Combining Advanced-RNP with SBAS Guided Precision Terminal Area Paths and Final Approach Guidance
Exploiting All Benefits from Performance Based Navigation
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Overview

I. PBN and advanced RNP, Terminal Area Paths and SBAS guidance

II. Segmented and curved approach paths in Braunschweig
   A. Boundary Conditions
   B. Procedure Design
   C. Flight Test Setup
   D. Results

III. Missed Approach Guidance at Egelsbach
   A. Boundary Conditions
   B. Procedure Design
   C. Flight Test Setup
   D. Results

IV. Greater Impact and Conclusion
Combining Advanced-RNP …

- **RNP (Required Navigation Performance)**
  - Guidance generally provided by GNSS
  - Error must be smaller than specified value 95% of the time (i.e. RNP 0.3)
- **RNP AR**
  - Special Aircraft and Aircrew Authorization Required (SAAAR)
  - Approach Capable (RNP AR APCH)
  - Curved Legs (Radius to Fix) with precise ground track
- **Advanced RNP APCH**
  - Scaled Down version of RNP AR APCH
...with SBAS Guided Precision ...

- SBAS – Satellite Based Augmentation Systems
...Terminal Area Paths...

- Originally from GBAS
- TAP functionality allows design of curved approach paths (MT4 of GBAS)
- Vertical Guidance is provided

Idea: Use SBAS instead of GBAS and store these in onboard database

- Additionally, a displacement sensitivity can be assigned to every individual leg
- Every TAP can be linked to a Final Approach Segment (FAS)
- FAS is a straight-in final segment in a ILS-look-alike fashion
- During a TAP the deviations are linear, during a FAS they are angular
... and Final Approach Guidance

- LPV
  - Localizer and glidepath computed from augmented GNSS data
  - Usually SBAS Augmentation
Error Sources

Total System Error (TSE) consists of:
- Navigation System Error (NSE); the error between actual position and the estimated position of the navigation system
- Flight Technical Error (FTE); the error between defined flight path and estimated position
- Path definition Error (PDE) is negligible
Braunschweig Research Airport
Boundary Conditions
Boundary Conditions

Noise Sensitive Areas

Segmented Vertical Profile
3° → 4.5° → 3°
Continuous Descent
Flight Test Setup

- DLR’s Advanced Technology Research Aircraft (ATRA)
- Airbus A320-232
Flight Test Setup

- Experimental cockpit display on F/O side
- Manual flight only for all approaches
Flight Test Setup
Results

![Chart 14]

**Chart 14**

**Results**

- NSE Vertical
- Vertical FTE
- Vertical TSE

**Graph Details**

- **Y-axis**: FTE/TSE/NSE [m]
- **X-axis**: Distance to Threshold [m]

- The graph illustrates the performance of different thresholding methods (NSE, Vertical FTE, Vertical TSE) evaluated based on their distance to a threshold.

**Data Analysis**

- The graph shows a nearly horizontal distribution of points for all methods, indicating a low variation or consistent performance across different distances to the threshold.

**Conclusion**

- The results suggest that the NSE Vertical, Vertical FTE, and Vertical TSE methods perform similarly, with minimal deviation from the threshold.
Results

![Graph showing NSE Vertical, Vertical FTE, and Vertical TSE over distance to threshold.](chart15.png)
Results

![Graph showing NSE Vertical, Vertical FTE, and Vertical TSE over Distance to Threshold (m).]
Results

![Graph showing results for NSE Horizontal, Horizontal FTE, and Horizontal TSE.](image)
Results

NSE Horizontal - Horizontal FTE - Horizontal TSE

Distance to Threshold [m]

FTE/TSE/NSE [m]
Results

NSE Horizontal  •  Horizontal FTE  •  Horizontal TSE

Distance to Threshold [m]
Egelsbach Airport
Boundary Conditions
Boundary Conditions
Boundary Conditions

2500ft

1.36 NM
Boundary Conditions
Boundary Conditions
Procedure Design

Vertical Profile

- UMSA
- UBER
- FAP
- ABAHN
- SEEJU

C Frankfurt 1500/FL100
C Frankfurt 3500/FL100
Flight Test Setup

- Netjets Hawker 750 CS-DUH
- Two full approaches with missed approach
- 150 kts IAS maximum in RF leg
- First approach with autopilot and LPV
- Second approach with flight director and LNAV/VNAV
- Data from Wintec G-Rays 2 GPS Logger (less accurate but higher frequency)
Flight Test Setup

- Surface wind calm
- Altitude wind from FMS 180/20
- Analysis of Total System Error (TSE)

Diagram:

- Total System Error
  - Desired Flight Path
  - Path Definition Error (PDE)
  - Defined Flight Path
  - Flight Technical Error (FTE)
  - Estimated / Calculated Flight Path
  - Navigation System Error (NSE)
  - Actual Flight Path

Chart:

- ATM Seminar 2015 > Dautermann/Geister • 376 > 23.06.2015 DLR.de
- Chart 28
Results Flight Track All Approaches
Results: Lateral Track Deviations

(a) Cross Final Approach Track [km] vs. Along Final Approach Track [km]

Wind from 180° at 20kts.

- Procedure Track
- Approach 1
- Approach 2

Lateral TSE [m] vs. time [s]

- UMSTA --> UBER
- flyby turn
- final
- RF leg
- ABAHN --> SEEJU
Conclusions

**Braunschweig**
- SBAS can provide 3D type B approaches similar to GBAS, but does not require ground infrastructure
- TAPs can and should also be coded in airborne database and provide vertical guidance in the terminal area.
- TSE is comparable to GBAS (manually flown with flight director)

**Egelsbach**
- Procedure could be implemented under advanced RNP specifications with RNP0.3 for the missed approach.
- Proposed amendment to ICAO Annex 14 would allow IAP to non-instrument runway. “Non-instrument runway: A runway intended for the operation of aircraft using visual approach procedures or an instrument approach procedure down to minima equal to or better than VMC.”
- Obstacle assessment must be performed and legal issues must be clarified (IFR in airspace G etc.). Balked Landing must remain VMC
Outlook on Future Operations and Research Topics

- SBAS guided approaches in fringe areas → Canaries, Azores, Bahamas
- SBAS approaches in overlapping service areas of different providers → also Acores
- Advanced RNP for General Aviation
- Advanced RNP for procedural independence and noise abatement
- Stabilization criteria for RNP to ILS approaches
Questions ?