RNP AR in Sweden

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RNAV evolution in Sweden

• RNAV arrivals 1986-1994
• Early GPS trials 1997-1998
• All Swedish airspace based on RNAV 1998
• 60 RNAV SIDs at Stockholm-Arlanda 2002-2003
• Baro-VNAV trials from 2004
• RNP AR curved approach trials 2005
• First Baro-VNAV approach published 2007
• First operator approved for Baro-VNAV 2009
• First RNP AR approach published 2009
• First operator approved for RNP AR 2010
RNAV arrivals to ILS LOC

- CAA cooperation with SAAB 340 operator Swedair led to trials with RNAV arrivals to ILS LOC
- After one year’s trials the procedure was approved for operational use 1986
- Later two more RNAV arrivals were approved
- The procedure was based on the use of RNAV equipment King KNS-660 with sensors:
  - DME/DME with high accuracy
  - VOR/DME with medium accuracy
  - OMEGA/VLF always failed when most needed (Canada)
  - Optional GPS not useful due to small number of satellites
Trials with GPS approach

• Design & trials with GPS to ESSP airport with Beech 1900 from 1997. Not successful due to faulty aircraft wiring from factory between GPS and A/P. Switched to half bank in procedure instead of full.

• Design & trials with GPS to ESSL airport with SAAB 340 and F-50 from 1999 (updated procedures published in AIP SUP 2004 for restricted use).

• Approval of GPS approach postponed due to delayed replacement of TGL-3 with AMC 20-27.

• First operator approval for GPS LNAV 2009.
Swedish airspace based on RNAV 1998

- B-RNAV was implemented in ECAC April 1998
- In October 1998, Swedish airspace changed from old airway system to a B-RNAV based route system
- Several problems were discovered during first day
  - Many big air carriers airplane FMS were not updated
  - Some pilots had not brought new maps (AIS copied maps)
  - Many pilots had not updated their Route Manuals (delays)
  - Many company routes were not updated for new airspace
  - One incident when a plane suddenly turned 90 degrees to head for a beacon in Latvia instead of a Swedish VOR caused by a mistake in manual input of FMS route
60 RNAV SIDs at Stockholm ESSA

- A new runway should open 2002 and needed 4 new VORs and 2-3 new NDB beacons
- RNAV based SID/STAR system was investigated, but SAS MD-80 FMS (without IRS) was not updated in time to make the first turn in a SID
- With 3 new low-effect DME stations around the airport, the MD-80s got an early DME/DME update
- Later two new DMEs on the TMA border made Arlanda to be “probably the best DME-equipped airport in the world”
DME-coverage at Stockholm/Arlanda TMA

1. DME-stations (1000 W) for BRNAV enroute use (ARL, HMR, TEB, TRS)
2. DME-stations (100 W) for RNAV SIDs (ANE, ANW, ASW)
3. DME-stations (1000 W) for complete TMA coverage (ARS, NTL)
Straight-in Baro-VNAV at ESTA

- Design of first Baro-VNAV procedure to Angelholm ESTA airport 2003
- Baro-VNAV trials ESTA under VMC with SAS B737 from 2004
- Delayed approval for public use, due to unclear rules in PANS-OPS for Baro-VNAV
- Updated version of PANS-OPS in March 2007
- First operator approval 2009 based on AMC 20-27
Climb on 314° to 1200, turn right to 417 AH climbing to 2000.
RNP AR approach trials at ESGG

- Design of an RNP AR arrival for Gothenburg ESGG airport started 2009
- Two RF turns lead in to an Baro-VNAV approach from 1000 ft
- Trial flights in VMC started 2010 with Novair A321
- Today 50 successful flights have been completed
- Goal for this project is 100 flights
- Benefit is a 3 min shorter flight, 150 kg less fuel burn and 500 kg less CO₂ emissions
- 

8.1.pdf

8.2 Novair A321.ppt
RNP AR Operation

Novair A321
The inability to achieve the required lateral navigation accuracy may be due to navigation errors related to aircraft tracking and positioning.

The three main errors in the context of on-board performance monitoring and alerting are Path Definition Error (PDE), Flight Technical Error (FTE), and Navigation System Error (NSE).
Path Definition Error (PDE) occurs when the path defined in the RNAV system does not correspond to the desired path, i.e. the path expected to be flown over the ground. The PDE has been demonstrated negligible, provided there is no systematic error such as navigation database coding error or error due to inadequate geodetic reference (other than WGS84).

Flight Technical Error (FTE) is a characteristic of the pilot performance using FD or AP guidance performance in the steering of the aircraft on the FMGS defined flight path.

Navigation System Error (NSE) is the error made by the navigation system in the computation of the aircraft position. The NSE has a circular statistical distribution around the aircraft true position. From this circular distribution, it is possible to derive a cross-track component of the NSE, which is relevant for the RNP lateral navigation.
**Estimated Position Error (EPE)**

**EPE:** The FMGC position is estimated with a 95 % probability to be within a circle of uncertainty. The estimated circle radius is shown on the PROGRESS page in the MCDU. By comparison of REQUIRED value with ESTIMATED value, the system determines a HIGH/LOW accuracy level.
**Estimated Position Error (EPE)**

EPE (Estimated Position Error) is a radial estimation of the navigation error and is more conservative than the statistically demonstrated NSE.
An amber message, “GPS PRIMARY LOST”, is displayed at the bottom of the ND (Navigation Display) and in the scratchpad of the MCDU (Multipurpose Control & Display Unit), when GPS PRIMARY capability is not achieved, associated with a “triple click” via the loudspeakers.
There is no automatic callout or alert when the FTE exceeds the budget allocated to ensure that the RNP is achieved. To be monitored by crew. (Extreme winds in the simulator is needed to generate this exceedance)

The FTE = XTK = 0,2 L NM
RNP AR approaches are only authorised based on GNSS as the primary navaid infrastructure.

RADIONAV to be deselected in order to use GPS/IRS as sole navigation source.
GNSS Navigation
OSNAK 1X transition to RNAV (RNP) ESGG RWY21
After OSNAK (TMA entry point)
After IAF

RNP = 0.3

EPE typically 0.08

[Image of flight display with approach information]
APP NAV ENGAGEMENT CONDITIONS:

Engagement conditions of APP NAV (Approach Nav laterally):

- A Non Precision Approach is selected in the Navigation Database (NDB) and,
- The FMGS is in approach phase (The flight area begins 5 NM before the 1st approach point in the database for the destination airport) and,
- APPR push button is selected and NAV mode is engaged or the NAV mode is armed (provided aircraft is above 400 ft AGL).

*If HDG/TRACK is engaged, APP NAV engages when the intercept conditions are met.*
Flight guidance prior to FAP

APP NAV is identical to NAV mode in terms of logic and performance
Flight guidance after FAP

FINAL APP on the FMA (Flight Mode Annunciator)

Each dot represents 100 feet
THANKS TO NOVAIR

For questions, contact
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Performance & Ecology Manager
e-mail: henrik.ekstrand@novair.se
mobile: + 46 708 87 02 08
Problems with Stockholm ESSA new rwy

• Was built too close to noise sensitive area
• Environment court has decided no flights allowed to fly over sensitive area from year 2018

9.1.pdf

• Was planned for a curved MLS approach, but no MLS is used for curved approach (risk of pilot error when entering turn data into the MLS system)
• New plan for a VOR approach with a 25° turn at 400-500 ft was OK, until ICAO reduced the turn to be max 15° (30° was allowed in old PANS-OPS)
• An offset LOC was tested in SIM for 15° turn at 500 ft. The result – not OK at night in low visibility!
Solution for ESSA is RNP AR

- RF leg coding developed for B737 in Smiths’ PDT (Procedure Design Tool for standard PC). Good result for heavy airplane in 40–50 knots crosswind
- Coding: [10.1.pdf](#) and plotting: [10.2.pdf](#)
- SIM trials 2004: [10.3.pdf](#) and plotting: [10.4.pdf](#)
- 5 production flight trials in VMC 2005: [10.5.pdf](#)
- Lateral procedure: [10.6.pdf](#) and vertical: [10.7.pdf](#)
| Route | Route Type | Path To | Wypt Hdg/Desc | Dir | Turn Altitude | Speed | Rec Limit | Time/Dist/Rad | Fix Radial | Vert Angle | Arc Center | RNP Val | To Fix Latitude | To Fix Longitude |
|-------|------------|---------|----------------|-----|---------------|-------|------------|--------------|------------|------------|------------|----------|-----------|----------|---------|---------------|----------------|
| FINAL | IF         | +SA1    | E              |     | +5000         | 220   |            |              |            |            |            |          | 302       | N59°27'03.--E018°11'44.-- |
| FINAL | TF         | *SA2    | E              |     |               | 200   |            |              |            |            |            |          | 302       | N59°28'56.--E018°00'37.-- |
| FINAL | TF         | *SA3    | E              |     |               | 180   |            |              |            |            |            |          | 302       | N59°31'01.--E017°59'44.-- |
| FINAL | RF         | *SA4    | E              | L   |               | 180   |            |              |            |            | *C3       |          | 302       | N59°32'24.--E017°57'52.-- |
| FINAL | RF         | *SA5    | E              | R   |               | 180   |            |              |            |            | *C4       |          | 302       | N59°34'26.--E017°55'54.-- |
| FINAL | CF         | RW01R   | G              | 7.0 | 188           | 150   | ARL        |              |            |            |            |          | 302       | N59°37'35.--E017°57'03.-- |
| FINAL | FM         | RW01R   | GEM            | 7.0 | +600          |       | ARL        |              |            |            |            |          | 302       | N59°37'35.--E017°57'03.-- |

<table>
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<tr>
<th>Arc Center ID</th>
<th>Arc Center Latitude</th>
<th>Arc Center Longitude</th>
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</thead>
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<tr>
<td>*C3</td>
<td>N59°30'53.--E017°56'11.--</td>
<td></td>
</tr>
<tr>
<td>*C4</td>
<td>N59°34'06.--E017°59'23.--</td>
<td></td>
</tr>
</tbody>
</table>
wind 090°/40kt
Test i FFS B737-700 040321

Procedur: STAR SA01R8
           APPR R01R7

RNAV-krav: RNP-RNAV

Vind: 090°/40 kt

Vikt: GW 66 ton (MLW för B737-800, dvs simulerade den högsta MLW som gäller för B737-800)

Väder: CAVOK

Resultat: Se bilaga 3.
SA1: ~ 5000 ft och ungefär 240 kt IAS.
SA2: ~ 3300 ft och ungefär 220 kt IAS. Bankning ~ 25°.
Mellan SA2 och SA3 tas landstället ut
SA3: ~ 2300 ft och ungefär 180 kt IAS. Bankning ~ 20°.
SA4: ~ 1900 ft och ungefär 150 kt IAS. Bankning ~ 10°.
SA5: ~ 1200 ft och ungefär 140 kt IAS.

En mycket lugn och fin inflygning utan några problem.

Piloternas synpunkter: Viktigt att konfigurera i tid i början av inflygning mellan SA1 och SA2. Reducera farten till 220 kt IAS vid SA1.
Attachment 1b
Lateral protection area
cat C/D

LFV/ASD
M Ullvetter 090427
Attachment 3 "Vertical assessment surface cat D"

RNP 0.3 in the Final combined with a conventional Missed approach.
Highest obstacle in Final surface is TWIR 73.1 m above THR 01R.
As this obstacle is not a Missed approach obstacle, only HL (49 m cat D) is required to add to the obstacle height.
The Missed approach procedure requires straight ahead climb until 600 ft MSL or ASE DME 1.0 (past ASE DME) whichever is latest, is obtained. That means that there will not be a turn below 600 ft MSL and this also means that, if the ACFT turns at 600 ft MSL the ACFT will still have more than 50 m MOC to all obstacles when turning.

OCA/H 600(470)

THR01R 41.1 m MSL
The linear measure is unchanged.
The vertical measure is multiplied with 10.
The height at obstacle is in MSL.
Scale 1:100 000
LFV/ASD
M Ulvetter 090427

VPA = Vertical Path Angle
VEB = Vertical Error Budget
HL = Height Loss
RDH = Reference Datum Height
In case of COM FAILURE see proc on IAC 10

TEMP RESTRICTION
Baro-VNAV Proc NA below -15°C

Special Authorization for RNP AR required from Swedish CAA.
Approval for Baro VNAV required. RNP 0.3 and RF-leg required.

See Chart

Climb on 006°. At 600 or D1 after ASE whichever, is latest, turn right 040° and climbing to 1500. RAD vectors for new APCH.

Note: Circling NA
First RNP AR approval in Sweden

• 5 years waiting for AMC 20-26 (and 20-27)
• Compliance list for 20-26 on request: 11.1.pdf
• SAS B737 RNP indicators: SAS B737 NPS.ppt
• RNP AR approval of SAS 2010
• SAS has now made 100 RNP AR approaches
B737 RNP INDICATORS
FMC RNP values

- Cruise: 2,0 nm (default)
- Off route/Oceanic: 5,0/12,0 nm (default)
- TMA <FL150: 1,0 nm (default)
- Appr: 0,5 nm (default)
- Appr: 0,3 nm (default)
- Appr w F/D: 0,15 nm
- Appr w A/P: 0,11 nm
- Appr w F/D or A/P: 0,10 nm (NPS req.)
Navigation Source

LNAV/VNAV is displayed as navigation source when either AFDS (Autopilot Flight Director System) LNAV or VNAV mode is engaged.

ILS is displayed as navigation source when APP or LOC is armed or active.
Navigation Performance Scales (NPS)

Magenta Deviation pointer: Indicate lateral path relative to the airplane. (X-track error)

White ANP bar indicates Actual (estimated) Nav Performance. If the ANP value increases, the ANP bars extend towards the centre indicator.

White vertical index has a **fixed** position and represents current FMC lateral RNP.
Lateral NPS on PFD (Primary Flight Display)

When entering airspace with different RNP, the new RNP is displayed on the MCDU (Multi-function Control & Display Unit).

- Deviation pointer sensitivity is changed.
- Room for manoeuvre changes with current ANP value.
- The RNP approach value (0.3) is automatically set as the FMC approaches the FAP or at a point programmed in the Nav Data Base.
As long as the NPS pointer is within the manoeuvrable area (RNP–ANP = manoeuvrable area), the ANP Bars are white.

If the NPS pointer enters the ANP Bar, the scales turn AMBER after 10 seconds and the NPS pointer start to flash at the same time.

If inside FAP: perform a missed approach as soon as the NPS pointer touch the ANP Bar.
Navigation Performance Scales

X-Track Error

High ANP value

Increased ANP value

Low ANP value

RNP / ACTUAL
1.00/0.75NM
RTE DATA>

RNP / ACTUAL
1.00/0.25NM
RTE DATA>

RNP / ACTUAL
1.00/0.05NM
RTE DATA>

1.00/0.75NM
RTE DATA>
Vertical NPS on PFD

White Vertical ANP Bars indicate vertical ANP the same way as lateral ANP

Magenta Vertical NPS pointer indicates vertical path relative to the airplane

Vertical RNP default value is 400 feet. Can be manually changed in FMC
Indications on Navigation Display (1)

White Path Deviation Band is a fixed line which always represents 400 ft.

Magenta Vertical Deviation Band, with a fixed pointer in the centre, represents the chosen RNP value. Here the value is set to 400 ft.

White triangle is airplane position. Here the XTK error is 1.8 L.
Indications on Navigation Display (2)

Magenta Vertical Deviation Band represents the chosen RNP value. Here the value is set to 125 ft.

For an RNAV approach a value of 125 ft shall be set. 75 ft (AMC 20-26) + 50 ft baro altimetry system fault

The magenta band slides up and down to show deviation from expected path

White triangle is airplane position. Here the XTK error is 0.7 L
With thanks to
SCANDINAVIAN AIRLINES

Contact: STC B737 SAS  jan-ove.starud@sas.se  +46 709 971024
### Extract from Compliance List RNP AR – EASA AMC 20-26

<table>
<thead>
<tr>
<th><strong>AMC 20-26 ref.</strong></th>
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#### GENERAL

A Baro-VNAV approval by an applicant’s National Aviation Authority is a prerequisite for an RNP AR approval.

#### 6. RNP AR Airworthiness Criteria

**6.1 ACCURACY**

Aircraft performance is evaluated around the path defined by the published procedure and EUROCAE/ED-75B, Section 3.2. All vertical paths used in conjunction with the final approach segment will be defined by a Flight Path Angle (EUROCAE/ED-75B, Section 3.2.8.4.3) as a straight line emanating from a fix and altitude.

**Displays**

Continuous Display of Deviation. The navigation system must provide the capability to continuously display to the pilot flying, on the primary flight instruments for navigation of the aircraft, the aircraft position relative to the defined lateral and vertical path (both lateral and vertical deviation) and manoeuvre anticipation. The display must allow the pilot to readily distinguish if the cross track deviation exceeds the RNP (or a smaller value) or if the vertical deviation exceeds +/- 75 feet (or a smaller value). Where the minimum flight crew is two pilots, means for the pilot not flying must be provided to verify the desired path and the aircraft position relative to the path.

To achieve this, an appropriately scaled non-

Date: 2010-03-19/Of
extract from compliance list RNP AR – EASA AMC 20-26

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<td>numeric deviation display (i.e. lateral deviation indicator and vertical deviation indicator) located in the pilot’s primary field of view may be provided. Alternatively: For lateral data presentation only For RNP 0.3 and above, - a navigation map display, readily visible to the flight crew, with appropriate map scales, giving equivalent functionality to an appropriately scaled non-numeric lateral deviation display, except that scaling may be set manually by the flight crew. or - a numeric display of the lateral deviation, readily visible to the flight crew, with a minimum resolution of 0.1 NM and direction relative to the track. For RNP &lt;0.3 - a numeric display of the lateral deviation, in the primary field of view, with a resolution of 0.01 NM and direction relative to the track. Note 1: A fixed-scale CDI is acceptable as long as the CDI demonstrates appropriate scaling and sensitivity for the intended navigation accuracy and operation. With a scalable CDI, the scale should be derived from the selection of RNP, and shall not require the separate selection of a CDI scale. Where a CDI is relied upon, alerting and annunciation limits must also match the</td>
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<td>scaling values. If the equipment uses default navigation accuracy to describe the operational mode (e.g. en-route, terminal area and approach), then displaying the operational mode is an acceptable means from which the flight crew may derive the CDI scale sensitivity.</td>
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Video from a SAS flight 2005

- In the video from 2005, the arrival from the north was not the same as today (RF turns not changed)
- The video will be stopped to view indicators
- Captain Orjan Goteman in the left seat has since been a PhD with a doctoral thesis on:  
  “Airborne Cognitive Systems in Search of an Appropriate Context”  
  - 12.1.pdf
- The “sweaty” pilot in the right seat is now SAS Director Flight Operations
- Conclusion: Work with RNP AR procedures, and your life will be successful!
Airborne Cognitive Systems in Search of an Appropriate Context

Studies of the introduction of new technology in aviation using a cognitive systems engineering approach

Örjan Goteman

Doctoral thesis

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