GNSS/EGNOS services and applications in civil aviation

Euromed GNSS II project/MEDUSA: Egypt national workshop
Index

EGNOS SoL operation in civil aviation

EGNOS benefits for civil aviation

EGNOS scenario in Europe for civil aviation
EGNOS SoL operation in civil aviation
EGNOS SoL main principles (1)

- Designed:
  - Compliant to APV- I
  - To support civil aviation operations down to LPV minima (CAT-I)
  - To meet ICAO SARPs
  - Compliant to RTCA Minimum Operational Performance Standards (MOPS) for airborne navigation equipment using the GPS augmented by SBAS

- Enabling Performance Based Navigation (PBN)
- Not requiring the installation (and maintenance) of ground-based landing NAVAIDs
- Requiring certified avionics in accordance with ICAO SARPs
- Interoperable with other SBAS to enable aircraft seamless transitions between SBAS systems and interoperable SBAS avionics
### EGNOS SoL main principles (2)

<table>
<thead>
<tr>
<th>Typical Operation</th>
<th>Horizontal Accuracy (95%)</th>
<th>Vertical Accuracy (95%)</th>
<th>Integrity</th>
<th>Time-To-Alert (TTA)</th>
<th>Horizontal Alert Limit (HAL)</th>
<th>Vertical Alert Limit (VAL)</th>
<th>Continuity</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>En-route (oceanic / continental low density)</td>
<td>3.7 km (2.0 NM) (Note 6)</td>
<td>N/A</td>
<td>1 - 1x10^{-7}/h</td>
<td>5 min</td>
<td>7.4 km (4 NM)</td>
<td>N/A</td>
<td>1 - 1x10^{-4}/h to 1 - 1x10^{-8}/h</td>
<td>0.99 to 0.99999</td>
</tr>
<tr>
<td>En-route (continental)</td>
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<td></td>
<td>3.7 km (2 NM)</td>
<td>N/A</td>
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<td></td>
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<tr>
<td>En-route, Terminal</td>
<td>0.74 km (0.4 NM)</td>
<td>N/A</td>
<td>1 - 1x10^{-7}/h</td>
<td>15 s</td>
<td>1.85 km (1 NM)</td>
<td>N/A</td>
<td>1 - 1x10^{-4}/h to 1 - 1x10^{-8}/h</td>
<td>0.99 to 0.99999</td>
</tr>
<tr>
<td>Initial approach, Intermediate approach, Non-precision approach (NPA), Departure</td>
<td>220 m (720 ft)</td>
<td>N/A</td>
<td>1 - 1x10^{-7}/h</td>
<td>10 s</td>
<td>556 m (0.3 NM)</td>
<td>N/A</td>
<td>1 - 1x10^{-4}/h to 1 - 1x10^{-8}/h</td>
<td>0.99 to 0.99999</td>
</tr>
<tr>
<td>Approach operations with vertical guidance (APV-I)</td>
<td>16.0 m (52 ft)</td>
<td>20 m (66 ft)</td>
<td>1 - 2x10^{-7} in any approach</td>
<td>10 s</td>
<td>40 m (130 ft)</td>
<td>50 m (164 ft)</td>
<td>1 - 8x10^{-6}/15 s</td>
<td>0.99 to 0.99999</td>
</tr>
</tbody>
</table>

**ICAO operational requirements**
EGNOS requirements

Applicable Document

SARPS

EGNOS MRD 2.1

<table>
<thead>
<tr>
<th></th>
<th>Open Service</th>
<th>Safety-of-Life Service</th>
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<tbody>
<tr>
<td></td>
<td>En Route to NPA</td>
<td>APV-1</td>
</tr>
<tr>
<td>Horizontal accuracy, 95%</td>
<td>3 m</td>
<td>220 m</td>
</tr>
<tr>
<td>Vertical accuracy, 95%</td>
<td>4 m</td>
<td>N.A.</td>
</tr>
<tr>
<td>Vertical NSE - fault-free conditions</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Vertical NSE - system failure conditions</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Integrity</td>
<td>N/A</td>
<td>10^-7 / hour</td>
</tr>
<tr>
<td>Time To Alarm</td>
<td>10 s</td>
<td>10 s</td>
</tr>
<tr>
<td>HAL</td>
<td>N/A</td>
<td>0.3 NM</td>
</tr>
<tr>
<td>VAL</td>
<td>N/A</td>
<td>N.A.</td>
</tr>
<tr>
<td>Continuity</td>
<td>N/A</td>
<td>10^-5 / hour</td>
</tr>
<tr>
<td>Global availability</td>
<td>99%</td>
<td>99.9%</td>
</tr>
<tr>
<td>Local Availability</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Area Covered

- Landmasses of: EU-27 (plus Norway / Switzerland)
- Mediterranean countries
- ECAC countries

FIRs of: Mediterranean countries

Landmasses of: ECAC countries

Mediterranean countries

Landmasses of: Mediterranean countries

Euromed GNSS II national w
SBAS in ICAO’s approaches

General Evolution of Approaches

NPA
Non Precision Approaches
- Conventional
- RNP APCH
  - LNAV
  - CDFA

APV
Approaches with Vertical Guidance
- Baro/VNAV
- SBAS LPV

PA
Precision Approaches
- Conventional
- GBAS Approach

Sensors
- VOR/DME/NDB Localizer
- GPS
- GPS + Baro
- GPS + SBAS
- ILS
- GPS + GBAS
EGNOS competitive space

- GPS
  - 400 – 600 ft DH
- GPS Inertial/SBAS
  - 350 – 400 ft DH
- SBAS
  - 250 – 300 ft DH
- SBAS/GBAS
  - 200 ft DH
- GBAS
  - 0 – 200 ft DH

- 3º
- 1/2 nm
- 3/4 nm
- 1 nm
- 2 nm

APCH GNSS NAVAIDs trade off
LPV is ILS look-alike
In Europe, EGNOS is subject to regulation/approval by “EASA system” (including NSAs)
EWA (for EU countries)

WHO

Between the ANSP and the EGNOS Service Provider

WHY

To define roles and responsibilities for the actors involved
To formalize the working procedures and interface

WHAT (contents)

Contractual document (including liability)
Contingency coordination
NOTAM proposal
Data recording
Collaborative decision making
Service commitment with reference to EGNOS SoL SDD Doc
Identification of the main focal points
Service arrangements

WHEN

As soon the procedures implementation process is defined and decided
EGNOS benefits for civil aviation
EGNOS added value for civil aviation

- **Back-up** for conventional NAVAIDs
- **Instrument approach capability** for those airdromes or runways where ILS cost is not justified, with a huge increase in safety
- **DDCs reduction**
- **Increased runway capacity and enhanced efficiency in air space use**:
  supporting en-route and terminal area PBN procedures
- **Instrument navigation** in those regions not covered by conventional ground NAVAIDs
- **Enabler of optimised procedures** for special applications, e.g. general and business aviation, helicopters serving oil rigs
- **Supporting operations in areas with insufficient conventional NAVAIDs infrastructure**
EGNOS economical benefits

- **DDCs reduction**: lower minima makes landing possible with lower visibility levels at airports not equipped with ILS (48% reduction ANSP/airlines estimate)
- **Time and fuel savings**: more flexible curved/segmented and continuous descent approach procedures result in time/fuel savings
- **Increased runway capacity**: EGNOS has no critical/sensitive areas, reducing the time between consecutive approach/departure aircraft operations. Approach terrain constraints are also easier to overcome. ILS backup in case of failure
- **Ground infrastructure cost savings**: decommissioning of ground based NAVAIDs, with expensive maintenance costs. Regional coverage enables operations in areas with insufficient conventional NAVAIDs infrastructure
- **Enhanced efficiency in air space use**: supporting en-route and terminal area PBN procedures, allows more aircraft to follow preferred trajectories
- **Reduced costs for procedure compared to ILS** (on other conventional NAVAIDs), since periodic flight verifications are not required
- **Reduced aircrew training costs** when all approaches can be flown using vertical guidance
EGNOS social benefits

Safety improvement: EGNOS enables APV approaches, providing significant safety improvements at airports where approaches with vertical guidance are currently not available (Non Precision Approaches NPA)

CFIT reduction

Environmental impact reduction:

- Noise reduction in urban areas
- CO2 emissions reductions due to optimised routes and CDA (continuous descent approach)
EGNOS scenario in Europe for civil aviation
EGNOS use in Europe for aviation

Source: ESSP
Examples of real case applications/scenarios of EGNOS use

- Scenario at Valencia (Spain)
- Scenario at Saarbrücken (Germany)
- Scenario at Pamplona (Spain)
- Scenario at Egelsbach (Germany)
- EGNOS pioneer operators
- EGNOS pioneer airports
Valencia (Spain)

Aircraft model/operator: CRJ-1000NG/Air Nostrum (RC-GPS 4000S)

Scenario characteristics: urban noise restrictions

Expected date: Q1 2014

Demonstration objectives:

- Curved departure for RWY 12
- Curved approach (RF leg) prior (2 nm) to FAP
- and final transition to LPV RWY30
**Aircraft model/operator:** Cessna 340 / Navart (Garmin G1000)

**Scenario characteristics:** noise restrictions, terrain and airspace limitations (France border & ATC coordination)

**Expected date:** Q1 2014

**Demonstration objectives:**
- Assessment and introduction of RF legs prior to FAF with transition to LPV
- RNP AR avionics requirement analysis with minima equivalent to LPV
Pamplona (Spain)

Aircraft model/operator: CRJ-1000NG/Air Nostrum (RC-GPS 4000S)

Scenario characteristics: very difficult terrain environment

Expected date: Q1 2014

Demonstration objectives:

- Reduction of approach minima (LPV to non ILS RWY 33)
- More stabilised final segment approach
- Reduction of departure climb gradient at RWY15
Egelsbach (Germany)

Aircraft model/operator: Hawker 750/NetJets (RC-GPS 4000S)
Scenario characteristics: airspace restrictions
Expected date: Q1 2014
Demonstration objectives:
• IFR procedures with lower minima
• Advanced RNP with transition to LPV (RWY 27)
• RF in the Missed Approach MAP final segment
• Avoid ATC conflicts & decongest Frankfurt TMA area
EGNOS pioneer operators

4 main avionics manufactures
- Thales
- Rockwell Collins
- Universal
- Garmin

+28 ATR 72-600
+28 Twin Otter
+28 Beechcraft 76
+28 Hawker 750
+28 Cessna Citation II

+15x CRJ-1000
+15x Bell 412
+15x Piper P28A
+15x King Air 1900D
+15x King Air 300

+5x Fokker-50
+5x BN2B Islander
+5x Diamond DA42

+2x CRJ-1000
+2x Bell 412
+2x Piper P28A
+2x Fairchild Metrol II

4 main avionics manufactures
- Thales
- Rockwell Collins
- Universal
- Garmin

42
Operators benefitting from EGNOS

**REGIONAL**
- Aurigny
  - 2x BN2B Trislander
  - Air Nostrum
    - 5x ATR 72-600
  - Skybus
    - 15x CRJ 1000
    - Twin Otter

- CityJet (VLM)
  - 8x Fokker 50
  - Loganair
    - 2x Twin Otter
  - Hebridean Air
    - 2x BN2B Islander

**BUSINESS**
- Inaer
  - Bell 412
- NetJets
  - Hawker 750
- Specsavers
  - 2x Beech 350

**GENERAL**
- NLR
  - Fairchild Metro II
  - Cessna Citation II
  - Air Charters Europe
    - King Air 300
  - Aviation South West
    - King Air 1900D
    - Beechcraft 76
  - Royal Star-Aero
    - Dutch & Martin Air Flight Academies
    - Piper PA-34 Seneca II
  - 4x Diamond DA42

Source: GSA/EC
Thank you!
Questions?
PBN (Performance-Based Navigation) concept

The PBN Concept (according to ICAO doc 9613)

Application: e.g. operations, en-route, approach, take-off, landing

Infrastructure: Ground-based NAVAIDs or Space-based NAVAIDs supporting the application (e.g. VOR, DME, GNSS, avionics)

Specification: performance indicators value required for the application using the infrastructure

Applications:
- RNAV x
- RNP x

With On-Board Performance Monitoring and Alerting

Use of the Navigation Specification and Navigation Infrastructure together

- Ground-based NAVAIDS
- Space-based NAVAIDS

(Refer to next slide)
PBN performance indicators

Required for a navigation specification:

- **Position accuracy** - difference between a computed and a true position
- **Integrity** - measure of the trust that can be placed in the correctness of the provided information
- **Availability** - the percentage of time that the positioning and integrity are available and according to the required values (performances) under stated conditions and within the specified coverage area
- **Continuity** - the capability to provide the positioning and integrity according to the specified performances without non-scheduled interruptions during the intended operation
- **Time-to-alert** - the maximum time allowed from the onset of a failure condition up to the annunciation in the aircraft
ICAO PBN Roadmap

<table>
<thead>
<tr>
<th>PBN</th>
<th>Block 0</th>
<th>Block 1</th>
<th>Block 2</th>
<th>Block 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>En-Route Oceanic and Remote Continental</strong></td>
<td></td>
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<tr>
<td>RNAV 10 (RNP 10)</td>
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<tr>
<td>RNP 4</td>
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<tr>
<td>RNP 2</td>
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<tr>
<td><strong>En-Route Continental</strong></td>
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<td>RNAV 5</td>
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<td>RNAV 2</td>
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<tr>
<td>RNAV 1</td>
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<tr>
<td><strong>Terminal Airspace: Arrival and Departure</strong></td>
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<tr>
<td>RNAV 1</td>
<td></td>
<td></td>
<td>Advanced RNP</td>
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<tr>
<td>Basic RNP 1</td>
<td></td>
<td></td>
<td>RNP 0.3 (Helicopter only)</td>
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<tr>
<td><strong>Approach</strong></td>
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<tr>
<td>RNP APCH (SBAS: LPV, BARO VNAV: LNAV/VNAV, Basic GNSS: LNAV)</td>
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<tr>
<td>RNP AR APCH (where beneficial)</td>
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</table>

Migration path based on Region/States requirements
## ICAO Navigation roadmap

<table>
<thead>
<tr>
<th>NAVIGATION</th>
<th>Block 0</th>
<th>2018</th>
<th>Block 1</th>
<th>2023</th>
<th>Block 2</th>
<th>2028</th>
<th>Block 3</th>
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<tr>
<td><strong>Enablers</strong></td>
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<tr>
<td>Conventional</td>
<td>ILS/MLS</td>
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<tr>
<td></td>
<td><em>Retain to support precision approach and to mitigate GNSS outage</em></td>
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<td>DME</td>
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<td></td>
<td><em>Optimize existing network to support PBN operations</em></td>
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<td>VOR/NDB</td>
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<td></td>
<td><em>Rationalize based on need and equipage</em></td>
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<tr>
<td>Satellite-based</td>
<td>Core GNSS Constellations</td>
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<td></td>
<td><em>Single frequency (GPS/GLONASS)</em></td>
<td>Multi-Freq/Multi-Constellation (GPS/GLONASS/Beidou/Galileo)</td>
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<tr>
<td></td>
<td>GNSS Augmentations</td>
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<tr>
<td></td>
<td>SBAS</td>
<td>GBAS Cat I</td>
<td>GBAS Cat II/III</td>
<td>Multi-Freq GBAS/GBAS</td>
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<tr>
<td>Capability</td>
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<tr>
<td>(see PBN Roadmap)</td>
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<td>PBN Operations</td>
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<tr>
<td></td>
<td>B0-65, B0-05, B0-10</td>
<td>B1-10, B1-40</td>
<td>B2-05</td>
<td>B3-05, B3-10</td>
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<td>Precision Approach</td>
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<tr>
<td></td>
<td>CAT I/II/III Landing</td>
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<tr>
<td></td>
<td>ILS/MLS</td>
<td>GBAS Cat I</td>
<td>GBAS Cat II/III</td>
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<tr>
<td></td>
<td>Cat I/II/III SBAS LPV 200</td>
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<td></td>
<td>B0-65</td>
<td>B1-65</td>
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</tbody>
</table>
ICAO recommendations (1/2)

- ICAO (36th Assembly Oct 2007) resolved

  "States and planning and implementation regional groups (PIRGs) should complete a PBN implementation plan by 2009 to achieve:

  - Implementation of RNAV and RNP operations for **en route and terminal areas** according to established timelines and intermediate milestones; and

  - Implementation of approach procedures with vertical guidance (APV) (Baro-VNAV and/or augmented GNSS) for all instrument runway ends, either as the primary approach or as a back-up for precision approaches by 2016 with intermediate milestones as follows:
    - 30% by 2010
    - 70% by 2014.  ""
ICAO recommendations (2/2)

- **37th ICAO Assembly (Oct 2010):**

  Concerning Approach with Vertical guidance (APV), the resolution added:

  “... implementation of straight-in LNAV only procedures, as an exception, for instrument runways at aerodromes where there is no local altimeter setting available and where there are no aircraft suitably equipped for APV operations.”

ICAO:

- Urges all States to implement RNAV and RNP air traffic services (ATS) routes and approach procedures in accordance with the ICAO PBN concept laid down in the PBN manual (ICAO PBN Manual/Doc. 9613)

- States that GNSS enables PBN and provides navigation guidance for all phases of flight, from en-route to precision approach
APCH NAVAIDs trade off

Non Precision Approaches (NPA)
Use Conventional Navigation: VOR, DME to the MDH for VFR landing

Higher minima
CFIT risk

Precision Approaches (PA)
Use Instrument Landing system: ILS, GBAS. Provide Lateral and Vertical guidance on stabilised continuous descent path

Lowest minima
Costly ground installation
Local coverage

Approach with Vertical Guidance (APV)
Use GNSS navigation and can use SBAS (LPV) or baro-VNAV for the vertical guidance

Low minima
Cost effective
Balanced solution

EGNOS
RNP approaches according to PBN

**Chart title: RNAV (GNSS)**

- **RNP APCH**
  - Without Vertical guidance
    - **LNAV**
    - **LP**
  - With Vertical guidance
    - **LNAV/VNAV**
    - **LPV**

**GPS NPA expected to be flown with CDFA**

**SBAS-based NPA SBAS supported Localiser Performance**

**APV Baro-VNAV**

**APV SBAS SBAS supported Localiser Performance with vertical guidance**

**Chart title: RNAV (RNP)**

- **RNP AR APCH**
  - With Vertical guidance
    - **LNAV/VNAV**

**PANS-OPS Terminology** | **PBN Terminology** | **Chart Minima** | **Minimum Sensor**
--- | --- | --- | ---
NPA | RNP APCH down to | LNAV (MDA) | Basic GNSS
APV Baro-VNAV | RNP APCH down to | LNAV/VNAV (DA) | Basic GNSS + Baro-VNAV
- | RNP APCH down to | LP (MDA) | SBAS
APV SBAS | RNP APCH down to | LPV (DA) | SBAS
SBAS in ICAO’s RNP approaches

**Chart title: RNAV (GNSS)**

- **RNP APCH**
  - Without Vertical guidance
    - LNAV (GPS NPA)
      - Approach expected to be flown with CDFA
  - With Vertical guidance
    - LP (SBAS)
      - SBAS supported Localiser Performance
    - LNAV/VNAV
    - APV Baro
    - LPV
      - APV SBAS
        - SBAS supported Localiser Performance with vertical guidance

**Chart title: RNAV (RNP)**

- **RNP AR APCH**
  - With Vertical guidance
    - LNAV/VNAV
EGNOS APV/CAT-I APCH benchmarking

Alert Limits

<table>
<thead>
<tr>
<th>Operation</th>
<th>Horizontal Alert Limit</th>
<th>Vertical Alert Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>APV-I</td>
<td>40m (130ft)</td>
<td>50m (164ft)</td>
</tr>
<tr>
<td>APV-II</td>
<td>40m (130ft)</td>
<td>20m (66ft)</td>
</tr>
<tr>
<td>CAT I</td>
<td>40m (130ft)</td>
<td>15m to 10m (50ft to 33ft)</td>
</tr>
</tbody>
</table>

Accuracy

<table>
<thead>
<tr>
<th>Type of Operation</th>
<th>Horizontal Accuracy</th>
<th>Vertical Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>APV-I</td>
<td>16.0m (52ft)</td>
<td>20m (66ft)</td>
</tr>
<tr>
<td>APV-II</td>
<td>16.0m (52ft)</td>
<td>8.0m (26ft)</td>
</tr>
<tr>
<td>Cat-I</td>
<td>16.0m (52ft)</td>
<td>6.0m to 4.0m (20ft to 13ft)</td>
</tr>
</tbody>
</table>

Procedure Minima

- ILS-CAT I minima ~ 200 ft
- APV-I (LPV) minima ~250 ft

APV-I is ILS look-alike
RNAV GNSS Approaches

The 36th ICAO Assembly resolution encourages States to implement approach procedures with vertical guidance (Baro-VNAV and/or LPV) for all instrument runway ends, either as the primary approach or as a back-up for precision approaches by 2016.

At the 37th ICAO Assembly recognized RNAV (GNSS) NPA as an acceptable alternative where APV cannot be implemented.

Charts can include all three minima: LPV, LNAV/VNAV, LNAV.

**RNAV**: aRea NAVigation

**APV**: Approach with Vertical Guidance

**LNAV**: Lateral Navigation

**VNAV**: Vertical Navigation

**LP**: Localiser Performance

**LPV**: Localiser Performance with Vertical Guidance

**MDA/H**: Minimum Descent Altitude/Height

**DA/H**: Decision Altitude/Height

Source: Eurocontrol
LPV procedures design

1. LPV are ordinary IFR procedures designed according to ICAO PANS-OPS 8168

2. OAS calculation follows ordinary rules

3. LPV validation follows ICAO general rules Doc 9906 AN/472

4. Output:
   - OCH for FAS per aircraft category
   - Minima of operation for each previous approach segment
   - FAS DB

5. Specific operational characteristics:
   - SBAS use requires monitoring means
   - Specific working agreement with SBAS service provider
   - Requires certified avionics (as all IFR procedures do)
RNAV APCHs to RWY 07 (currently ILS)
In a “3 minima lines combined chart”

<table>
<thead>
<tr>
<th>Category of Aircraft</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPV – 2.5%</td>
<td>258</td>
<td>270</td>
<td>278</td>
<td>289</td>
</tr>
<tr>
<td>Baro-VNAV</td>
<td>450</td>
<td>450</td>
<td>450</td>
<td>450</td>
</tr>
</tbody>
</table>

Currently ILS minima 320 ft
RNAV APCHs to RWY 25 (currently NPA)
In a “3 minima lines combined chart”

<table>
<thead>
<tr>
<th>Category of Aircraft</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPV – 2.5%</td>
<td>275</td>
<td>287</td>
<td>295</td>
<td>305</td>
</tr>
<tr>
<td>Baro-VNAV</td>
<td>360</td>
<td>360</td>
<td>360</td>
<td>360</td>
</tr>
</tbody>
</table>

Currently VOR-DME NPA 460 ft
EGNOS retrofitting for aircraft in service (1)

SBAS receiver
- Integration
- Installation
- Documentation
- Certification
- Other cost

Number of aircraft

Crew training

+ ×
EGNOS retrofitting for aircraft in service (2)

EU certification process

Diagram:
- Aircraft in Service Process
- Service Bulletin available
- STC available
- Minor change?
- Minor change
  - Contact a DOA approved by EASA Part 21
  - Technical report for the installation
  - DOA acceptance
  - EASA acceptance
- STC release
  - Technical report for the installation
  - EASA application Form 33 (*)
  - EASA acceptance
- Installation and Certification approval
  - Installation of the receiver
  - Certificate to Release to Service (CRS)
  - Installation manual
    - SB / STC
  - REMARKS:
    - The installation has to be performed by a Maintenance centre approved by EASA Part 145
  - (*) The application should be done by a DGA approved by EASA Part 21