PBN Airspace Design Workshop

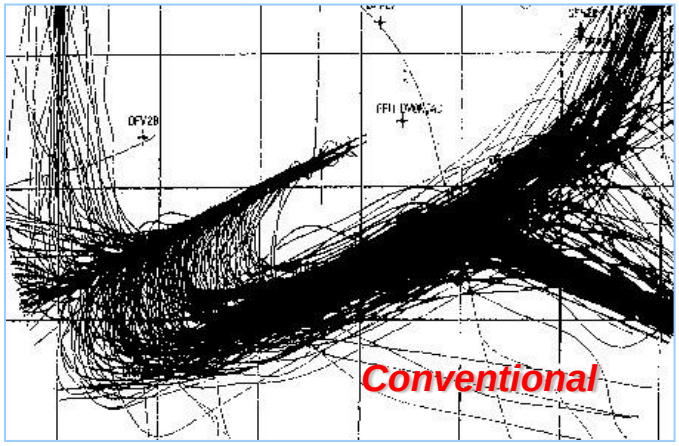
INTRODUCTION TO PBN

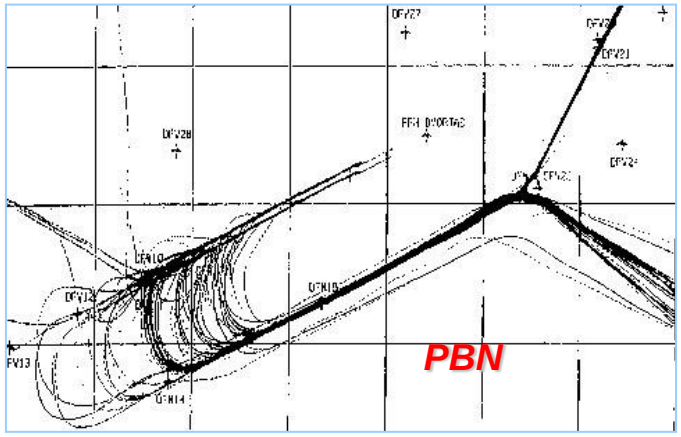
Asia and Pacific Regional Sub-Office
Beijing, China

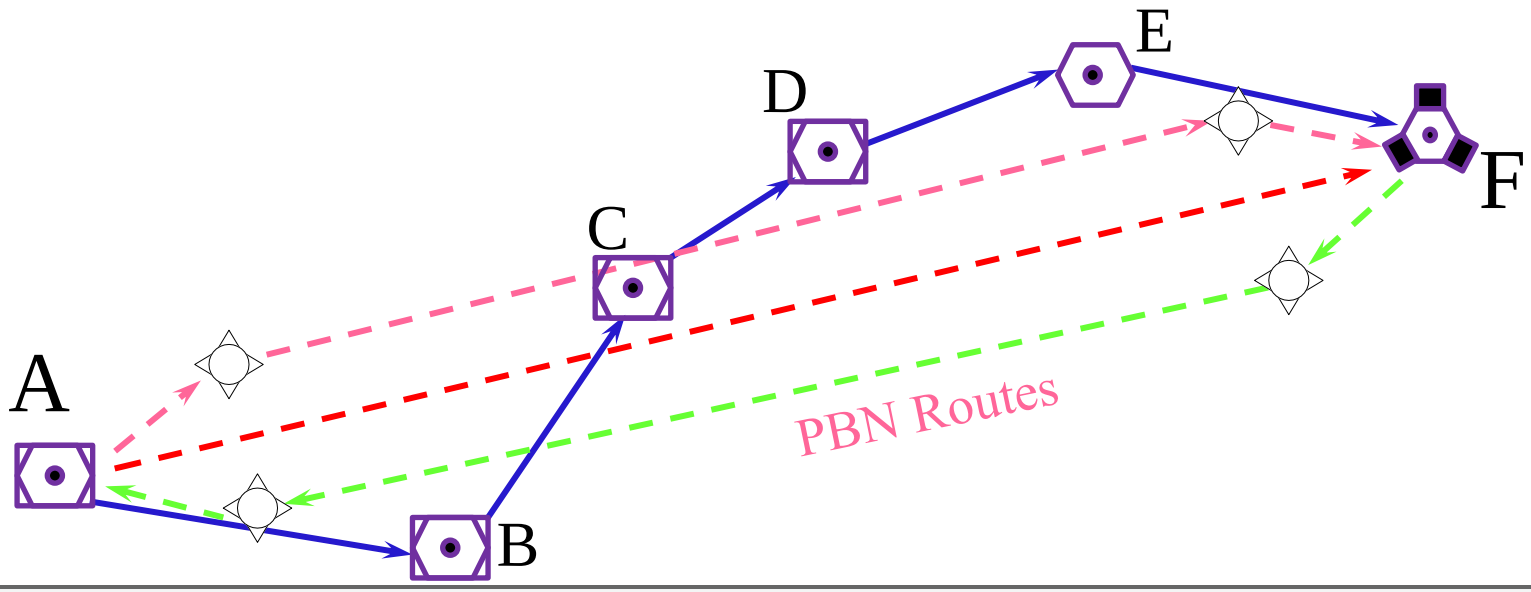
Learning Objectives

- **By the end of this presentation, you should:**
  - Understand what is RNAV and RNP and how correct use of PBN can improve operational efficiency and Airspace Capacity
- **This presentation will discuss**
  - Navigation in Context
  - Evolution to Performance Based Navigation
  - Performance Based Navigation
    - What is it?
    - What is RNAV?
    - What is RNP?
    - What is the Key Difference?

What is PBN?







What is PBN?

- PBN stands for “Performance Based Navigation”.
- Performance can be derived from any means of equipment.
- PBN specifies SYSTEM PERFORMANCE REQUIREMENTS for aircraft operating on air traffic routes, instrument approach procedures, or in a designated airspace.
- The performance requirements for PBN are defined in terms of accuracy, integrity, continuity and availability.

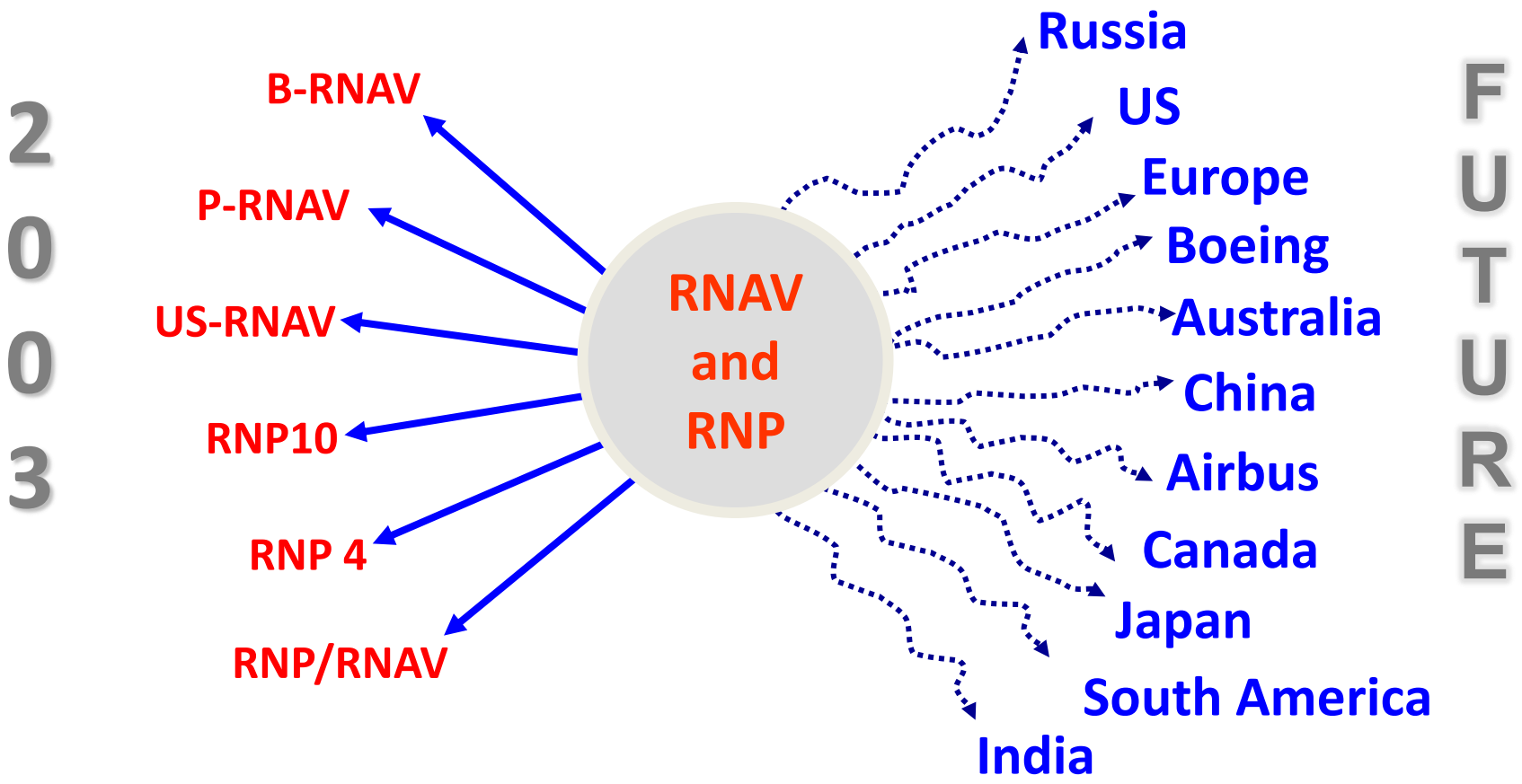
What is PBN?

- **Accuracy**
  - Position accuracy is the difference between the actual and estimated position in fault free conditions (NSE)
  - Track-keeping accuracy is the difference between the actual and desired position in fault free conditions (TSE)
- **Integrity** : the ability to provide timely warnings when the system is not safe to use
- **Continuity** : the ability of the navigation system to provide its service without interruption during an operation
- **Availability** : the ability of the total system to perform its function at the initiation of the intended operation

History of PBN

- **RNP concept was introduced in 1990s**
  - A statement of the navigation performance accuracy necessary for operation within a defined airspace (Doc 9613 – RNP Manual).
  - A statement of the navigation performance accuracy, integrity, continuity and availability necessary for operation within a defined airspace (Doc 9650 – Special COM/OPS Divisional Meeting Report)
- **RNP concept was insufficient**
  - Not specify relationship between RNAV and RNP and need for an RNAV system
  - Focused on oceanic and remote area applications
  - No specific guidelines for continental en-route, terminal and approach applications
  - Led to proliferation of national standards, wide variety of functional requirements, variety of required navigation sensors, different crew requirements, lack of global harmonization
- **The result**
  - Cost to operators, who had to qualify several times to operate in 'RNP' airspace where the RNP 'value' was the same
  - Confusion in the stakeholder community – uncertainty as to what RNP meant

History of PBN



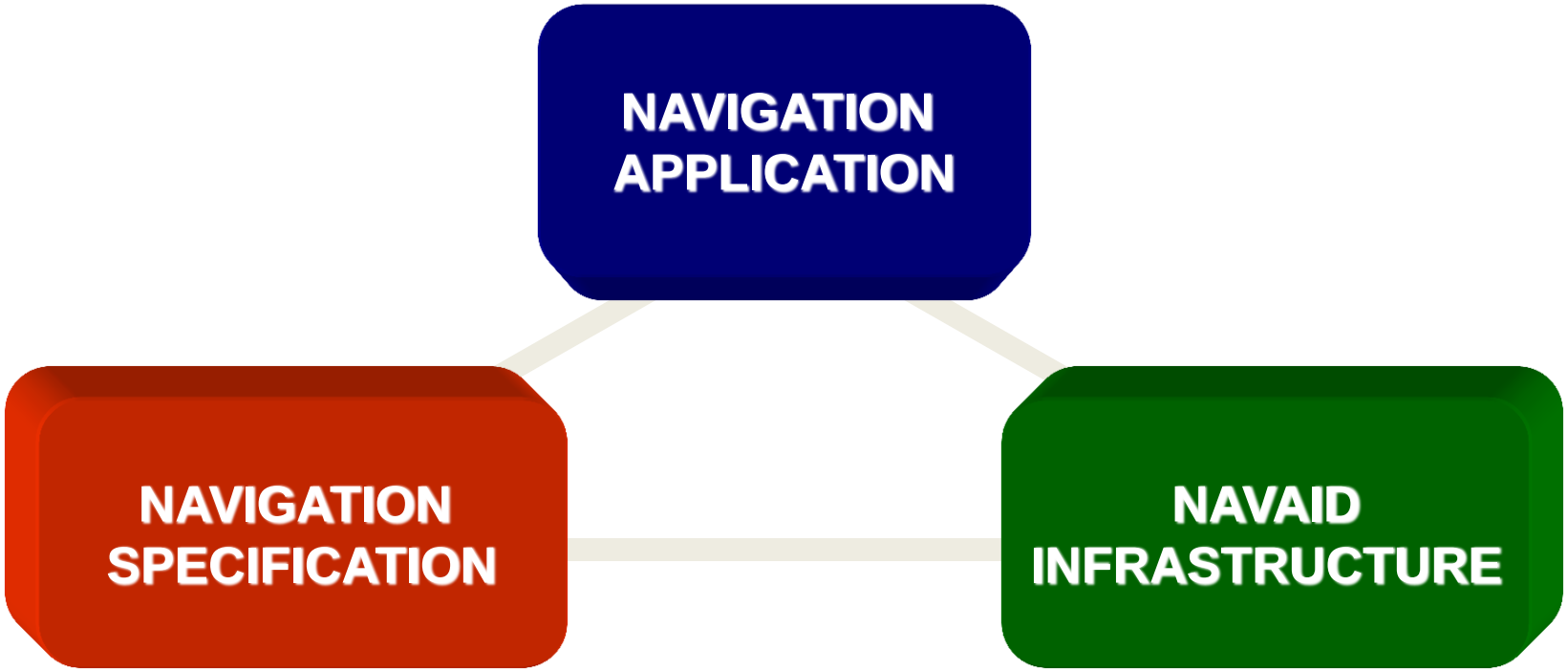
History of PBN

- **ICAO began to act in 2004**
  - To stop proliferation of regional RNAV/RNP standards
  - To review and redefine RNAV/RNP concept
  - To include new NavSpecs to meet operational demands
- **Set up ICAO RNPSORSG**
  - To achieve and document a common understanding of RNP/RNAV and associated concepts and functionalities
    - Clarify RNAV and RNP definition and Terminologies
    - How do they relate to each other?
    - What is the essential distinction?
  - To harmonize the use of RNAV and RNP on global bases, for benefit of operators and service providers
    - Identified operational and airworthiness requirements for RNAV/RNP

History of PBN

- **Enter Performance Based Navigation**
  - PBN Concept replaced RNP concept
  - PBN Manual (Doc 9613) was published in 2007 and updated in 2013
  - ICAO's 36th Assembly Resolution in 2007 supported PBN Implementation and then reiterated it at 37th Assembly in 2010
  - ICAO Global Seminars were held around the world
- **ICAO PBN Study Group (PBN SG)**
  - Replaced RNPSORSG in November 2008
    - To consolidate information learnt during ICAO Seminars
    - To develop Operational Requirements for RNAV and RNP
  - Published RNP APCH OPS Approval Guidance and updated PBN Manual including new NavSpecs (RNP2, A-RNP, RNP 0.3, etc.)

Components of PBN Concept



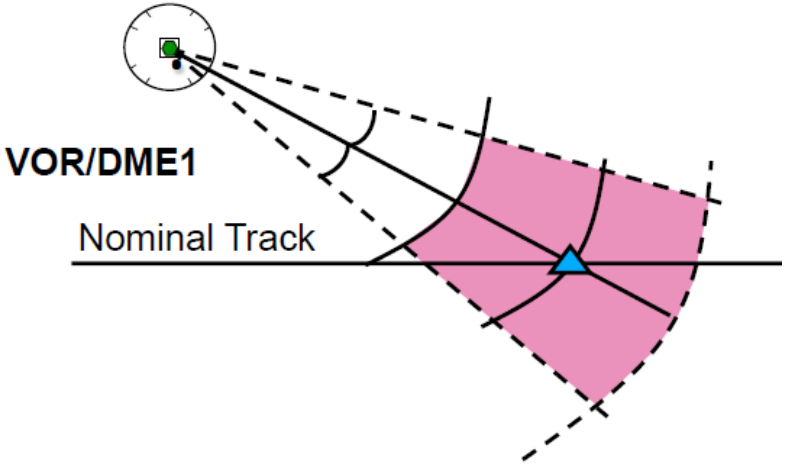
Components of PBN Concept

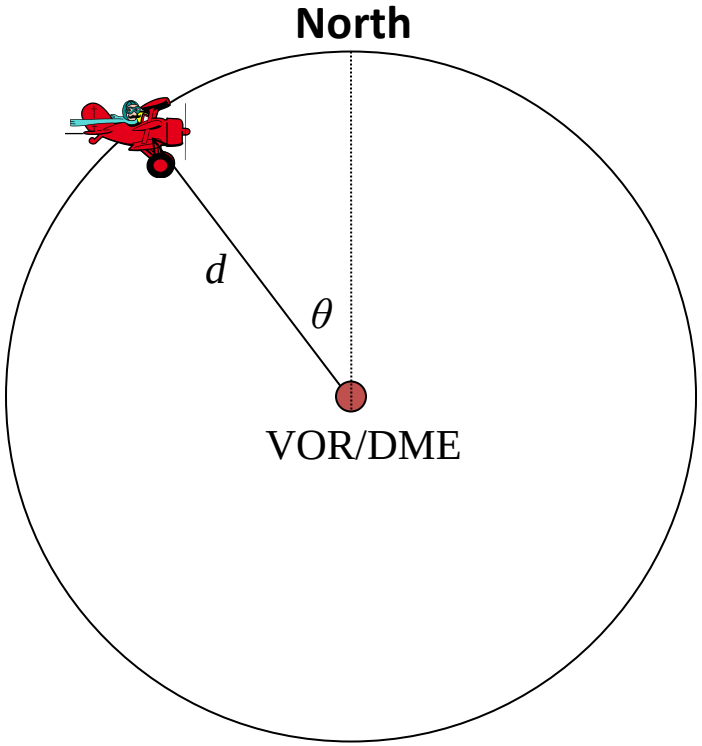
- Ground-based Navigation Aids (NAVAIDs)
  - VOR, DME, (Not NDB)
- Space-based NAVAIDs
  - GNSS
    - GPS, GLONASS, Galileo, BEIDU (COMPASS)
- (Aircraft-based NAVAIDs)
  - INS/IRS, FMS

NAVAID INFRASTRUCTURE

Navigation Infrastructure

- **VOR/DME**
  - **Positioning is calculated based on**
    - **the distance information from a DME,**
    - **the bearing information from a VOR (co-located), and**
    - **VOR/DME location in the database**

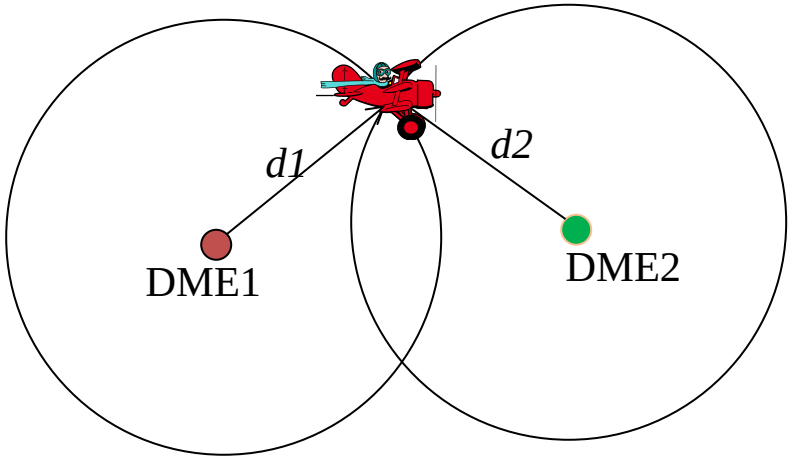




Navigation Infrastructure

❖ DME/DME

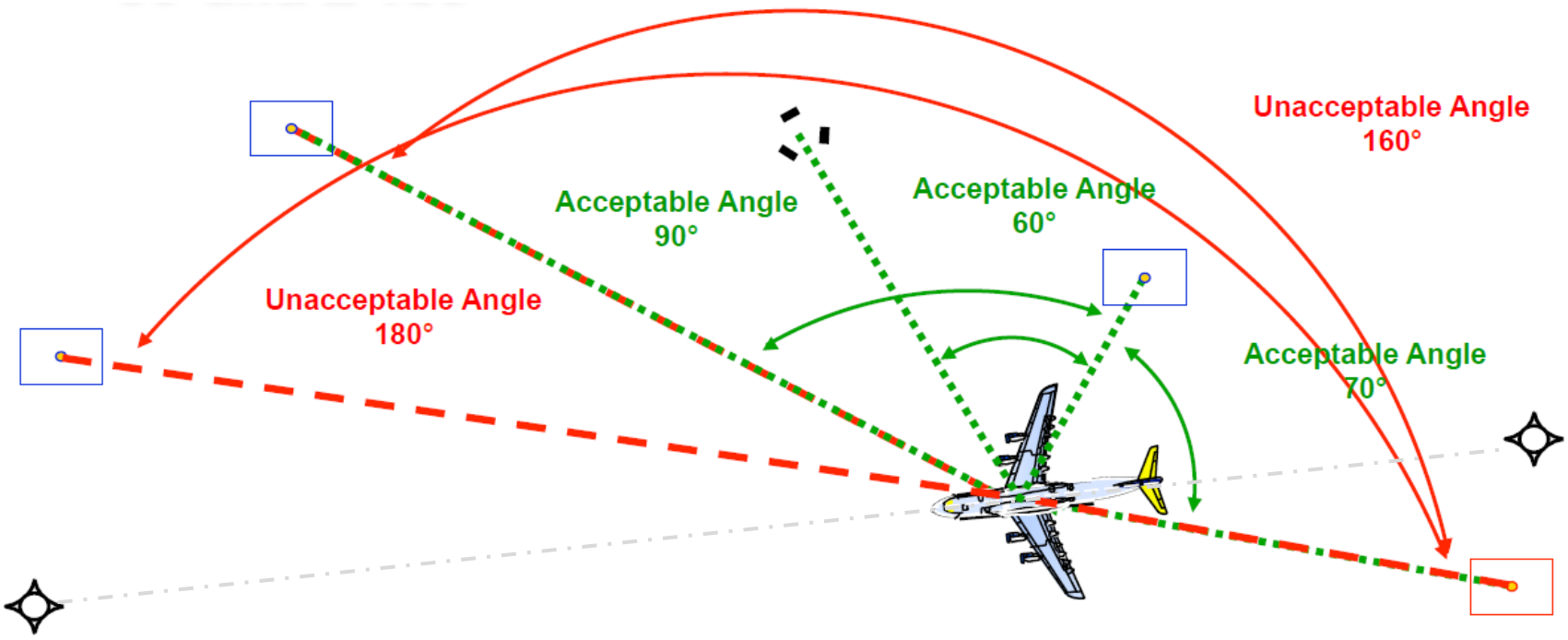
- ➢ **Positioning is calculated based on**
  - **the distances from two DMEs and**
  - **their locations in the database**



Navigation Infrastructure

❖ DME/DME

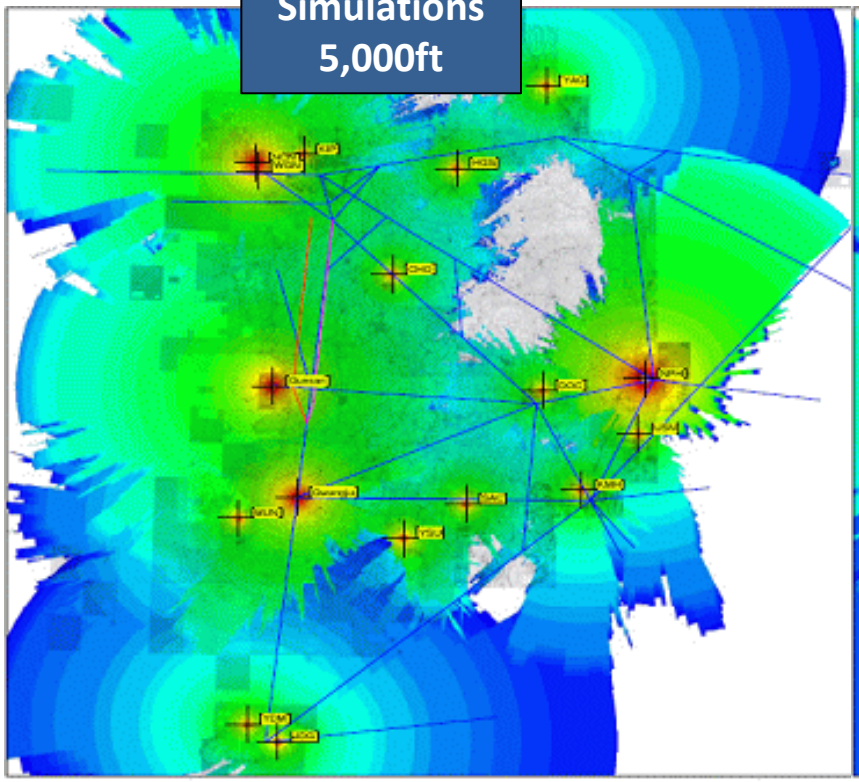
- ➢ For DME/DME systems using DME facility fairs, geometry solutions require two DMEs to be ≥ 30˚ and ≤ 150˚



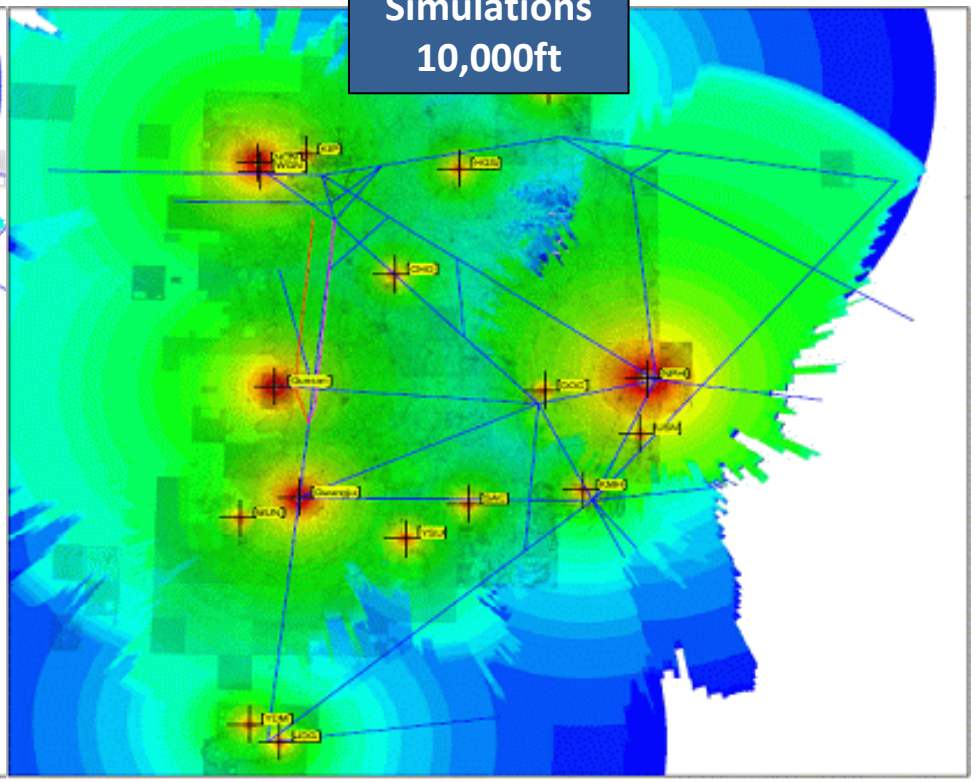
Navigation Infrastructure

- **DME/DME Coverage**

DME/DME Simulations 5,000ft



DME/DME Simulations 10,000ft



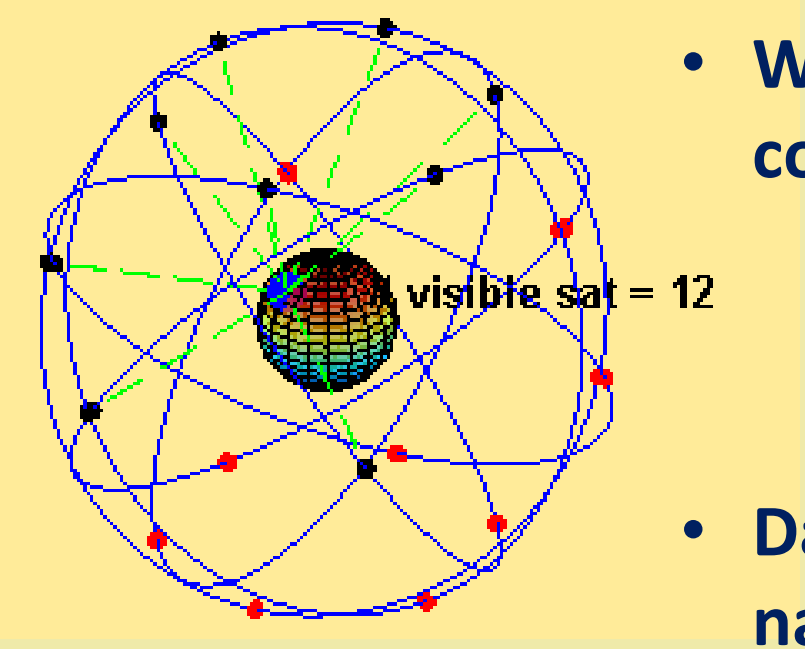
Navigation Infrastructure

❖ **GNSS - GPS**

- **A 24 satellite constellation**

- **Position computed in WGS84**

- **Accuracy of 10 meters or better**



- **Worldwide coverage**

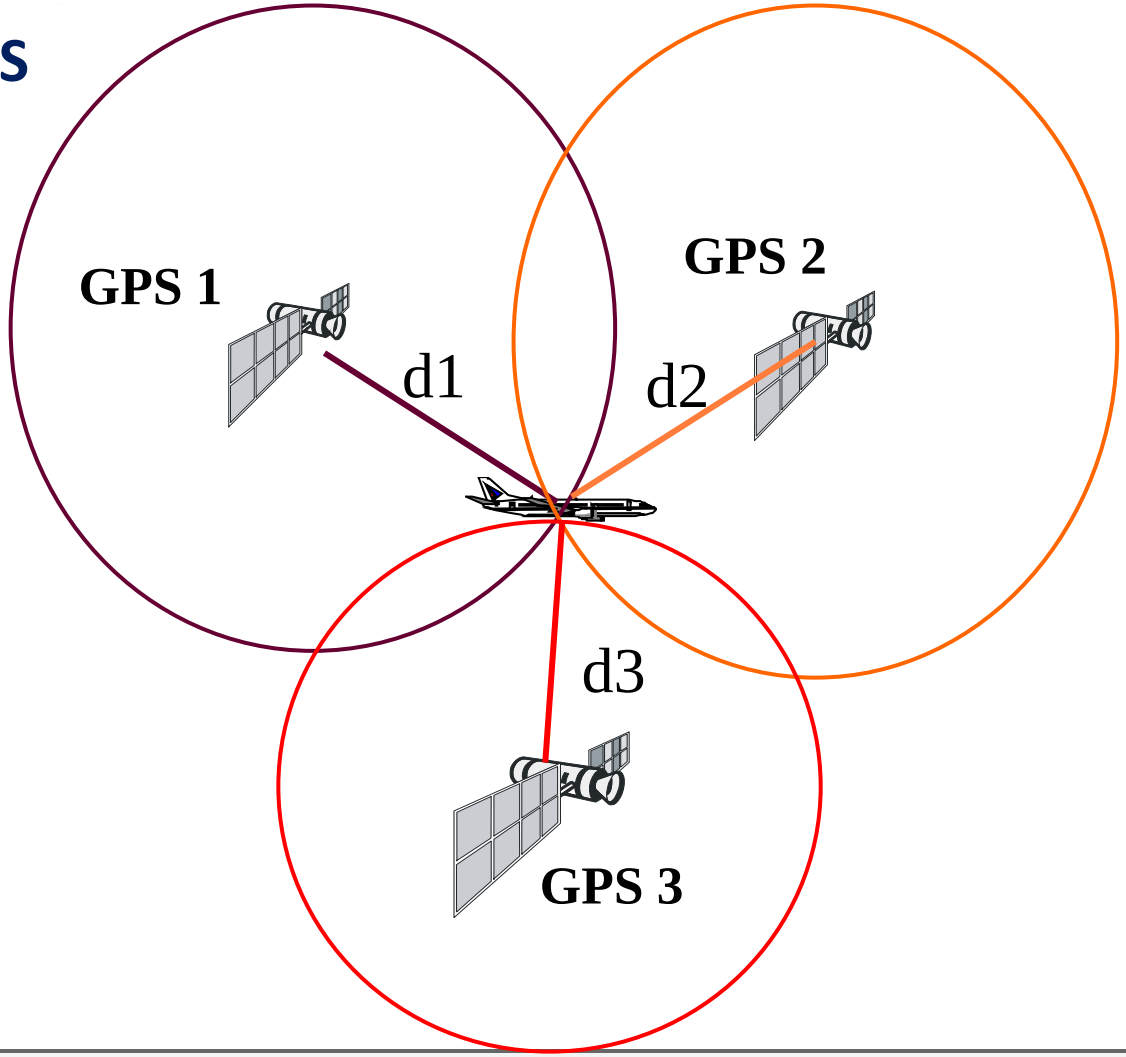
- **Database navigation**

Navigation Infrastructure

- **GNSS - Other Systems**
  - **GLONASS : 24 satellites by 2013**
  - **Galileo : 30 Satellites by 2019**
  - **Beidou-2 (COMPASS) : 35 Satellites by 2020**
  - **GAGAN : 7 Satellites by 2014 for regional IRNSS**

Navigation Infrastructure

- GNSS

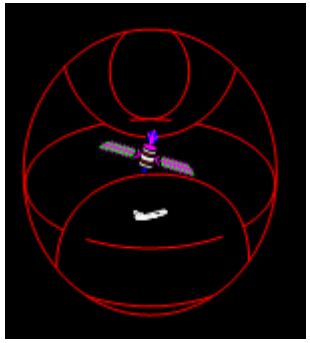


Navigation Infrastructure

❖ GNSS

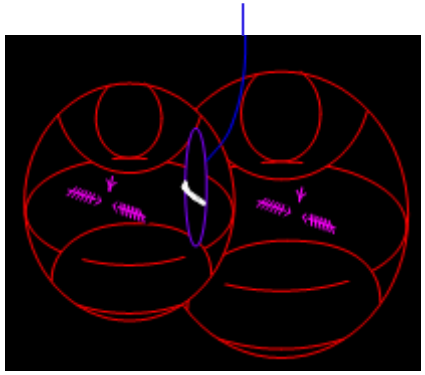
➢ Satellite Navigation – 3D

Aircraft is somewhere on the surface of this sphere



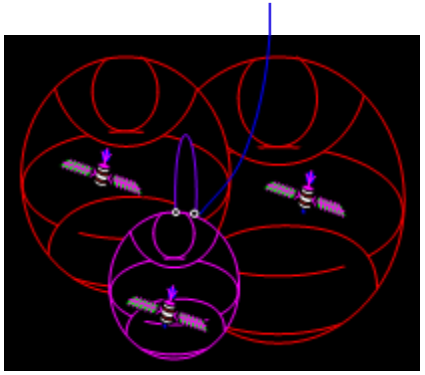
1 Satellite Position

Aircraft is somewhere on this circle



2 Satellite Position

Aircraft is at one of these two points



3 Satellite Position

*** Reference to a forth Satellite is required to eliminate clock errors**

Navigation Infrastructure

- **GNSS**
  - **RAIM (Receiver Autonomous Integrity Monitoring)**
    - Requires redundant satellite measurements
    - 5 Satellites allow to detect the problem caused by one satellite – FD as known as RAIM
    - 6 Satellites allow to define which satellite is wrong - FDE
  - **Aircraft Augmentation System**
    - RAIM - Airborne GNSS Receiver/Processor to Autonomously Monitor the Integrity of the Signals From GNSS Satellites
    - AAIM - An Inertial Navigation System for GPS or GLONASS used short periods of time when the satellite navigation antennas are shadowed by the aircraft maneuvers or when insufficient satellites are in view
    - Others Augmentation techniques - Barometric Altimeter Aiding, Combination of Sensor Inputs (e.g. VOR/DME)

Navigation Infrastructure

- **Harmonizing Modern and Conventional NAVAIDs**
  - **By providing Performance-specific System, operational procedures can be harmonized, even for aircrafts with different equipment**
  - **PBN enables co-use of both conventional and satellite-based navigation aids**

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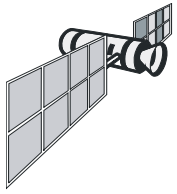
GNSS



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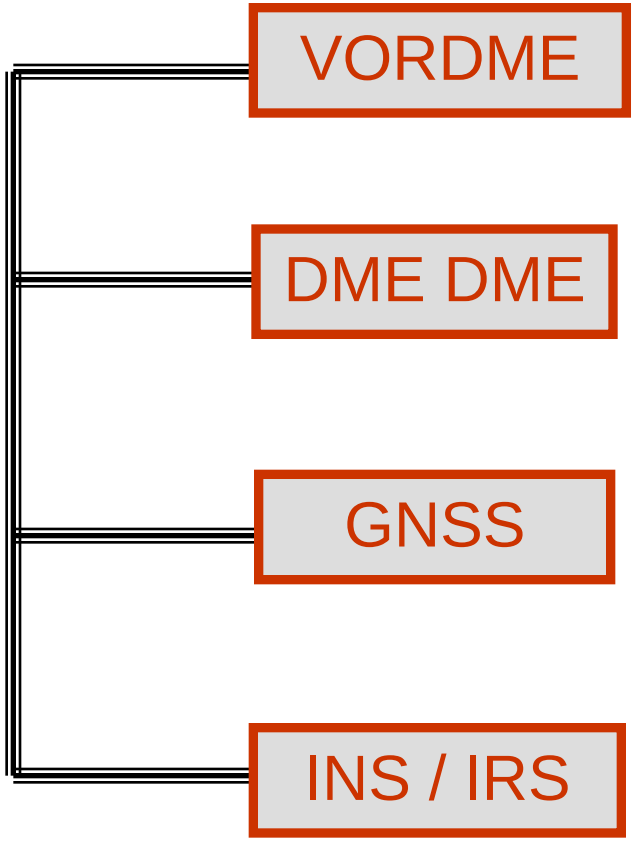
PBN Navigation Infrastructure

Navigation Infrastructure

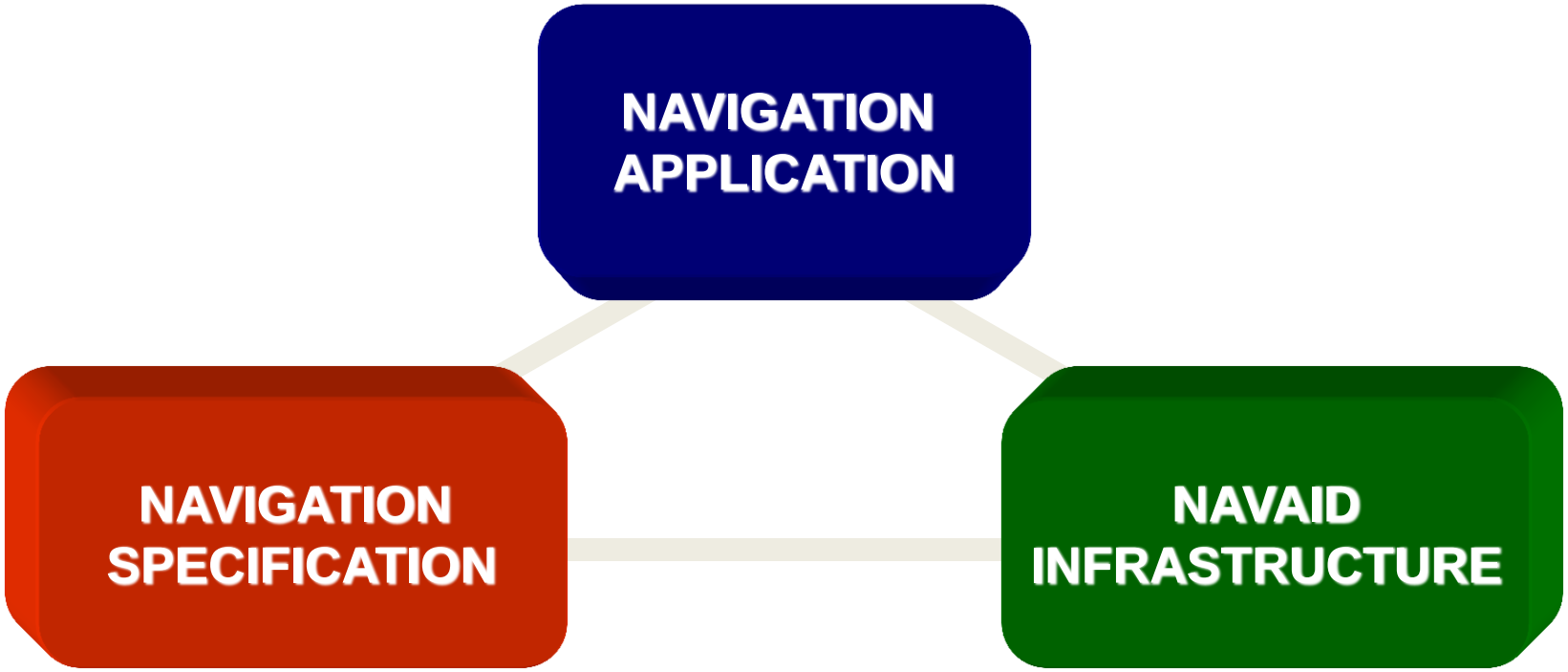
- **Flight Management System (FMS)**
  - Install in modern aircraft for multi function automatic flight in NAV mode
  - Include satellite base navigation mode.
  - Provide flight management for
    - navigation (positioning, flight planning, trajectory prediction);
    - performance prediction and optimization (speed, altitude, vertical profile, etc.);
    - navigation radio tuning; and
    - information display management
  - Save cost for commercials airlines by aviation technology and precision flight instrument.

Navigation Infrastructure

- **FMS**



Components of PBN Concept



Components of PBN Concept

Accuracy
Integrity
Continuity
Availability

ICAO aim is to limit the number of Nav. Specs in global use

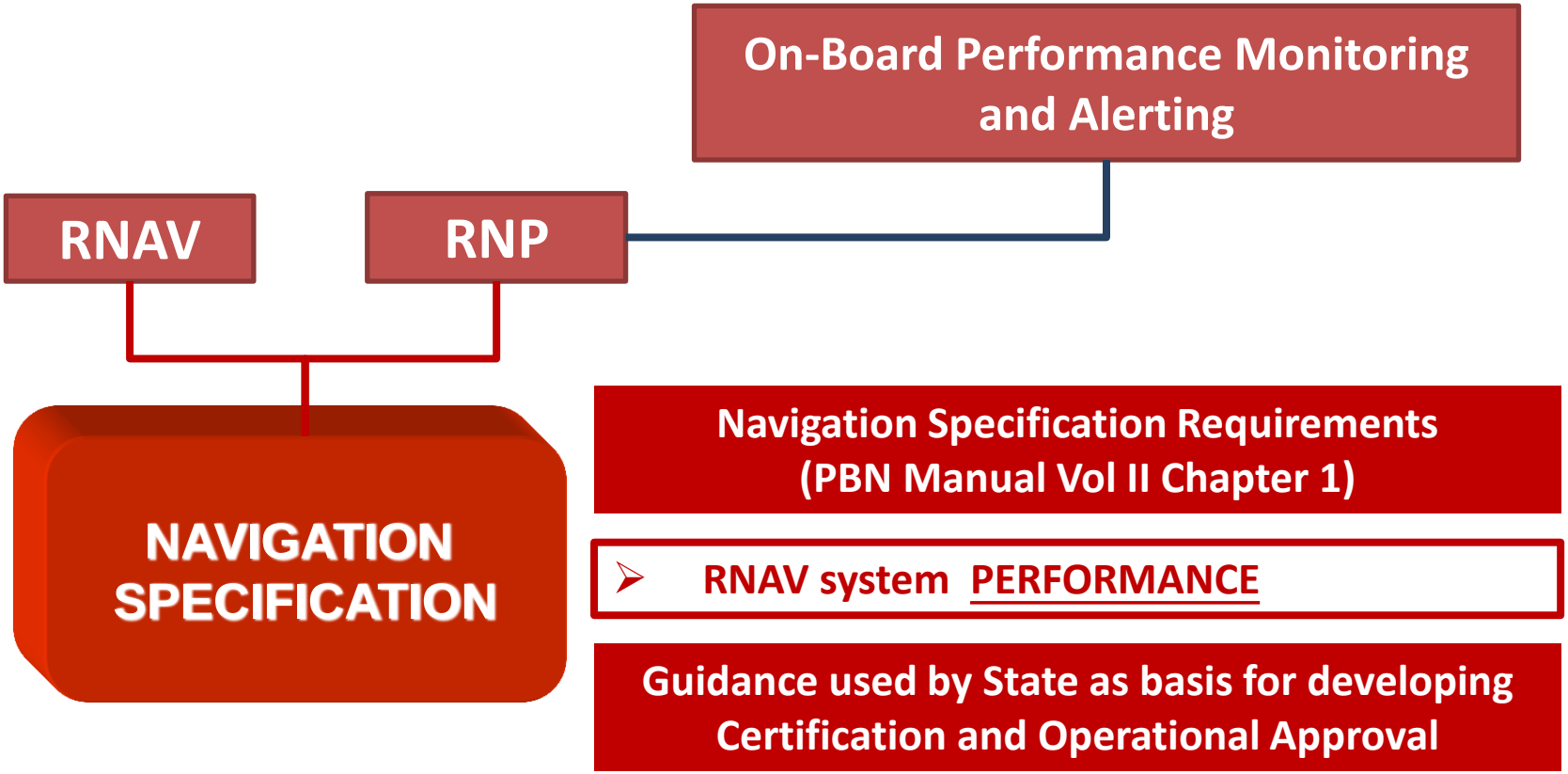
NAVIGATION SPECIFICATION

Navigation Specification Requirements (PBN Manual Vol II Chapter 1)

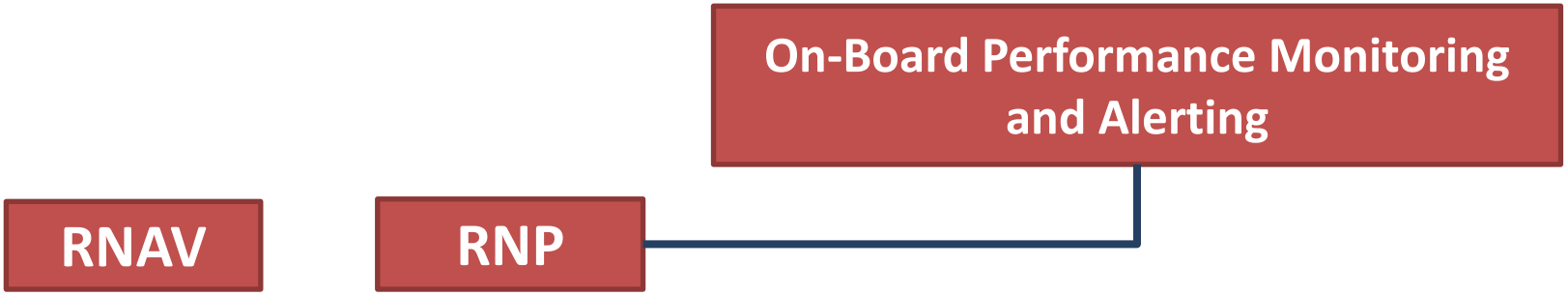
- What PERFORMANCE of RNAV system is required?
- What FUNCTIONALITIES must RNAV system have to achieve performance?
  e.g. display type, leg type
- What NAVIGATION SENSORS must be integrated in RNAV system to achieve performance?
- What REQUIREMENTS are placed on AIR CREW to achieve the required performance from the RNAV system?

Guidance used by State as basis for developing Certification and Operational Approval

Components of PBN Concept



Components of PBN Concept



- **On-board performance monitoring and alerting:**
  - **Does not only refer to 'containment' in the MASPS; Annex 11 or PANS-OPS**
  - **Allows the air crew to detect that the RNP system is not achieving the navigation performance required of the RNP system**

Navigation Specification

- **RNAV and RNP**

RNAV 1

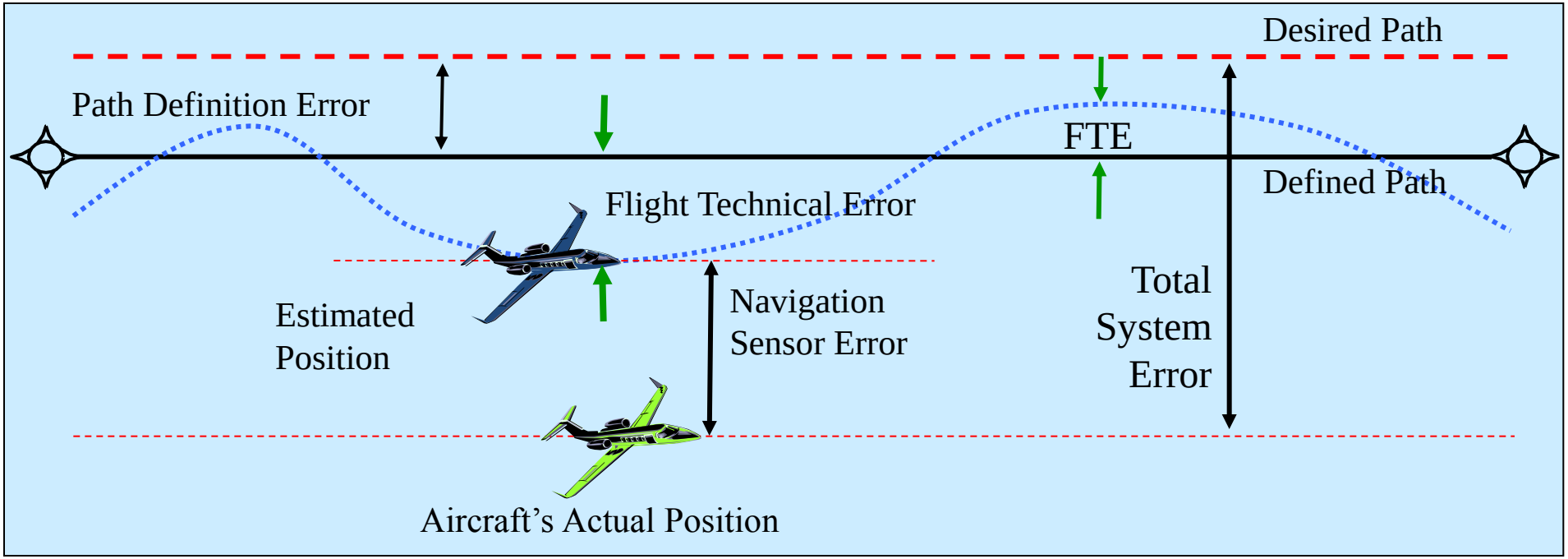
RNP 1

2*RNP Alert to Pilot

RNP isn't "fundamentally different" from RNAV ,
But RNP is MORE than RNAV
The Key Difference : On-Board Performance Monitoring and Alerting

Navigation Specification

- **Total System Error (TSE)**
  - **Lateral navigation errors (95% of flight time)**
  - **Calculated as the Root Sum Square (RSS) of 3 errors: PDE, NSE and FTE**

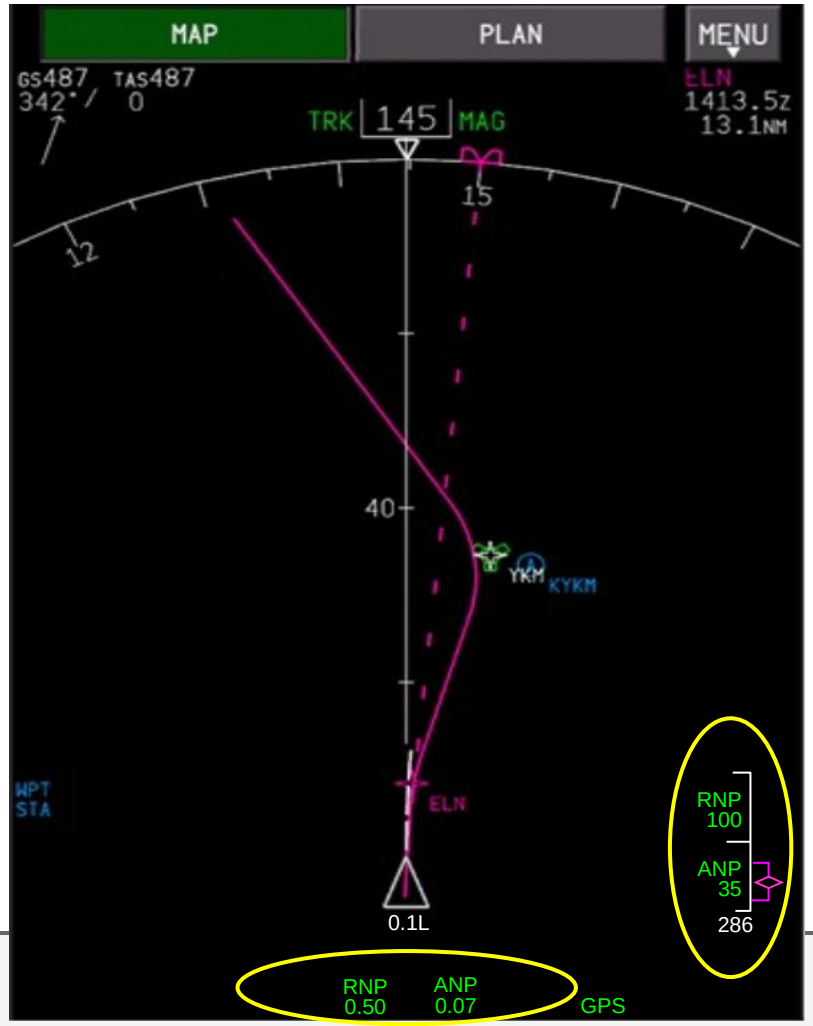


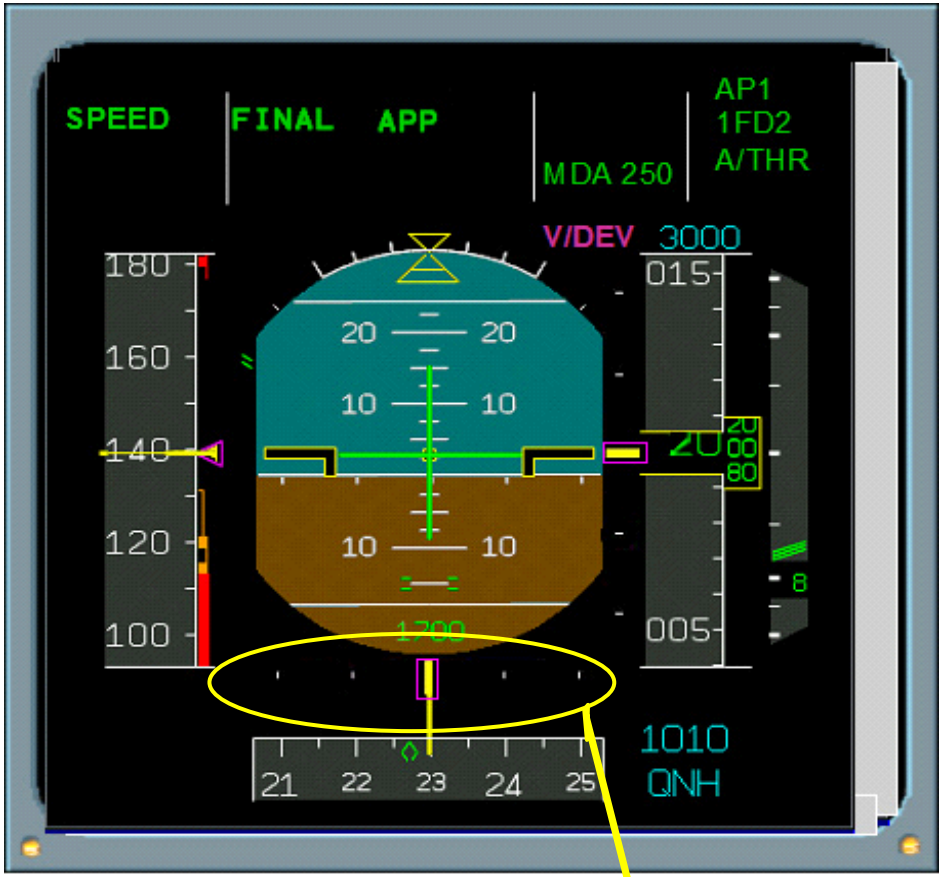
Navigation Specification

- **Navigation Performance**

Navigation Specification

- **Navigation Performance**





L/DEV Scale 0.2NM

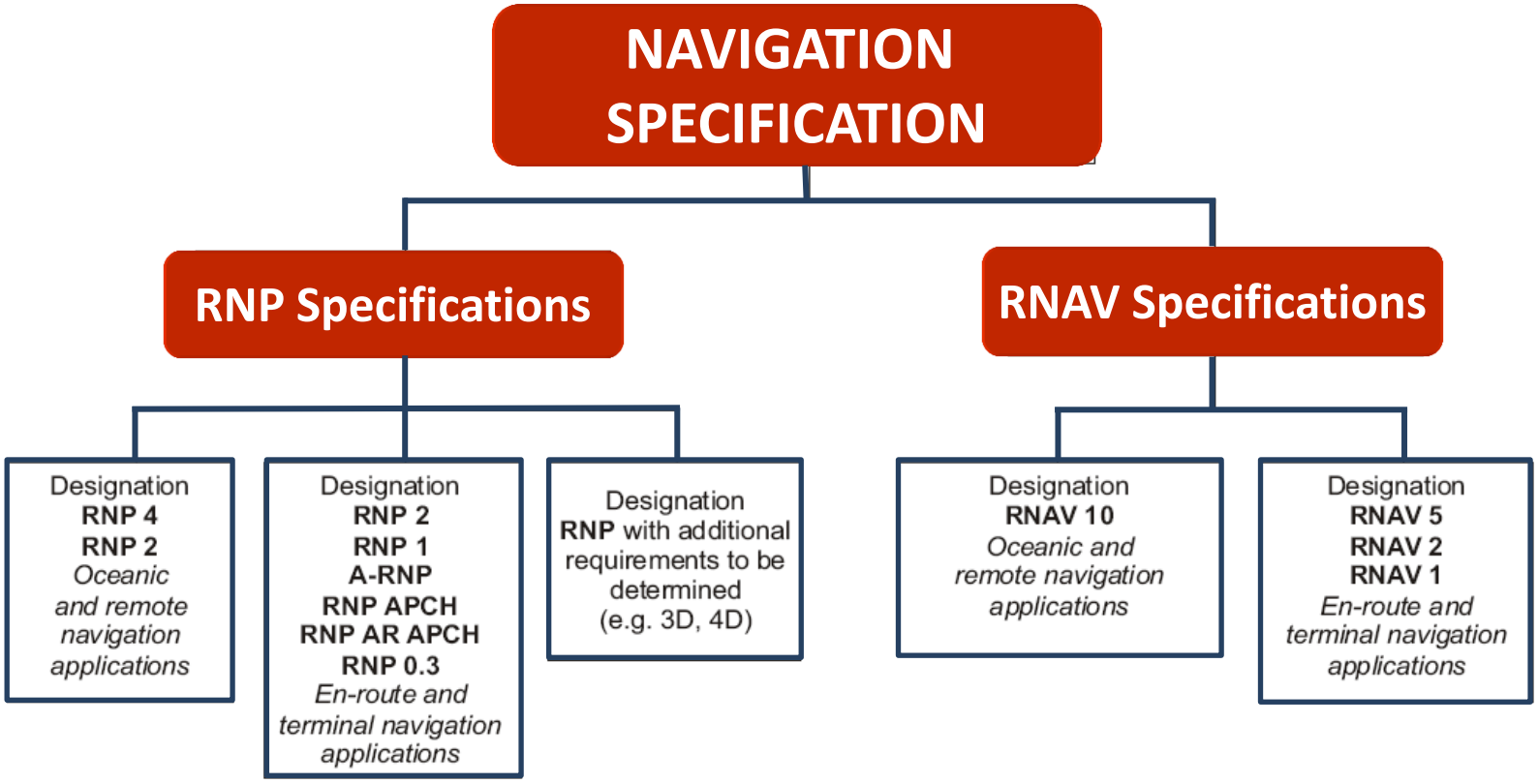
Navigation Specification

- **Navigation Performance**
  - **If GPS signal is lost**

Navigation Specification

- **Navigation Performance**
  - **In case of Navigation Accuracy is downgraded**

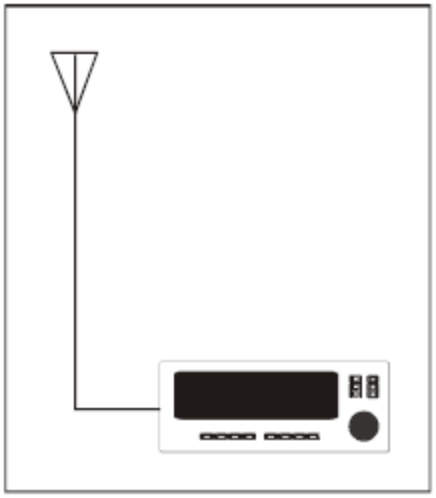
Navigation Specification



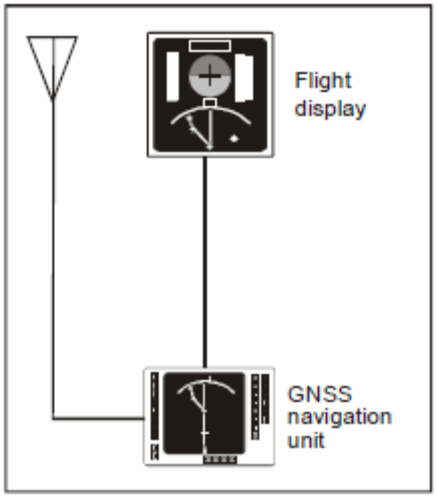
Navigation Specification

- **RNAV and RNP systems – from basic to complex**

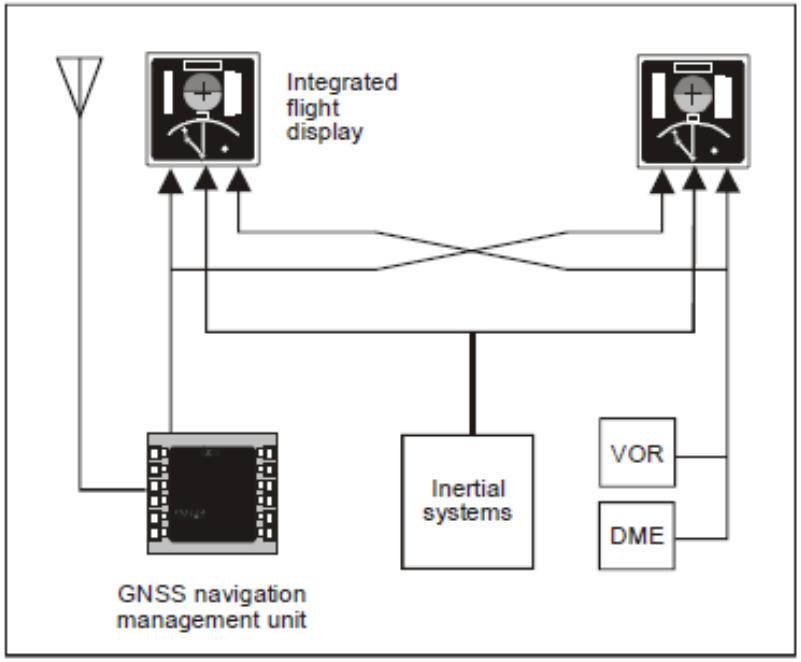
a) Basic



b) RNAV map

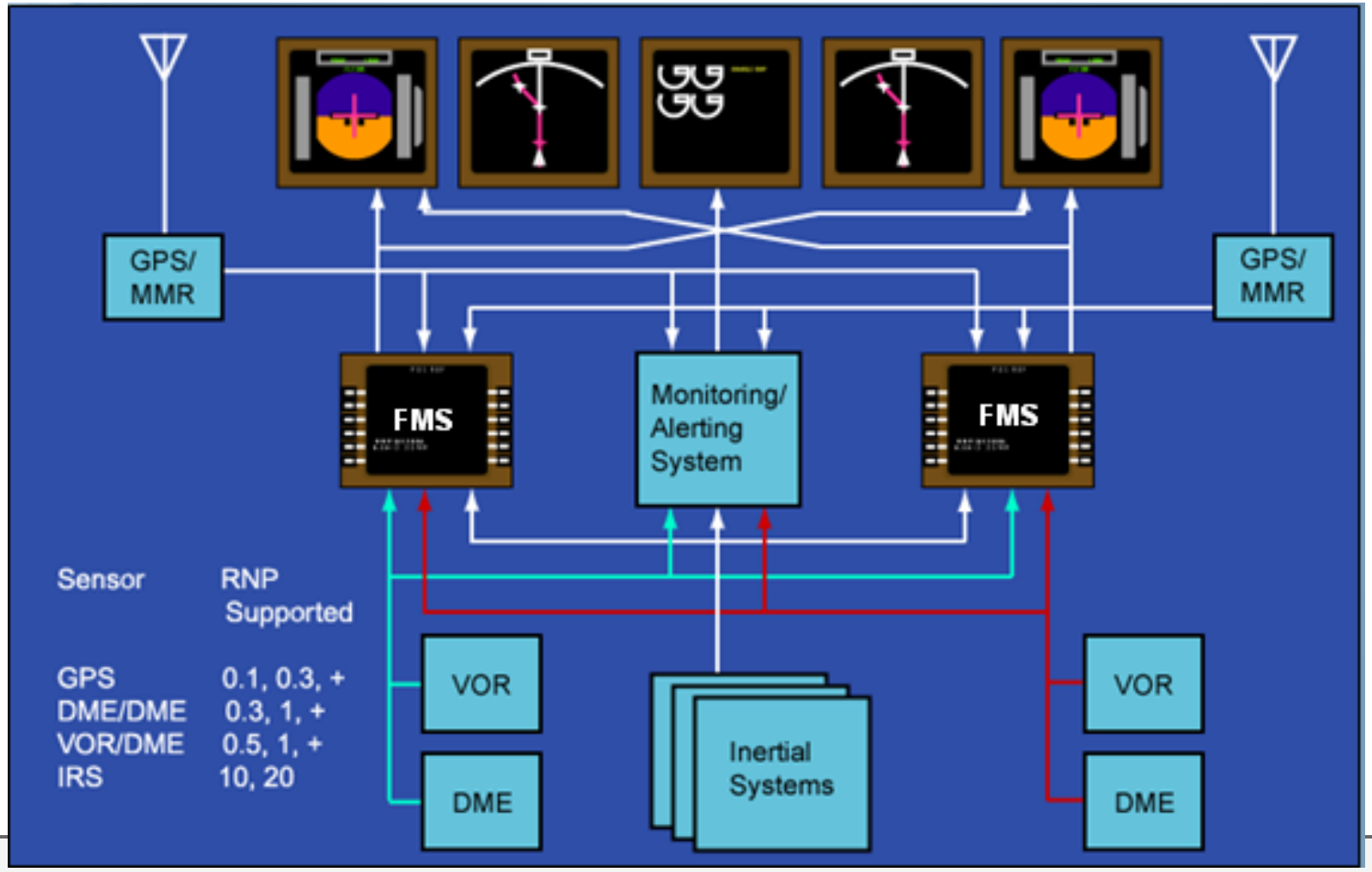


c) Simple multi-sensor avionic



Navigation Specification

d) Complex multi-sensor avionic



Navigation Specification
(PANS-OPS, Doc 8168)

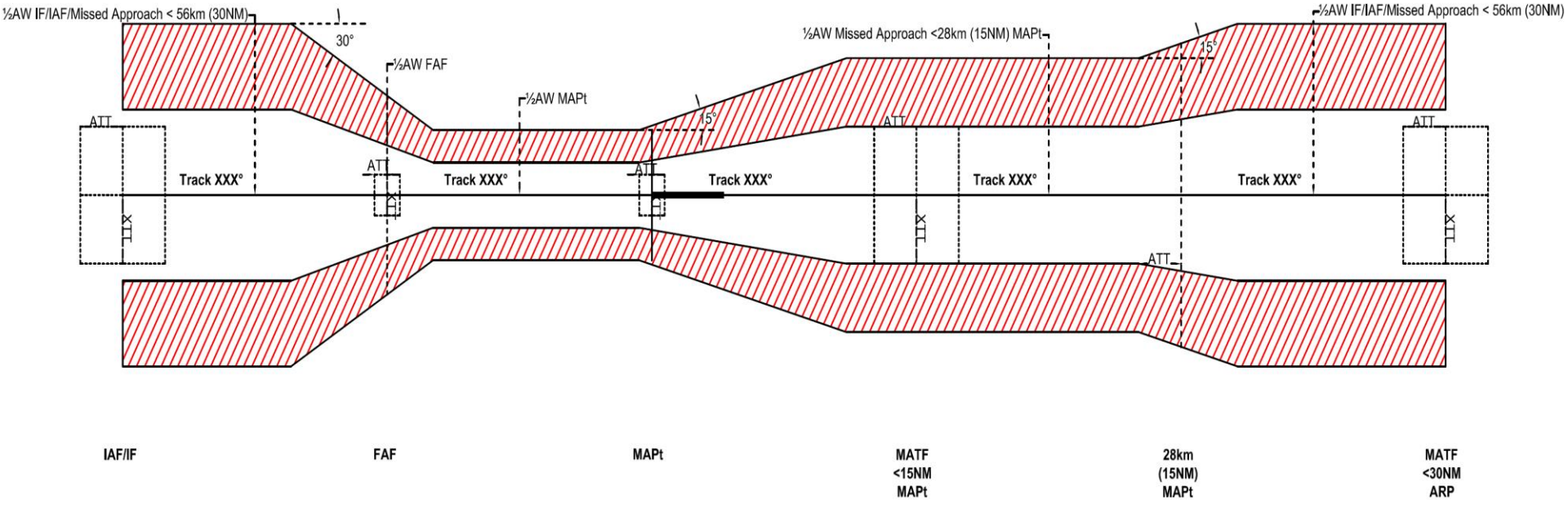
	Flight Phase							
	Oceanic/Remote	*En-route*	*Arrival*	*Approach*				*Departure*
				Initial	*Intermediate*	*Final*	*Missed*[1]	
RNAV 10	10							
RNAV 5		5	5[2]					
RNP 4	4							
RNP 2	2	2						
RNAV 2		2	2					2
Advanced RNP[3]	2	2 or 1	1 – 0.3	1 - 0.3	1 - 0.3	0.3	1 - 0.3	1 - 0.3
RNP 1			1	1	1		1	1
RNAV 1		1	1	1	1		1	1
RNP 0.3 (Cat H)		0.3	0.3	0.3	0.3		0.3	0.3
RNP APCH (Part A)[4]				1	1	0.3	1	
RNP APCH (Part B)[4]				1	1	Angular	1 or 0.3 (initial straight MISAP)	
RNP AR APCH				1-0.1	1-0.1	0.3-0.1	1-0.1	

Navigation Specification
(PBN Manual, Doc 9613)

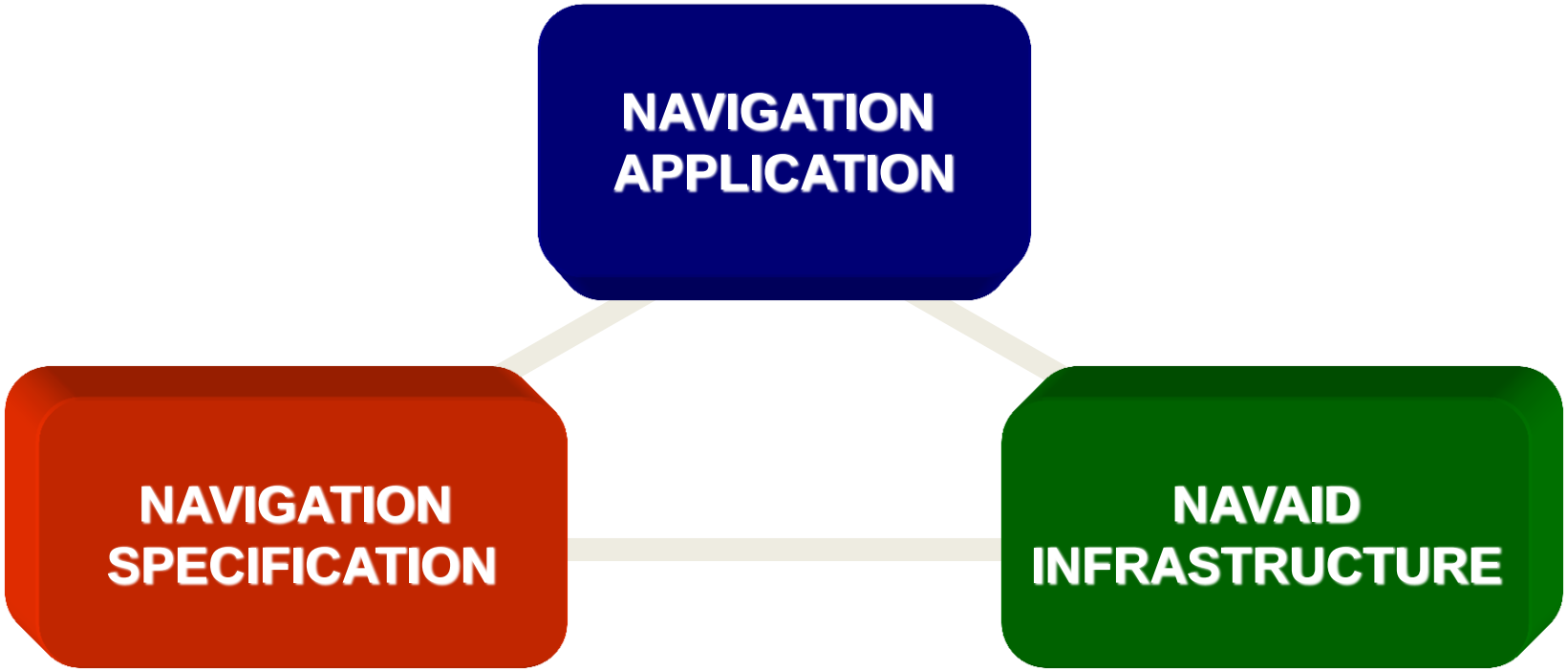
Doc 9613 Part / Chapter	Navigation Specification	Flight phase							
		En-route oceanic/remote	En-route continental	Arrival	Approach				DEP
					Initial	Intermediate	Final	Missed[1]	
B Ch.1	RNAV 10	10							
B Ch.2	RNAV 5[2]		5	5					
B Ch.3	RNAV 2		2	2					2
B Ch.3	RNAV 1		1	1	1	1		1	1
C Ch.1	RNP 4	4							
C Ch.2	RNP 2	2	2						
C Ch.3	RNP 1[3]			1	1	1		1	1
C Ch.4	Advanced RNP[4]	2[5]	2 or 1	1	1	1	0.3	1	1
C Ch.5	RNP APCH[6]				1	1	0.3[7]	1	
C Ch.6	RNP AR APCH				1-0.1	1-0.1	0.3-0.1	1-0.1	
C Ch.7	RNP 0.3[8]		0.3	0.3	0.3	0.3		0.3	0.3

Navigation Specification

❖ RNP APCH



Components of PBN Concept



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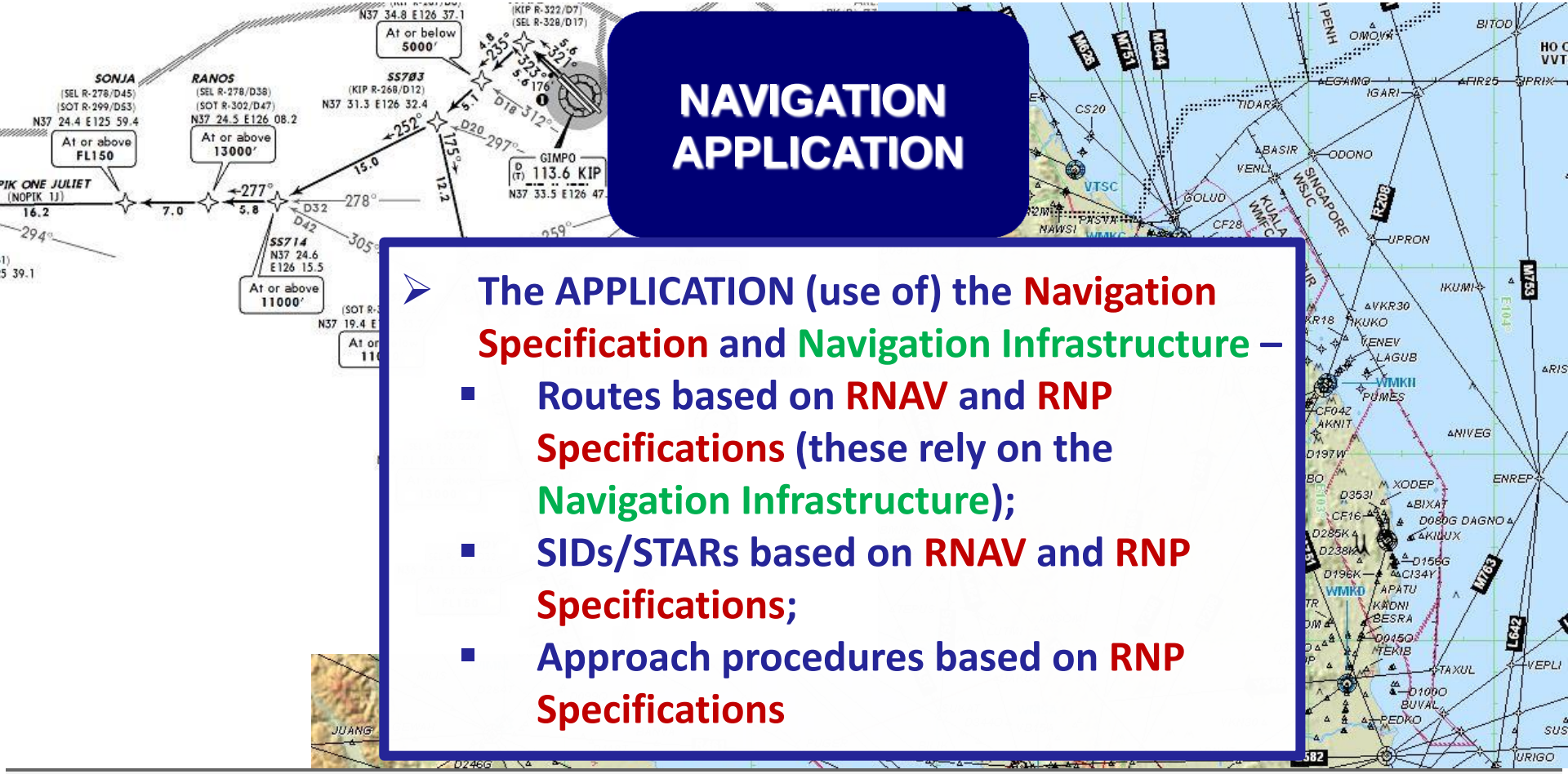
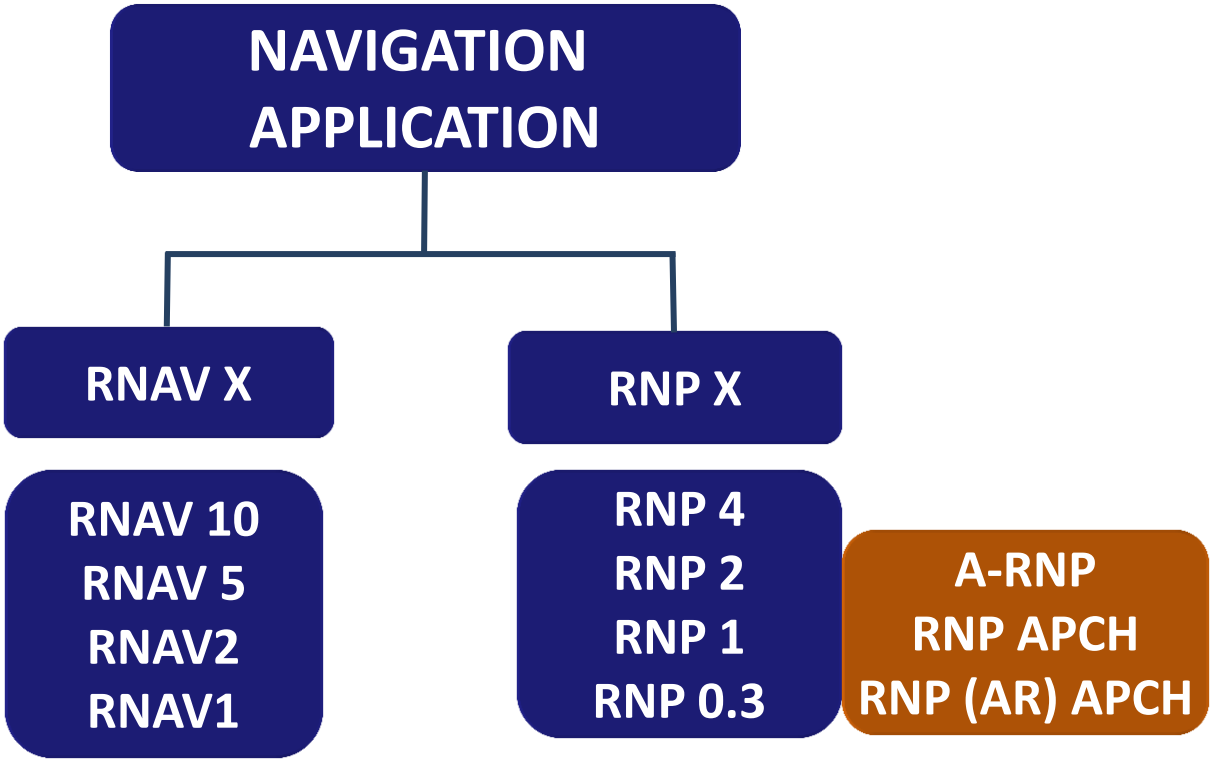


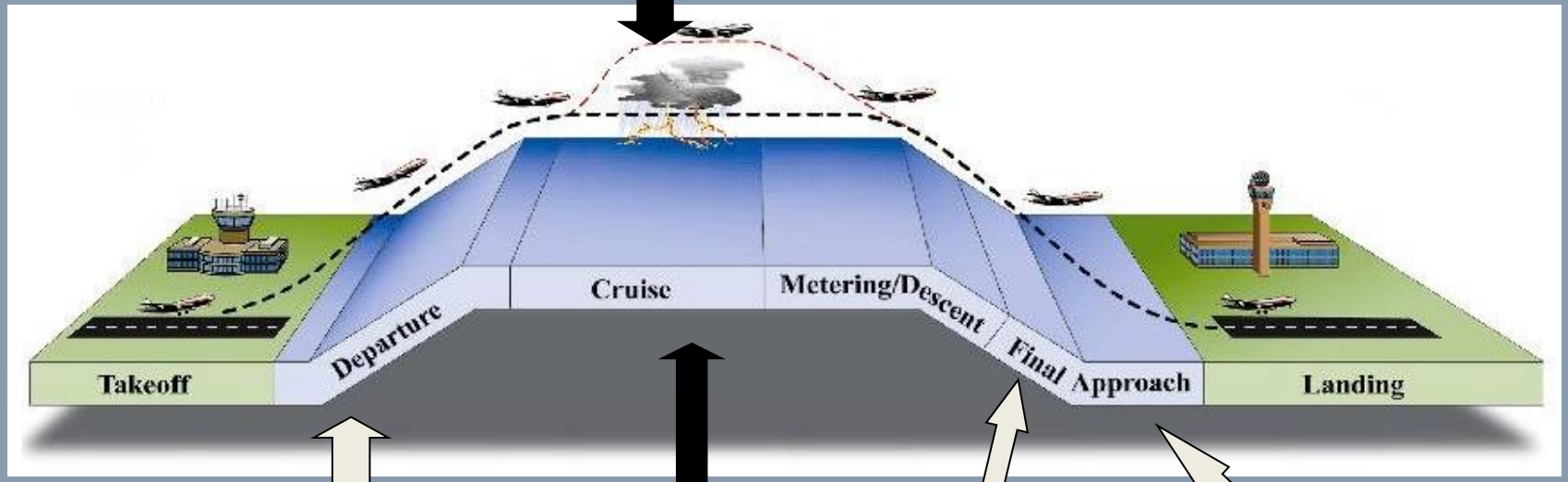
Components of PBN Concept



X = Navigation Accuracy in NM 95% of flight time

Navigation Application

OCEANIC / Enroute Remote (nonSUR)
RNAV 10, RNP 4, RNP 2, Advanced RNP 2



RNAV 1/2 &
RNP 1 SIDs
ARNP 1 SIDs

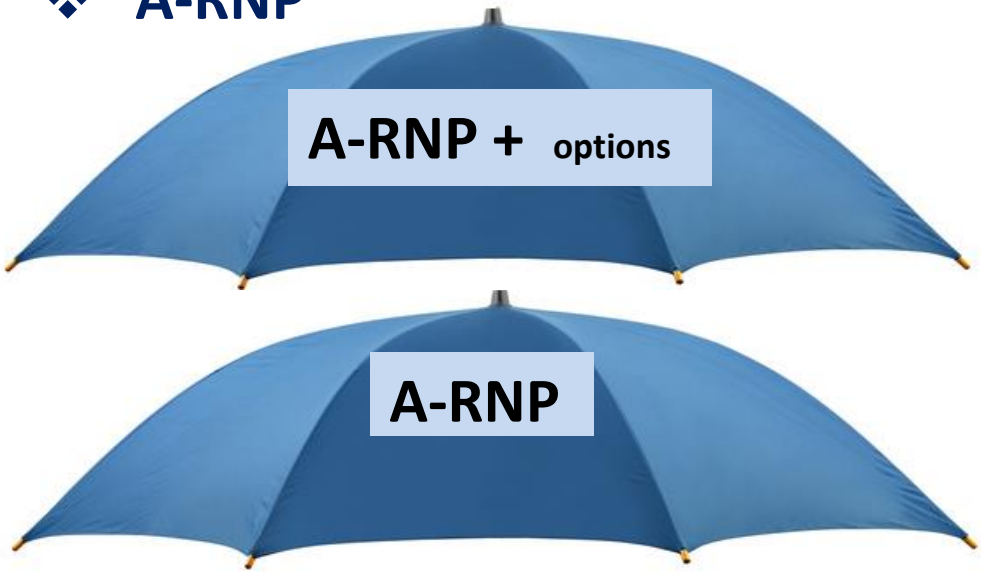
RNAV 5/2/1
RNP 2
Advanced RNP 2 or 1
Enroute Continental

RNAV 1/2 &
RNP 1 STARs
ARNP 1 STARs

RNP Approach
ARNP Approach
RNP-AR Approach

Navigation Application

❖ **A-RNP**



- Optional Performance/Functionality
- RNP Scalability
- RNP 2 oceanic/remote
- Fixed Radius Transition (FRT)
- Time of Arrival Control
- Barometric VNAV

RF legs

Parallel offset

RNAV holding

Continental enroute: RNP 2, 1

Final approach: RNP 0.3

RNAV 1

RNAV 2

RNAV 5

RNP 1

RNP APCH

RNAV 10

RNP 4

Navigation Application

❖ Navigation Specification vs. Navigation Infrastructure

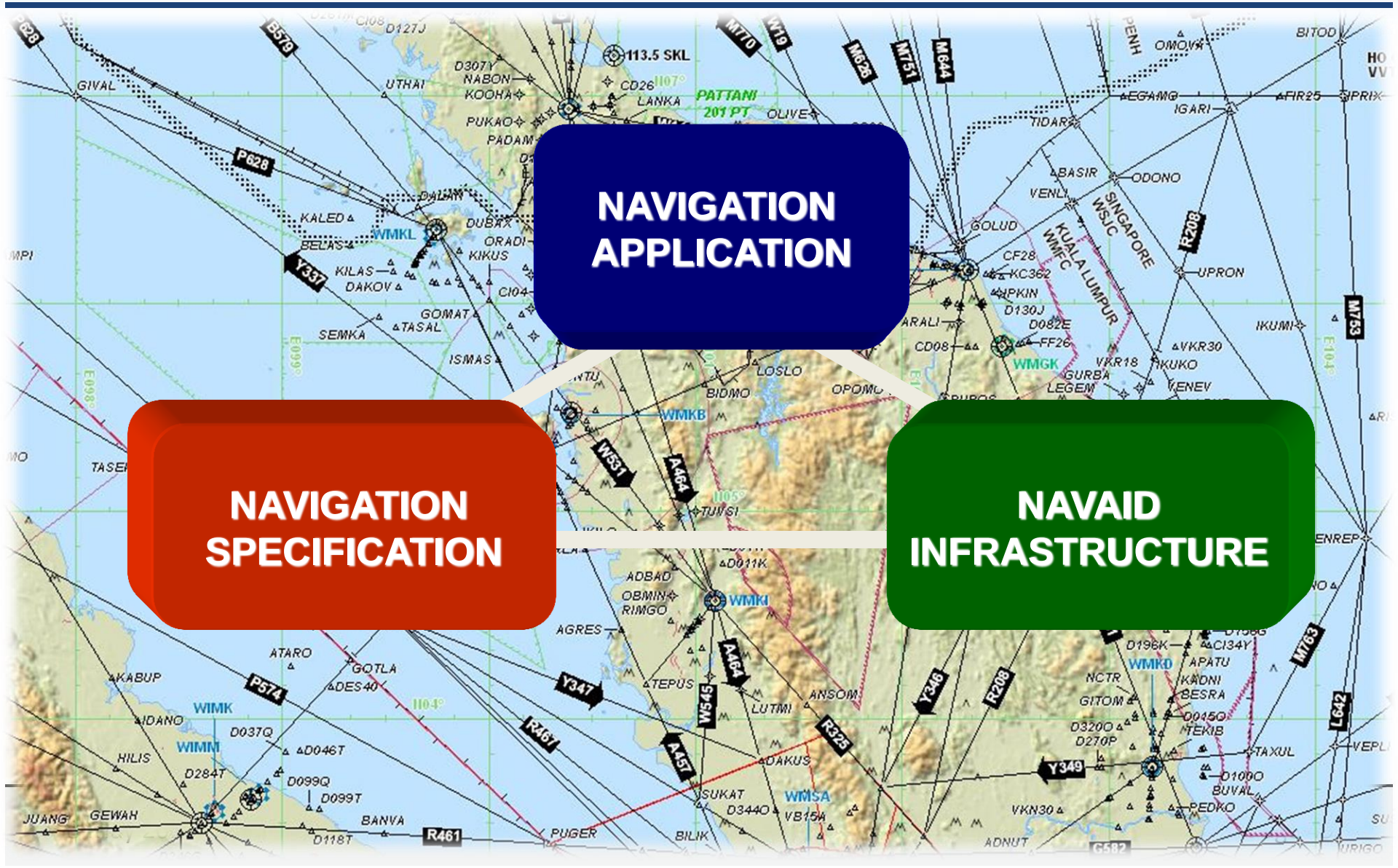
	GNSS	IRU	D/D	D/D/I	VOR/D
RNAV-10	X	X			
RNAV-5	X	X	X	X	X
RNAV -1 and RNAV -2	X		X	X	
RNP-4	X				
RNP-2	X				
RNP-1	X				
Advanced RNP	X				
RNP APCH	X				
RNP AR APCH	X				
RNP 0.3	X				

Navigation Application

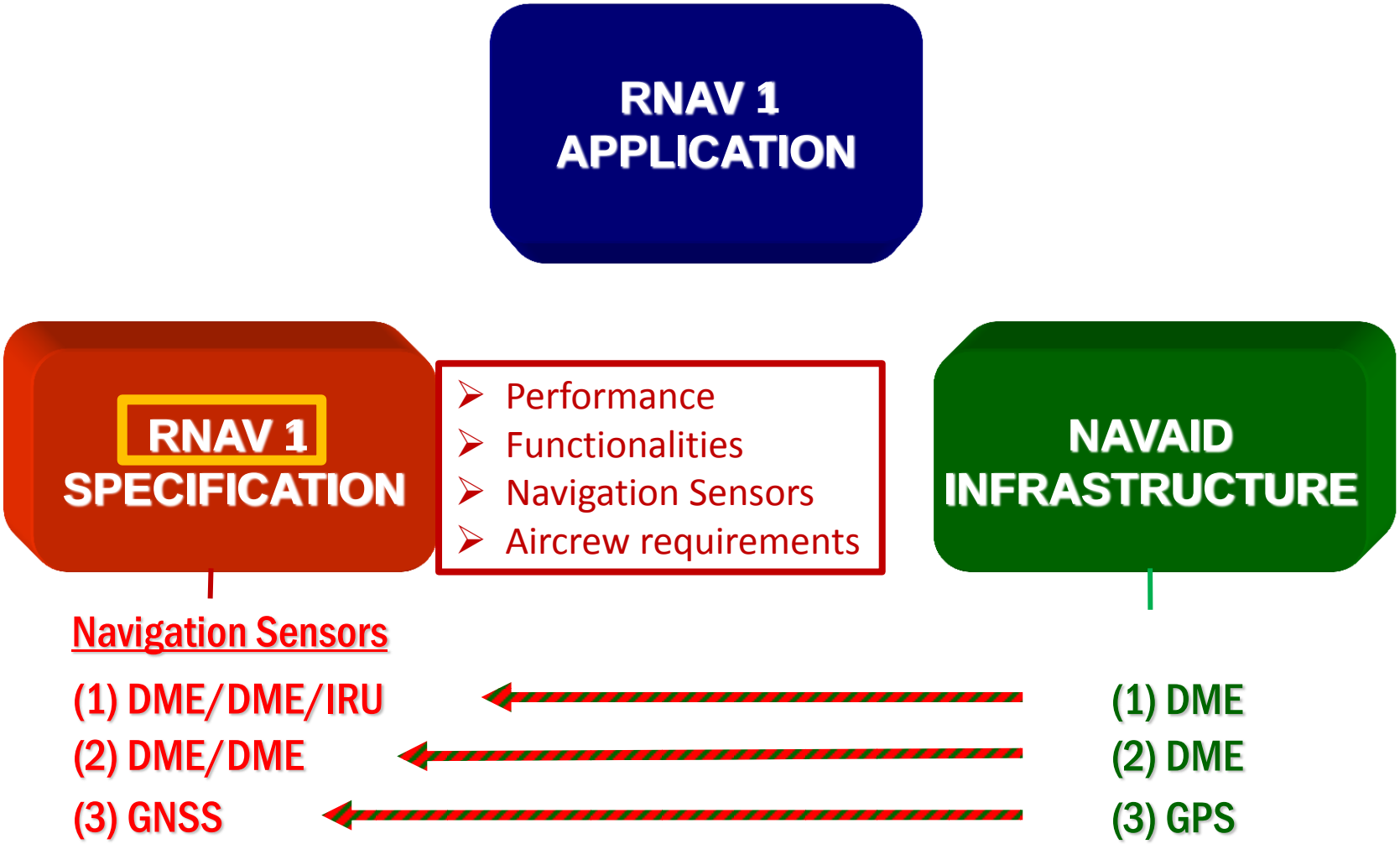
- **Link between Airspace Design and PBN**
  - **Separation minima in procedural environment;**
  - **Configuration/proximity of ATS Routes (including SIDs, STARs and IFP) for an airspace organization;**
  - **Above determined in part, *but not exclusively by*:**
    - **Area navigation system performance stipulated in the Navigation Specification (required for operation in an airspace)**

Accuracy
Integrity
Continuity

Components of PBN Concept



Example : RNAV1 Specification



Example : RNAV1 Specification

STATE A

STATE A
RNAV 1
APPLICATION

STATE A
RNAV 1
SPECIFICATION

NAVAID
INFRASTRUCTURE

Navigation Sensors

(1) DME/DME/IRU ← (1) DME

(3) GNSS ← (3) GPS

Example : RNAV1 Specification

STATE B

STATE B
RNAV 1
APPLICATION

STATE B
RNAV 1
SPECIFICATION

NAVAID
INFRASTRUCTURE

Navigation Sensors

(1) DME/DME/IRU ← (1) DME

(2) DME/DME ← (2) DME

Example : RNAV1 Specification

STATE C

STATE C
RNAV 1
APPLICATION

STATE C
RNAV 1
SPECIFICATION

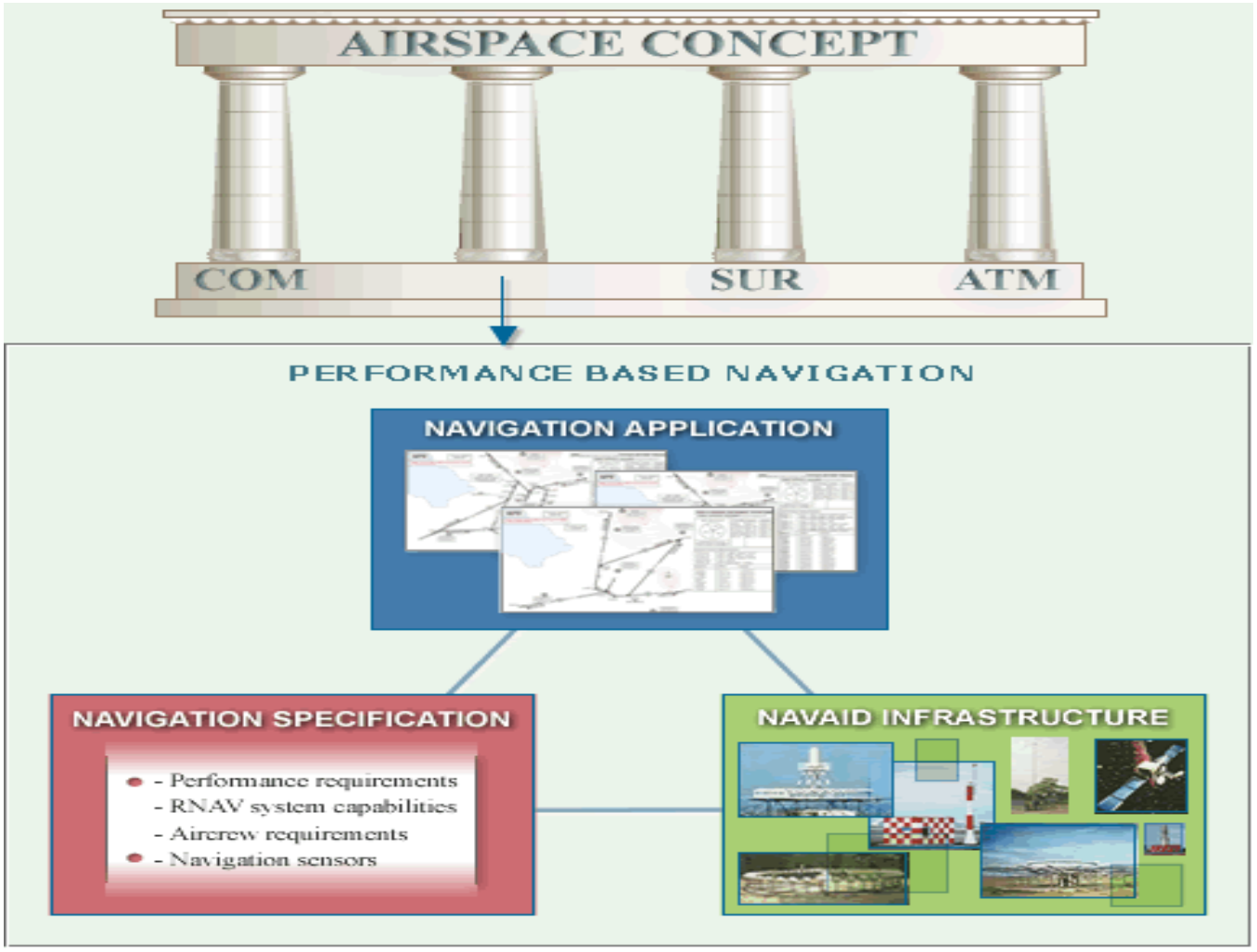
NAVAID
INFRASTRUCTURE

Navigation Sensors

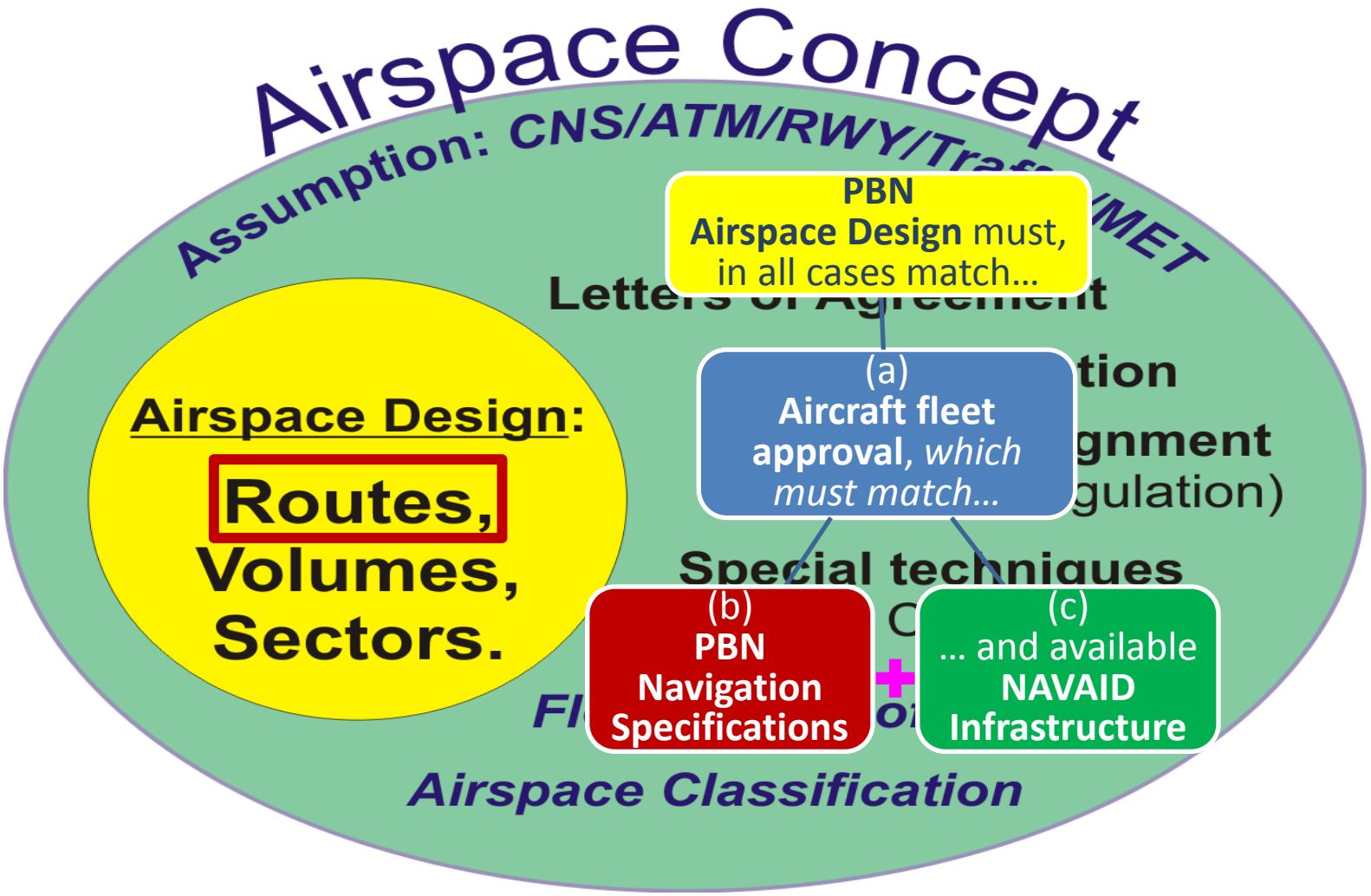
(3) GNSS

(3) GPS

PBN as the 'N' Element of Airspace Concept



Airspace Concept

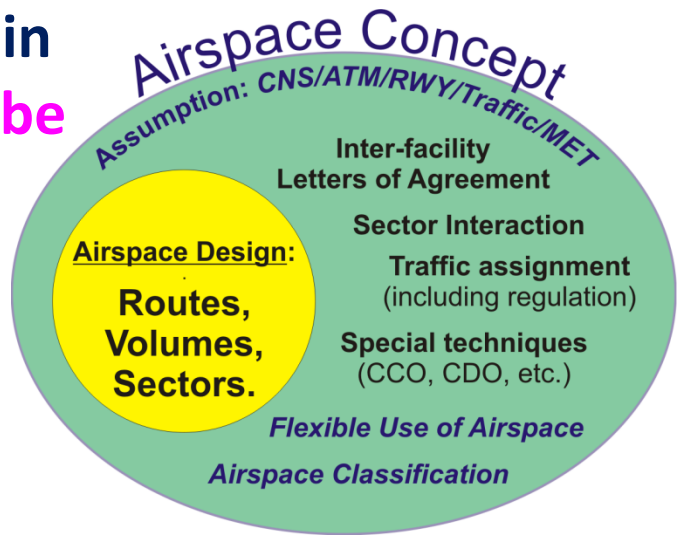


Stakeholder uses of PBN

- **Airspace Planners and procedure designers use PBN for spacing ATS routes, procedural aircraft separation minima and procedure design (obstacle clearance)**
- **Airworthiness and regulatory authorities ensure that aircraft and aircrew satisfy the operating requirements of the intended RNP or RNAV application**
- **Aircrew and ATC must know pilot/aircraft PBN qualification**

Current Limits of PBN

- To apply an RNAV/RNP specification in an airspace, it is necessary to prescribe the performance to an ATS route
- In context, an ATS route is one designated in accordance with ICAO Annex 11, Appendix 1 or Appendix 3
- Thus for ATM purpose
  - DCT tracks are excluded
  - So are company routes



- Navigation performance cannot be specified to a route which is not an ATS route
- The notion of 'PBN airspace' is yet to be developed

ATS routes and PBN

- Navigation Performance cannot specified to a route which is not a designated ATS route
- Designated ATS route are packed into the navigation database and navigation performance requirement designated to the route
- Thus GOOD and high INTEGRITY data are essential to PBN
- The related criteria for aeronautical data management exist in ICAO Annex 15

What's new with PBN

- PBN requires the use of an on-board RNAV system;
- PBN creates requirements for airworthiness certification and operational approval to use RNAV system in airspace implementation;
- The RNAV system's performance and the general operation must conform to the requirements stipulated in the relevant ICAO navigation specifications

Benefits of PBN

- **Transition to a total RNAV/RNP environment**
  - Flight efficiency, optimization of airspace etc.
- **PBN systematizes RNAV and RNP**
  - Avoid proliferation of standards (cost for certification)
- **RNP allows increased reliance on area navigation**
  - Closer routes
  - Avoid need to cross check against point source NAVAIDs (e.g. VOR)
- **Infrastructure**
  - Once Dual GNSS (supported in certain dense airspace by DME)
  - VOR and NDB can be decommissioned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Questions?


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Thank You