Vertically-guided Instrument Approaches Using the Wide Area Augmentation System (WAAS)

Emily Q. Calle
S.V. Massimini, DSc

H. Leslie Crane
Frederick A. Niles

21 May 2003
Wide Area Augmentation System (WAAS)
Wide Area Augmentation System
Initial Equipment Locations

[Map showing initial equipment locations across the United States, including key points such as San Juan, Jacksonville, Aurora, and others.]

Key:
- Phase 1 WRS
- Phase 1 WMS/WRS
- Phase 1 GES
- WMS = Wide-area Master Station
- WRS = Wide-area Reference Station
- GES = Ground Earth Station

© 2003 The MITRE Corporation. All Rights Reserved.
WAAS Benefits

• WAAS will provide increased accuracy and availability for navigation throughout CONUS (and much of Alaska), and provide advanced navigation procedures, such as departures and curved approaches

• A significant safety benefit will be the provision of vertically-guided approaches to nearly all runways
  – USA has 5000 airports with at least one runway 3000 ft long

• Initial plans were to provide vertical guidance to Category I approach minima
  – 200 ft Height Above Touchdown (HAT)
  – Integrity re-evaluation in 1999 indicated this goal was overly optimistic for single-frequency WAAS
Instrument Approaches

• **GNSS Landing System (GLS)**
  – Equivalent to ILS Category I approach with lowest HAT of 200 ft and lowest visibility of \( \frac{1}{2} \) statute mile
  – Generally not considered possible with high availability for single-frequency WAAS

• **LNAV/VNAV – BARO/VNAV**
  – Originally designed for FMS-equipped aircraft with sophisticated barometric altimetry system
  – Flyable with DME/DME Inertial, GPS or WAAS

• **LNAV**
  – Nonprecision approach flyable with DME/DME Inertial, GPS or WAAS
Visibility Values

- **Visibility Values**
  - **HAT < 740 ft ==> Visibility = 1 sm (Category A/B aircraft)**
  - **HAT < 400 ft ==> Visibility = 1 sm (Category C aircraft)**

**LNAV**

- **3960’ = 3/4 sm**
- **5280 ft = 1 sm**

**LNAV/VNAV, APV, and GLS**

- **Decision Height**
- **HAT < 326 ft ==> Visibility < 1 sm**
- **HAT < 257 ft ==> Visibility < 3/4 sm**

* With approach lights, the visibility requirement can be less.

** Based on 3° slope, 50 ft crossing height
GPS Approach Minima Estimator
(GAME) Model

Terrain Data Base

Obstacle Data Base

Airports Data Base

Approach Design Criteria

Minima Estimation Software

Repeat for Thousands of Runway Ends

Generate Statistics
GAME Airports:
1534 airports and 5073 runway ends

CONUS: 1429
Alaska: 104
Hawaii: 1
Estimated HAT for LNAV Approaches (Existing Capability without WAAS)

5147 runway ends at 1534 airports
Estimated LNAV/VNAV HAT

<table>
<thead>
<tr>
<th>HAT (ft)</th>
<th>Visibility (smi)</th>
<th>Number of Runways</th>
</tr>
</thead>
<tbody>
<tr>
<td>250-257</td>
<td>3/4</td>
<td>400</td>
</tr>
<tr>
<td>258-326</td>
<td>1</td>
<td>1000</td>
</tr>
<tr>
<td>327-395</td>
<td>1 1/4</td>
<td>1200</td>
</tr>
<tr>
<td>396-465</td>
<td>1 1/2</td>
<td>1800</td>
</tr>
<tr>
<td>466-534</td>
<td>1 3/4</td>
<td>2000</td>
</tr>
<tr>
<td>535-603</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>More</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>GQS</td>
<td>Fail</td>
<td>1</td>
</tr>
</tbody>
</table>
Estimated Improvement in HAT with LNAV/VNAV (Available at WAAS Phase I)

All LNAV/VNAV approaches have equal or lower HAT than the associated LNAV approach.

5147 runway ends at 1534 airports
Estimated Visibility Benefit for LNAV/VNAV vs. LNAV (Cat A/B Aircraft)

For Category A/B, only about 5% of LNAV/VNAV have visibility minima less than the associated LNAV approach.

5147 runway ends at 1534 airports
New Approaches

• To improve near-term instrument approach benefits of WAAS, the FAA investigated instrument approach criteria that used the horizontal and vertical integrity available from WAAS

  LNAV/VNAV - RNP .3 (556 m horizontal by 50 m vertical)

  LPV (40 m horizontal by 50 m vertical)

  GLS (40 m horizontal by 12 m vertical)
Comparison of LNAV/VNAV with LPV Primary & Secondary Obstacle Surfaces
Comparison of LNAV/VNAV with LPV

5142 runway ends at 1534 airports
LPV

- Significant increase in capability for no additional investment in WAAS ground facilities
- The FAA has decided to implement LPV
  - First approaches are to be implemented this year
- LPV criteria will be incorporated into ICAO Satellite-Based Augmentation System (SBAS) standards and recommended practices as Approach with Vertical Guidance I (APV-I)
Rounding of HATs

5142 runway ends at 1534 airports
Required Navigation Performance (RNP) Instrument Approach Procedures

• Enhancement to navigation specifying accuracy and containment areas

• For instrument approaches, containment area is generally 2 x RNP value (in nautical miles)

• Provides for rectangular versus trapezoidal obstacle clearance areas
  – BARO-VNAV vertical obstruction areas

• Generally flyable
  – By GPS or WAAS equipped aircraft for RNP .3 or higher
  – By FMS equipped aircraft for all RNP values
    • GPS and inertial often required for RNP ≤ .3
    • Specific certification required

© 2003 The MITRE Corporation. All Rights Reserved.
RNP .11 and LPV
Horizontal Depiction
RNP .11 and LPV Draft Criteria
Vertical Depiction from End of Runway

Cross Section At
200' from RWT

Cross Section At
50.200' from RWT

Primary Area
2 x RNP

Secondary Area
1 x RNP
Obstacle Clearance Surfaces
Side View

Touchdown Elevation

- 23:1 LNAV/VNAV OCS
- 27:1 APV-1.5 OCS
- 34:1 Precision ILS OCS
- 3° Glideslope

LPV
RNP

HAT

954'
200'
2,379'
1,237'
7,983'
12,753'

954'
1,154'
3,533'
4,770'

© 2003 The MITRE Corporation. All Rights Reserved.
RNP Approaches Versus LPV and LNAV VNAV

5142 runway ends at 1534 airports
RNP .11 and LPV Draft Criteria Depiction with Controlling Obstacles
Improving Vertically Guided Approaches

- **Horizontal Improvement**
  - LPV obstacle clearance standards are very ‘wide’ far from the runway, but narrow close to the runway
  - RNP are wider near the runway, but narrow far from the runway
  - Developed combination approach that uses RNP when far from the runway, and transitioning to LPV as the aircraft approaches the runway
RNP .11 and LPV
Horizontal Depiction

LPV and RNP .11

Distance from RWT (ft)

Distance from C/L (ft)
RNP/LPV Horizontal Combination (Unrounded)

5142 runway ends at 1534 airports
Improving Vertically Guided Approaches

• Vertical Improvement
  – RNP approaches use BARO-VNAV vertical obstacle clearance profiles
    • The BARO-VNAV profile has the same vertical integrity limit as the LPV profile, but is temperature compensated and seemingly more conservative
  – Developed combination approach that uses RNP horizontal obstacle clearance profiles with LPV vertical profile
Vertical Obstruction Surfaces

LPV/Combo

Touchdown Elevation

954' 1,154' 2,379' 3,533' 4,770' 7,983' 12,753'

954' 200' 2,379' 1,237'

34:1 Precision ILS OCS

27:1 APV-1.5 OCS

23:1 LNAV/VNAV OCS

185' HAT

250' HAT

668' HAT

3° Glideslope
RNP/LPV Vertical Combination (Unrounded)

5142 runway ends at 1534 airports
Observations

- LPV will provide a significant increase in capability for WAAS-equipped aircraft with little cost to the FAA WAAS program
- RNP provides reasonable instrument approach capability for non-WAAS equipped aircraft
  - Minima are not as low as LPV
- Some improvement may be possible for RNP with improved criteria
  - Overall with improved vertical criteria for RNP
  - Airport specific for improved horizontal criteria