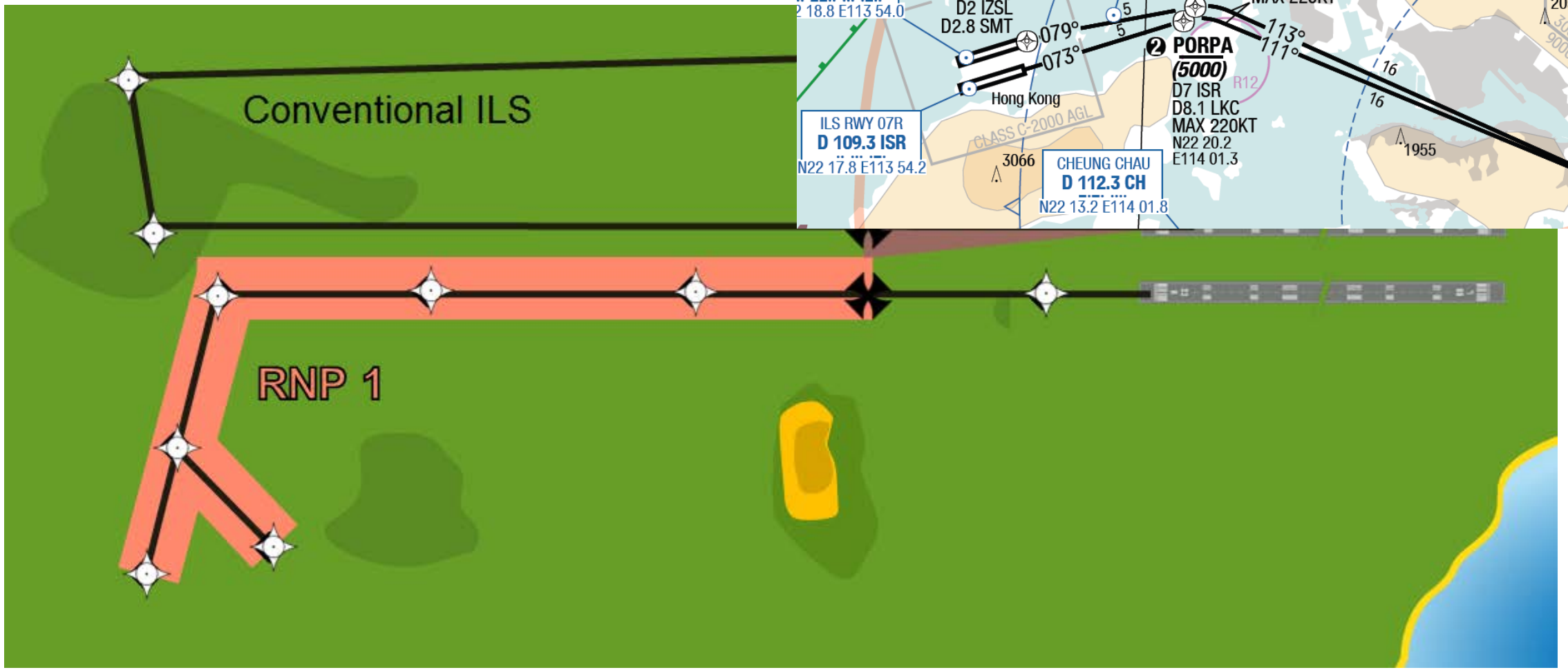


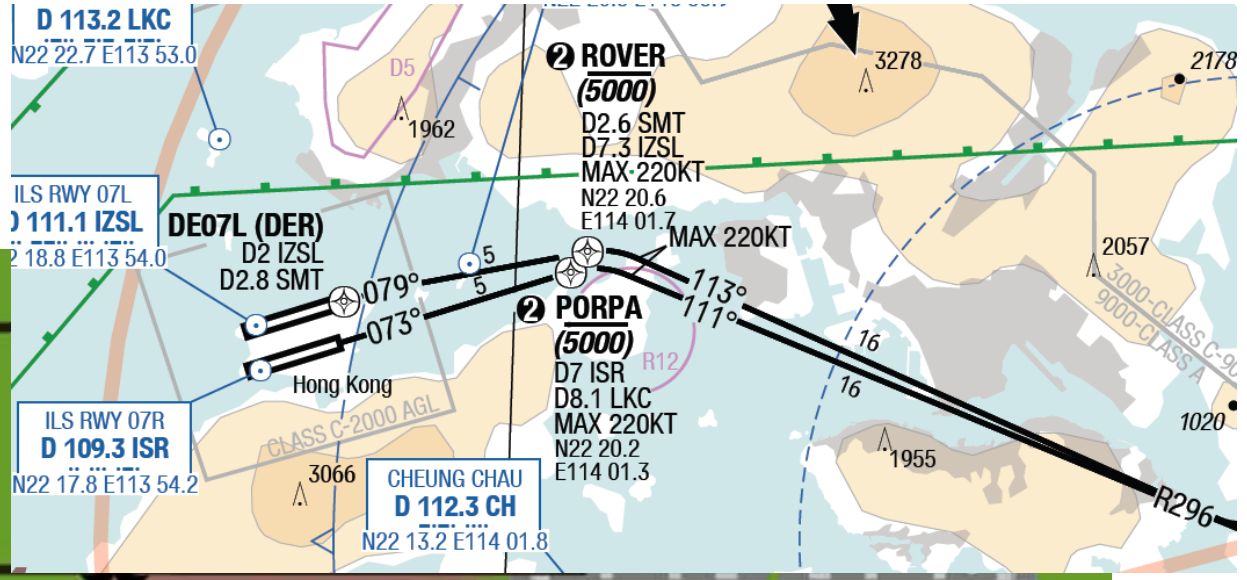


- Compliance: All Airbus aircraft
- Airspace example: SIDs or STARs

AIRBUS

RNP 1 (BRNP1 or Basic RNP1)





- Compliance: A380, A350, A320/A330/A340 with FMS 2 and GPS
- Airspace example: SIDs or STARs

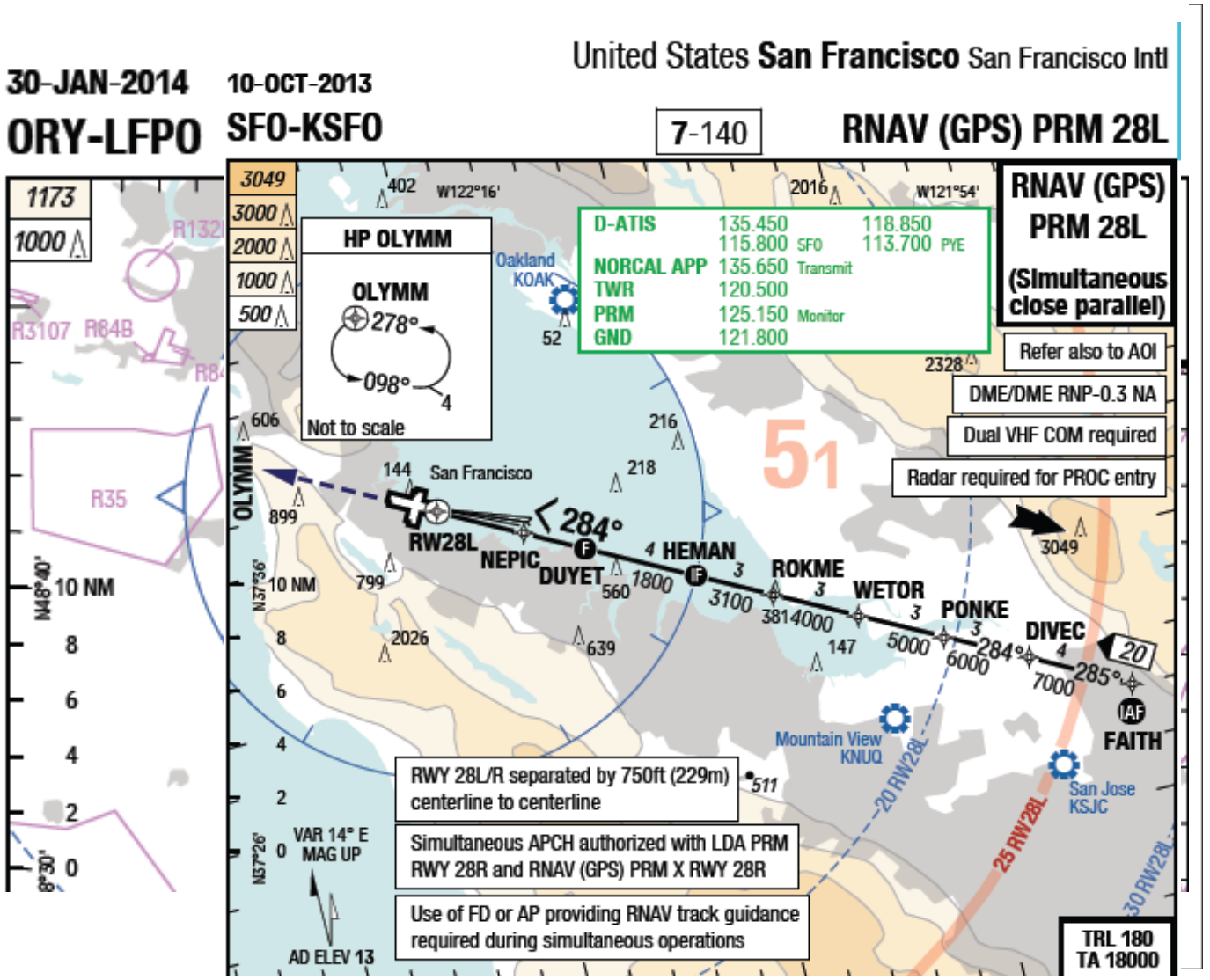
AIRBUS

RNP APCH concept

+Overlay of existing procedure

+RNP value 0.3NM in final

+Decongestion of Terminal Airspace



AIRBUS

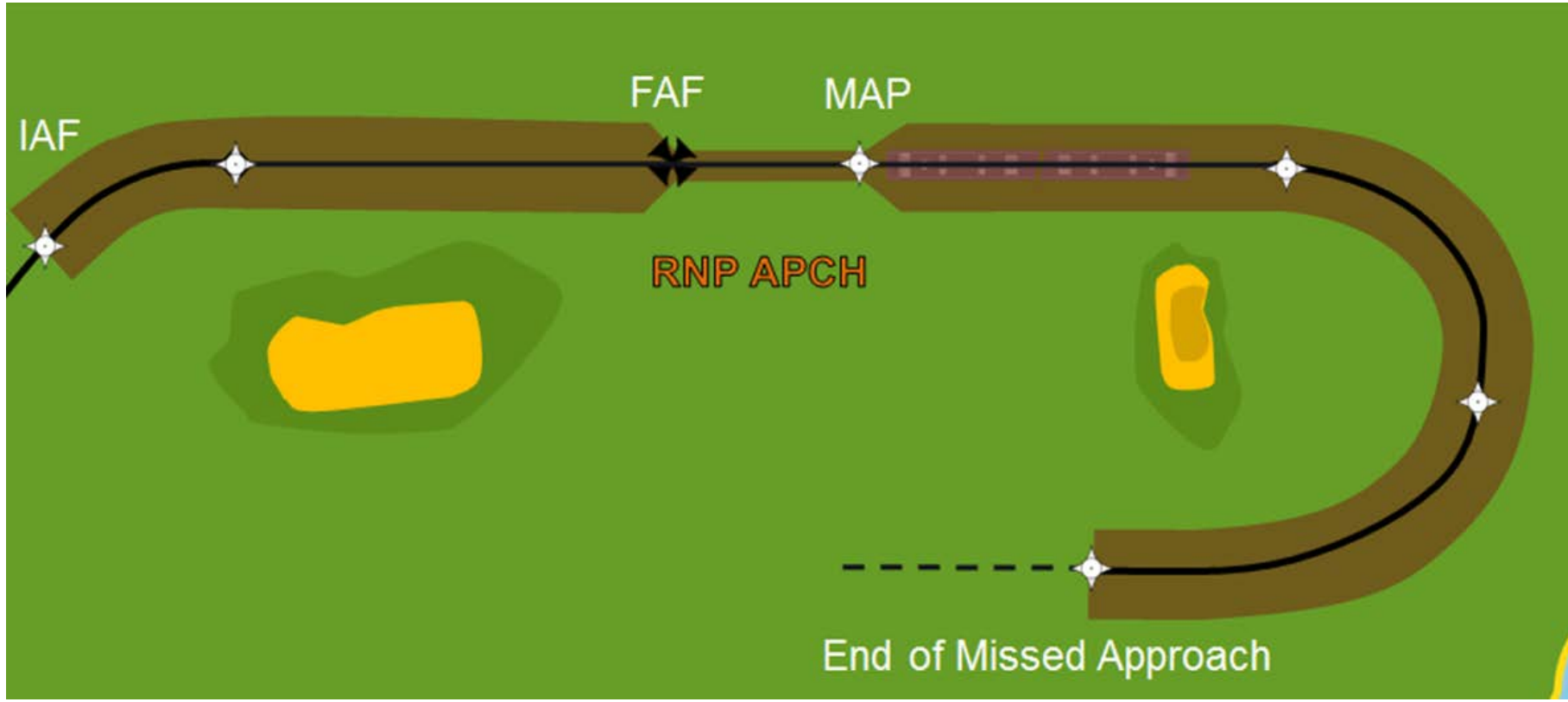
RNP APCH

Concept:

+ **Straight approach after FAF**

+ **RNP 0.3 NM in Final Leg**

+ **RNP 1 NM in Initial, Intermediate and Missed Approach**



AIRBUS

RNP APCH concept

Concept:

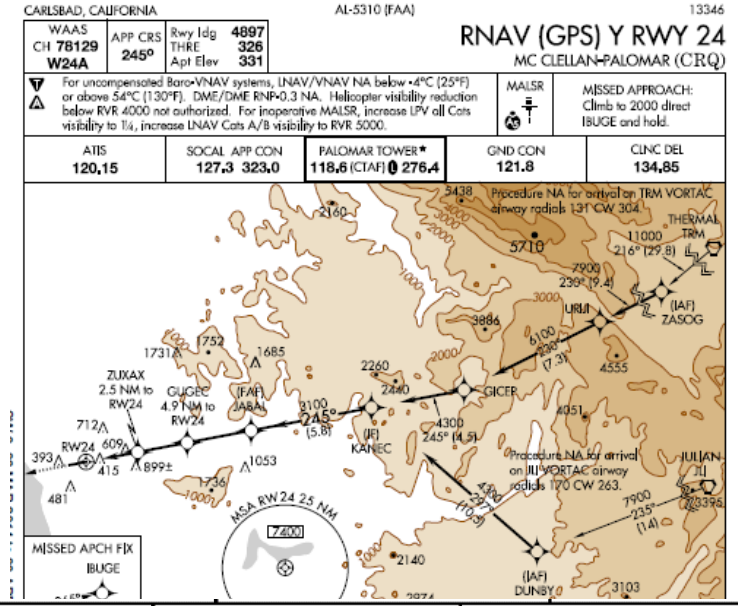
+ **Straight approach after FAF**

+ **RNP 0.3 NM in Final Leg**

+ **RNP 1 NM in Initial, Intermediate and Missed Approach**

+ **Several minima**

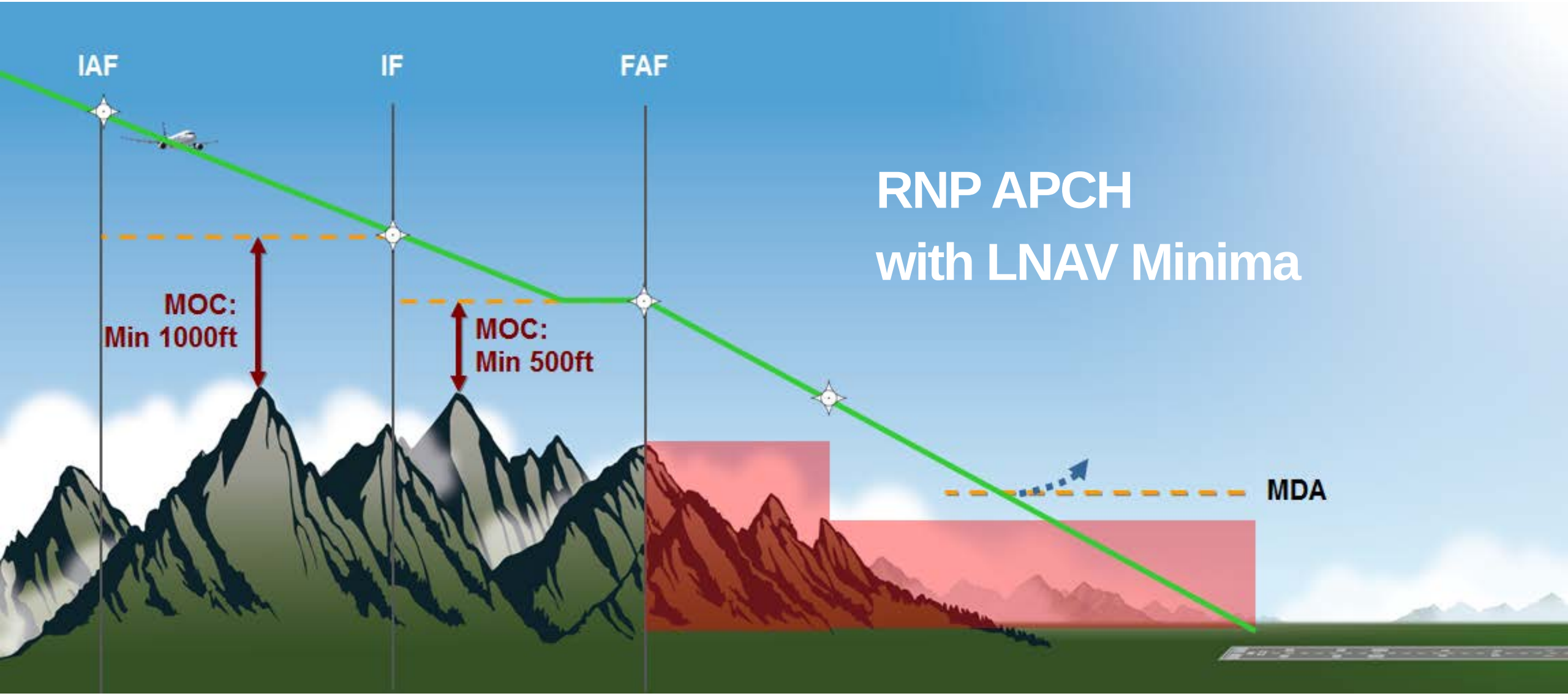
Compliance (LNAV and LNAV/VNAV): All Airbus aircraft with GPS (but A300)



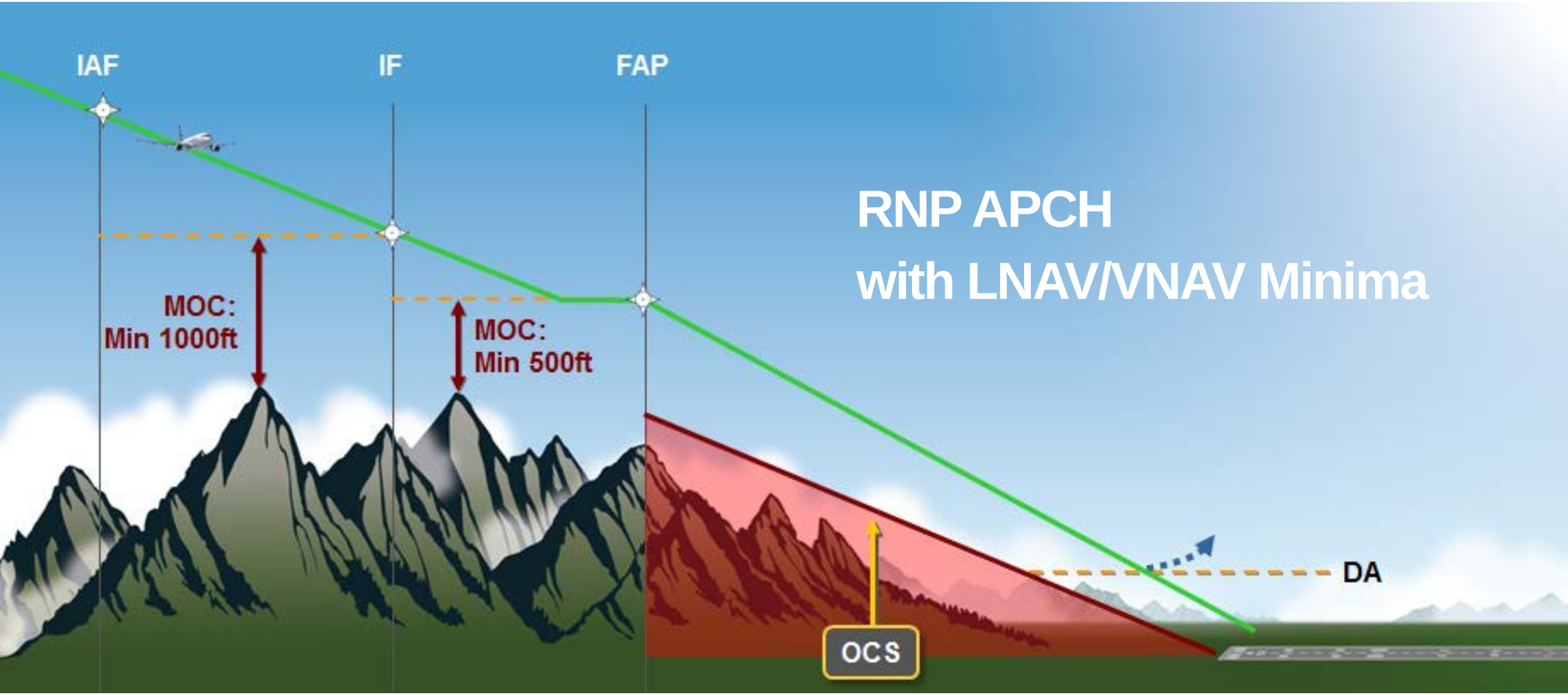
CATEGORY	A	B	C	D
LPV DA	737/45 411 (500-⅞)			NA
LNAV/VNAV DA	927-1½ 601 (600-1½)			NA
LNAV MDA	1000/40 674 (700-¾)		1000-1½ 674 (700-1½)	NA
CIRCLING	1000-1 669 (700-1)		1080-2¼ 749 (800-2¼)	NA

AIRBUS

RNP APCH concept

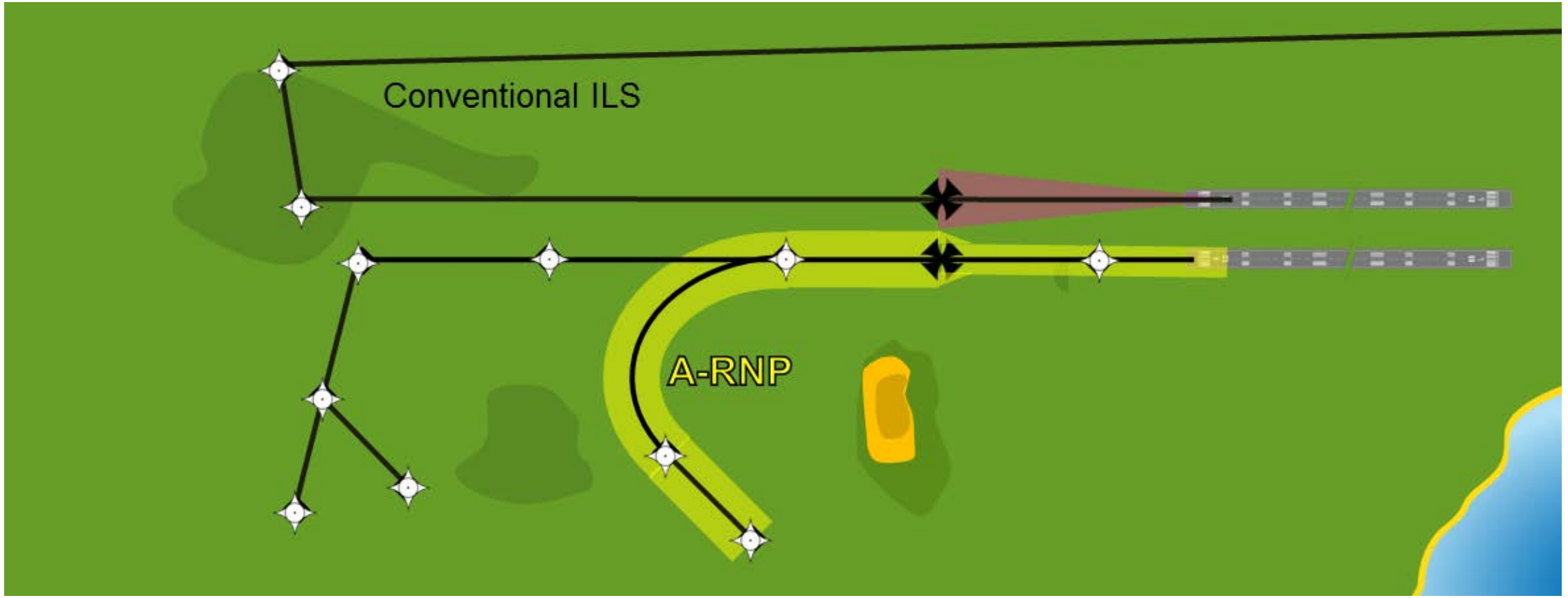


RNP APCH concept



AIRBUS

Advanced RNP and RF leg



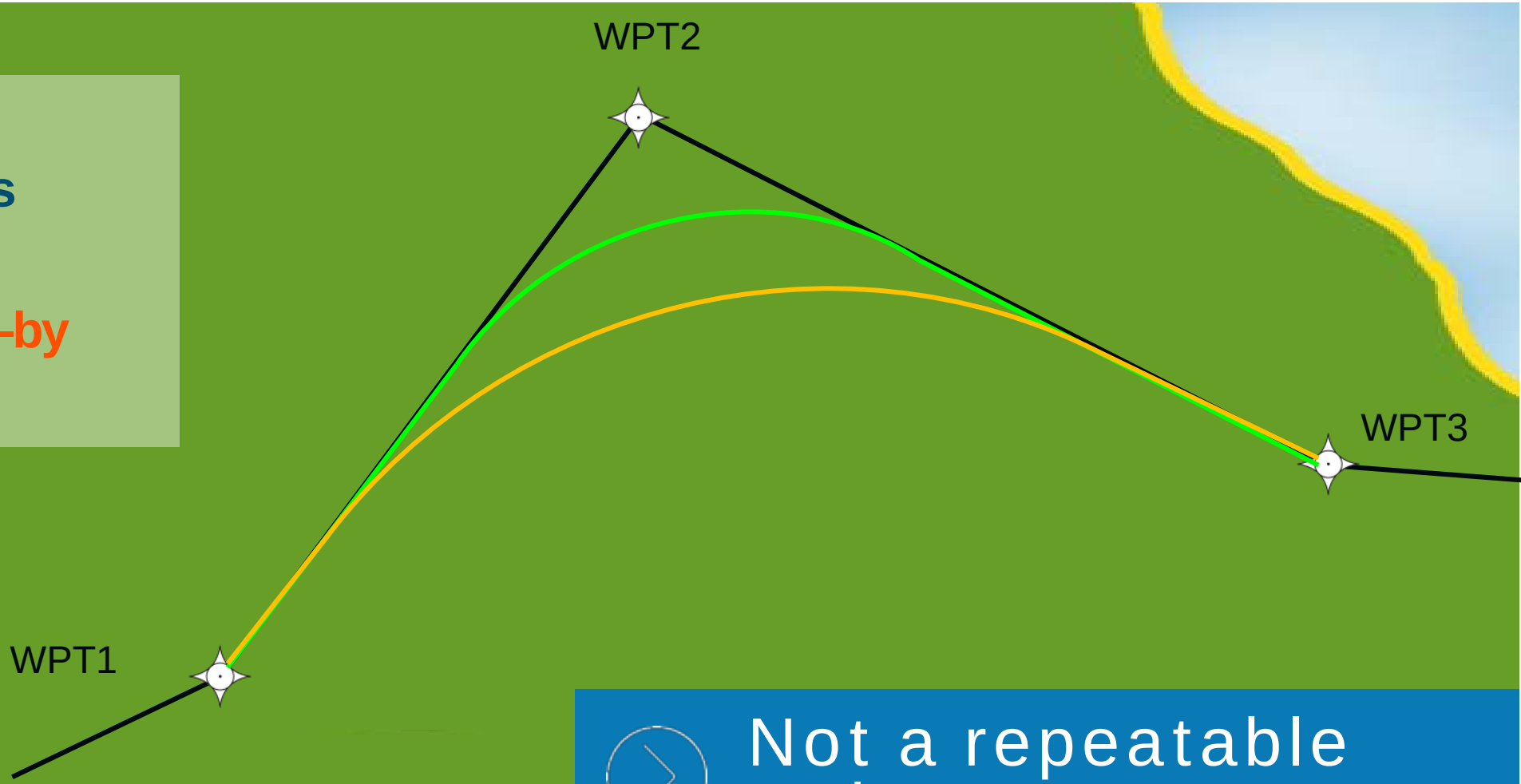
- Compliance: Airbus aircraft with FMS2 (RF capable) + GPS
- Airspace example: RNAV/RNP 1 or 2, SIDs and STARs, RNP APCH (not after FAF)

AIRBUS

RF legs

Without RF legs

Fixed bank flight –by



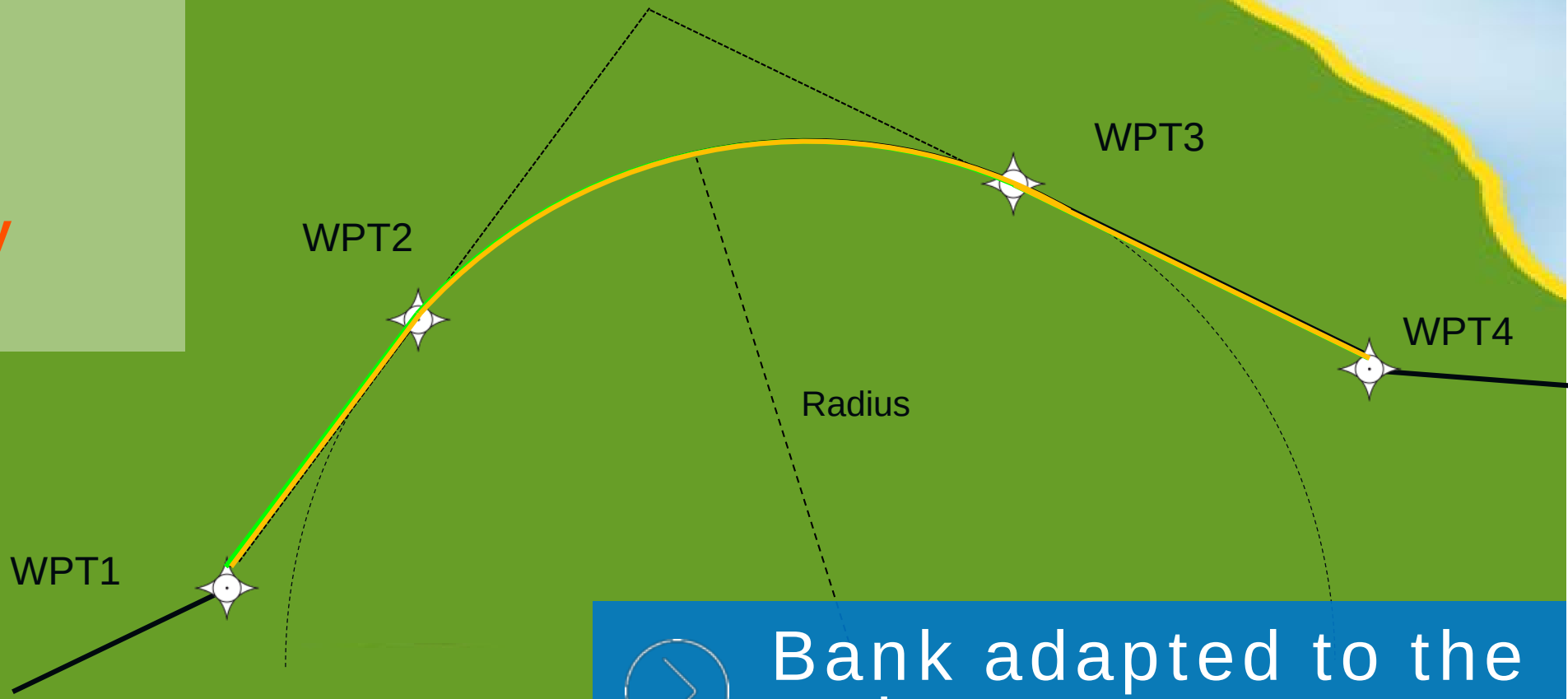
Not a repeatable trajectory

AIRBUS

ADVANCED RNP: RF legs

With RF legs

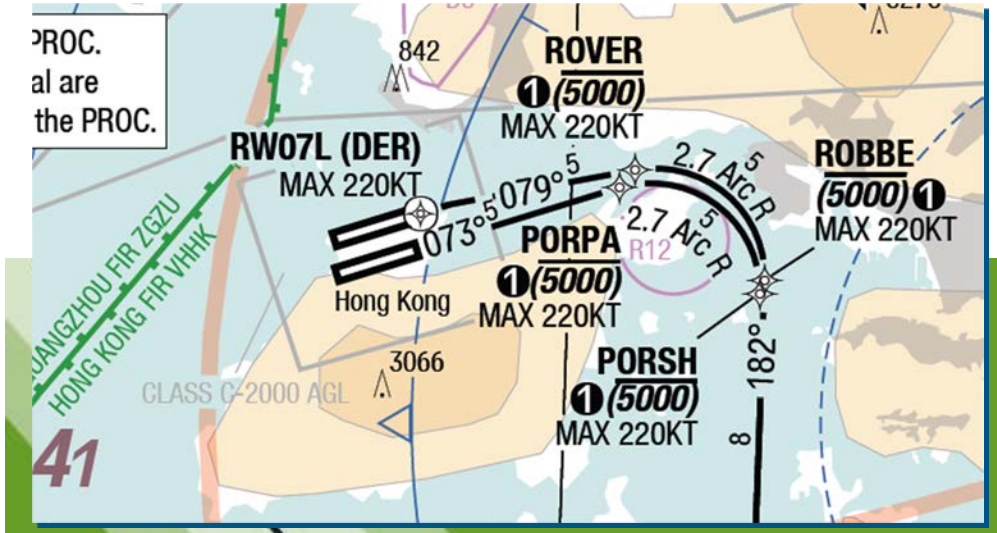
Fixed trajectory



Bank adapted to the trajectory

AIRBUS

ADVANCED RNP: RF legs



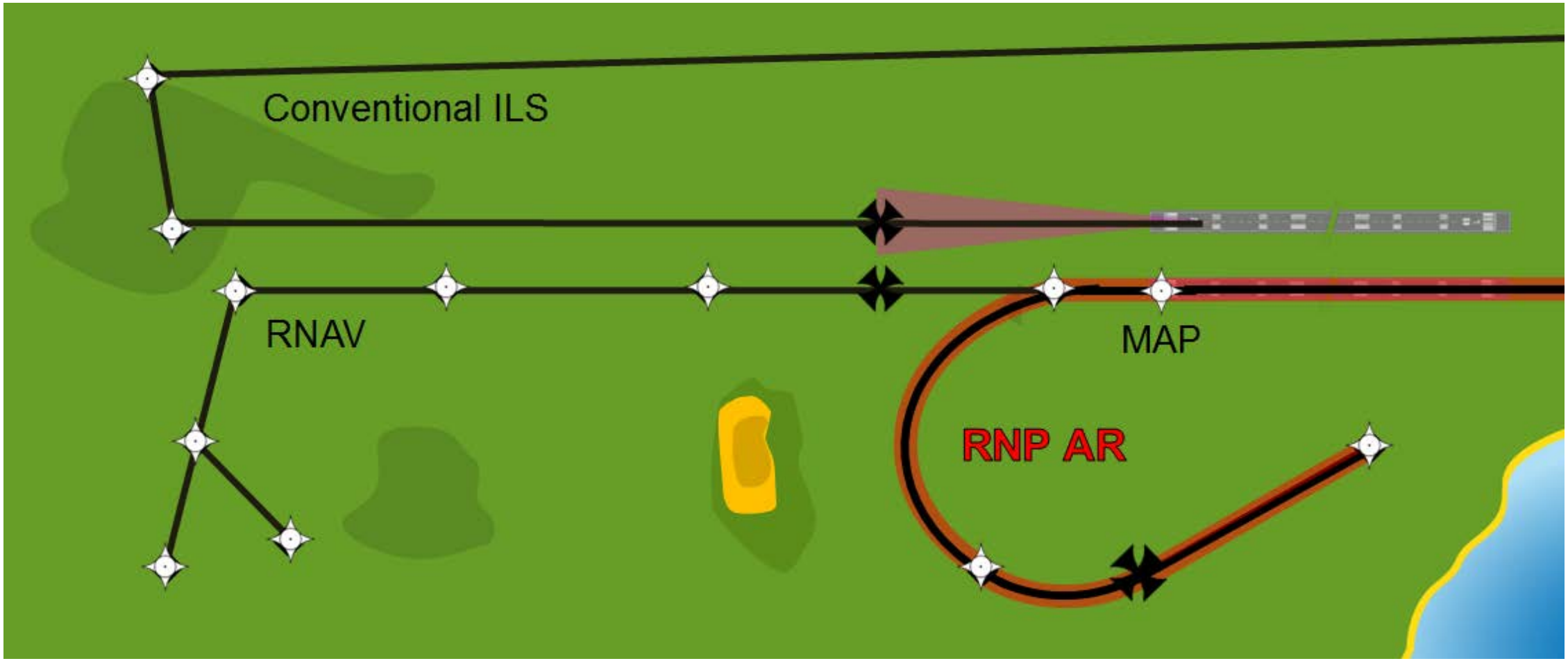
Smaller protection zone
Gain of Airspace

Without RF legs

With RF legs

AIRBUS

RNP AR: Authorisation Required



- Compliance: Airbus aircraft with specific modifications and specific equipments

RNP AR in terrain-challenging environment

+**RNP turn after FAP**

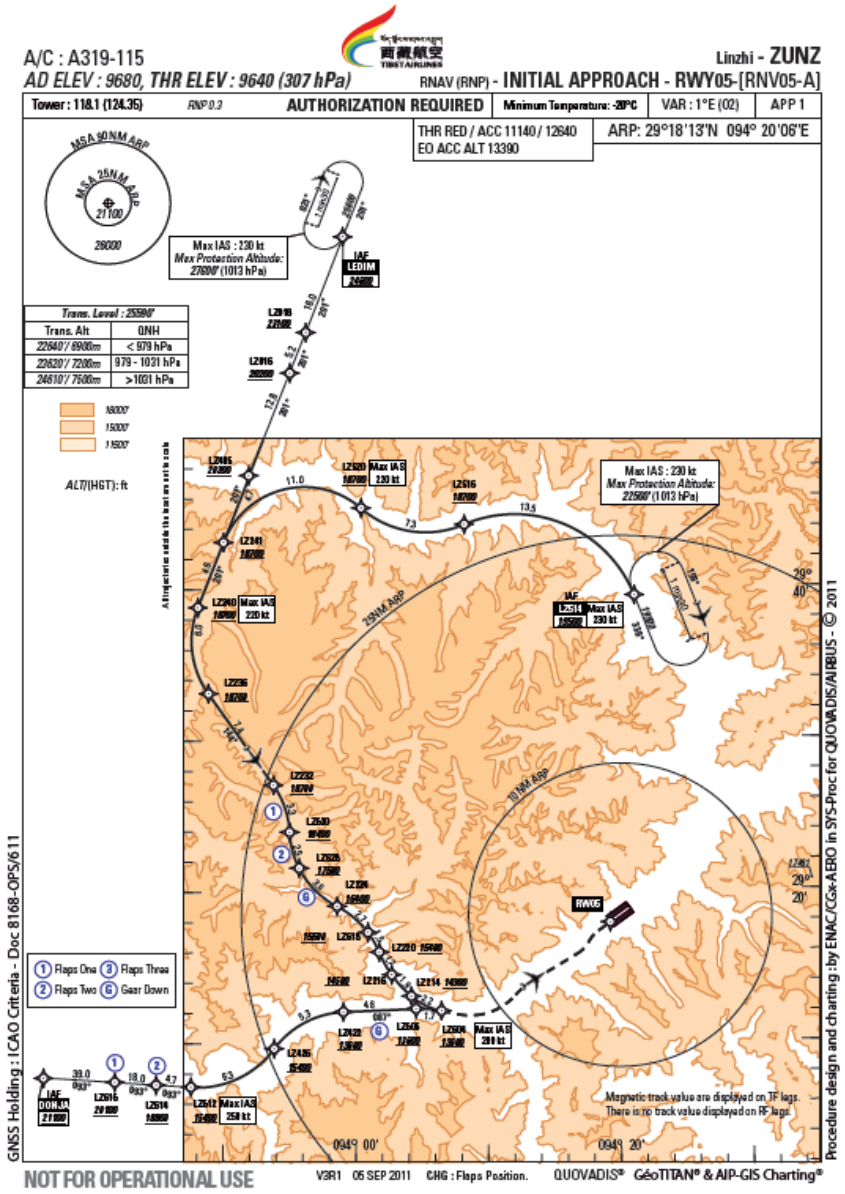
+**No Buffers**

+**Low RNP value**

→ **Design flexibility for terrain avoidance**

+**Better accessibility**

+**LNAV and VNAV guidance** including on turn

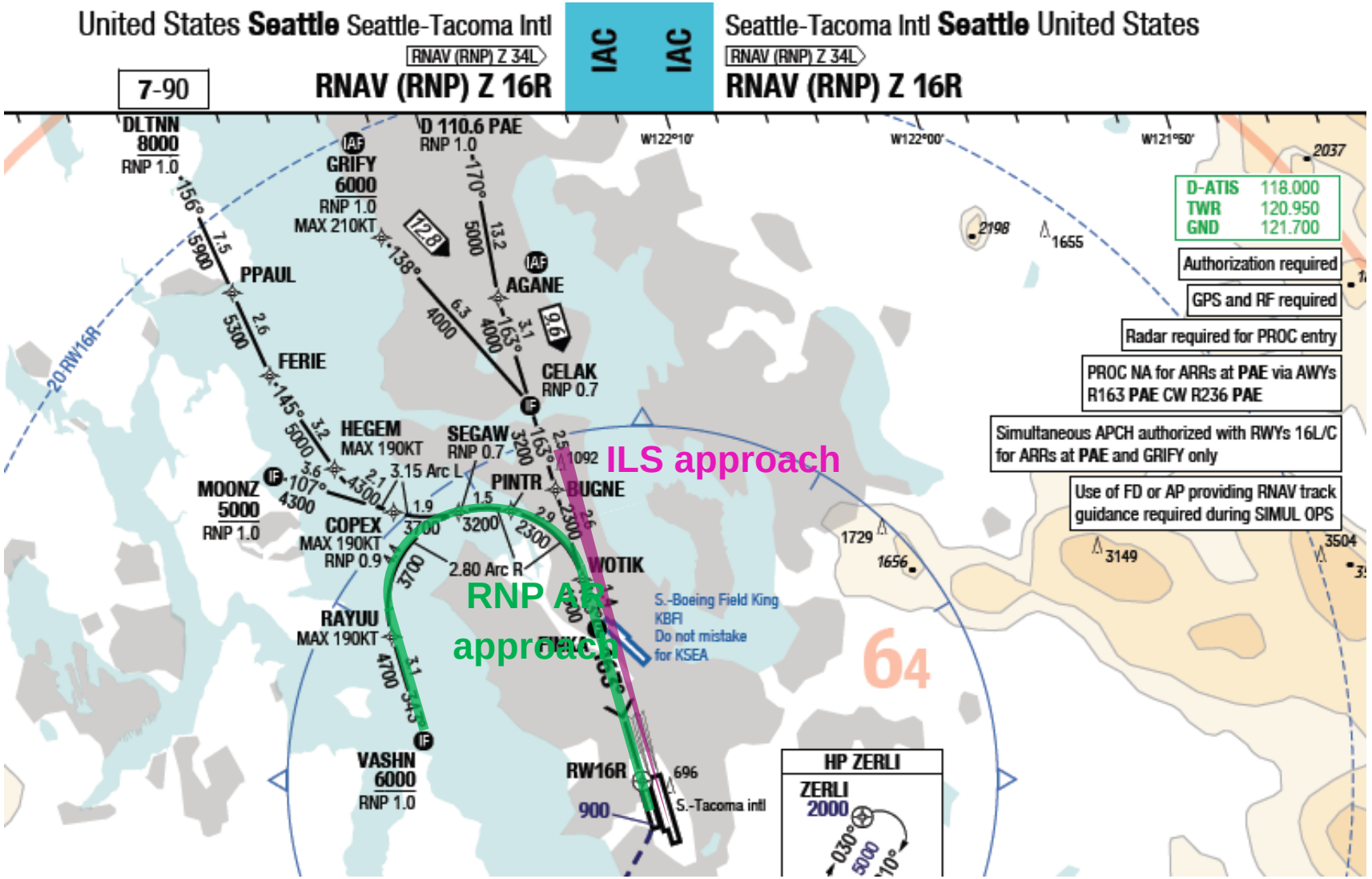


AIRBUS

RNP AR in traffic-challenging environment

+**Late turn**

+**Closely Space Parallel Operation**



AIRBUS

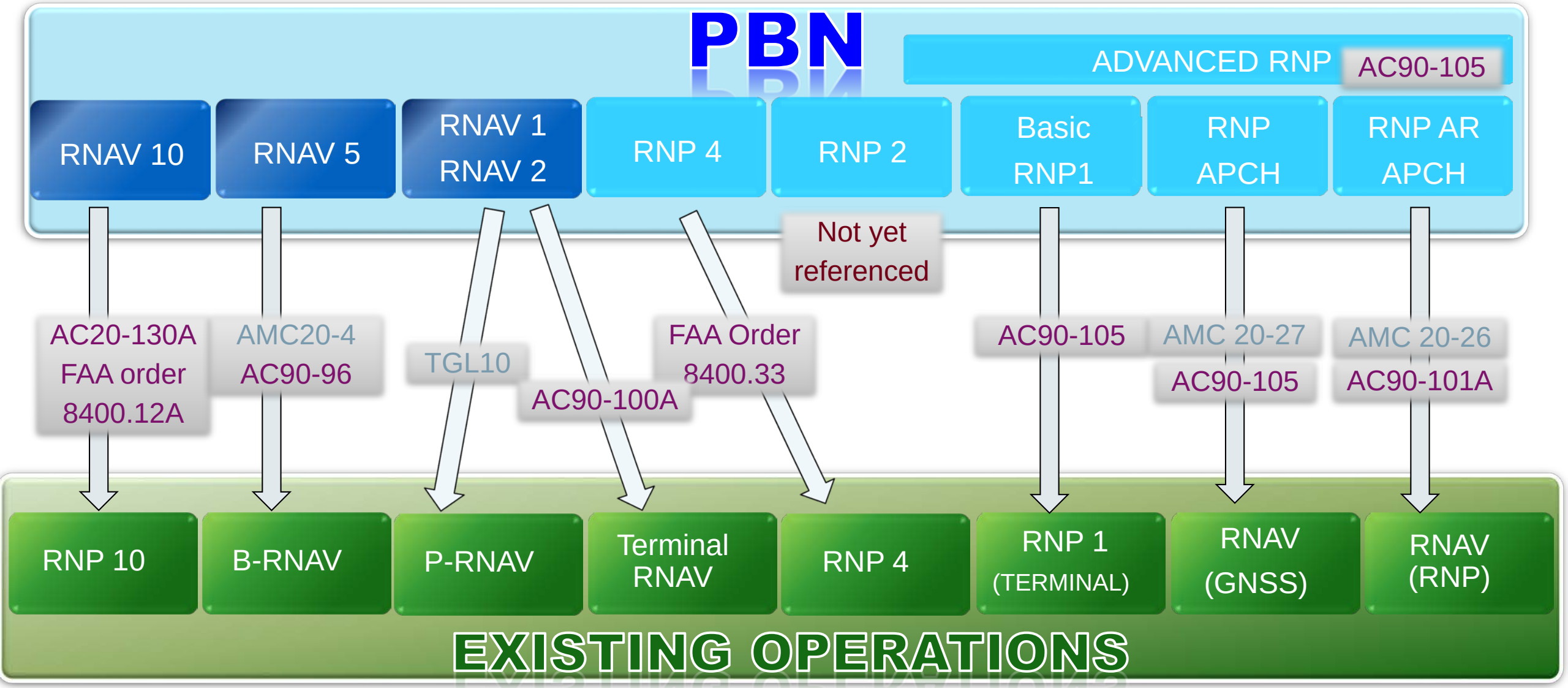
Current Airbus RNP AR MOD

	RNP AR MOD Limited to 0.3 NM	RNP AR MOD Below 0.3 NM
A320 family	Option	Option
A330	Option	Option
A340-500/600	Option	Option
A380	Option	
A350	Basic RNP AR 0.10 NM	

RNP AR 0.3 NM will be soon available on A300-600/A310 (Cockpit Upgrade)

AIRBUS

Link with existing operations Sum Up

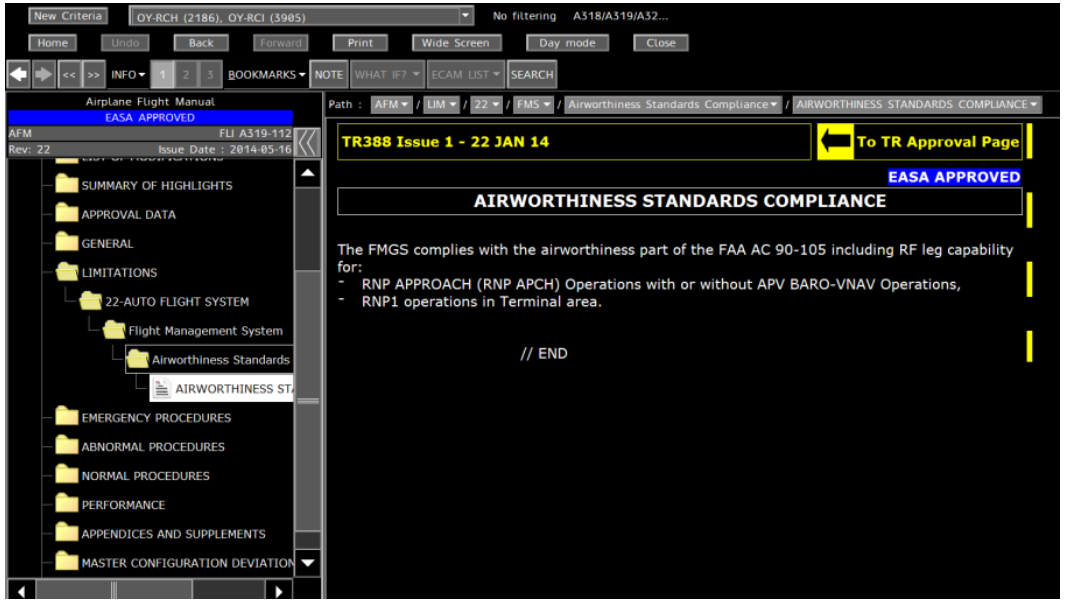


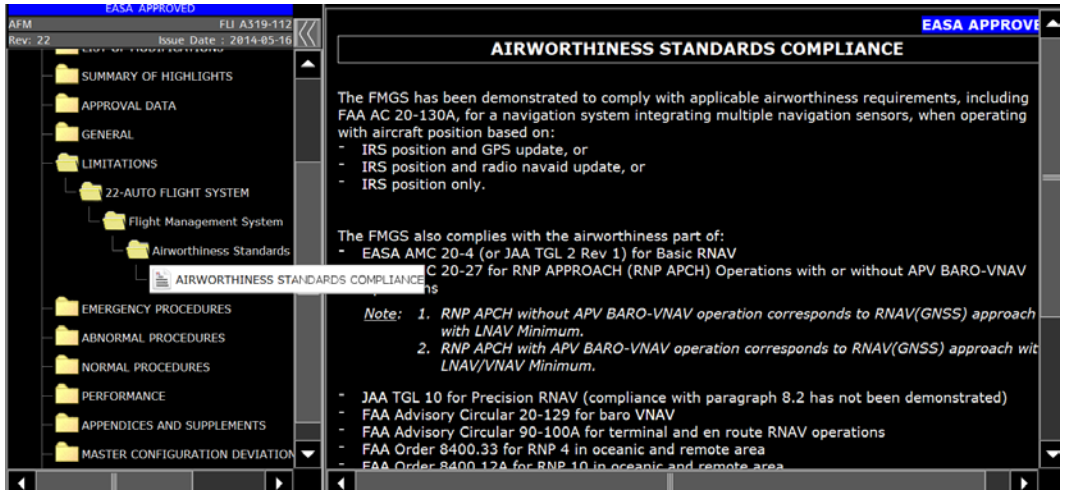
Ops documentation: Compliance to regulations in AFM

Compliance with existing regulations must be indicated in the AFM

- On Airbus A/C : in LIM / 22 AFS for A/C capable of the intended operation

- Specific chapter added with RNP AR MOD



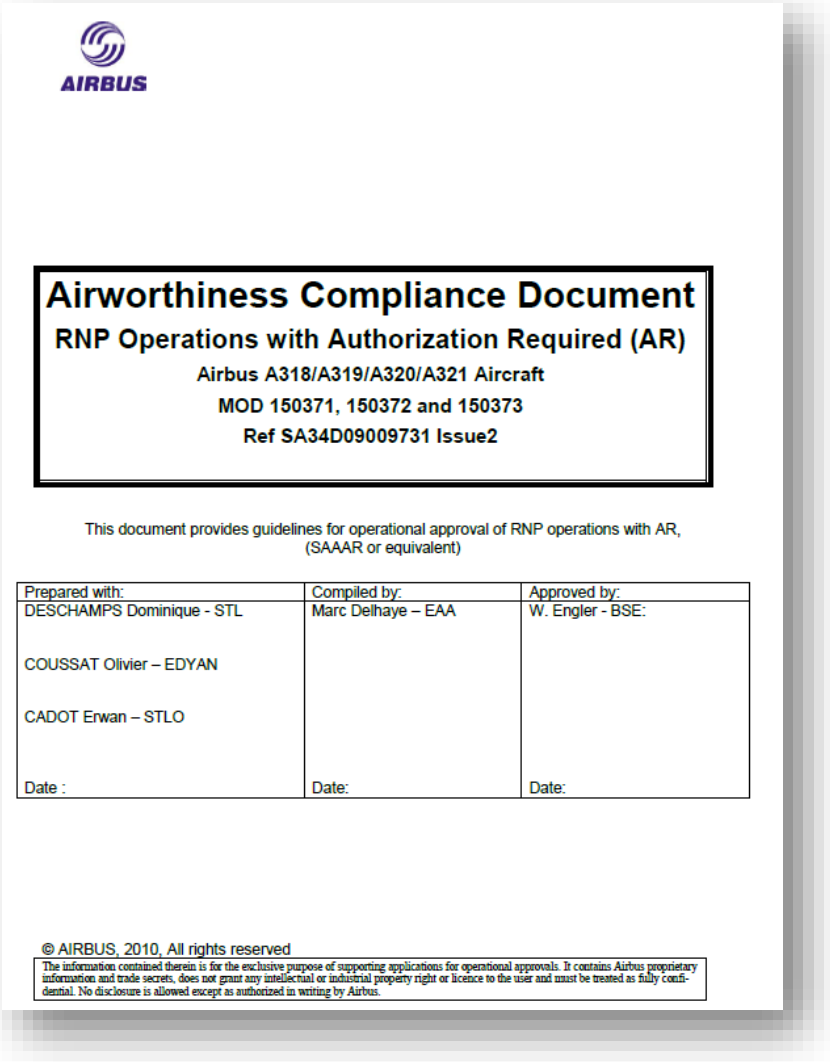


Airbus documentation : Airworthiness Compliance Document

- Linked with the RNP AR MOD
- Can be asked directly through TechRequest (Flight Operations / Other Topics / CNS-ATM)

→ Provide useful information to alleviate the ops approval

- No ACD on A350: in the FCOM



AIRBUS

Airworthiness Compliance Document

RNP Operations with Authorization Required (AR)

Airbus A318/A319/A320/A321 Aircraft

MOD 150371, 150372 and 150373

Ref SA34D09009731 Issue2

This document provides guidelines for operational approval of RNP operations with AR, (SAAAR or equivalent)

Prepared with:	Compiled by:	Approved by:
DESCHAMPS Dominique - STL COUSSAT Olivier – EDYAN CADOT Erwan – STLO Date :	Marc Delhaye – EAA Date:	W. Engler - BSE: Date:

AIRBUS

Airbus documentation: FCOM contents / FCTM contents

Specific chapter in PRO / SPO / 51 RNP for PBN operation

Specific chapter on RF legs in FCTM

→ Procedure proposed and ease ops approval

RNP 1 / TERMINAL RNP 1 BASIC RNP 1

GENERAL

RNP 1 operations correspond to Terminal RNP 1 - Basic RNP 1.
In RNP 1 airspace, GPS or DME/DME coverage supports the RNP value of 1 nm.

REQUIRED RNP 1 EQUIPMENT

The minimum navigation equipment required to enter RNP 1 airspace is:
- One FMS
- One GPS or 2 DMEs to update the aircraft position
- Two IRS
- One FD in NAV mode

PROCEDURE

BEFORE ENTERING RNP 1 AIRSPACE

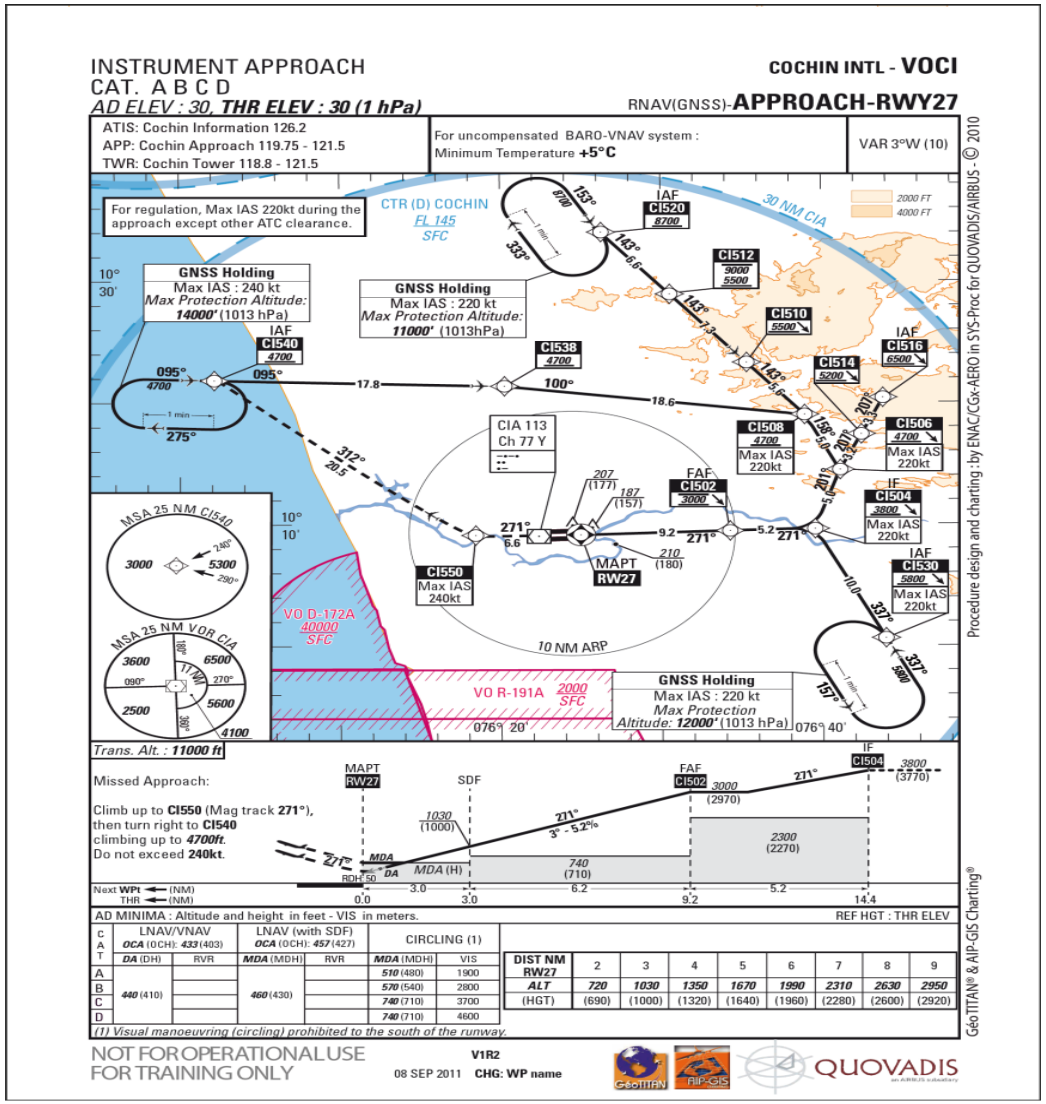
The FMS navigation database provides the terminal procedure (RNAV SID, RNAV STAR, RNAV TRANSITION, etc.) of the flight plan. The flight crew must check the terminal procedure from the published charts with the FMS navigation database on the F-PLN page (waypoint sequences, tracks, distances, and altitude or speed constraints).
The flight crew must not modify the procedure that is provided by the navigation database, unless required by the ATC (DIR TO, radar vectoring, insertion of waypoints from the navigation database).

Operational Approval

Operation	Ops approval	Training
RNAV 10, 5, 2, 1 RNP 4, RNP 1	Generic and light	Ground training (FCOM)
A-RNP (RF legs)	With intended operation	Ground training (FCOM)
RNP APCH	Generic	Approved generic training (*May be integrated in the current type training program)*
RNP-AR	Specific, significant In US: Generic for “non-special” airports	Approved Training *(Specific Training if Category **C** Airport)*

Example: RNP APCH Ops package

- A/C qualification (compliance in AFM)
- OPS procedure + RAIM prediction
- NDB validation (recommended)
- Training program
- Operation manual and Checklist
- MEL



AIRBUS

Agenda

PBN

PBN Concept

GNSS augmentation

Aircraft Design

Next Step

AIRBUS

Differential GPS concept – New concept

Augmentation of the accuracy and integrity

+**GPS augmented position**

thanks to reference stations

+**Vertical geometrical**

Not barometric sensitive

+ **2 solutions:**

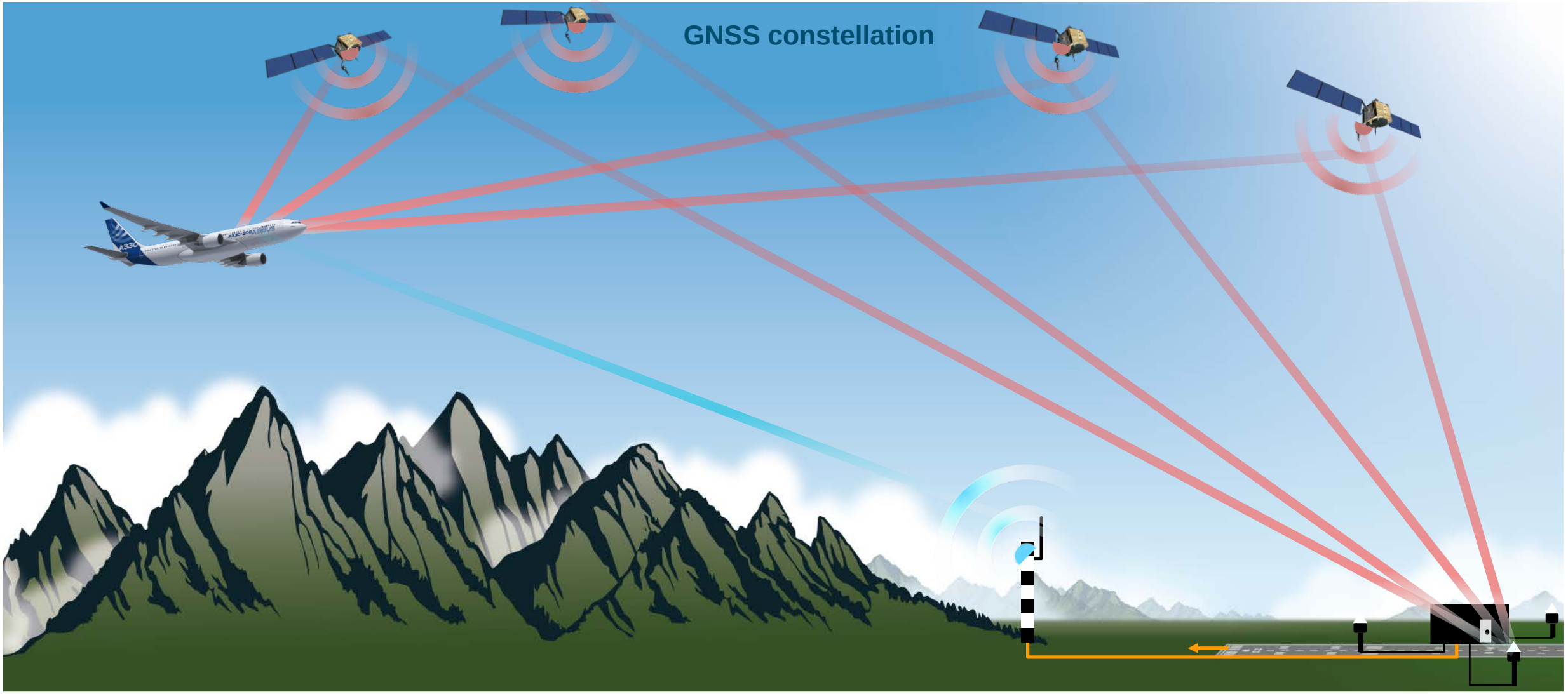
GBAS (not part of PBN ops)

SBAS

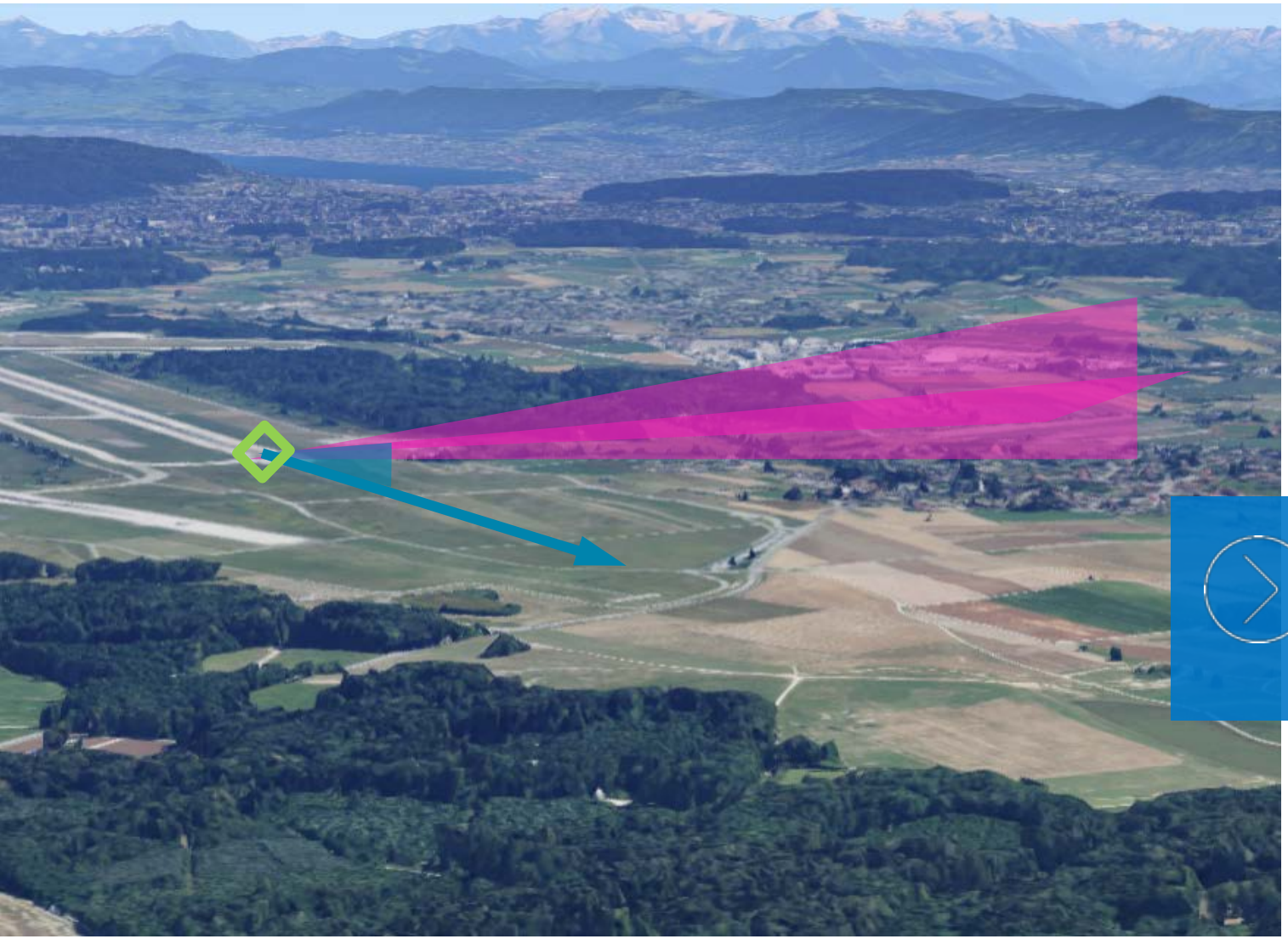
GBAS: Ground Based Augmentation System
SBAS: Satellite Based Augmentation System

AIRBUS

GBAS Landing System: GLS



GLS: Data transmitted to the A/C



+GPS augmented position by VHF

+Final Approach Segment data by VHF

VHF

Anchor point coordinate

Course

Slope

MMR computes a virtual beam

+Flown in G/S | LOC

MMR: Multi-Mode Receiver

AIRBUS

xLS concept: GLS

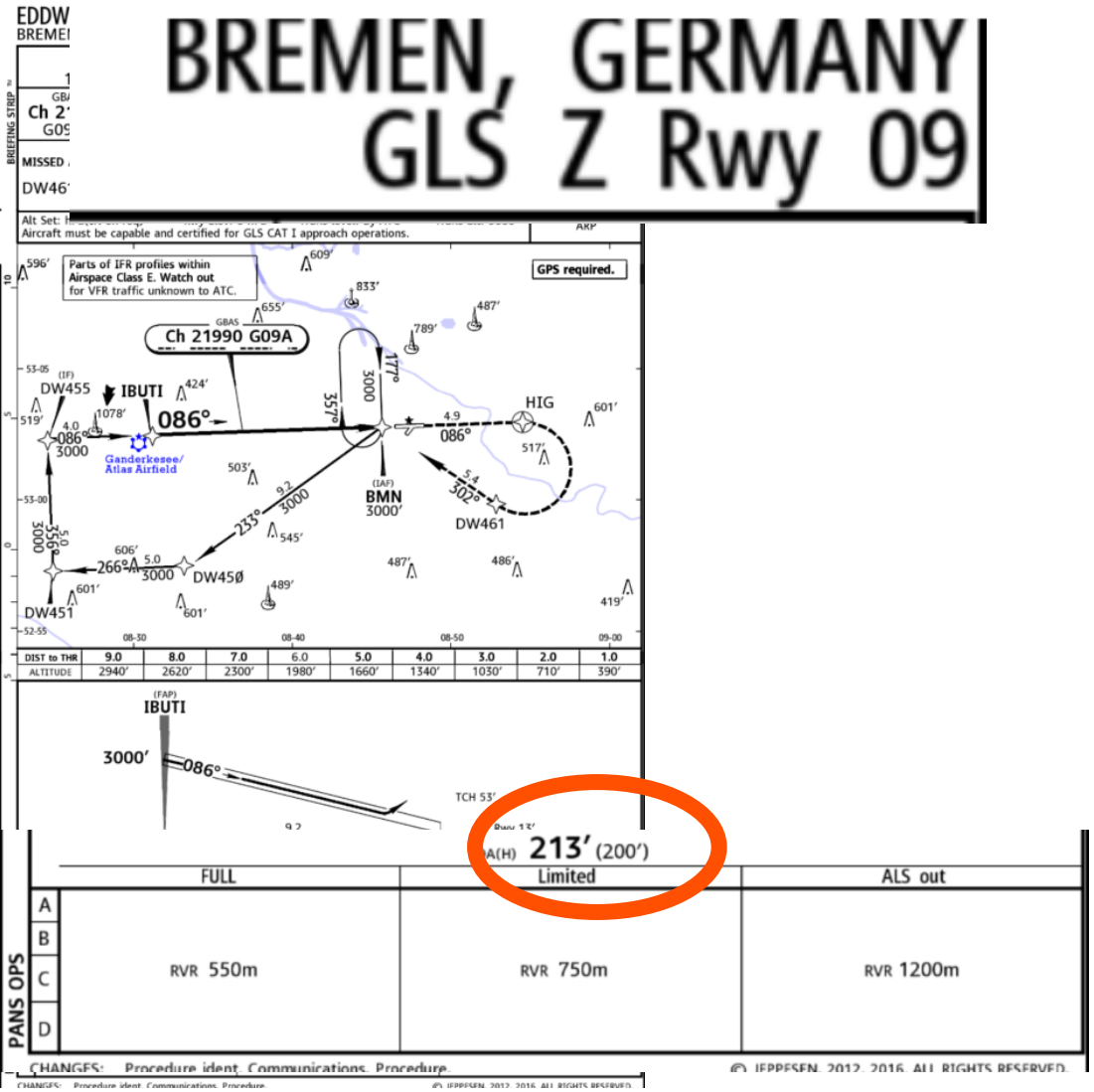
Same guidance mode as ILS

+Geometric

+Common FCOM/SOP for all straight in approaches

AIRBUS

GBAS on charts: GLS approach



+**Charted as GLS**

- Angular protection **same as ILS**
- **Geometric** vertical guidance
- Minima down to **200 ft** (CAT1)

LPV: Localiser Performance with Vertical guidance

AIRBUS

GLS approaches

Operational (with dot: charts published)

Planned Installations

Special Category, S-CAT I (with dot: charts published)

Prototype/Research (with dot: actively transmitting**)**

+**One station for all runways** with different channel

+**Customisation**

- Displaced Threshold
- Various slope

+**CAT I autoland capability**

available on A380, 350, 330 and 320

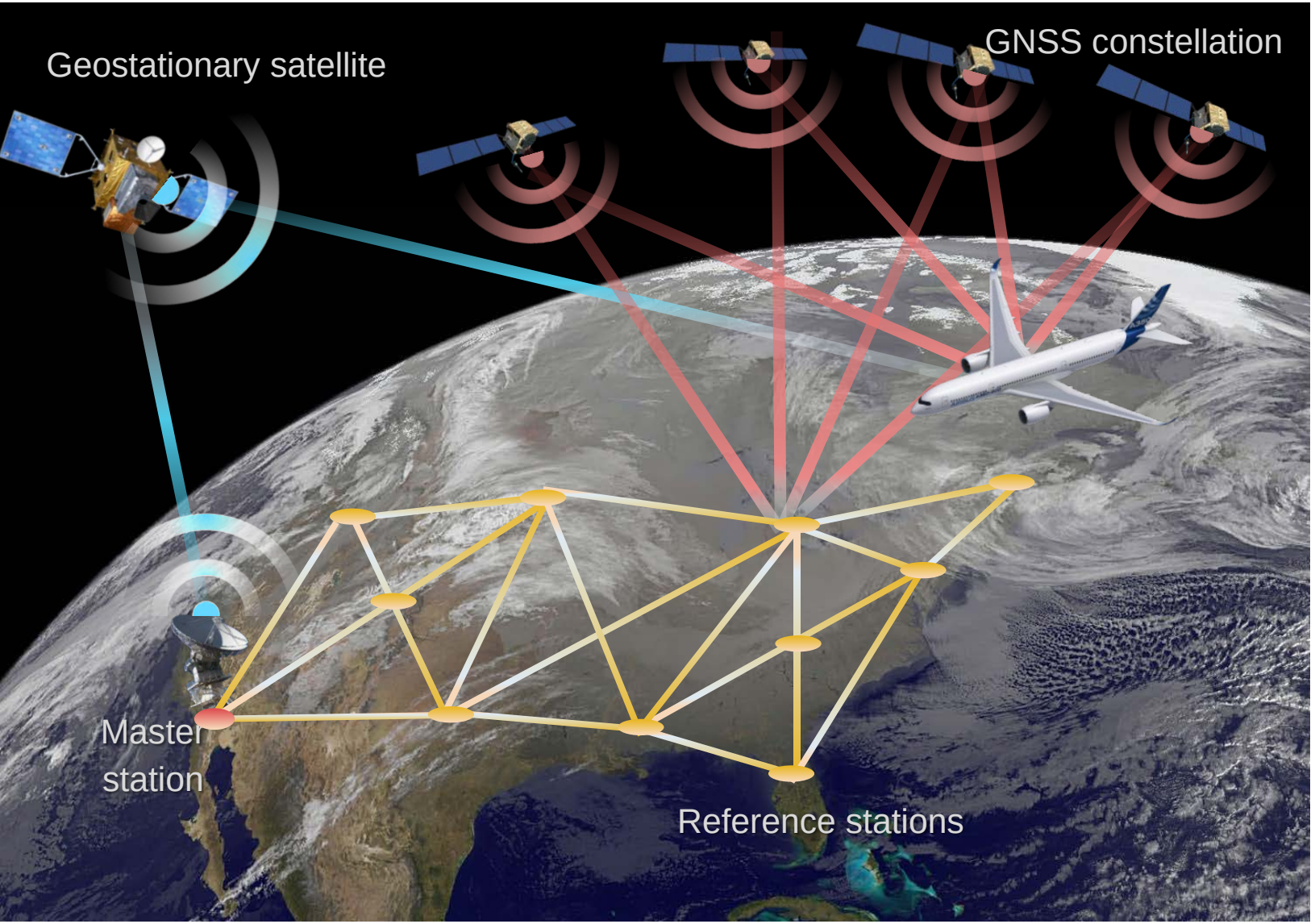
+ **CAT III autoland**

Under study

GLS
More and more deployed

AIRBUS

Satellite Based Augmentation System



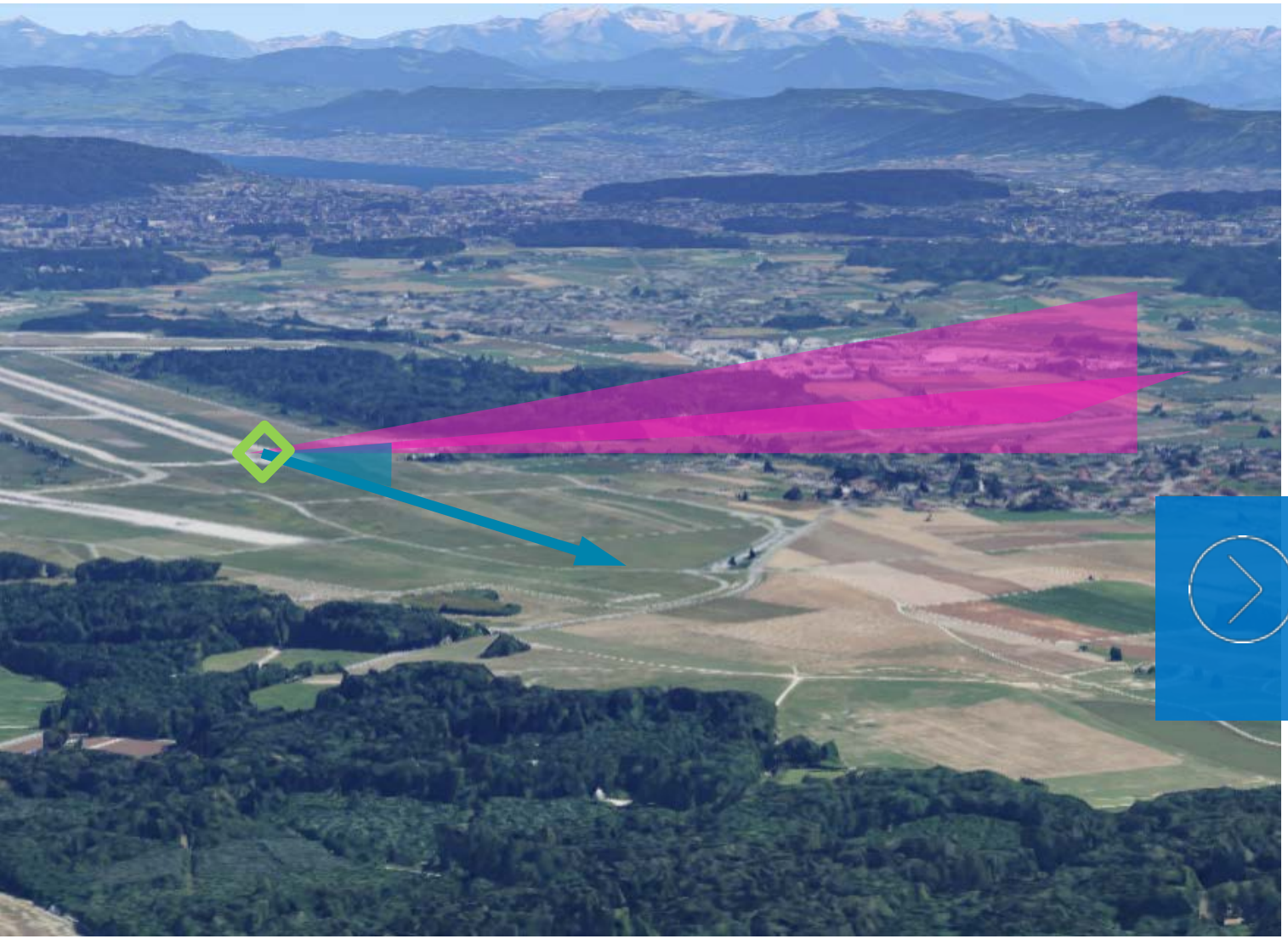
+**Wide Area Network**
of reference stations

+**Transmission of the data**
via geostationary satellite

+**A/C system computes a virtual beam**
Angular geometric guidance

AIRBUS

Data transmitted to the A/C



+**GPS augmented position by geostationary satellite**

+**Final Approach Segment data in NDB**

- Anchor point coordinate
- Course
- Slope

MMR computes a virtual beam

+**Flown in G/S | LOC**

AIRBUS

xLS concept: SLS

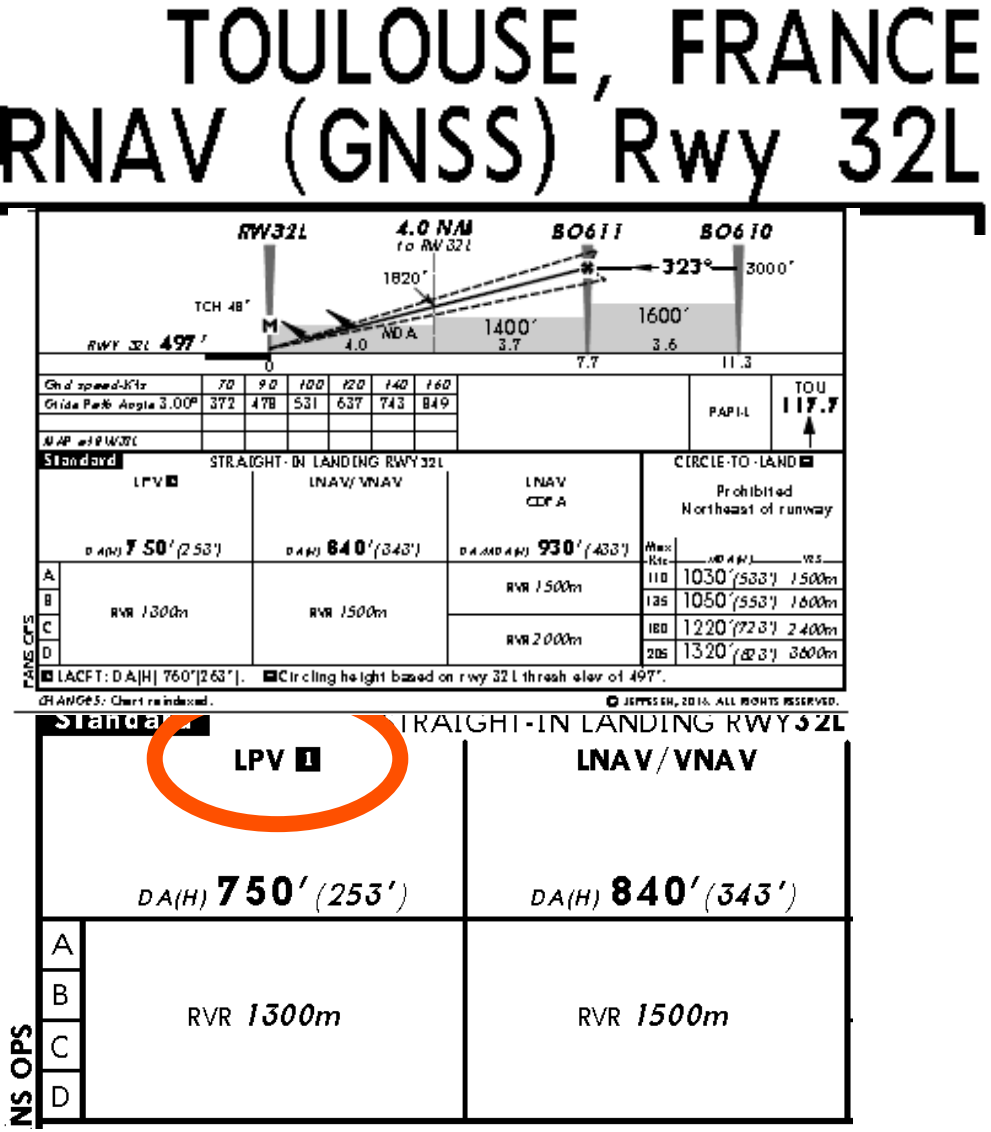
Same guidance mode as ILS

+Geometric

+Common FCOM/SOP for all straight in approaches

AIRBUS

SBAS on charts: LPV minima



+**RNAV(GNSS) with LPV minima**

+**RNAV(GNSS) Approach BUT**

- Angular protection (in addition to linear) **same as ILS**
- **Geometric** vertical guidance
- Minima down to **200 ft** (CAT1)

LPV: Localiser Performance with Vertical guidance

AIRBUS

Agenda

PBN

PBN Concept

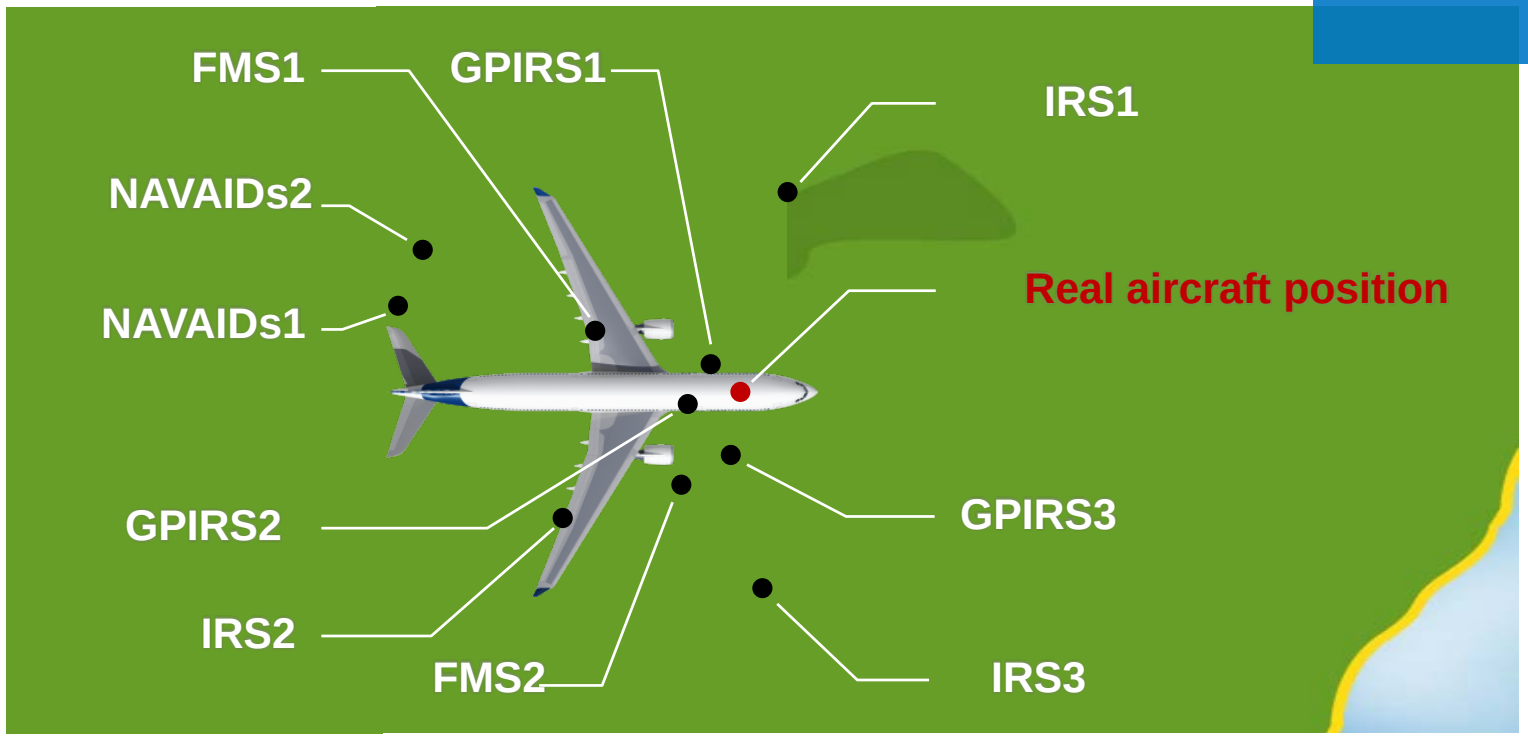
GNSS augmentation

Aircraft Design

Next Step

AIRBUS

AIRCRAFT POSITION



Based on different position sources

+ **Inertial position**
  ADIRS
+ **GNSS position**
  MMR
+ **Radio position**
  NAVAIDs

→ **FMS position**

AIRBUS

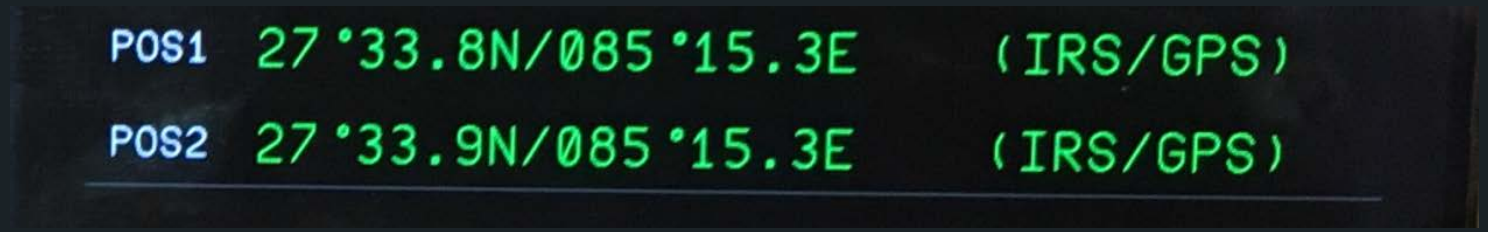
AIRCRAFT POSITION

Position sources

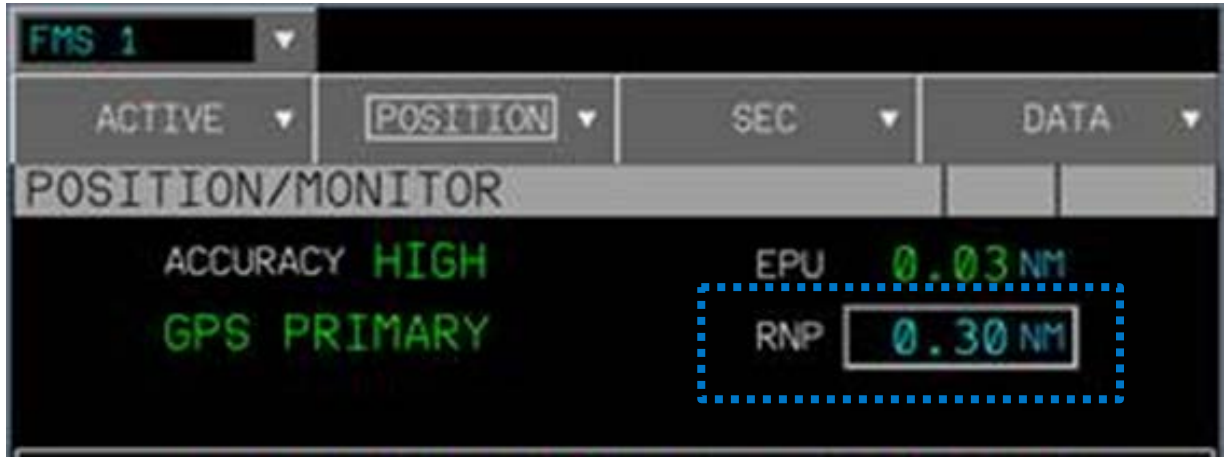
+ **Inertial position**
  ADIRS
+ **GNSS position**
  MMR
+ **Radio position**
  NAVAIDs

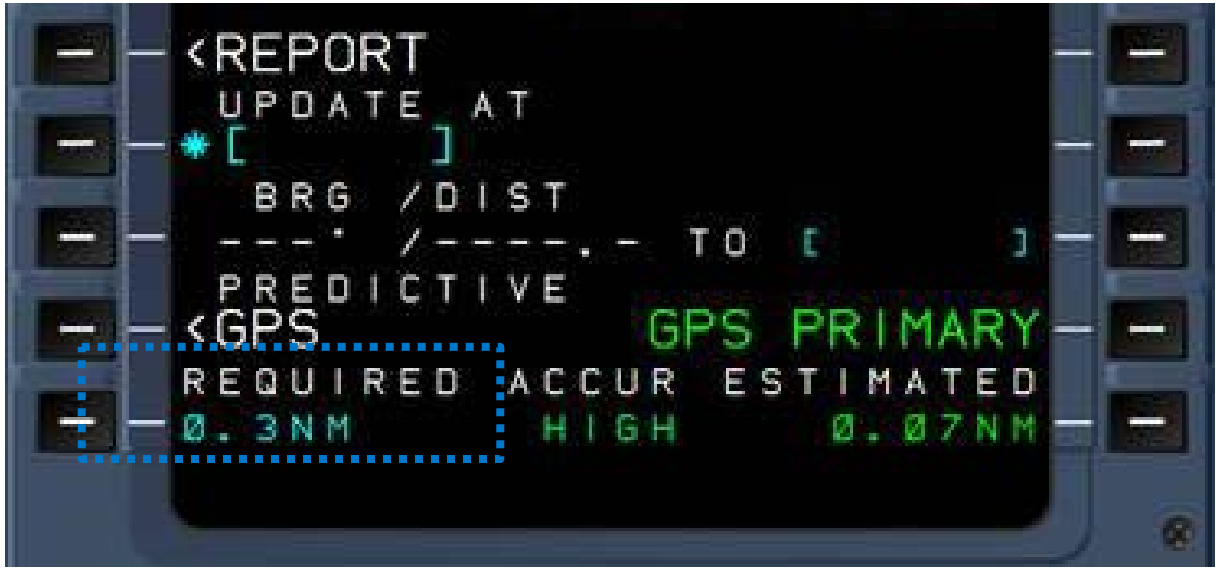
Navigation modes

+ **GNSS/Inertial**
+ **NAVAIDS/inertial**
+ **Inertial Only**



AIRCRAFT POSITION : ACCURACY & INTEGRITY LIMITS





RNP value

\+ **From NDB**

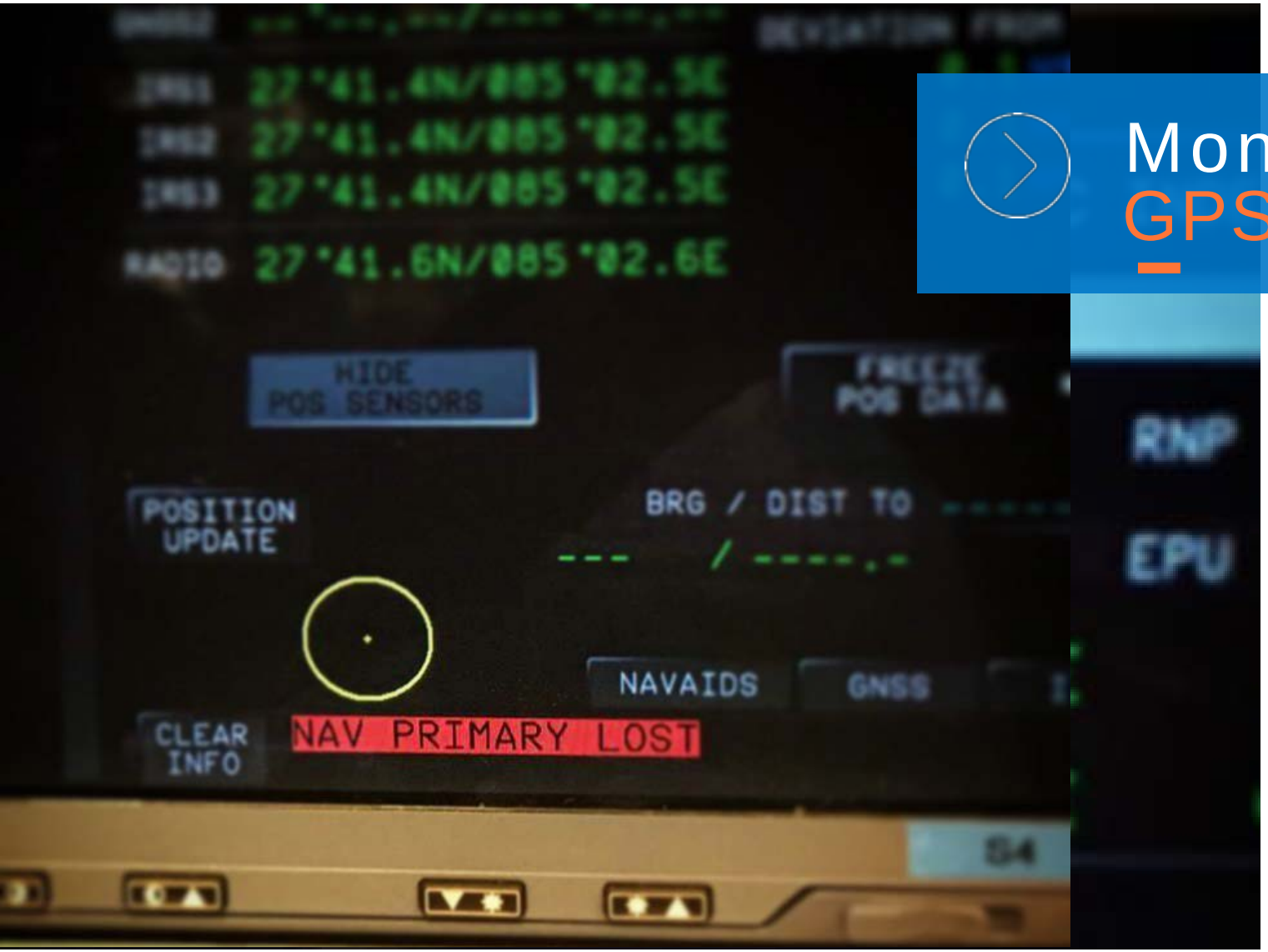
\+ **Default value**

\+ **Manually entered**

(Not recommended)

AIRBUS

MONITORING / **INTEGRITY**



Monitoring and Alerting: GPS/NAV PRIMARY LOST

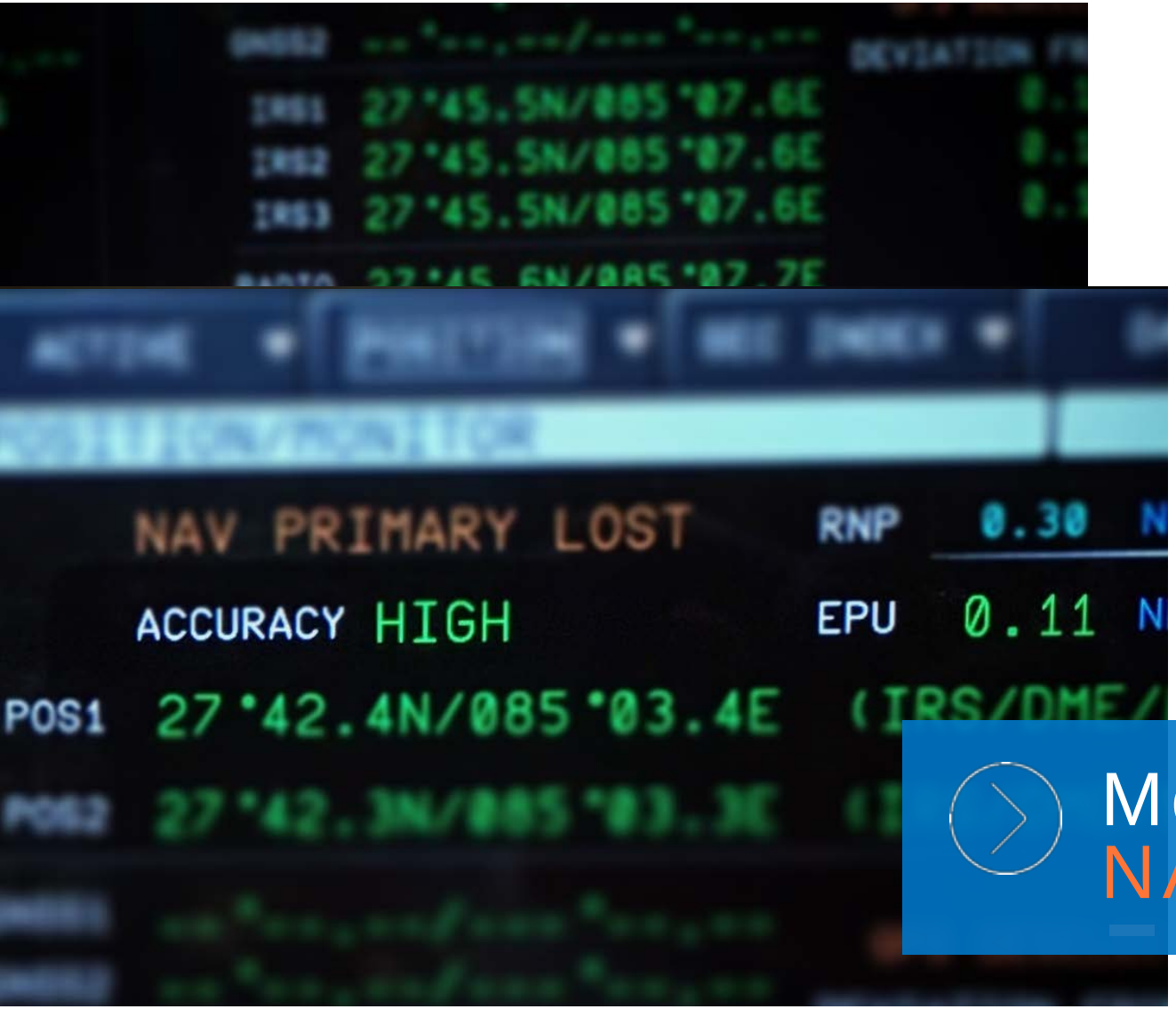
+**Based on GNSS/Inertial mode**

Integrity monitoring related to threshold

Except RNP AR below 0.15 NM, **GPS/NAV PRIMARY LOST** message triggered regardless of the selected RNP value

AIRBUS

MONITORING / **ACCURACY**



+ **If GNSS/Inertial mode lost**

  Reversion to NAVAIDS/Inertial or Inertial only

No more integrity monitoring

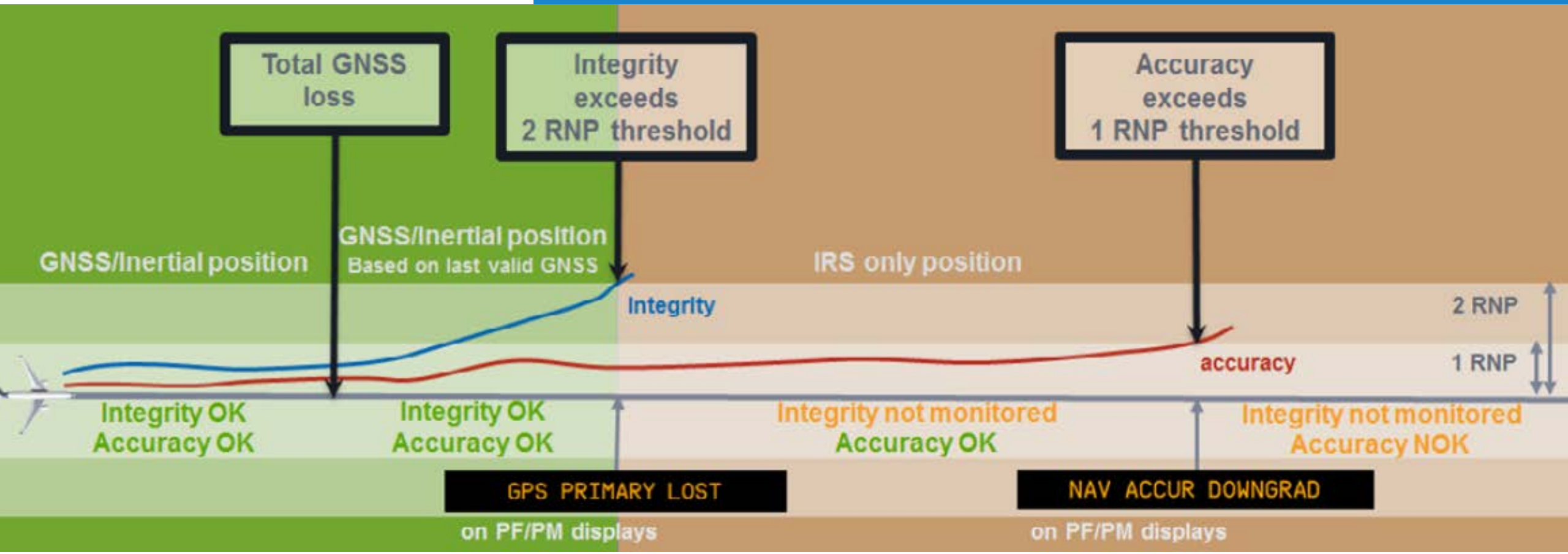
Accuracy monitoring related to RNP Value

Monitoring and Alerting:
NAV ACCUR DOWNGRADED

AIRBUS

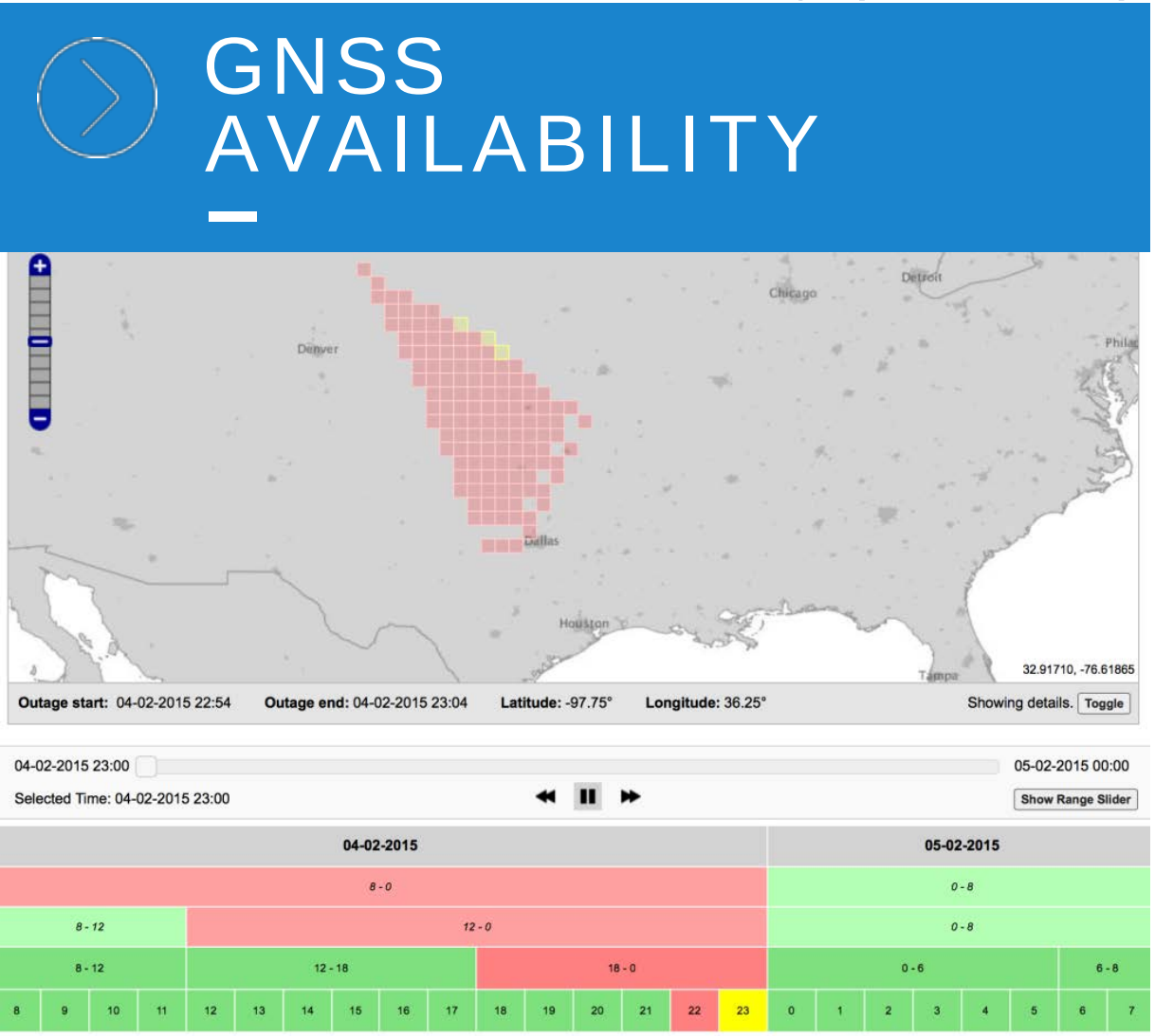
MONITORING example on A320 aircraft

Example of GNSS loss in low RNP operations



AIRBUS

CHECK GNSS Availability (on-board) at dispatch



Otherwise, **use Ground Based Prediction Program** when

+GNSS availability demonstration not declared in the AFM

+less than 24 satellites available

+Potential terrain masking of GNSS signal (RNP AR)

+Low RNP values (RNP AR below 0.2 NM)

AIRBUS

Flight Guidance modes

With Managed Modes

+ **NAV mode**

+ **Approach modes**

  FPA|NAV

  FINAL APP

  APP-DES|NAV (A350)

  FLS

  SLS

AIRBUS

APPROACH MODES

FINAL APP
APP-DES|NAV

+**Lateral guidance** equivalent to the NAV mode

+**Vertical guidance** tracking the FMS profile

+**Barometric reference**

+**Not temperature compensated**

AIRBUS

APPROACH MODES: xLS concept

Same guidance mode as ILS

+Common FCOM/SOP for all straight in approaches

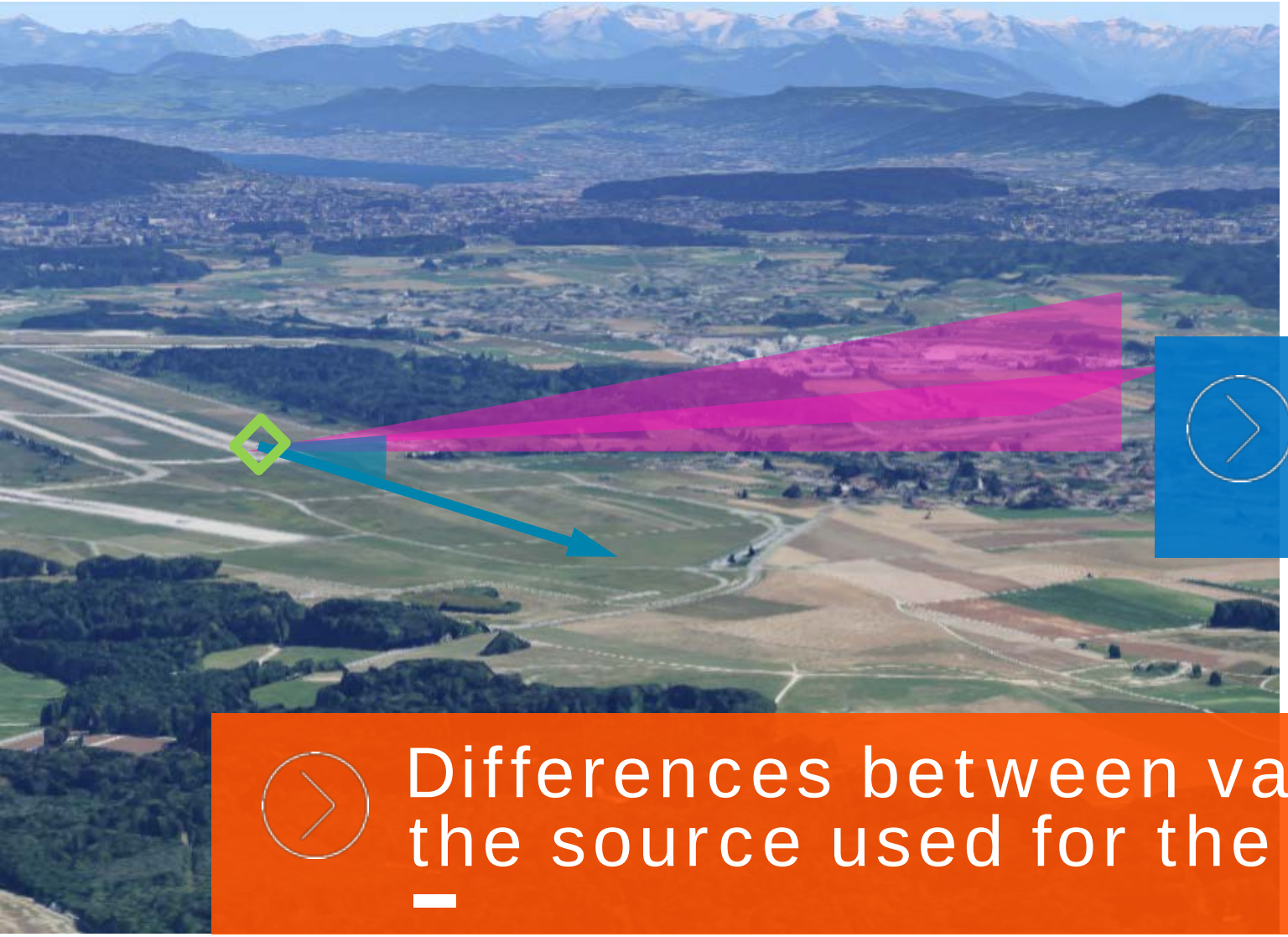
+New concept

+Basic on A350 and A380

+in deployment on A320 and A330 family

AIRBUS

GLS/SLS/FLS: computation of the virtual beam



+**Final Approach Segment data**

Anchor point coordinate

Course

Slope

MMR computes a virtual beam

+**Flown in G/S | LOC**

Differences between various xLS modes is the source used for the beam computation

MMR: Multi-Mode Receiver

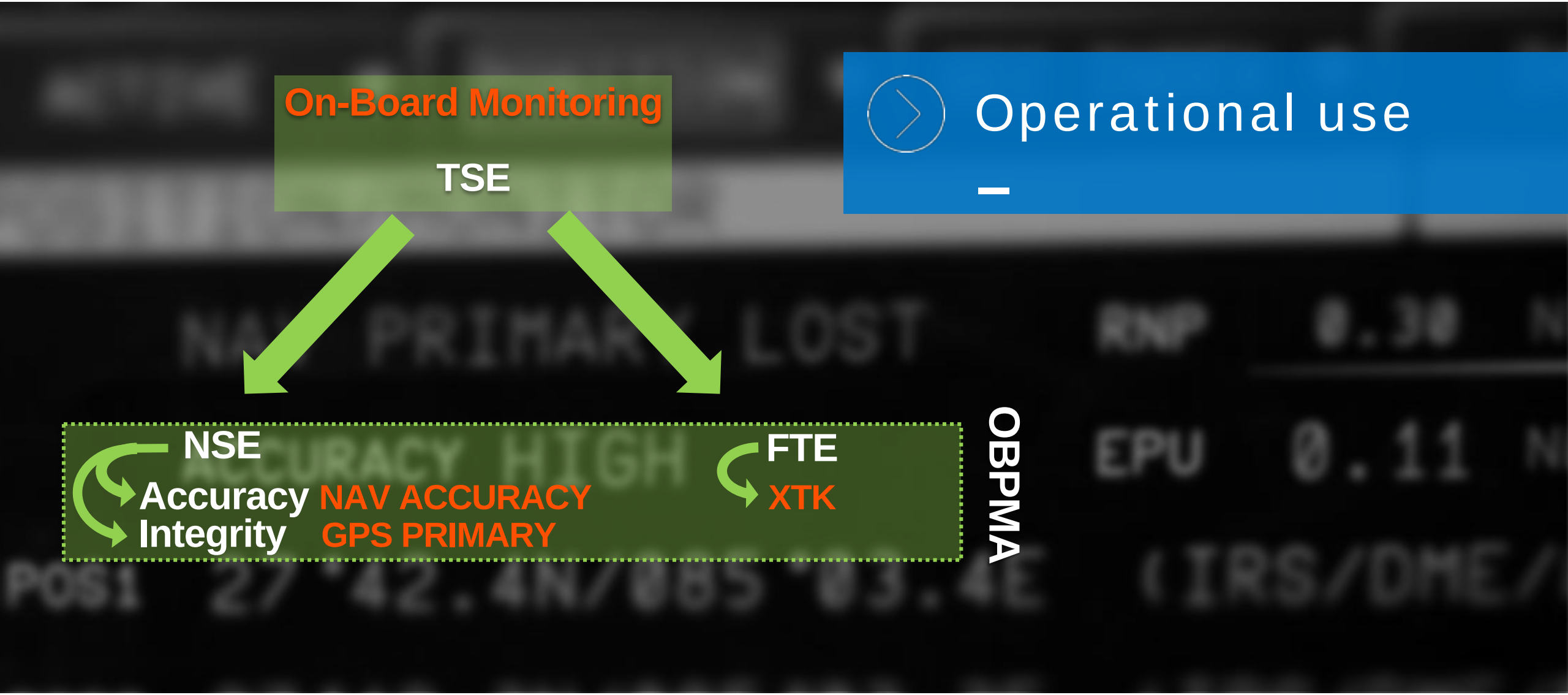
AIRBUS

APPROACH MODES: xLS concept

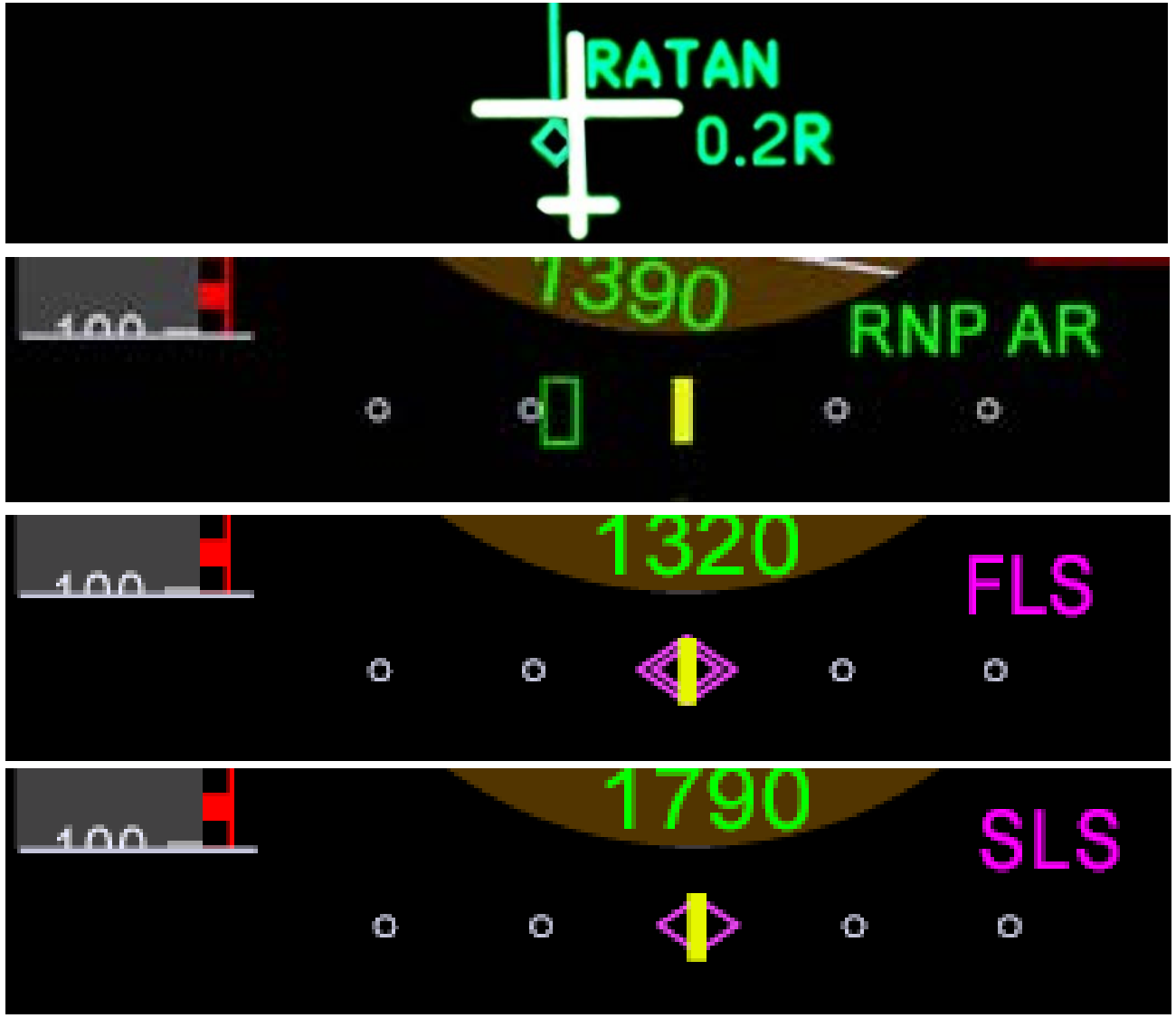
xlS mode	Source used for lateral deviations	Source used for vertical deviations	Final approach segment data	Type of approach	Lowest minima
FLS	IRS/GNSS	**Barometric** Altitude With temperature compensation	From NDB onboard	NDB, VOR RNAV(GNSS) LNAV, LNAV/VNAV	250ft
SLS	GNSS augmented SBAS	GNSS SBAS Altitude **Geometric**	FAS data block onboard	RNAV(GNSS) LPV	200ft
GLS	GNSS augmented GBAS	GNSS GBAS Altitude **Geometric**	Transmitted by VHF Ground station	GLS	CAT I 200ft
ILS MLS	LOC signal	G/S signal **Geometric**	N/A	ILS MLS	CAT IIIB 0ft

AIRBUS

COCKPIT HMI


On-Board Monitoring
TSE
Operational use
NSE
Accuracy
Integrity
NAV ACCURACY
GPS PRIMARY
FTE
XTK
OBPMA

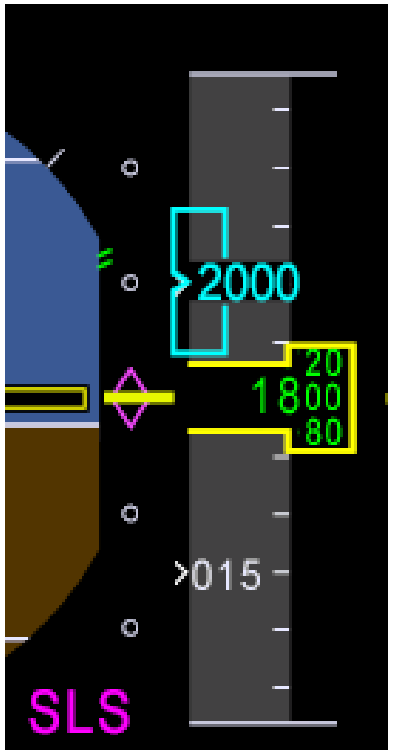
COCKPIT HMI – Lateral excursion monitoring

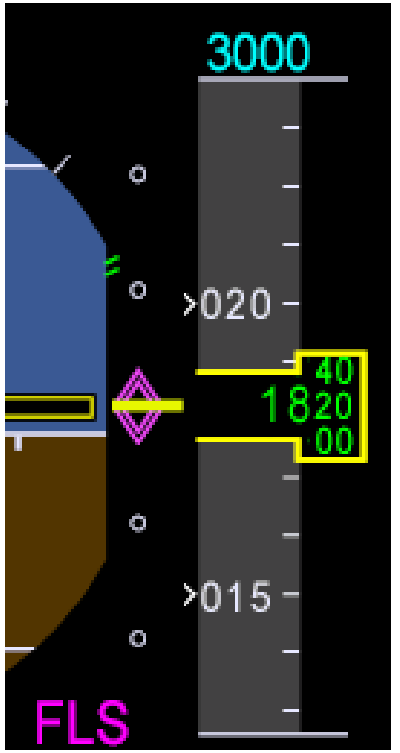


- XTK on ND
- L/DEV on PFD
- xLS deviations

AIRBUS

COCKPIT HMI – Vertical excursion monitoring





V/DEV on PFD

xLS deviations

AIRBUS

Agenda

PBN

PBN Concept

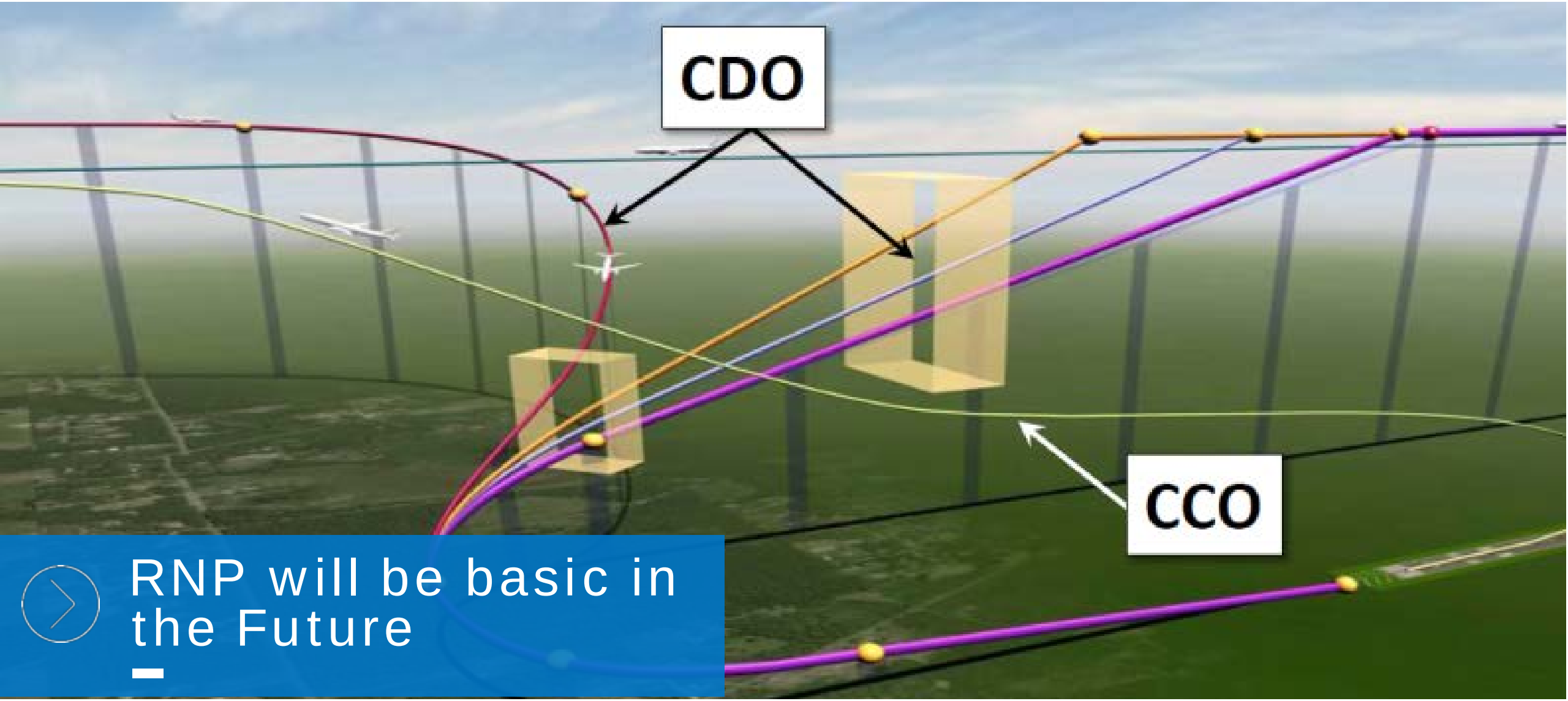
GNSS augmentation

Aircraft Design

Next Step

AIRBUS

Next Steps: Regulation changes on PBN



RNP will be basic in the Future

AIRBUS

Next Steps: Regulation changes on PBN

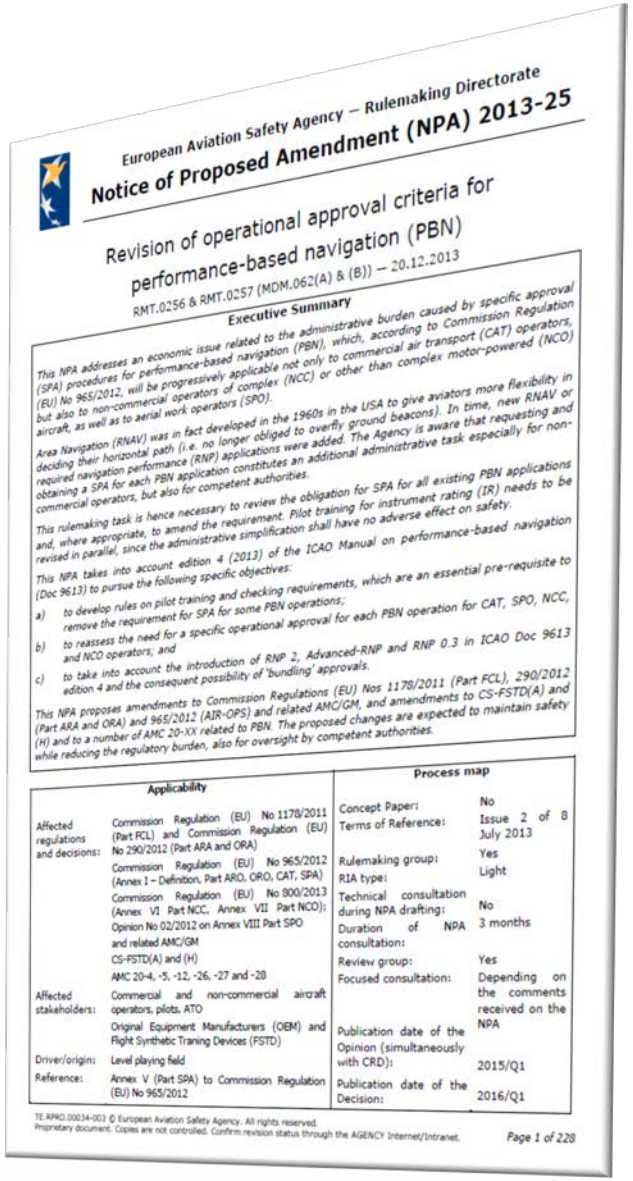
+**No more ops approval**, except for RNP AR (SPA.PBN.100)

+**Generic ops approval** for non specific RNP AR (SPA.PBN.105)

+RNP will be **part of ATPL and IR**

+Generic RNP AR (Same rules for specific RNP AR (need of FOSA))

Target : 2018



European Aviation Safety Agency – Rulemaking Directorate

Notice of Proposed Amendment (NPA) 2013-25

Revision of operational approval criteria for performance-based navigation (PBN)

RMT.0256 & RMT.0257 (MDM.062(A) & (B)) – 20.12.2013

Executive Summary

This NPA addresses an economic issue related to the administrative burden caused by specific approval (SPA) procedures for performance-based navigation (PBN), which, according to Commission Regulation (EU) No 965/2012, will be progressively applicable not only to commercial air transport (CAT) operators, but also to non-commercial operators of complex (NCC) or other than complex motor-powered (NCO) aircraft, as well as to aerial work operators (SPO).

Area Navigation (RNAV) was in fact developed in the 1960s in the USA to give aviators more flexibility in deciding their horizontal path (i.e. no longer obliged to overfly ground beacons). In time, new RNAV or required navigation performance (RNP) applications were added. The Agency is aware that requesting and obtaining a SPA for each PBN application constitutes an additional administrative task especially for non-commercial operators, but also for competent authorities.

This rulemaking task is hence necessary to review the obligation for SPA for all existing PBN applications and, where appropriate, to amend the requirement. Pilot training for instrument rating (IR) needs to be revised in parallel, since the administrative simplification shall have no adverse effect on safety.

This NPA takes into account edition 4 (2013) of the ICAO Manual on performance-based navigation (Doc 9613) to pursue the following specific objectives:

a) to develop rules on pilot training and checking requirements, which are an essential pre-requisite to remove the requirement for SPA for some PBN operations;

b) to reassess the need for a specific operational approval for each PBN operation for CAT, SPO, NCC, and NCO operators; and

c) to take into account the introduction of RNP 2, Advanced-RNP and RNP 0.3 in ICAO Doc 9613 edition 4 and the consequent possibility of 'bundling' approvals.

This NPA proposes amendments to Commission Regulations (EU) Nos 1178/2011 (Part FCL), 290/2012 (Part ARA and ORA) and 965/2012 (AIR-OPS) and related AMC/GM, and amendments to CS-FSTD(A) and (H) and to a number of AMC 20-XX related to PBN. The proposed changes are expected to maintain safety while reducing the regulatory burden, also for oversight by competent authorities.

Applicability		Process map	
Affected regulations and decisions:	Commission Regulation (EU) No 1178/2011 (Part FCL) and Commission Regulation (EU) No 290/2012 (Part ARA and ORA) Commission Regulation (EU) No 965/2012 (Annex I – Definition, Part ARO, ORO, CAT, SPA) Commission Regulation (EU) No 800/2013 (Annex VI Part NCC, Annex VII Part NCO); Opinion No 02/2012 on Annex VIII Part SPO and related AMC/GM CS-FSTD(A) and (H) AMC 20-4, -5, -12, -26, -27 and -28	Concept Paper:	No
		Terms of Reference:	Issue 2 of 8 July 2013
		Rulemaking group:	Yes
		RIA type:	Light
		Technical consultation during NPA drafting:	No
		Duration of NPA consultation:	3 months
Affected stakeholders:	Commercial and non-commercial aircraft operators, pilots, ATO Original Equipment Manufacturers (OEM) and Flight Synthetic Traning Devices (FSTD)	Review group:	Yes
		Focused consultation:	Depending on the comments received on the NPA
Driver/origin:	Level playing field	Publication date of the Opinion (simultaneously with CRD):	2015/Q1
Reference:	Annex V (Part SPA) to Commission Regulation (EU) No 965/2012	Publication date of the Decision:	2016/Q1

TE.RPRO.00034-003 © European Aviation Safety Agency. All rights reserved.
Proprietary document. Copies are not controlled. Confirm revision status through the AGENCY Internet/Intranet.

Page 1 of 228

AIRBUS