Global Positioning Systems Directorate

GPS Status & Modernization Progress: Service, Satellites, Control Segment, and Military GPS User Equipment

18-19 May 2016

Lt Col Andrew Zinn
Global Positioning Systems Directorate
Global Positioning Systems Directorate

Mission:
Professionals acquiring, delivering and sustaining reliable GPS capabilities to America’s warfighters, our allies, and civil users

“We are... the Green Monsters!”

Col Steve Whitney
Director
GPS Overview

Civil Cooperation
- 1+ Billion civil & commercial users worldwide
- Search and Rescue
- Civil Signals
  - L1 C/A (Original Signal)
  - L2C (2nd Civil Signal)
  - L5 (Aviation Safety of Life)
  - L1C (International)

Department of Defense
- Services (Army, Navy, AF, USMC)
- Agencies (NGA & DISA)
- US Naval Observatory
- PNT EXCOMS
- GPS Partnership Council

International Cooperation
- 57 Authorized Allied Users
- 25+ Years of Cooperation
- GNSS
  - Europe - Galileo
  - China - Beidou
  - Russia - GLONASS
  - Japan - QZSS
  - India - IRNSS

Spectrum
- World Radio Conference
- International Telecommunication Union
- Bilateral Agreements
- Adjacent Band Interference

Department of Transportation
- Federal Aviation Administration

Department of Homeland Security
- U.S. Coast Guard

39 Satellites / 31 Set Healthy
Baseline Constellation: 24 Satellites

<table>
<thead>
<tr>
<th>Satellite Block</th>
<th>Quantity</th>
<th>Average Age</th>
<th>Oldest</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS IIR</td>
<td>12</td>
<td>14.3</td>
<td>18.8</td>
</tr>
<tr>
<td>GPS IIR-M</td>
<td>7</td>
<td>8.8</td>
<td>10.6</td>
</tr>
<tr>
<td>GPS IIF</td>
<td>12</td>
<td>2.3</td>
<td>5.9</td>
</tr>
<tr>
<td>Constellation</td>
<td>31</td>
<td>8.4</td>
<td>18.8</td>
</tr>
</tbody>
</table>

AS OF 4 MAY 16
Accuracy: Civil Commitments

Standard Positioning Service (SPS) Performance Standard

Standard Positioning Service (SPS) Signal-in-space Performance

2008 SPS Performance Standard (PS)

Worst of Any Healthy Satellite, 7.8 m @ 95%

User Range Error (URE) in Meters

- 2001 SPS PS 6 m RMS
- 2008 SPS PS 4 m RMS

Compare to (example):
- ≈ 4.9 m RMS User residual iono delay error (L1 only)
- ≈ 0.5 m RMS User residual tropo delay error

System accuracy better than published standard

Better Performance
### Accuracy: Military Commitments

#### Precise Positioning Service (PPS) Performance Standard

#### Precise Positioning Service (PPS) Signal-in-Space Performance

<table>
<thead>
<tr>
<th>Year</th>
<th>User Range Error (URE) in Meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>1.5</td>
</tr>
<tr>
<td>2002</td>
<td>1.3</td>
</tr>
<tr>
<td>2003</td>
<td>1.1</td>
</tr>
<tr>
<td>2004</td>
<td>1.1</td>
</tr>
<tr>
<td>2005</td>
<td>1.0</td>
</tr>
<tr>
<td>2006</td>
<td>1.0</td>
</tr>
<tr>
<td>2007</td>
<td>0.9</td>
</tr>
<tr>
<td>2008</td>
<td>0.9</td>
</tr>
<tr>
<td>2009</td>
<td>0.8</td>
</tr>
<tr>
<td>2010</td>
<td>0.8</td>
</tr>
<tr>
<td>2011</td>
<td>0.8</td>
</tr>
<tr>
<td>2012</td>
<td>0.8</td>
</tr>
<tr>
<td>2013</td>
<td>0.7</td>
</tr>
<tr>
<td>2014</td>
<td>0.7</td>
</tr>
<tr>
<td>2015</td>
<td>0.6</td>
</tr>
</tbody>
</table>

**Signal-in-Space User Range Error** is the difference between a GPS satellite’s navigation data (position and clock) and the truth, projected on the line-of-sight to the user.

**Better Performance**

**System accuracy better than published standard**
## Current & Historical Statistics

<table>
<thead>
<tr>
<th>Period</th>
<th>SIS vs JPL RMS URET (cm)</th>
<th>Mean AoD hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Period Ending</td>
<td>SIS</td>
</tr>
<tr>
<td>Current Week</td>
<td>05/04/2016</td>
<td>51.0</td>
</tr>
<tr>
<td>Last Week</td>
<td>04/27/2016</td>
<td>51.7</td>
</tr>
<tr>
<td>Rolling Quarter</td>
<td>05/04/2016</td>
<td>51.9</td>
</tr>
<tr>
<td>Rolling 1/2 Year</td>
<td>05/04/2016</td>
<td>51.9</td>
</tr>
<tr>
<td>Rolling Year</td>
<td>05/04/2016</td>
<td>53.9</td>
</tr>
<tr>
<td>Best Day Ever</td>
<td>04/14/2016</td>
<td>45.3</td>
</tr>
<tr>
<td>Best Week Ever</td>
<td>04/14/2016</td>
<td>45.3</td>
</tr>
<tr>
<td>Worst Week Rolling Year</td>
<td>05/27/2015</td>
<td>64.4</td>
</tr>
</tbody>
</table>

**Best day/week ever achieved this year!**
CNAV message types currently being broadcast

<table>
<thead>
<tr>
<th>Type</th>
<th>Title</th>
<th>Description/Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Ephemeris 1</td>
<td>Keplerian orbital parameters</td>
</tr>
<tr>
<td>11</td>
<td>Ephemeris 2</td>
<td>Keplerian orbital parameters</td>
</tr>
<tr>
<td>30</td>
<td>Clock, IONO &amp; Group Delay</td>
<td>SV Clock correction parameters, ionospheric and SV group delay correction parameters</td>
</tr>
<tr>
<td>33</td>
<td>Clock &amp; UTC</td>
<td>SV Clock correction parameters, Coordinated Universal Time parameters</td>
</tr>
<tr>
<td>32</td>
<td>Clock &amp; EOP</td>
<td>SV clock correction parameters, Earth Orientation Parameters (On hold until AEP 5.12.2 June 2016)</td>
</tr>
</tbody>
</table>

- **Current CNAV broadcast is “Pre-Operational”** and intended to support modernized civil receiver development:
  - L2C CNAV marked Healthy
  - L5 CNAV marked un-Healthy (supports test)
- **Benefits:**
  - Provides basic PNT service to CNAV developers
4 Generations of Operational Satellites

- **Block IIA - 8 Residual**
  - 7.5 year design life
  - Launched 1990-1997

- **Block IIR - 12 Operational**
  - 7.5 year design life (oldest operational satellite will be 19 yrs old in Jul)
  - Launched 1997-2004

- **Block IIR-M - 7 Operational, 1 Residual**
  - 7.5 year design life
  - Launched 2005-2009
  - Added 2nd civil navigation signal (L2C)

- **Block IIF - 12 Operational**
  - 12 year design life
  - Launched 2010-2016
  - Added 3rd civil navigation signal (L5)

*Current as of 5 May 16*
• 12 total GPS IIFs on-orbit

• Final IIF launch complete!
  - GPS IIF-12 satellite successfully launched 5 Feb 16
• **GPS III is the newest block of GPS satellites**
  – 4 civil signals: L1 C/A, L1C, L2C, L5
    • First satellites to broadcast common L1C signal
  – 4 military signals: L1/L2 P(Y), L1/L2M

• **SV01-SV08 on contract; SV09 & SV10 approved**
  – 2 year delay due to technical challenges w/ payload
  – SV09-10 same requirements baseline as SV01-08 but with no NDS payload

• **SV01 In Assembly Integration and Testing**
  – Baseline thermal vacuum testing completed 23 Dec 15
  – Electromagnetic Interference (EMI) test completed 14 May 16
Anticipate competing GPS III SV11-32 Production
- Drive down SV costs & mitigate reliance on single nav payload vendor
- Promote effective competition and reduce risk with production design phase

Two-phase acquisition allows contractors time to mature designs
- Phase 1: Production Readiness Feasibility Assessment
  - Awarded 5 May 16 to Boeing, Lockheed Martin, and Northrop Grumman
  - Determine if viable, low-risk, high confidence sources exist
  - Deliverables include nav payload design and brass board (hardware) test results, initial SV design, manufacturing/production process and facilities maturity
- Phase 2: Full & open competition for GPS III SV11-32 production
  - FY18 projected award
  - First SV delivery in FY23 (SV11)
GPS III SV11+ Technical Baseline

• Current Enterprise technical baseline being updated to reflect AFROC-approved GPS III Follow-On Production CDD
  – SV01-10 baseline plus additional requirements:

<table>
<thead>
<tr>
<th>Requirements (SV01-10 Baseline)</th>
<th>Additional Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backward Compatibility</td>
<td>Redesigned Nuclear Detonation Detection System (NDS) (KSA)</td>
</tr>
<tr>
<td>Availability of Position Accuracy</td>
<td>Laser Retro-reflector Array (KSA)</td>
</tr>
<tr>
<td>Position and Time Transfer Integrity (10^{-4})</td>
<td>Search and Rescue/GPS (KSA)</td>
</tr>
<tr>
<td>Availability of Time Transfer Accuracy</td>
<td>Unified S-Band Interface Compliance</td>
</tr>
<tr>
<td>Net Ready</td>
<td>Regional Military Protection – M-Code Power (TBD-KPP)</td>
</tr>
<tr>
<td>Sustainment – Materiel Availability</td>
<td></td>
</tr>
</tbody>
</table>

• Capability Development Document (CDD) update will seek JROC approval to add Regional Military Protection – M-Code Power
  – Provides up to -140dBW M-Code Regional Power
  – Currently unfunded

• Synchronization of the tech baseline underway
Ground Segment

- Master Control Station
- Alternate Master Control Station
- Ground Antenna
- AFSCN Remote Tracking Station
- Air Force Monitor Station
- NGA Monitor Station
Ground Segment

• **Architecture Evolution Plan (AEP)**
  – Day-to-day command and control of up to 31 satellites
  – 4 dedicated Ground Antennas and AFSCN capability
  – 6 dedicated and 10 NGA Monitor Stations

• **Launch, Anomaly Resolution, and Disposal Operations (LADO)**
  – Day-to-day command and control residual satellites using AFSCN
  – State-of-health monitoring
  – Leverage for some vehicle emergencies
  – Launch prep and initial post-launch operations
  – Satellite end of life disposal operations
GPS Next Generation Operational Control System (OCX)

- Modernized command & control system
  - GPS III command & control
  - M-Code
  - Robust cyber security infrastructure
  - Modern civil signals & monitoring
  - Improved PNT performance

- Prime: Raytheon (Aurora, CO)

- OCX Block 0: launch & checkout for GPS III
  - Currently in test
  - Successfully completed seven launch exercises/simulations

- OCX Block 1: replaces AEP, adds modern features
  - Currently in design and risk reduction testing prior to restart of coding

- OCX Block 2: adds advanced NAVWAR and Civil Signal Performance Monitoring capabilities
OCX Status

• Root cause of OCX problems:
  – Schedule was unrealistic at contract award in 2010
  – Appropriate systems engineering and system integration was not implemented in early phases
  – Initial cybersecurity requirements not well understood

• Holding quarterly reviews with Mr. Kendall, SecAF, and Raytheon CEO
  – Detailed reviews to measure progress and schedule ahead
  – Mobilizing resources across government and industry to enable system fielding

• Contingencies and “off ramps” are in place to meet GPS commitments in-case of further OCX issues
Military GPS User Equipment (MGUE)

- **Commercial market-driven acquisition approach**
  - Three vendors developing modernized receiver cards
  - Feedback from initial testing flowing back to vendor developments
- **Conducting early integration activities with platform program offices**
  - Agreements in place to support integration and test of service nominated lead platforms
  - Progress integrating MGUE into B-2 software integration lab and prototype MAGR-2k box
- **MGUE program is in process of finalizing the Increment 1 Acquisition Program Baseline (APB) per OUSD(AT&L) direction to support a Milestone B decision**
- **Draft MGUE Increment 2 Capability Development Document (CDD) in coordination; includes space receiver, hand-held, and Precision Guided Munitions (PGM)**
GPS Director’s Perspectives

• Recognize the global utility of GPS
  – Committed to maintaining uninterrupted service – “the Gold Standard”

• Embracing Gen Hyten’s Space Enterprise Vision by continuing to enhance PNT resiliency
  – Includes examination of multi-GNSS receivers

• Appreciate the need for alternative PNT sources, and challenge the community (labs, industry, others) to propose & explore solutions

• Next-Generation Operational Control System (OCX) addressing cost and schedule challenges

• Looking at opportunities to provide operational modernized signal capabilities prior to OCX delivery
Back-Up
Civil Signal Coverage

Current Constellation - L2C - 4-Fold Visibility Gaps

1 May 2016 - No Failures

Latitude

Longitude

-0.25 hrs to 0.5 hrs
0 hrs to 0.25 hrs
0.5 hrs to 1 hrs
1 hrs to 2 hrs
Greater than 2 hrs

Friday, May 06, 2016 8:04:39 AM
Civil Signal Coverage

Current Constellation - L2C - 1-Fold Visibility Gaps

1 May 2016 - No Failures
Civil Signal Coverage

Current Constellation - L2C - PDOP < 6 Gaps

1 May 2016 - No Failures

CV: 98.08%
CVMin: 92.11%

Friday, May 06, 2016 8:27:11 AM
Civil Signal Coverage

Current Constellation - L5 - 4-Fold Visibility Gaps

1 May 2016 - No Failures
Civil Signal Coverage

Current Constellation - L5 - 1-Fold Visibility Gaps

1 May 2016 - No Failures

Friday, May 06, 2016 8:02:48 AM
Civil Signal Coverage

Current Constellation - L5 - PDOP < 6 Gaps

1 May 2016 - No Failures

Latitude

Longitude

0 hrs
0 hrs to 2 hrs
2 hrs to 4 hrs
4 hrs to 8 hrs
8 hrs to 16 hrs
Greater than 16 hrs

CV: 51.68%
CVMin: 29.40%

Friday, May 06, 2016 8:26:44 AM