AFI Flight Operations Safety Awareness Seminar (FOSAS)

Performance-Based Navigation
PBN

ICAO/Airbus
Nairobi, 19-21 Sep. 2017
History

Aircraft Navigation
From Conventional to PBN

1920
1930
1920- First Step toward Instrumental flight

LE PERTHUS (Pyr. Or) — Phare de la ligne aérienne
Barcelone-Perpignan-Toulouse

1923
Aeronautical lighthouse

First NAVAID at night!
1920 - 1930 The pioneers of instrumental flight

- 1929
  First Instrumental flight by Jimmy Doolittle

- 1930's
  ILS, gonio, NDB, VOR...

- 1938
  First ILS approach

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

Aircraft Navigation
From Conventional to PBN

1920
1930
1970's
1980's
1990's
Up to 1970’s- ILS and NAVAIDs era

DME: Distance Measurement Equipment
VOR: VHF Omni Range
Up to 1970’s- ILS and NAVAIDs era

+ Precision Approach
  ILS with vertical guidance

+ Non Precision Approach
  Navaids (VOR DME)

No complex system onboard

Based on ground facilities
Aircraft Navigation
From Conventional to PBN

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

FMS+IRS: revolution in the cockpit
**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**

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1990’s - The GNSS – Global Navigation Satellite System

SA Transition -- 2 May 2000

Bring accuracy and integrity on position

PBN concept
the Navigation Performance

PBN: Performance Based Navigation
RNP AR: required Navigation Performance with Authorization required
RNP objectives

RNP AR Approach
Queenstown RWY 05

Sept 19-21, 2017 ICAO/Airbus FOSAS
RNP objectives

Give access to remote areas

Vagar

Lhassa

Queenstown
PBN in terminal Area to face congested airspace

Manage
High density Traffic
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
From a specific to a wide use of RNP

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

RNP 1
RNP APCH
A-RNP
RNP AR

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
PBN Concept: Positioning

**Total System Error**

- **Path Definition Error (PDE)**
- **Guidance Error (GTE)**
- **XTK**
- **Position Error (NSE)**

**computation**

- **Desired path**
- **Coded path**
- **Total System Error**
- **Real aircraft position**
- **Computed aircraft position**

**PDE (Path Definition Error)**
**FTE (XTK Error)**
**NSE (Position Error)**
The GNSS – Global Navigation Satellite System

+ GNSS Position
+ Accuracy parameter
+ Integrity parameter
PBN Concept: Design of a RNP or RNAV procedure

+ On-board position error estimated

Accuracy
PBN Concept: Design of a RNP or RNAV procedure

+ On-board position error estimated

Accuracy

Integrity
PBN Concept

**Accuracy criteria**

TSE 95% < 1 RNP

Under normal condition

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

+ **Integrity criteria**

TSE $99.999\% < 2 \text{ RNP}$

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

Demonstration considering probable failure
  • Guidance failures $\rightarrow$ impact on FTE
  • Navigation failures $\rightarrow$ impact on NSE
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.
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
External Monitoring
ATC (mode S, ADS-B, ....)

On-Board Monitoring
TSE

NSE: Navigation System Error
FTE: Flight Technical Error

Accuracy
Integrity

NAV ACCURACY
GPS PRIMARY

OBPMA
<table>
<thead>
<tr>
<th>Navigation Specification</th>
<th>Navigation Accuracy (NM) per flight phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>En-route</td>
</tr>
<tr>
<td></td>
<td>Oceanic</td>
</tr>
<tr>
<td>RNAV 10 (RNP 10)</td>
<td>10</td>
</tr>
<tr>
<td>RNAV 5</td>
<td>5</td>
</tr>
<tr>
<td>RNAV 2</td>
<td>2</td>
</tr>
<tr>
<td>RNAV 1</td>
<td>1</td>
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<tr>
<td>RNP 4</td>
<td>4</td>
</tr>
<tr>
<td>RNP 2</td>
<td>2</td>
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<tr>
<td>RNP 1</td>
<td>1</td>
</tr>
<tr>
<td>RNP APCH</td>
<td></td>
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<tr>
<td>RNP AR APCH</td>
<td></td>
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</tbody>
</table>
ADVANCED RNP (Advanced features: RF, FRT, …)

RNAV
On Board Perf. Monitoring and Alerting system not mandatory

- EN-ROUTE
  - RNAV 10
- TERMINAL
  - RNAV 5
  - RNAV 1
  - RNAV 2

RNP
On Board Perf. Monitoring and Alerting system mandatory

- EN-ROUTE
  - RNP 4
- TERMINAL
  - RNP 2
  - RNP1
- APPROACH
  - RNP APCH
  - RNP AR APCH

RNAV: Area Navigation
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
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

Conventional ILS

RNP 1
or RNAV 1

A-RNP

RNP APCH

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

- Compliance: All Airbus aircraft
- Airspace example: SIDs or STARs
RNP 1 (BRNP1 or Basic RNP1)

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

+ Overlay of existing procedure

+ RNP value 0.3NM in final

+ Decongestion of Terminal Airspace
RNP APCH

Concept:

+ **Straight approach** after FAF

+ **RNP 0.3 NM** in Final Leg

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

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPV DA</td>
<td>737/45</td>
<td>411 (500-7/6)</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>LNAV/VNAV DA</td>
<td>927-1 1/2</td>
<td>601 (600-1 1/2)</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>LNAV MDA</td>
<td>1000/40</td>
<td>674 (700-3/4)</td>
<td>1000-1 1/2</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>674 (700-1 1/2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CIRCLING</td>
<td>1000-1</td>
<td>669 (700-1)</td>
<td>1080-2 1/4</td>
<td>749 (800-2 1/4)</td>
</tr>
</tbody>
</table>

Sept 19-21, 2017 ICAO/Airbus FOSAS
RNP APCH concept

RNP APCH
with LNAV Minima

IAF

MOC: Min 1000ft

IF

MOC: Min 500ft

FAF

MDA
RNP APCH concept

RNP APCH with LNAV/VNAV Minima

MOC: Min 1000ft

MOC: Min 500ft

IAF

IF

FAP

DA

OCS
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)
RF legs

Without RF legs

Fixed bank flight – by

Not a repeatable trajectory
ADVANCED RNP: RF legs

With RF legs

Fixed trajectory

Radius

Bank adapted to the trajectory
ADVANCED RNP: RF legs

Smaller protection zone
Gain of Airspace

Without RF legs

With RF legs
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
RNP AR in traffic-challenging environment

+ Late turn

+ Closely Space Parallel Operation
### Current Airbus RNP AR MOD

<table>
<thead>
<tr>
<th>A320 family</th>
<th>RNP AR MOD Limited to 0.3 NM</th>
<th>Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>A330</td>
<td></td>
<td>Option</td>
</tr>
<tr>
<td>A340-500/600</td>
<td></td>
<td>Option</td>
</tr>
<tr>
<td>A380</td>
<td></td>
<td>Option</td>
</tr>
<tr>
<td>A350</td>
<td>Basic RNP AR 0.10 NM</td>
<td></td>
</tr>
</tbody>
</table>

#### RNP AR MOD Below 0.3 NM

<table>
<thead>
<tr>
<th>A320 family</th>
<th>Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>A330</td>
<td>Option</td>
</tr>
<tr>
<td>A340-500/600</td>
<td>Option</td>
</tr>
<tr>
<td>A380</td>
<td>Option</td>
</tr>
</tbody>
</table>

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RNP AR 0.3 NM will be soon available on A300-600/A310 (Cockpit Upgrade)
Link with existing operations Sum Up

**PBN**

- RNAV 10
- RNAV 5
- RNAV 1
- RNAV 2
- RNP 4
- RNP 2
- Basic
- RNP1
- RNP APCH
- RNP AR APCH

**ADVANCED RNP**

- AC90-105

**EXISTING OPERATIONS**

- RNP 10
- B-RNAV
- P-RNAV
- Terminal RNAV
- RNP 4
- RNP 1 (TERMINAL)
- RNAV (GNSS)
- RNAV (RNP)

**AC20-130A**

- FAA order 8400.12A

**AMC20-4**

- AC90-96

**TGL10**

- FAA Order 8400.33

**AC90-100A**

**AC90-101A**

**AC90-105**

**AMC 20-27**

**AMC 20-26**

**Not yet referenced**

19-21 Sep, 2017 ICAO/AIRBUS FOSAS, Nairobi
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 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
## Operational Approval

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

PBN

PBN Concept

GNSS augmentation

Aircraft Design

Next Step
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
GBAS Landing System: GLS

GNSS constellation
GLS: Data transmitted to the A/C

- GPS augmented position by VHF
- Final Approach Segment data by VHF
  - Anchor point coordinate
  - Course
  - Slope

MMR computes a virtual beam

- Flown in G/S | LOC
xLS concept: GLS

- Same guidance mode as ILS
  - Geometric
  - Common FCOM/SOP for all straight in approaches
GBAS on charts: GLS approach

Charted as GLS

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

+ **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

More and more deployed
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
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
xLS concept: SLS

Same guidance mode as ILS

- Geometric
- Common FCOM/SOP for all straight in approaches
SBAS on charts: LPV minima

TOULOUSE, FRANCE
RNAG (GNSS) Rwy 32L

+ 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)
Agenda
PBN

PBN Concept
GNSS augmentation
Aircraft Design
Next Step
AIRCRAFT POSITION

Based on different position sources

- Inertial position
  ADIRS
- GNSS position
  MMR
- Radio position
  NAVAIDs

→ FMS position
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)
Monitoring and Alerting: 

- 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.
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
MONITORING example on A320 aircraft

Example of GNSS loss in low RNP operations

- Total GNSS loss
- Integrity exceeds 2 RNP threshold
- Accuracy exceeds 1 RNP threshold

GNSS/Inertial position

- GNSS/Inertial position: Based on last valid GNSS
- IRS only position

Integrity OK Accuracy OK

Integrity not monitored Accuracy OK

GPS PRIMARY LOST on PF/PM displays

NAV ACCUR DOWNGRAD on PF/PM displays
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)
Flight Guidance modes

With Managed Modes

+ NAV mode

+ Approach modes
  - FPA|NAV
  - FINAL APP
  - APP-DES|NAV (A350)
  - FLS
  - SLS
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**
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
GLS/SLS/FLS: computation of the virtual beam

MMR computes a virtual beam

- Final Approach Segment data
- Anchor point coordinate
- Course
- Slope

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

- Flown in G/S | LOC

MMR: Multi-Mode Receiver
## APPROACH MODES: xLS concept

<table>
<thead>
<tr>
<th>xLS mode</th>
<th>Source used for lateral deviations</th>
<th>Source used for vertical deviations</th>
<th>Final approach segment data</th>
<th>Type of approach</th>
<th>Lowest minima</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLS</td>
<td>IRS/GNSS</td>
<td><strong>Barometric</strong> Altitude With temperature compensation</td>
<td>From NDB onboard</td>
<td>NDB, VOR RNAV(GNSS) LNAV, LNAV/VNAV</td>
<td>250ft</td>
</tr>
<tr>
<td>SLS</td>
<td>GNSS augmented SBAS</td>
<td>GNSS SBAS Altitude <strong>Geometric</strong></td>
<td>FAS data block onboard</td>
<td>RNAV(GNSS) LPV</td>
<td>200ft</td>
</tr>
<tr>
<td>GLS</td>
<td>GNSS augmented GBAS</td>
<td>GNSS GBAS Altitude <strong>Geometric</strong></td>
<td>Transmitted by VHF Ground station</td>
<td>GLS</td>
<td>CAT I 200ft</td>
</tr>
<tr>
<td>ILS</td>
<td>LOC signal</td>
<td>G/S signal <strong>Geometric</strong></td>
<td>N/A</td>
<td>ILS MLS</td>
<td>CAT IIIB 0ft</td>
</tr>
<tr>
<td>MLS</td>
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</tbody>
</table>
On-Board Monitoring
TSE

NSE
Accuracy
Integrity
NAV ACCURACY
GPS PRIMARY

FTE
XTK

OBPMA

Operational use

COCKPIT HMI

On-Board Monitoring
TSE

NSE
Accuracy
Integrity
NAV ACCURACY
GPS PRIMARY

FTE
XTK

OBPMA

Operational use
COCKPIT HMI – Lateral excursion monitoring

- XTK on ND
- L/DEV on PFD
- xLS deviations
COCKPIT HMI – Vertical excursion monitoring

V/DEV on PFD

xLS deviations
Agenda

PBN

PBN Concept
GNSS augmentation
Aircraft Design

Next Step
Next Steps: Regulation changes on PBN

RNP will be basic in the Future

RNP will be basic in the Future
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**