Ground Based Augmentation Systems (GBAS) Introduction

Technical and Operational Overview
Key GNSS Performance Requirements

Use only with **augmentations**

- **ABAS (RAIM, Baro-RAIM, AAIM)** - enroute
- **SBAS (WAAS, EGNOS, MSAS, …)** - regional
- **GBAS (LAAS, …)** - landing
GBAS Principle

Space Vehicle

VHF-Datalink

Space Vehicle

HF-Cable

LAAShowItWorks.exe
GBAS Introduction

Aircraft Sub-system Processing

- Receives GNSS SIS
- Measures pseudo range from each Satellite
- Applies Corrections from Ground stations
- Calculates Position, Velocity and Time

Aircraft sub-system extracts from Ground Station:
- Satellite corrections
- Satellite Integrity Information
- FAS path construction data
Aircraft Sub-system Outputs

- Mode Annunciation “GLS”
- Navigation selection panel
- Approach selection pilot interface
- Available Approaches
- Status
- Selected Approach
- Guidance Lat/Vert deviations
- Multi-mode Receiver GNSS sensor, (VHF-localiser) data-link & precision approach navigator
- VHF
- Conventional Displays and Auto-pilot ILS “Look-alike” CDI & VDI
- Flight control
- FMS interfaces
- FMS
- (Differential) Position and Time
- Available Approaches
- GNSS Signals
GBAS Service Volume

LTP/FTP: Landing/Fictitious Threshold Point
GPIP: Glide Path Intersection Point
FPAP: Flight Path Alignment Point

Plan view

± 450 ft

FPAP  LTP/FTP

Profile view

10.000 ft

Greater than 7° or 1.75θ

0.3-0.45θ

θ

Minimum Service Volume
GBAS and ILS Vertical Performance

- GBAS users may use linear or angular outputs
- Transition from CAT I to II/III may require better performance along entire approach
- GBAS horizontal and vertical performances are linked – unlike ILS
GBAS Services

• **Approach Service**
  Note: GAST: GBAS Approach Service Type
  future SARPS designation, used here for clarity, not in current standards
  • GAST-A – for operations to APV I performance
  • GAST-B – for operations to APV II performance
  • GAST-C – for operations to CAT I performance level
  • GAST-D – for operations to CAT III performance with specific aircraft integration assumptions
  • GAST-E – TBD – either CAT II performance or L5/E5 CAT III with integration assumptions
  • GAST-F – TBD – planned for multi-constellation, multifrequency CAT III performance level

• **Differentially Corrected Positioning Service (DCPS)**
  defined in Standards, but revision ongoing due to practical approval issues

• **Ground-based Regional Augmentation Service (GRAS)**
  Positioning service and GAST-A with more frequency-efficient coding
GBAS
Development History

• Differential GPS automated landing experiments (FAA, TUBS 1989)
• "Stanford Integrity Beacons" (1993)
• S-CAT 1
  • AVINOR/Widerøe operations: inauguration flight 2007
• GBAS SARPS
  • Initial Version - Amendment 76 (2001)
  • GRAS and APV – A.81 (2006)
  • CAT I maintenance package – A.86 (2011)
• GBAS Equipment
  • Rockwell-Collins MMR FAA certified 2006
  • NPPF-Spectr LKKS-2000 MAK certified 2008
  • Honeywell SmartPath FAA certified 2009

Widerøe shoots world’s first approved precision GPS approach
By David Learmount

The world’s only certificated global navigation satellite system (GNSS) precision approach system guided its first passenger-carrying aircraft to touchdown on 25 October at a remote airport in Norway.

A Bombardier Dash 8-100 of SAS subsidiary Widerøe carried out the inaugural approach to Runway 04 at Brønnøysund.

Already approved by the Norwegian civil aviation authority and certificated by the European Aviation Safety Agency, the system will be installed at 24 of Norway’s local airports where terrain or steep glideslopes make the installation or use of instrument landing systems impossible, says Steinar Hamar, the SCAT-1 programme manager at the country’s airports and air navigation service provider Avinor.
Standardisation Status 1
ICAO Technical Aspects

- Annex 10 Vol. 1, Sixth Edition
  - Chapter 2.4: GNSS as navigation aid, recording and termination requirements
  - Chapter 3.7: General Provisions, GBAS definition and performance requirements
  - Chapter 3.7.3.5: Functions, Coverage, data link characteristics
  - Appendix B, 3.6: detailed technical characteristics for GBAS and GRAS
  - Attachment D, 7.: Guidance material and explanations

Other Technical ICAO (NSP) material
- DOC 8071 Flight Test Manual
- DOC 8949 GNSS Manual
- Iono White Paper
Standardisation Status 2
RTCA/EUROCAE/FAA

- **RTCA**
  - LAAS MASPS DO-245
  - LAAS MOPS DO-253C – includes GAST-D
  - LAAS ICD DO246D – includes GAST-D
  - Antenna MOPS DO301

- **EUROCAE**
  - ED-114 – GBAS Ground System MOPS
  - ED-144 – high level GBAS CAT II/III requirements
  - ED-88(A) – MMR MOPS

- **FAA**
  - FAA-E-AJW44-2937A
    Nonfed. Specification for LAAS CAT I ground facility
  - Draft GAST-D ground facility specification
  - Draft LAAS siting order
Standardisation Status 3
ICAO Operational

ICAO Global provisions
• ANNEX 4 – Charts - Definitions related to PA procedures
• ANNEX 6 – Operations - Flight data recording
• ANNEX 11 – ATC – approach naming conventions
• ANNEX 14 – Aerodromes - OFZ and other I/MLS related provisions
• ANNEX 15 – AIS - approach data to be promulgated
• DOC 8168 PANS OPS – multiple aspects of PA operations
• DOC 4444 PANS ATM – phraseology and controller tasks
• DOC 9137 Airport services – obstacle control
• DOC 9365 AWO Manual – precision approach operations

ICAO EUR DOC
• EUR DOC 011 – Frequency Management Manual
• EUR DOC 013 – Limited Visibility Airport Operations
• EUR DOC 015 – Building Restricted Areas

Note: details in separate presentation
Standardisation Status 4
Other standards

- ARINC
  - ARINC 424 – GBAS message in onboard database format
  - ARINC 429 – definition of digital avionics outputs
  - ARINC 755 - MULTI-MODE RECEIVER (MMR) - DIGITAL
  - ARINC 756 - GNSS NAVIGATION AND LANDING UNIT (GNLU)

- AIS Data provision (Jeppesen as example)

**ADVANCE NOTIFICATION of NavData Output Change**

IMPLEMENTATION OF GLS APPROACH AND
GLS NAVAID RECORDS

02 September 2009

In accordance with ARINC 424 documentation, Jeppesen will begin offering GLS Approach records (PF) and GLS Navaid records (PT) as standard NavData. This document serves as the contractually required advanced notification for implementation of the new coding rules and practices.
Certification/Approval Situation

• Generic:
  • GBAS is a precision approach aid and regulatory actions are performed according to the xLS concept

• GBAS specific:
  • FAA TSO161A: GBAS airborne equipment
  • FAA TSO162A: GBAS VDB reception equipment
  • EASA E-TSO161: GBAS equipment (equivalent TSO-161)
  • GBAS CAT-I generic CRI
  • Currently no EU Implementing Rule planned
  • EU Mandate for GBAS CAT I Community Specification currently on hold
Implementation overview – Airborne

Cumulative Population

Based on personal extrapolation from public order data
GBAS Introduction

Implementation Overview – Ground

- Operational S-CAT1
- Pre-operational GBAS
- Experimental GBAS
- Planned GBAS
Useful sources

- LATO – EUROCONTROL Landing and Take Off task force
- I-GWG – FAA/EUROCONTROL International GBAS Working Group

Presentations, Papers and Minutes available via EUROCONTROL OneSky GBAS team at extranet.eurocontrol.int

- www.flygls.com – status of GBAS implementation (from I-GWG)
- laas.tc.faa.gov - FAA GBAS information and status
GBAS autoland at Sydney – courtesy of ASA
Supplemental Slides

Eurocontrol support to Precision Approach implementation

- MLS CAT II/III
- Improved ILS CAT III
- GBAS CAT I
GBAS Performance
Introduction

- GBAS Cat-I Performance
  - For GBAS Approach Service
  - Positioning Service may define other requirements
  - Defined by ACCURACY, INTEGRITY, CONTINUITY and AVAILABILITY

<table>
<thead>
<tr>
<th>Typical operations</th>
<th>Accuracy lateral 95%</th>
<th>Accuracy vertical 95%</th>
<th>Integrity</th>
<th>Time to alert</th>
<th>Continuity in any 15 s</th>
<th>Availability</th>
<th>Associated type of RNP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial approach, intermediate approach, non-precision</td>
<td>220 m</td>
<td>N/A</td>
<td>1-10^{-7} /h</td>
<td>10 s</td>
<td>1-10^{-4} /h to 1-10^{-6} /h</td>
<td>0.99 to 0.99999</td>
<td>0.5 to 0.3</td>
</tr>
<tr>
<td>Non precision approach with vertical guidance NPV I</td>
<td>220 m</td>
<td>20 m</td>
<td>1-2x10^{-7} per approach</td>
<td>10 s</td>
<td>1-8x10^{-6} in any 15 s</td>
<td>0.99 to 0.99999</td>
<td>0.3/125</td>
</tr>
<tr>
<td>Non precision approach with vertical guidance NPV II</td>
<td>16.0 m</td>
<td>8.0 m</td>
<td>1-2x10^{-7} per approach</td>
<td>6 s</td>
<td>1-8x10^{-6} in any 15 s</td>
<td>0.99 to 0.99999</td>
<td>0.3/50</td>
</tr>
<tr>
<td>CAT I</td>
<td>16.0 m</td>
<td>6.0 m to 4.9 m</td>
<td>1-2x10^{-7} per approach</td>
<td>6 s</td>
<td>1-8x10^{-6} in any 15 s</td>
<td>0.99 to 0.99999</td>
<td>0.02/40</td>
</tr>
</tbody>
</table>
GBAS Performance Availability

- Availability
  - The system is defined to be available for a particular performance type (level of service) when it meets the accuracy, integrity, and continuity requirements throughout the coverage region.
    - GBAS availability should be greater than 0.9975
      - For providing the same level of performance as an ILS Category I.
  - Including:
    - Geometry dependent component availability
    - Aircraft subsystem availability
    - Ground subsystem availability

- Two types
  - Short-Term Availability
    - Probability that the aircraft can conduct the approach at the destination given that the service at the destination was predicted to be available at dispatch.
      - At least 95%
  - Long-Term Availability
    - Probability that the signal in space from the service provider will be available for any aircraft desiring to perform the precision approach operation.
      - Between 0.99 and 0.99999
GBAS Performance

Continuity

• Continuity of Service
  • GBAS System Continuity of Service
    • The GBAS continuity of service risk is defined as the probability, that within any 15 second period, a Category I approach cannot be continued due to an unscheduled loss of lateral or vertical guidance or warning annunciation onboard the aircraft
      • Not Quantified
  • GBAS Signal-In-Space Continuity of Service
    • The Signal in Space continuity of service is the probability that a fault-free aircraft subsystem provides valid outputs during any 15s period, assuming that outputs were valid at the start of the period
      • Outputs are considered as valid if the X Protection levels are lower than X Alert Limits and if there is no warning
      • Equal to $8 \times 10^{-6}$ during any 15s period approach
  • GBAS Aircraft Subsystem Continuity of Service
    • Must guarantee that the risk of loss of integrity due to SIS geometry dependent causes is less than $10^{-6}$ during any 15 seconds in the approach
GBAS Performance

Integrity

- Integrity
  - GBAS System Integrity
    - Not Quantified
  - GBAS Signal-In-Space Integrity
    - Is the probability that the NSE, at the deviation output of a fault-free aircraft subsystem, exceeds the alert limits without annunciation for a period longer than the Signal in Space time-to-Alert
      - Must be less than $2 \times 10^{-7}$ in any one approach
      - Allocated between the ground sub-system integrity risk ($1.5 \times 10^{-7}$) and the Protection Levels integrity risk of the aircraft subsystem ($0.5 \times 10^{-7}$)
  - GBAS Aircraft Subsystem Integrity
    - This subsystem assesses signal-in-space geometry dependant Integrity through the calculation of Protection Levels
      - Allocation of $0.5 \times 10^{-7}$ per approach
GBAS Performance

Accuracy

• Accuracy
  • Lateral Accuracy
    • Defined in terms of Lateral NSE
      • Horizontal displacement from the Final Approach Path
    • Accuracy limit depends on Horizontal distance of aircraft position to the LTP/FTP (D)
  • Vertical Accuracy
    • Defined in terms of Vertical NSE
      • Vertical displacement from Final Approach Path
    • Accuracy limits depends on the product of \( \sin(GPA) \) and the slantrange distance from the aircraft position to the GPIP.
GBAS Performance
Accuracy

• Lateral Accuracy

<table>
<thead>
<tr>
<th>D</th>
<th>Lateral Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between 291 and 873 m</td>
<td>16 m</td>
</tr>
<tr>
<td>Between 873 and 7212 m</td>
<td>Linear value varying from 16 to 27.2 m</td>
</tr>
<tr>
<td>Over 7212 m, in the limit of coverage</td>
<td>Constant 27.2 m</td>
</tr>
</tbody>
</table>
GBAS Performance Accuracy

- Vertical Accuracy

<table>
<thead>
<tr>
<th>H</th>
<th>Vertical Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between 100 and 200 ft HAT</td>
<td>4 m</td>
</tr>
<tr>
<td>Between 200 and 1290 ft HAT</td>
<td>Linear value varying from 4 to 16.7 m</td>
</tr>
<tr>
<td>Above 1290 ft HAT, in the limit of coverage</td>
<td>Constant 16.7 m</td>
</tr>
</tbody>
</table>

Note: HAT Height above Threshold
GBAS Cat-I Architecture

GBAS Ground Subsystem

• GBAS Ground Subsystem
• GBAS Coverage Volume
GBAS Cat-I Architecture

GBAS Ground Subsystem

• Ground Processing Functions
  • 1. Signals-in-space receive and decode
  • 2. Carrier smoothed code and differential correction calculation
  • 3. Integrity monitoring
  • 4. Performance categorisation
  • 5. Data broadcast processing and monitoring
GBAS Cat-I Architecture
GBAS Aircraft Subsystem

- GBAS Aircraft Subsystem
  - Primary Functions
    - 1. Receive and decode the GNSS satellite and GBAS signals
    - 2. Provide availability of the service
    - 3. Determine the aircraft position
    - 4. Compute deviations from the desired flight path calculated from the Final Approach Segment (FAS) data
    - 5. Provide guidance signals and integrity information
  - More details included in the “GBAS Cat-I User Processing” Section
GBAS Cat-I Signal-In-Space
Application Layer

Note 1. Each Type 1 message or linked Type 1 message pair broadcast in a given frame includes the complete set of measurement blocks for its measurement type.

<table>
<thead>
<tr>
<th>Message Type</th>
<th>Message Name</th>
<th>Minimum Broadcast Rate</th>
<th>Maximum Broadcast Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Differential Correction</td>
<td>For each measurement type</td>
<td>For each measurement type</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All measurement blocks, once per frame (Note 1)</td>
<td>All measurement blocks, once per slot (Note 1)</td>
</tr>
<tr>
<td>2</td>
<td>GBAS Related Data</td>
<td>Once per 20 consecutive frames</td>
<td>Once per frame</td>
</tr>
<tr>
<td>3</td>
<td>Reserved for GBRS (APL) Acquisition Data</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Final Approach Segment (FAS) Construction Data</td>
<td>All FAS blocks once per 20 consecutive frames</td>
<td>All FAS blocks one per frame</td>
</tr>
<tr>
<td>5</td>
<td>Ranging Source Availability (optional)</td>
<td>All impacted sources once per 20 consecutive frames</td>
<td>All impacted sources once per 5 consecutive frames</td>
</tr>
<tr>
<td>6</td>
<td>Reserved for Carrier Corrections</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>Reserved for Military</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>Reserved for Test</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
GBAS Cat-I Signal-In-Space
GBAS Messages: MT4

- GBAS Message Type 4
- FAS Data Block
  - Contains the Parameters that define a single Precision Approach
GBAS Cat-I User Processing

Introduction

- GNSS Receiver Function
  - Received Pseudoranges, carrier phases and navigation/clock data
  - Corrected Pseudoranges
  - Satellite corrections
  - Satellite integrity information
  - FAS Path construction data

- Computation of Outputs function

- Corrected Pseudorange Function

- Message Processing Function

- Display Pilot/FMS

- AIRCRAFT SUBSYSTEM

- GNSS SUBSYSTEM

- GROUND SUBSYSTEM

PVT Output Guidance Output
References

- [REF.1]: EUROCAE ED-114
- [REF.2]: ICAO SARPS
- [REF.3]: RTCA/DO-253C
  - Minimum Operational Performance Standards for GPS. Local Area Augmentation System Airborne Equipment. 16/12/08
- [REF.4]: RTCA/DO-246D
  - GNSS-Based Precision Approach Local Area Augmentation System (LAAS) Signal-In-Space Interface Control Document (ICD).
- [REF.5]: RTCA/DO-245
  - Minimum Aviation System Performance Standards for the Local Area Augmentation System (LAAS)
- [REF.6]: EUROCAE ED-95
GBAS Architecture

- G/S (UHF)
- ILS
- MLS
- VDB
- GLS
- GNSS
- I/O

Guidance, Flags, Distance to Threshold
Command, Control
Position, Time, Integrity

Corrections
FAS Data
Position, XPL