FAA GNSS Programs & GPS Evolutionary Architecture Study (GEAS) Status

Presented to: Stanford PNT Symposium
By: Leo Eldredge, FAA
Date: November 6th, 2007
Agenda

• Wide Area Augmentation System (WAAS) Status
• Local Area Augmentation System (LAAS) Status
• GNSS Evolutionary Architecture Study (GEAS) Status
WAAS Architecture

38 Reference Stations
3 Master Stations
4 Ground Earth Stations
2 Geostationary Satellite Links
2 Operational Control Centers
### WAAS LPV Performance

<table>
<thead>
<tr>
<th></th>
<th>GPS Standard</th>
<th>GPS Actual</th>
<th>WAAS LPV-200 Standard</th>
<th>WAAS LPV-200 Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal 95%</td>
<td>36 m</td>
<td>2.74 m</td>
<td>16 m</td>
<td>1.08 m</td>
</tr>
<tr>
<td>Vertical 95%</td>
<td>77 m</td>
<td>*3.89 m</td>
<td>4 m</td>
<td>1.26 m</td>
</tr>
</tbody>
</table>

*Use of GPS vertical not authorized for aviation without augmentation (SBAS or GBAS)*

**WAAS Performance evaluated based on a total of 1,761 million samples (or 20,389 user days)**
WAAS Enterprise Schedule

| FLYears | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
|---------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| FLP Segment (Phase II) | Development | Operational | FOC | JRC | Technical Refresh | Operational | JRC | Technical Refresh | Operational |
| LPV-200 Segment (Phase III) | Inmarsat | GEO #3 – Intelsat | Operational | Lease Extension 9/06 | Operational | Launch 10/05 |
| Dual Frequency (Phase IV) | GEO #4 – PanAmSat | GEO #5 – TBD | Operational | Launch 9/05 | Operational | Launch 7/12 |
| | GEO #6 – TBD | Approach Development | Operational | Launch 7/15 | WAAS Procedure Development | 6,000 |
WAAS Phase II Status

- Expand LPV Service to all of CONUS and Significant Portions of Alaska, Canada, Mexico
  - Install 13 Additional WAAS Reference Stations (WRS)
    - 4 Alaska – Complete
    - 4 Canada – Complete
    - 5 Mexico - Complete
    - Software Modifications - Underway
- Provide Redundant GEO Coverage
  - Replace Both GEO Satellites - Complete
- Improve Service Reliability
  - Add Third WAAS Master Stations (WMS) - Complete
  - Software Improvements To Broadcast Corrections - Underway
- Approve LPV Service Down to 200 Feet
  - Complete Safety Analysis to Approve WAAS Users For ILS Equivalent Service - Complete
GEO Satellite Improvements

- **Phase I – IOC**
  - Inmarsat Satellites
    - AOR-W – 54W
    - POR – 178E
  - AOR-W Moved to 142W
  - Leases Expired July 2007

- **Phase II**
  - New GEOs
    - Panamsat (Galaxy XV) – 133W
    - Telesat Canada (Anik F1R) – 107W
  - Operational July 2007
WAAS LPV Coverage
- IOC 2003 -
WAAS LPV Coverage
- Current 2007 -

LPV200 Service Contour
(solid yellow line)

LPV Service Contour
(solid red line)

LNAV/VNAV Service Contour
(dashed black line, includes LPV)

Color Scale is Vertical Protection Level (VPL)

05-Nov-07 12:00:10 GMT (WJH FAA Tech. Cntr., NJ USA)
WAAS Program – Phase III
(2009-2013)

Full LPV-200 Performance
• Continue To Improve Service For LPV-200

• Support Transition Of WAAS Maintenance And Development Capabilities To The FAA

• Planned WAAS Algorithm Updates For Phase III
  – Acquisition Of Additional GEO Satellite
  – Continued GIVE Algorithm Tuning to Maximize Availability During the Approaching Solar Maximum

• Conduct Planning and Engineering Analysis to Prepare for Dual Frequency Operations
  – GPS Evolutionary Architecture Study (GEAS)
WAAS Program – Phase IV
(2014-2028)

• Dual Frequency Operations
  – Maintain a robust, reliable, and sustainable LPV-200 capability
  – Support Single frequency WAAS users through end of Phase IV (2028)
  – Implement WAAS Changes Needed for Dual Frequency (L1/L5) GPS Operations
WAAS Avionics Status

- Approximately 40% Of Est. 140,000 GA Aircraft Are Equipped With Garmin Receivers
  - Total WAAS Equipped Users ~20,000

- Rockwell-Collins: FAA Flight Inspection Challenger Aircraft Approval – August 2007

- Canadian Marconi: Contract To Integrate WAAS Sensor Into FAA Global 5000 Aircraft To Complete In 2008

- Universal Avionics: Developing WAAS Enabled Capability In Dual Thread UNS-1 Flight Management System
  - Approval Completed in October in 2007
  - Retro-Fit of FAA Citations Expected in 2008
**Instrument Approach Services**

- **GPS**: 400 – 600 ft MDA
- **WAAS**: 350 – 400 ft DA
- **WAAS**: 200 – 300 ft DA
- **LAAS**: 200 – 0 ft

Cat I/II/III

LNAV/VNAV

LPV

GLS

NPA

Stanford PNT Symposium
November 6th, 2007
LPVs  925
LNAV/VNAVs  1121
LNAVs  4225

LP procedure criteria under development for use at runways where obstacles prevent a vertically guided approach
Each dot represents an airport with an LPV and/or LNAV/VNAV minima on an RNAV (GPS) instrument approach procedure (As of: July 12, 2007)
Procedure Production Goals

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<tr>
<th>Year</th>
<th>Flight Plan Cum Goal</th>
<th>Non-ILS RWY ENDS</th>
<th>ILS RWY ENDS</th>
<th>Total</th>
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<td>328</td>
<td>286</td>
<td>614</td>
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<td>700</td>
<td>516</td>
<td>409</td>
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<td>FY16</td>
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<td>FY17</td>
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<tr>
<td>FY18</td>
<td>6000</td>
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Local Area Augmentation System (LAAS)

- Precision Approach For Category I, II & III
- Multiple Runway Coverage At An Airport
- Terminal Area Procedures for Arrival and Departure
LAAS Status

• **Integrity Analysis and Prototype Development**
  – FAA GBAS prototype work under Honeywell Contract
  – Hazardous Misleading Information (HMI) Analysis underway to validate GBAS architecture/design

• **GBAS CAT I Approval Process**
  – System Design Approval for Honeywell architecture (SLS 4000) Planned to Complete by 2008

• **GBAS Avionics**
  – GBAS/LAAS Standards (MASPS / MOPS / TSO / SARPS) completed
  – Boeing 737-800 series GBAS equipped
  – Airbus A320, A380 certification planned for 2007

• **CAT-III Research & Development Activities**
  – Continuing Work to Develop Requirements Compatible with Aircraft Operations and Approval Process

• **International GBAS Cooperation**
  – International GBAS Working Group
  – FAA Memorandum of Cooperation established with Australia, Brazil, Spain, Germany
GNSS Evolutionary Architecture Study (GEAS)

Presented to: Stanford PNT Symposium
By: Leo Eldredge, FAA GNSS Group
Date: October 30, 2007
GEAS Purpose

- Chartered By The FAA To Investigate Long Range Planning Considerations For WAAS
  - Recognized That Meeting Aviation Integrity Requirements Is One Of The Most Challenging Aspects
  - Facilitate Common Understanding Through Technical Interchange Between DoD and FAA
- Strategic Planning For:
  - GPS Modernization
  - User Equipment Standards Development
  - WAAS Dual Frequency Upgrade
GEAS Objectives

To Evaluate GNSS-Based Architectures To Provide Robust LPV-200 Service Worldwide Circa 2025-30

Corollary Objectives:

- Assess Capability Of Modernized GPS To Simplify Fault Detection And Provide An Alternate Broadcast Channel
- Technical Feasibility Of World Wide Autoland
- Interaction With National PNT Architecture Effort
  - Coordinated By The DoD National Space Security Office (NSSO) And DoT Research & Innovative Technology Administration (RITA)
## GEAS Panel

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
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<tbody>
<tr>
<td>Deane Bunce (Co-Chair)</td>
<td>FAA ATO-W</td>
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<tr>
<td>Leo Eldredge</td>
<td>FAA ATO-W</td>
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<tr>
<td>Deborah Lawrence</td>
<td>FAA ATO-W</td>
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<td>Calvin Miles</td>
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<td>Kevin Bridges</td>
<td>FAA AVS</td>
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<td>Hamza Abduselam</td>
<td>FAA AVS</td>
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<td>Tom McHugh</td>
<td>FAA ATO-P</td>
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<td>David Schoonenberg</td>
<td>NSSO</td>
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<td>Mike David</td>
<td>NSSO</td>
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<tr>
<td>Karen Van Dyke</td>
<td>RITA/Volpe</td>
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<td>Navin Mathur</td>
<td>GPS TAC</td>
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<td>Geoff Harris</td>
<td>G-Wing/Aerospace</td>
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<td>Karl Shallberg</td>
<td>GREI</td>
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<td>Boris Pervan</td>
<td>IIT</td>
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<td>John Dobyne</td>
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<td>Karl Kovach</td>
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<td>Willie Bertiger</td>
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<td>Young Lee</td>
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<td>JP Fernow</td>
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<td>Frank Van Grass</td>
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<td>Juan Blanch</td>
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<td>Per Enge (Co-Chair)</td>
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<tr>
<td>Todd Walter</td>
<td>Stanford University</td>
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<tr>
<td>Pat Reddan</td>
<td>Zeta Associates</td>
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GEAS Architecture Options

- A Large Challenge In Providing Global Coverage is Meeting The 6 Second Time-to-alarm (TTA)
- The GEAS Is Currently Investigating Three Architectures That Address This Problem
  - GPS Integrity Channel (GIC)
  - Relative RAIM (RRAIM)
  - Absolute RAIM (ARAIM)
GNSS Integrity Channel (GIC)

- **Avionics**
  - No RAIM/FDE Required – WAAS Scenario
  - Dual Frequency (L1/L5) – Ionosphere Delay Estimation

- **Worldwide Monitor Network**
  - Monitors External to the User Detect All SV Faults
  - Requires Monitoring Network Capable of Continuous Monitoring of All GPS Satellites From At Least Two Locations
  - Latency to Support Time to Alarm of 6 Seconds or Less

- **Broadcast at High Data Rate**
  - Data Rate Comparable to Current WAAS Broadcast of 250 bps
Relative RAIM: *Range Rate Residuals*

- **Avionics**
  - RRAIM Algorithms Check Residuals Between Carrier Phase Measurements and Estimated Change in Position
  - Integrity/Correction Messages Provide Starting Point
  - Dual Frequency (L1/L5) – Ionosphere Delay Estimation

- **Worldwide Monitor Network**
  - Provide Slow Integrity/Correction Messages
  - Time to alarm of 60 to 600 seconds

- **Broadcast at Slow Data Rate**
  - May Be Suitable For GPS Messages or eLoran
Relative RAIM Concept

Since the most recent monitored position propagate with carrier phase only

Most recent monitored position with corresponding HPL and VPL

Growth in HPL and VPL due to RAIM on the carrier phase-based delta position updates

From Prof. van Graas, Ohio University
Absolute RAIM: Range Residuals

• **Avionics**
  – Relies on Receiver Autonomous Integrity Monitoring as the Primary Integrity Solution
  – Dual Frequency (L1/L5) – Ionosphere Delay Estimation

• **Worldwide Monitor Network**
  – Update error variance and mean for each SV
  – Time to alarm of 10 minutes or more

• **Broadcast at Low Data Rate**
  – Reliability Estimates (Prior Probability) for Each SV
    • Used by the Avionics ARAIM Algorithms
  – Potential to Broadcast Via GPS Message
  – VHF Networks or eLoran
Absolute RAIM Concept
GIC Preliminary Results

<table>
<thead>
<tr>
<th>URA / UDRE from monitor network (m)</th>
<th>24 minus worst case 1 SV</th>
<th>24</th>
<th>27 minus worst case 1 SV</th>
<th>27</th>
<th>30 minus worst case 1 SV</th>
<th>30</th>
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<tbody>
<tr>
<td>1.0/6.6</td>
<td>17.25%</td>
<td>52.90%</td>
<td>38.00%</td>
<td>83.12%</td>
<td>76.55%</td>
<td>97.45%</td>
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<td>0.7/4.6</td>
<td>62.17%</td>
<td>92.09%</td>
<td>71.65%</td>
<td>99.30%</td>
<td>95.63%</td>
<td>99.83%</td>
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<tr>
<td>0.35/2.3</td>
<td>87.84%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

LPV-200 Coverage Estimates at 99.5% Availability for +/- 70 Degrees Latitude
## RRAIM Preliminary Results

<table>
<thead>
<tr>
<th>URA &amp; UDRE from monitor network (m)</th>
<th>24 minus worst case 1 SV</th>
<th>24</th>
<th>27 minus worst case 1 SV</th>
<th>27</th>
<th>30 minus worst case 1 SV</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 &amp; 6.6</td>
<td>27.8%</td>
<td>70.41%</td>
<td>46.15%</td>
<td>86.55%</td>
<td>82.53%</td>
<td>97.88%</td>
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<tr>
<td>0.7 &amp; 4.6</td>
<td>75.7%</td>
<td>98.55%</td>
<td>86.32%</td>
<td>100%</td>
<td>98.49%</td>
<td>100%</td>
</tr>
<tr>
<td>0.35 &amp; 2.3</td>
<td>76.9%</td>
<td>98.55%</td>
<td>87.31%</td>
<td>100%</td>
<td>98.49%</td>
<td>100%</td>
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LPV-200 Coverage Estimates at 99.5% Availability for +/- 70 Degrees Latitude
## ARAIM Preliminary Results

LPV-200 Coverage Estimates at 99.5% Availability for +/- 70 Degrees Latitude

<table>
<thead>
<tr>
<th>URA from monitor network (m)</th>
<th>24 minus worst case 1 SV</th>
<th>24</th>
<th>27 minus worst case 1 SV</th>
<th>27</th>
<th>30 minus worst case 1 SV</th>
<th>30</th>
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</thead>
<tbody>
<tr>
<td>1.0</td>
<td>2.1%</td>
<td>20.2%</td>
<td>12.5%</td>
<td>73.2%</td>
<td>70.5%</td>
<td>98.3%</td>
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<tr>
<td>0.7</td>
<td>3.4%</td>
<td>24.8%</td>
<td>19.3%</td>
<td>84.4%</td>
<td>79.2%</td>
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<tr>
<td>0.35</td>
<td>5.6%</td>
<td>36.9%</td>
<td>25.6%</td>
<td>91.8%</td>
<td>87.0%</td>
<td>99.8%</td>
</tr>
</tbody>
</table>
GEAS Initial Results

Current GPS Commitment
(21 out of 24 – 98%) - URE NTE 30 meters

Max Bias = 1 meter

Predicted URA (m) with 10^-5 bound

WAAS (No RAIM)

Fast GIC (No RAIM)

RRAIM Slow GIC

ARAIM Offline Monitoring

#SV Constellation
No Satellite Failures

21 24 27 30

More (Multi-constellation)

1.0

0.7

0.35

0.25
Summary

• GEAS Panel Investigating Three Potential Architectures
  – GIC
  – RRAIM
  – ARAIM

• Results Indicate Satellite Constellation Size and Quality Are Most Significant Contributors
  – Reasonable Availability Can Be Expected From All Three Options With A 30 SV Constellation And URA Of Less Than 0.7 Meters of Less

• Initial Findings Will Be Documented In A Report By December 2007
Questions