The Wide Area Augmentation System (WAAS)

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http://waas.stanford.edu
Outline

- Aviation Metrics
- GPS/Aviation Timelines
- The Wide-Area Augmentation System
- Integrity Analyses
- Comparison with Terrestrial Navigational Aids
- Future Directions
Aircraft Guidance Goals

Key Elements:

- **Accuracy**
- **Availability**
- **Integrity**
- **Continuity**

Integrity: Accuracy < Protection Limit
Vertical Guidance

Benefit: Lower DH

CAT III
0-50 ft DH

CAT II
200 ft DH

CAT I
250 ft DH

GLS
350 ft DH

L-NAV
V-NAV

NPA

Requirement: More Accuracy, Tighter Bounds

DH = Decision Height

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Courtesy: Sherman Lo
GPS Timeline

- **1966**: DoD development results in approval to proceed with program
- **1972**: First survey receiver by Trimble
- **1978**: Garmin GPS 45
- **1982**: GPS Initial Operating Capability
- **1986**: GPS Final Operating Capability
- **1990**: Turn off Selective Availability
- **1994**: GPS chip sets support over 500 million users
- **2002**: 31
- **2006**: 32
- **2010**: 31

Number of operational satellites:
- 1966: 4
- 1972: 6
- 1978: 5
- 1982: 7
- 1986: 7
- 1990: 16
- 1994: 21
- 1998: 26
- 2002: 27
- 2006: 28
- 2010: 31
GPS Timeline for Aviation

- 1966: ICAO notes potential of satellites for aeronautics
- 1972: KAL 007
- 1978: ICAO recommends research on aeronautical satellites
- 1982: ICAO identifies satellite technology as central to air navigation
- 1986: GPS Integrity Channel Proposed
- 1990: Initial WAAS MOPS Development
- 1994: WAAS Contract Award
- 1998: IFR approval TSO-C129 supplemental
- 2002: ICAO approves global implementation plan
- 2006: WAAS Approved
- 2010: SLS-4000 (GBAS) SDA

Additional points:
- 1972: First aviation receiver
- 1978: WAAS MOPS Development
- 1982: GPS Integrity Channel Proposed
- 1990: WAAS Contract Award
- 1994: IFR approval TSO-C129 supplemental
- 1998: ICAO approves global implementation plan
- 2002: WAAS Approved
- 2006: SLS-4000 (GBAS) SDA

ICAO notes potential of satellites for aeronautics
ICAO recommends research on aeronautical satellites
ICAO identifies satellite technology as central to air navigation
ICAO approves global implementation plan
WAAS Approved
SLS-4000 (GBAS) SDA
WAAS

Reference Station
Master Station
Ground Uplink Station
WAAS Architecture

Wide Area Augmentation System (WAAS) – Program Status

- 38 Reference Stations
- 3 Master Stations
- 4 Ground Earth Stations
- 2 Geostationary Satellite Links
- 2 Operational Control Centers

Courtesy: Federal Aviation Administration
Geostationary Satellites (GEO)

- Provides Dual Coverage Over United States

Wide Area Augmentation System (WAAS) – Program Status
WAAS LPV and LPV-200 Vertical Position Error Distributions July 2003 to June 2006

CONUS WAAS Vertical Position Error (VPE) Distribution when VPL <= 35 & VPL <= 50

- 95% error = 1.256 m
- 99% error = 1.705 m

Sample Count vs. Vertical Position Error (m)

Total Samples 1,761 million or 20,389 User*days

Courtesy:
FAA Technical Center

3 years
20 WRSs
1 Hz data

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Integrity Approach

- Aviation integrity operates on a guilty until proven innocent principle
  - *Error bound is the maximum possible value given the measurements*

- This is unlike conventional systems that describe the most likely errors

- Protection level is a 99.99999% bound on worst reasonable conditions
  - *Very different from 95% achieved accuracy*
Error Sources

- Satellite errors
  - Ephemeris
  - Clock
  - Signal
- Propagation errors
  - Ionosphere
  - Troposphere
- Local Errors
  - Multipath
  - Receiver Noise
GPS Performance (Usually)

On a good day, the red circle encloses 95% of the GPS position fixes.
Major GPS Faults About Twice a Year
Example: Ephemeris Failure on April 10, 2007

On a bad day, the GPS errors can be much worse.

WAAS & GBAS eliminate these large errors.
Failure of Thin Shell Model

Quiet Day  
10/28/2003, 20:35:00UT

Disturbed Day  
10/29/2003, 20:31:00UT
Undersampled Condition

10/30/2003, 05:50:00UT

Vertical Ionospheric Delay, in m

Courtesy: Seebany Datta-Barua
Localizer Performance Vertical (LPV) Coverage

Current WAAS Vertical Navigation Service Snapshot Display

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)
02-Mar-09 19:53:01 GMT (WJH FAA Tech. Cntr., NJ USA)

Wide Area Augmentation System (WAAS) – Program Status

Federal Aviation Administration
WAAS RNP 0.3 Current Coverage

![Map showing WAAS RNP 0.3 current coverage with color scale indicating Horizontal Protection Level (HPL)].

**WAAS RNP 0.3 Service**: Dashed Black line HPL = 556 m
**RNP 0.3 Service**: Dashed Red line HPL = 185 m
Color Scale is Horizontal Protection Level (HPL)
02-Mar-09 19:53:01 GMT (WJH) FAA Tech. Ctr., NJ USA

**Wide Area Augmentation System (WAAS) – Program Status**

**Federal Aviation Administration**
Navigational Aids

- Instrument Landing System (ILS)
  - *Glideslope antenna for vertical*
  - *Localizer for horizontal*
ILS Installations: Each Runway End Requires At Least Two Transmitters

1318 ILS’s nationwide
No GPS Equipment Required at Airport
50 Pieces of WAAS Equipment Serve the Continent

As of November, 2009
• 1820 WAAS-based LPV’s
• ~1000 for non ILS runways
Localizer Approaches at Moffett Field

Cross Runway Position [ft]

Distance to Touchdown [nm]

-2000 -1500 -1000 -500 0 500 1000 1500 2000

-20 18 16 14 12 10 8 6 4 2 0

Needle RMS Horizontal FTE: 517.0 [ft]
Tunnel RMS Horizontal FTE: 23.8 [ft] (3 runs)

tunnel boundary

one dot on CDI

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Courtesy: Sharon Houck
Utility of Protected Accuracy from WAAS

- Localizer performance with vertical guidance (LPV)
- Safer than lateral nav. (non-precision approach)
- Same decision ht. as Cat I
- GBAS for Cat. II & III

WAAS (& GBAS) tunnels:
- Do not flare like ILS
- Do not have beam bends
- Are programmable
- Are adaptable
Current WAAS Performance
Future L1/L5 Performance
Potential of L1/L5 GPS/Galileo Performance
Conclusions

- WAAS is used to provide aircraft navigation from enroute through vertically guided approach
- Integrity was and is the key challenge
  - Important to understand what can go wrong and how to protect users
  - Careful analysis of feasible threats
- New civil frequencies and additional constellations may further improve performance