The Future of Satellite Navigation for Aviation

Todd Walter
Stanford University

http://waas.stanford.edu
## Current Satellite Navigation Use by Aviation

- Receiver Autonomous Integrity Monitoring (RAIM)
- Ground Based Augmentation Systems (GBAS)
  - LAAS
- Space Based Augmentation Systems (SBAS)
  - WAAS
  - EGNOS
  - MSAS
RAIM Protection

Horizontal Error Bound
GBAS/LAAS Concept

Courtesy: FAA
WAAS Concept

- Network of Reference Stations
- Master Stations
- Geostationary Satellites
- Geo Uplink Stations

Courtesy: FAA
Aviation Pace of Adoption

- Avionics are designed into airplane
- Aircraft stay in service for 20+ years
  - Rarely retrofitted after production
- Certified avionics are slow to develop
  - Must work with other components
- GPS functionality still not in all commercial aircraft
  - In late 2009 Boeing estimated that the majority of existing fleet had no GNSS
Outline

Current challenges

- Geometry weakness
- Ionospheric delay
- Radio Frequency Interference (RFI)
- Ionospheric scintillation

Opportunities

- Multiple constellations
- Multiple frequencies
- Augmentations/ARAIM
- Integration with other sensors
Nominal WAAS Vertical Guidance Performance

WAAS LPV Coverage Contours
04/22/11
Week 1632 Day 5

<table>
<thead>
<tr>
<th>Percent</th>
<th>CONUS Coverage</th>
<th>Alaska Coverage</th>
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<tr>
<td>95</td>
<td>100.00%</td>
<td>98.99%</td>
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<tr>
<td>90</td>
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<tr>
<td>75</td>
<td>100.00%</td>
<td>93.56%</td>
</tr>
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</table>

K.J., FAA Technical Center
AWS Test Team
WAAS Vertical Guidance without a Primary Satellite
Vertical Guidance with Major Ionospheric Disturbance

WAAS LPV Coverage Contours
10/25/11
Week 1659 Day 2

Courtesy: FAA
Nominal WAAS Horizontal Guidance Performance

WAAS RNP 0.1 Coverage Contours
04/22/11
Week 1632 Day 5

Percent NPA Service Area
Available Coverage
99
99.9
100

0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

Courtesy: FAA
WAAS Horizontal Guidance without a Primary Satellite
Horizontal Guidance in Major Ionospheric Disturbance
Announced GPS Testing
March – Dec 2009
Supreme Court’s GPS case asks: How much privacy do we expect?

By Jonathan Turley, Published: November 11

In December 1967, the Supreme Court issued what many consider to be one of its greatest and most eloquent decisions, in *Katz v. United States*. That case, which is celebrated as saving privacy in the United States, articulated the principle that “the Fourth Amendment protects people, not places.” The decision reversed a long erosion of privacy protection and required greater use of warrants by the government.
Ionospheric Scintillation
Regions with Scintillation

**FIGURE 1** Scintillation map showing the frequency of disturbances at solar maximum. Scintillation is most intense and most frequent in two bands surrounding the magnetic equator, up to 100 days per year. At poleward latitudes, it is less frequent and it is least frequent at mid-latitude, a few to ten days per year.
New GNSS Constellations

- A solution to constellation weakness
  - Many more ranging sources
  - Fills in gaps
  - Provides extra redundancy
  - Averages down uncertainty
Multiple Frequencies

- GPS is adding new civil frequencies
  - Including L5 (in an aviation band)
- Other constellations also including signals at or near L1 and L5
- Two frequencies allow direct removal of ionospheric delay error
  - Ionospheric scintillation may still cause loss of continuity in equatorial areas
- Offers protections against unintentional RFI and PPDs
Advanced RAIM (ARAIM)

- Dual Frequency - Multi-constellation
  - Eliminates multiple SV iono threat
  - Strong geometries

- Support for vertical guidance
  - Requires a more stringent level of certification than RAIM for lateral
  - May require ground monitoring by approving agency

- Potential for near global coverage
  - Modest infrastructure requirements
Currently, GBAS is focusing on obtaining CAT-III service with single-frequency, GPS-only equipment.

Desire for service in near term

Multiple frequencies and multiple constellations can provide higher availability.
Current SBAS Coverage

Availability as a function of user location

Availability with VAL = 35, HAL = 40, Coverage(99%) = 7.54%
Dual Frequency Coverage (WAAS, EGNOS, MSAS)

Availability as a function of user location

Availability with VAL = 35, HAL = 40, Coverage(99%) = 28.64%
Dual Frequency Coverage (with GAGAN + Russia)

Availability as a function of user location

Availability with VAL = 35, HAL = 40, Coverage(99%) = 36.82%
Dual Frequency + Second Constellation (Galileo)

Availability as a function of user location

Availability with VAL = 35, HAL = 40, Coverage(99%) = 62.15%
Dual Frequency, Dual GNSS, Expanded Networks

Availability as a function of user location

Availability with VAL = 35, HAL = 40, Coverage(99%) = 92.65%
Conclusion

- New aeronautical frequencies eliminate ionospheric delay threats
  - Provides service in equatorial areas
- Ranging signals from new constellations significantly improve user geometry
- Enormous opportunity to improve coverage and levels of service provided
- RFI and scintillation are threats that still need to be addressed
  - Potential for mitigation through integration with other sensors
Predictions

- All three systems will incorporate multiple constellations and multiple frequencies
  - ARAIM, GBAS, & SBAS
  - Different countries will choose different solutions
    - Some will choose more than one
- There will be greater integration with other sensors
  - Must be able to survive outages caused by RFI
L1 C/No, WAAS GEOs
Access / Sovereign Control

- Currently only GPS used for Aviation
  - Countries either allow it or not
- Russian Federation has issued a mandate for use of GLONASS
  - Other countries may follow suit
- Countries may want to allow use of some constellations and not others
  - Trust, liability, monitoring, …
  - May want method to allow some satellites, but exclude others
ADS-B mandate effectively requires all aircraft to have GNSS by 2020

May require better than basic RAIM

Ideally, link mandate to multi-constellation, multi-frequency receiver

ARAIM, GBAS, SBAS?

Whatever does not make it in, may not be put on an aircraft for a very long time
RAIM Protection

True Position

Estimated Position

Horizontal Error Bound

Faulted Satellite

Courtesy: Juan Blanch
Approved GPS Aviation Operations (as of 2007)

Courtesy: FAA
Current SBAS Coverage

Courtesy: FAA Technical Center