Wide Area Augmentation System (WAAS) Status and History

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ION GNSS 2014

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Agenda

- **WAAS Status and History**
- **User Adoption**
- **Future Efforts**

Wide Area Augmentation System

- WAAS is a combination of ground based and space based systems that augments the GPS Standard Positioning Service (SPS)
- WAAS provides the capability for increased availability and accuracy in position reporting, allowing more time for uniform and high quality worldwide air traffic management
- WAAS provides coverage over the entire National Airspace, with a precision approach capability at over 3,000 runway ends

3 Geostationary Satellite Links

2 Operational Control Centers

38 Reference Stations

3 Master Stations

6 Ground Earth Stations

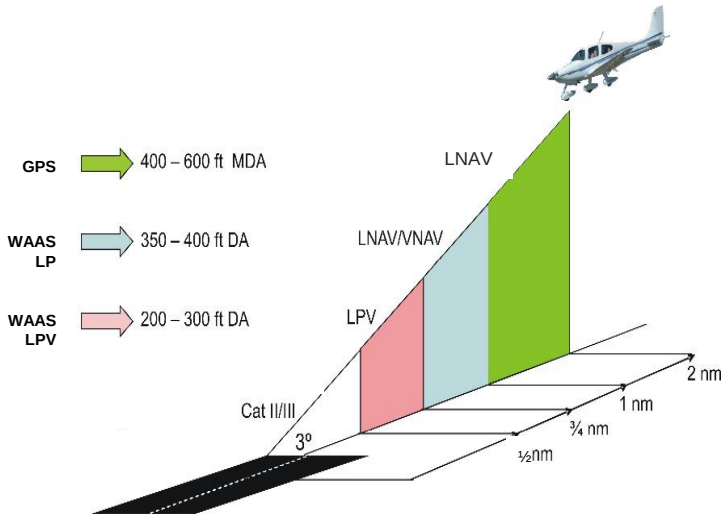
GPS and WAAS Core Systems

GPS

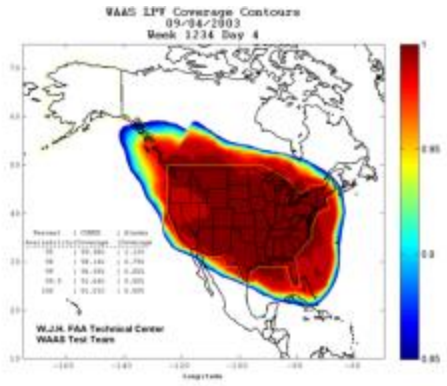
- **Approved for Aviation use in 1993**
- **Established as global leader and gold standard for satellite navigation**
- **Extensive modernization efforts underway that will make available additional civil signals (L1C, L2C, L5)**

WAAS

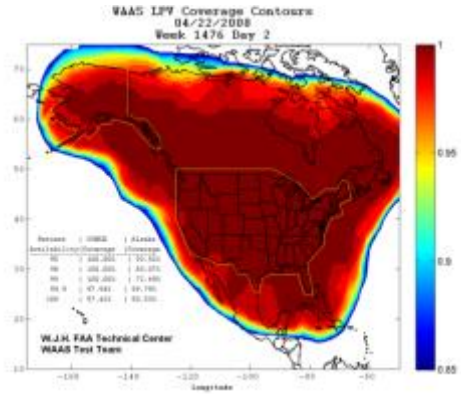
- **Commissioned for service in 2003**
- **Provided lessons learned in support of development of foreign SBAS in Japan, Europe and India**
- **Currently augments the GPS L1 signal providing improved accuracy and integrity**
- **WAAS modernization efforts tied directly to GPS modernization**



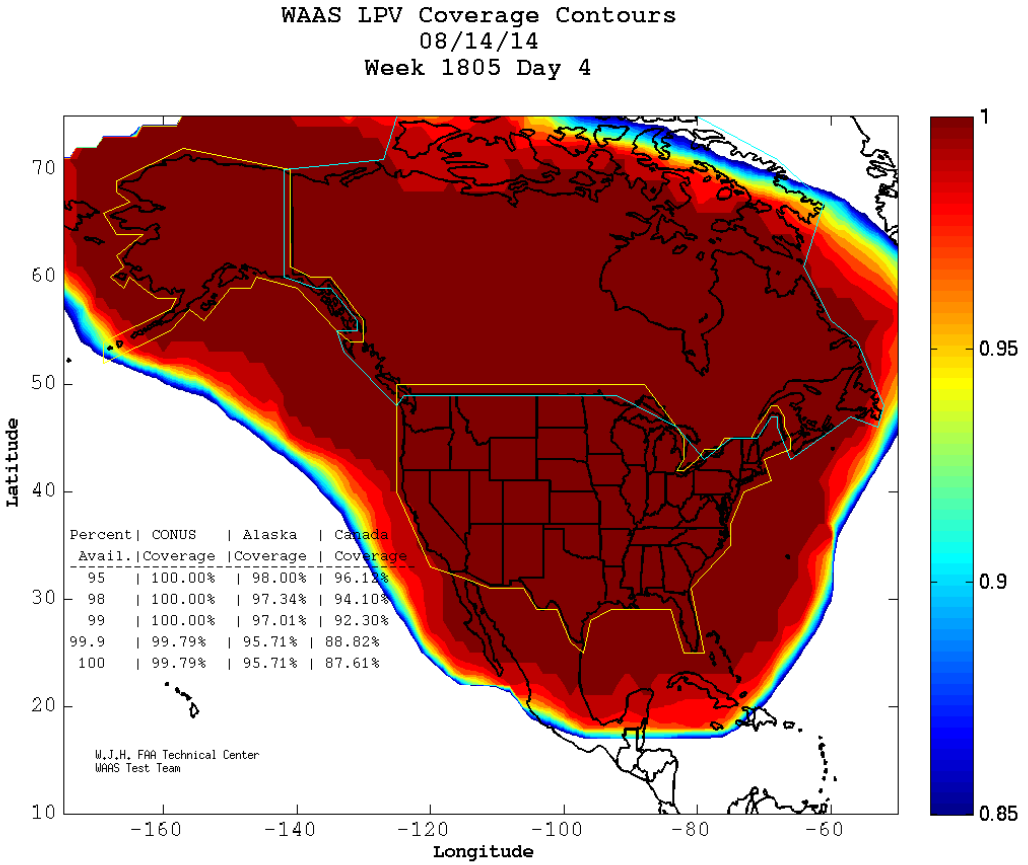
WAAS Coverage Improvements



2003 IOC – LPV Coverage in lower 48 states only



2008 Coverage - Full LPV 200 Coverage in CONUS (2 Satellites)



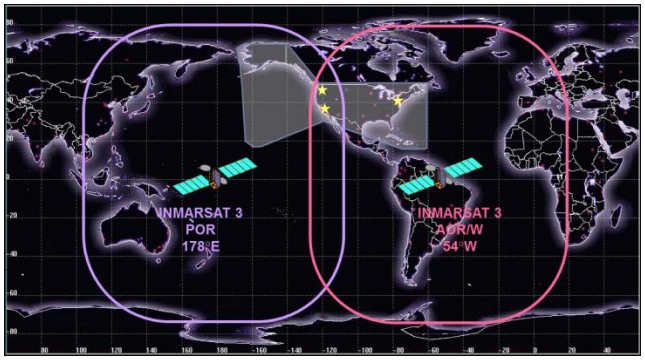
2014 Coverage - Full LPV 200 Coverage in CONUS (3 Satellites)

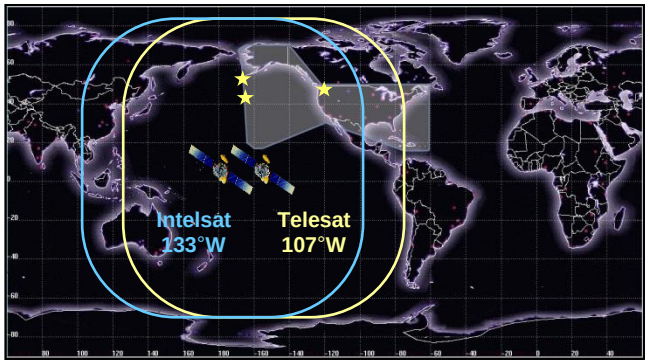
WAAS Development Phases

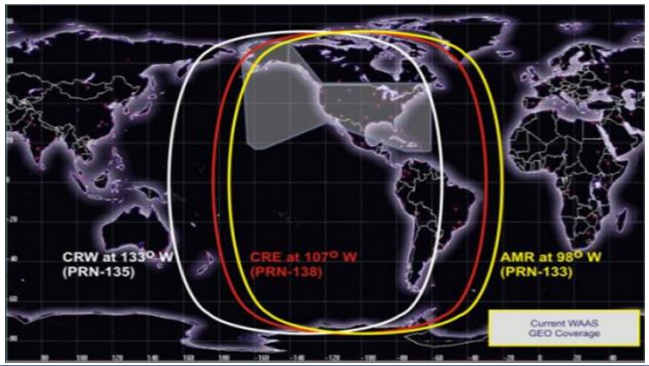
- **Phase I: IOC (July 2003) Completed**
  - Included Development of a robust safety architecture
  - Included establishment of WAAS expert panel to evaluate potential integrity threats
- **Phase II: Full LPV (FLP) (2003 – 2008) Completed**
  - Completed a Safety Risk Management Decision (SRMD) to support LPV-200 (VAL of 35m)
  - Expanded WAAS coverage to Mexico and Canada while modifying the System to address observed Ionospheric threats
- **Phase III: Full LPV-200 Performance (2009 – 2013)**
  - Completed System updates to improve performance during moderate ionospheric activity
  - Supported continuous monitoring of system data that contributes to continued integrity assurance
  - Began transition of Second Level Engineering from contractor based to organic FAA capability
- **Phase IV: Dual Frequency (L1,L5) Operations (2014 – 2044)**
  - Includes the transition from use of L2 to L5 in WAAS reference stations
  - Infrastructure modifications to support future L1/L5 user capability
  - Support sustainment of WAAS GEOs

GEO Satellite Availability Improvements

- **IOC WAAS (Commissioned system) utilized two Inmarsat satellites**
  - Provided single satellite coverage over the majority of the U.S.
  - Removed from WAAS July 2007
- **Replacement satellites launched in 2005**
  - Intelsat (Galaxy XV) - Operational November 2006
  - Telesat Canada (Anik F1R) - Operational July 2007
- **Implemented Gap-filler GEO**
  - Inmarsat I4F3 (AMR) - Operational December 2010







Derived Requirement for a 3 GEO System

- **WAAS receiver is required to track two GEOs if available…if one GEO is lost, then the other is used seamlessly with no loss in continuity**
- **Continuity requirement is met as long as we have two GEOs in service…if we have only one GEO then the continuity is not met**
- **Individual satellite availability averages 96% based on historical data**
  - GEO takes 4-5 years minimum to replace
- **GEO constellation:**
  - Availability of continuity (1 GEO) = zero
  - Availability of continuity (2 GEOs) = 96%
  - Availability of continuity (3 GEOs) = 99.98%
- **GEO constellation is only one source of loss of continuity**
  - Availability allocation to GEOs must be significantly >99%
- **WAAS continuity is a key service parameter enabling the capability to reduce ground-based NAVAID infrastructure identified in the FAA Navigation Evolution Plan**

2 GEO constellation represents single point of failure for meeting continuity requirement

Addresses 99% Requirement

- **It takes 4-5 years to replace a GEO**
- **In a two GEO system if the remaining GEO fails, then we have a catastrophic loss of all service**

GEO Sustainment

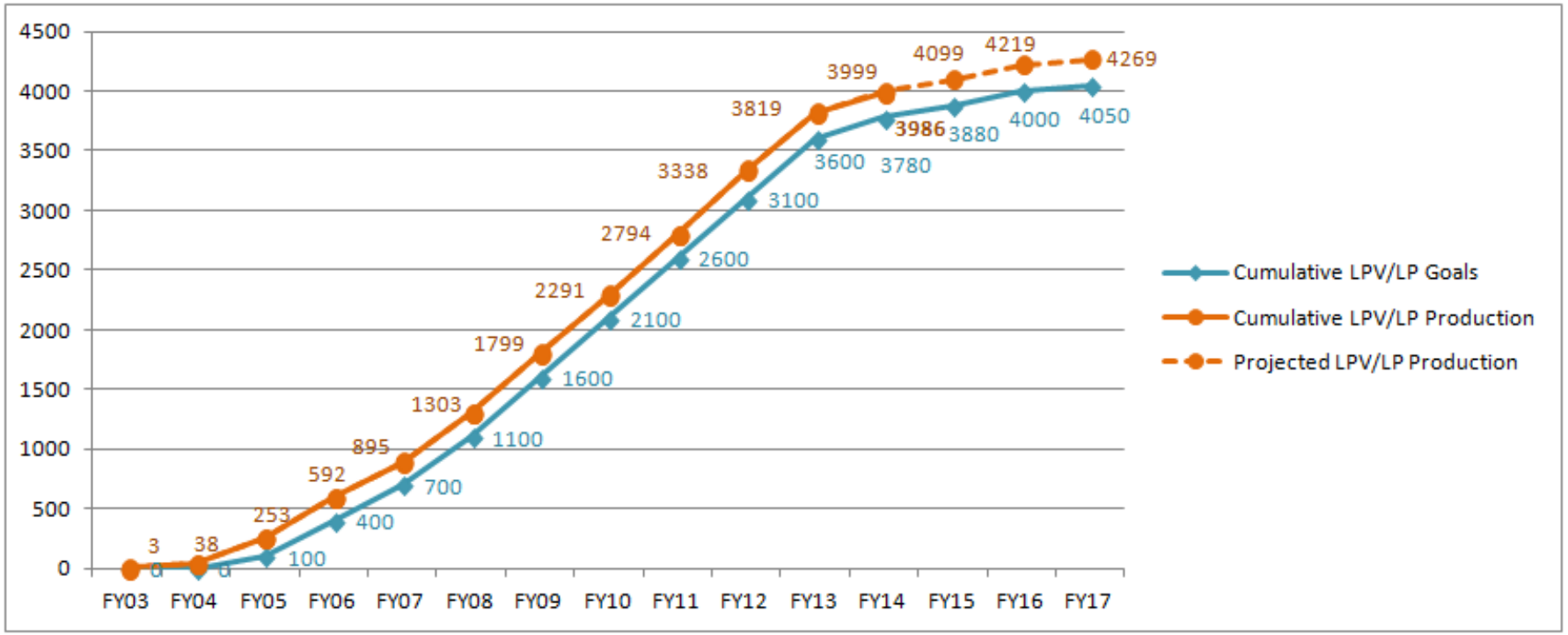
- **GEO 5/6 Satellite Acquisition**
  - Awarded GEO 5/6 Satellite Service Lease contract to Raytheon September 2012
  - SatMex 9 satellite will host the WAAS GEO Satellite Payload
    - Orbital slot (117^{o}W) will provide full coverage over CONUS and Alaska
    - Critical Design Review (CDR) completed July 2014
    - Scheduled for operations in the 2017 timeframe
  - GEO 6 Satellite opportunities currently under investigation

- **User Adoption - Build it and they will come…**

WAAS Procedures

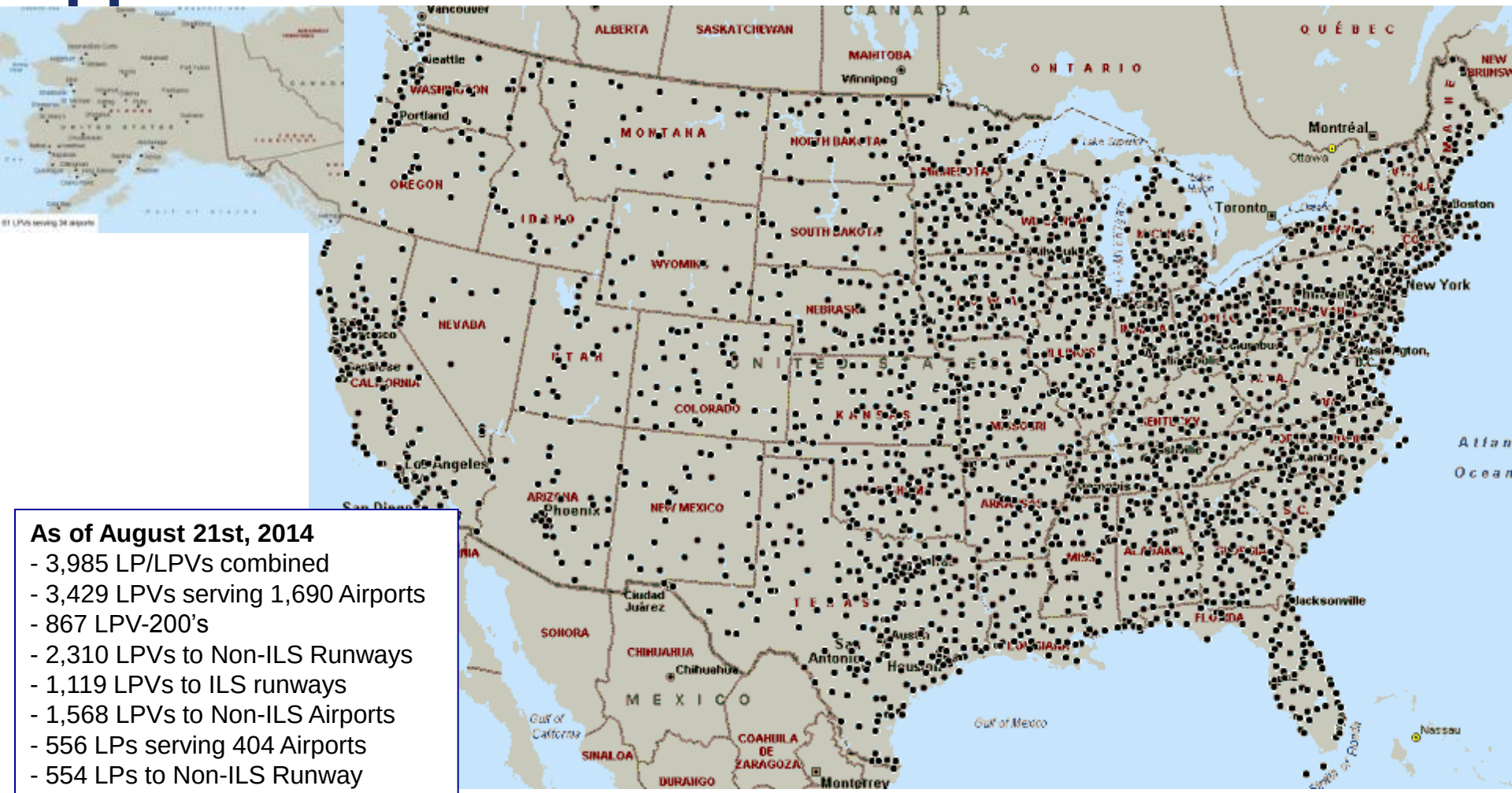
- **IOC Commissioning July 2003**
  - LNAV/VNAV
  - 350’ / 1½
- **LPV - 250’ Minimums**
  - 1st LPV September 2003
- **LPV - 200’ Minimum**
  - Minimum decision height of new LPV approaches lowered 250’ → 200’DA in March 2006
  - 1st LPV-200 January 2008
  - Re-evaluating LPVs’ for lower decision height
- **LP Approach**
  - 1st LP March 2011
  - Flown like a Localizer approach
  - Can be developed at approaches that fail to meet LPV criteria due to obstacle clearance surface (OCS) penetrations (same TERPS for ILS)
  - Unlike an ILS, will have LPV or LP on approach chart, but not both
  - If WAAS correction is lost, avionics defaults to LNAV procedure

Annual LPV and LP Production



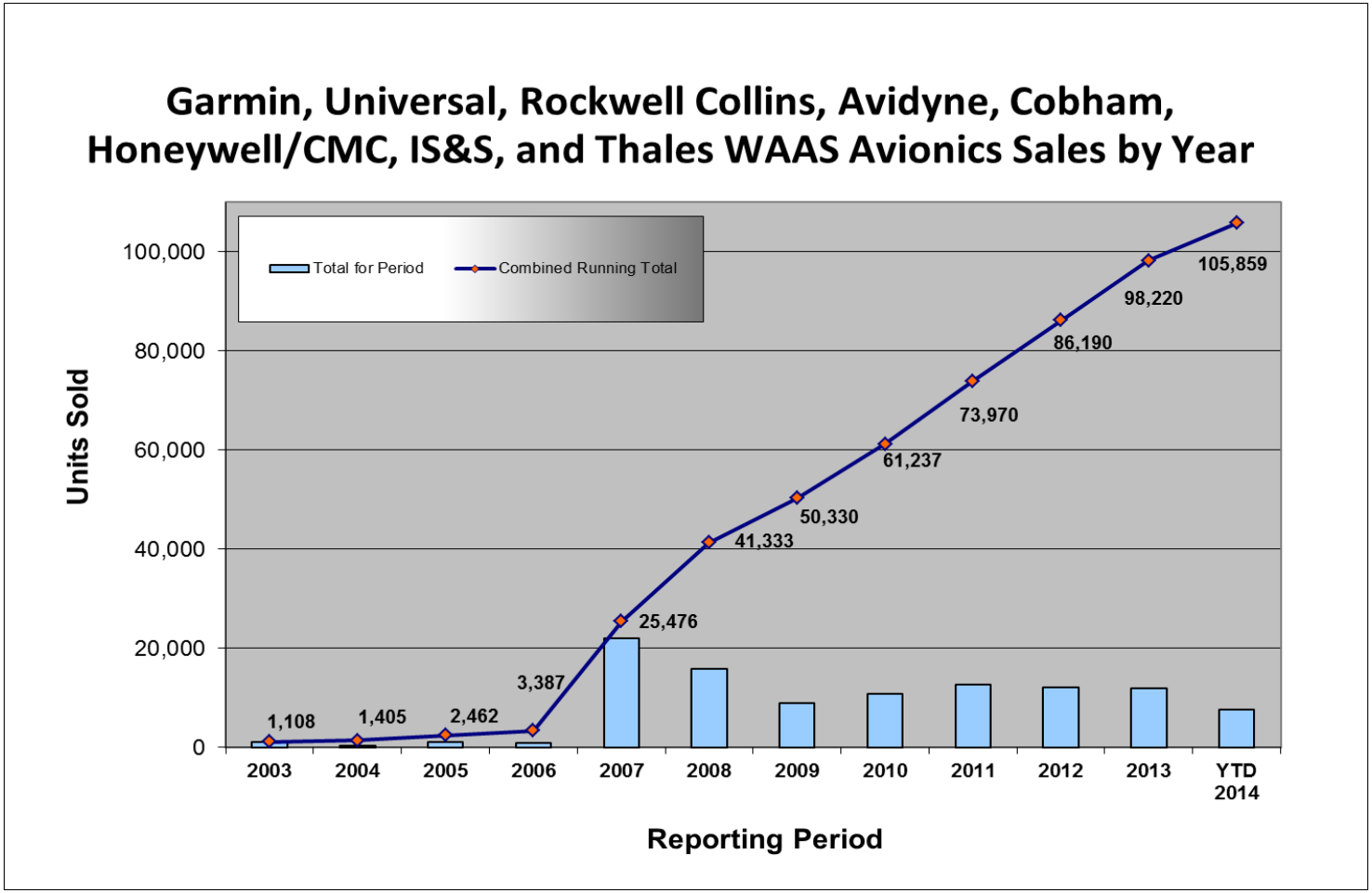
	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17
Non-ILS Runway Ends	0	7	83	191	198	266	263	379	420	468	446	158	0	0	0
ILS Runway Ends	3	28	132	148	105	142	233	113	83	76	35	9	0	0	0
LPVs/LPs	3	35	215	339	303	408	496	492	503	544	481	167	0	0	0
Annual LPV/LP Goals	0	0	100	300	300	400	500	500	500	500	500	180	100	120	50
Cumulative LPV/LP Goals	0	0	100	400	700	1100	1600	2100	2600	3100	3600	3780	3880	4000	4050
Cumulative LPV/LP Production	3	38	253	592	895	1303	1799	2291	2794	3338	3819	3986	3986	3986	3986

Airports with WAAS LPV/LP Instrument Approaches



As of August 21st, 2014
- 3,985 LP/LPVs combined
- 3,429 LPVs serving 1,690 Airports
- 867 LPV-200's
- 2,310 LPVs to Non-ILS Runways
- 1,119 LPVs to ILS runways
- 1,568 LPVs to Non-ILS Airports
- 556 LPs serving 404 Airports
- 554 LPs to Non-ILS Runway
- 2 LPs to ILS Runways

WAAS LPV Annual Avionics Sales



Data current as of August 6, 2014

Total combined avionics sales (all vendors): 105,859 units

Program office estimate for total WAAS-LPV equipped aircraft: 76,115 (all vendors)

WAAS LPV Equipped Aircraft August 2014

Garmin
- GA Aircraft (See FAA Garmin Approved Model List (AML)). Most GA Part 23 aircraft.
- GTN series – Lear 35/35A, 36/36A,24 – Phenom300 with G-3000

Universal Avionics
- 122 fixed wing and 12 helicopter types and models

RockwellCollins
- 37 Types and models

Honeywell /CMC Electronics)
- 22 types and models

Avidyne
- 6 types and models (Cirrus SR 20 & 22, Piper Matrix & Mirage, Piper Saratoga NX, and EA-500)
- IFD 540 WAAS LPV - (STC complete July 2014 – AML STC approved for over 1,000 aircraft makes and models)

Genesys Aerosystems (Chelton)
- Bell-407 & 412, Cessna 501, 550, Piper PA-42, Beechcraft C-90&A, EurocopterAS-350, AgustaAW109SP, Beechcraft T-34B, Kawsaka

Innovative Solutions & Support (IS&S)
- Eclipse 550/500
- Boeing 737-400 (pending)
- MD-88/90 (pending)

Thales
- Airbus A300-600ST (Beluga)
- Airbus A400M (Military)
- Airbus A350XWB - pending

Transition to Performance Based Navigation

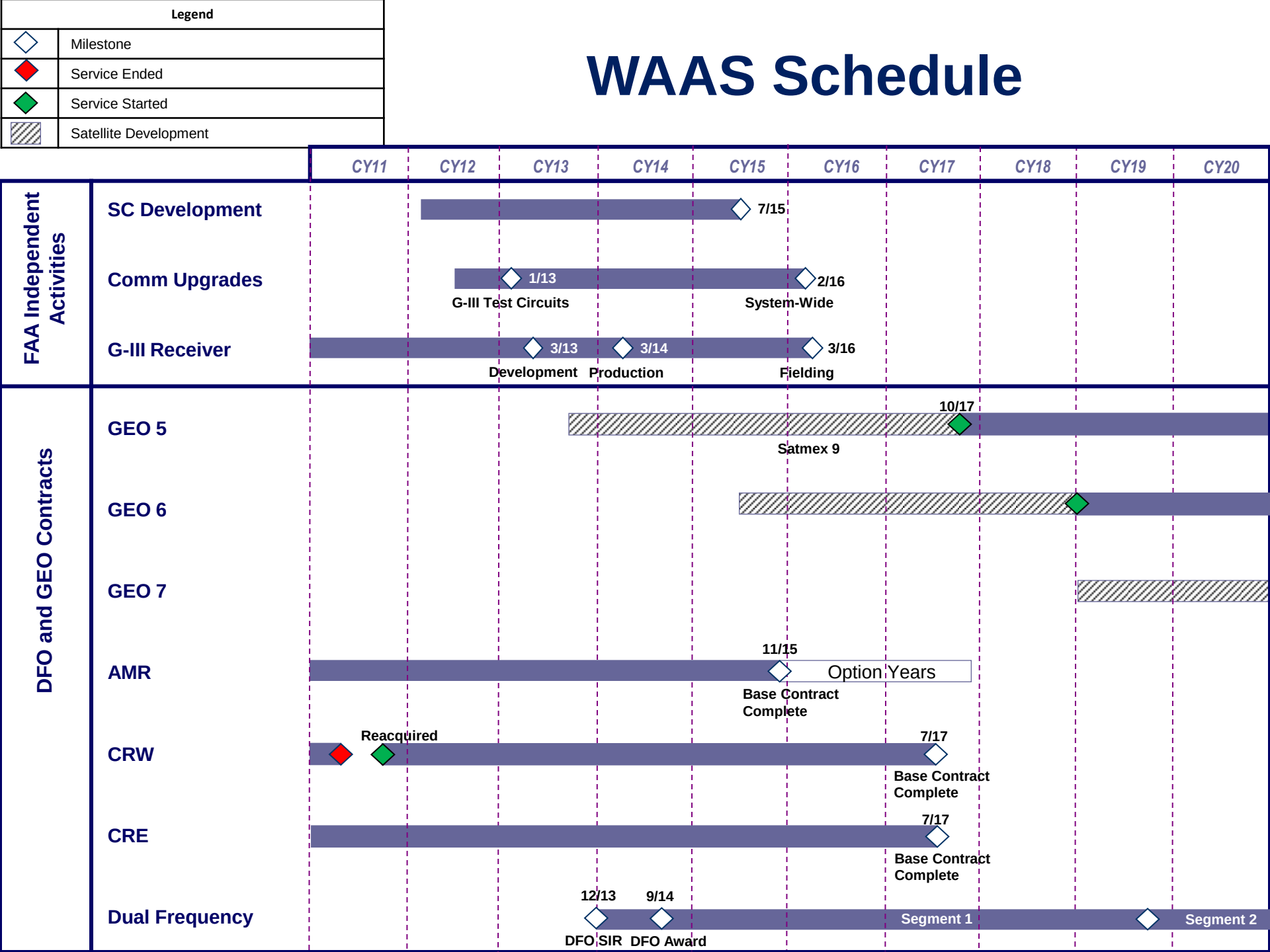
- **In September 2008 the number of published LPVs surpassed the number of published ILSs**
- **As of August 2014 the number of published LPVs are more than twice the number of published ILSs**
- **In 2013 the FAA policy was to no longer publish any new CAT I ILSs**
- **In 2016 the FAA has committed to begin efforts towards a draw down of ILS based on WAAS implementation**

WAAS – A Multi User System

- **WAAS has become a relied upon utility for a number of non-aviation uses:**
  - Shipping
    - Navigation of Harbors
  - Recreational Boating
    - Navigation of Channels
    - Location of Crab pots
  - Mapping & Survey
    - Precise location identification
  - Farming
    - Sub-meter accuracy for spreading, seeding and harvesting

- **Future Efforts**

WAAS Schedule



Next Steps

- **Dual Frequency (DF)**
  - Award a Dual Frequency Contract
  - Development of DF WAAS MOPS capability
  - Maintain legacy Single Frequency availability
- **Ground based infrastructure upgrade**
  - Safety Computer
  - G-III Receivers
  - Terrestrial Comm upgrade
- **Develop Dual Frequency User concepts**
  - ARAIM
    - Offline vs Online
  - Dual Frequency Multi-Constellation (DFMC) SBAS
    - Beginning initial research and development
  - Validate concepts and propose standards

Future Applications

- **WAAS is an enabler for multiple FAA initiatives**
  - Performance-Based Navigation (Area Navigation) (RNAV)
  - Required Navigation Performance (RNP)
    - WAAS meets the requirement for RNP AR as defined in FAA Advisory Circular 90-101A
    - No restriction due to temperature
  - Point in Space (PinS) procedures
  - Automatic Dependent Surveillance Broadcast (ADS-B)
    - WAAS is currently the only technology that meets all of the most stringent requirements for a positioning source for ADS-B

GNSS Enables Performance Based Navigation

	Navigation (≥ 99.0% Availability)		Surveillance (≥99.9% Availability)			Positioning
	Accuracy (95%)	Containment (10^{-7})	Separation	NACp (95%)	NIC (10^{-7})	GNSS PNT (99.0 – 99.999%)
En Route	*10 nm	20 nm	5 nm	185.2m (7)	1 nm (5)	GPS
	*4 nm	8 nm				
	*2 nm	4 nm				
Terminal	*1 nm	2 nm	3 nm	92.6m (8)	0.6 nm (6)	Legacy APNT GAP
LNAV	*0.3 nm	0.6 nm				
RNP (AR)	*0.1 nm	**0.1 nm	2.5 nm DPA	92.6m (8)	0.2 nm (7)	SBAS/WAAS
LPV	16m/4m	40m/50m	2.5 nm DPA	92.6m (8)	0.2 nm (7)	
LPV-200	16m/4m	40m/35m				
GLS Cat-I	16m/4m	40m/10m	2.0 nm IPA	92.6 m (8)	0.2 nm (7)	GBAS
GLS Cat-III	16m/2m	40m/10m				

* Operational requirements are defined for total system accuracy, which is dominated by fight technical error. Position accuracy for these operations is negligible.

** Containment for RNP AR is specified as a total system requirement; value representative of current approvals.

Dependent Parallel Approach (DPA)
Independent Parallel Approach (IPA)

Surveillance Integrity Level (SIL)
Navigation Integrity Category (NIC)

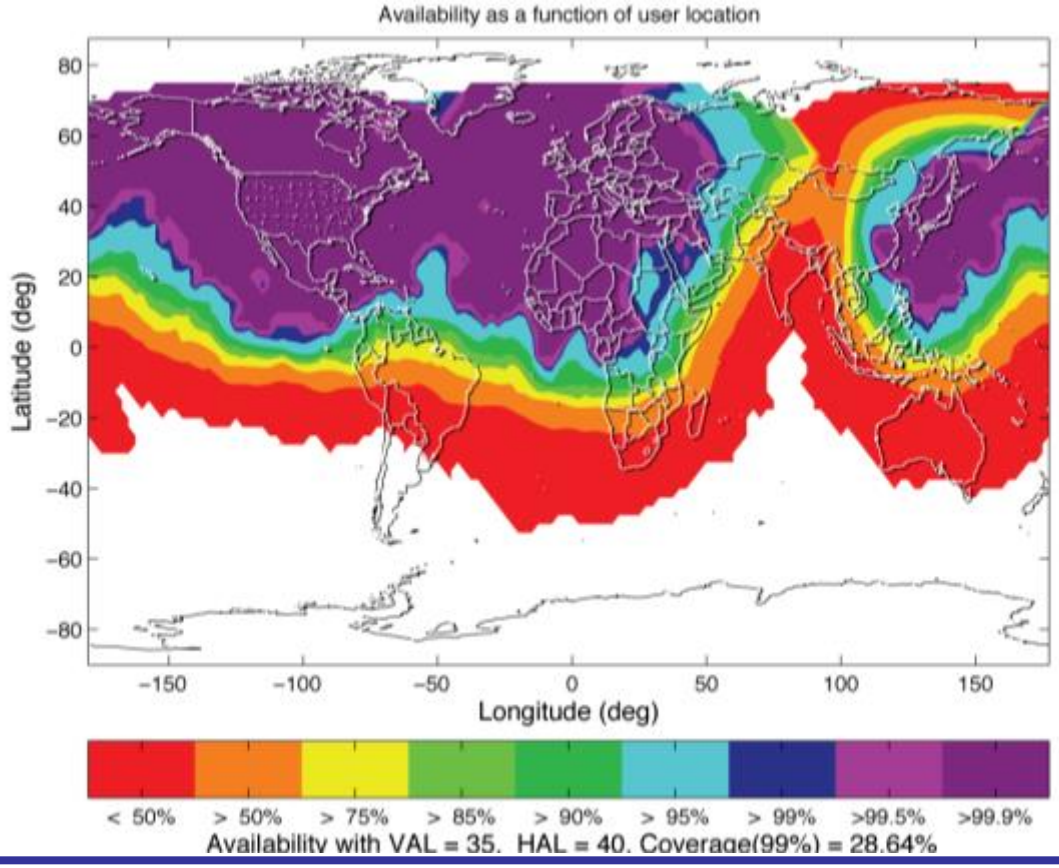
Navigation Accuracy Category for Position (NACp)

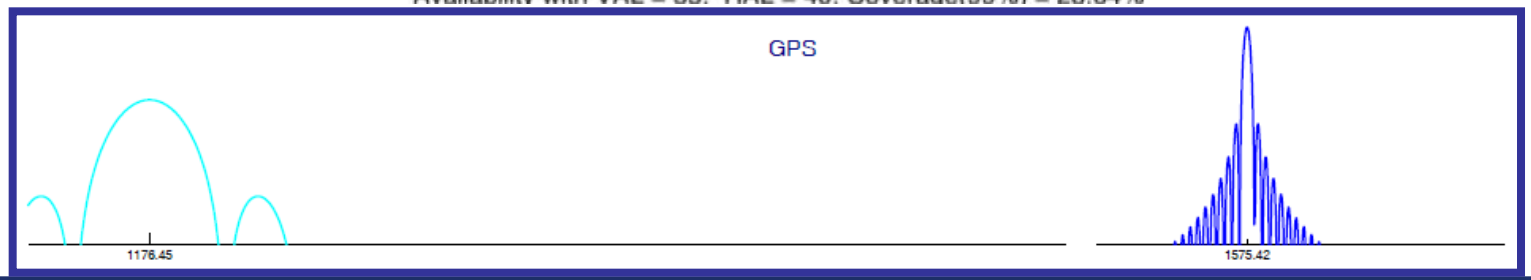
User Adoption Outreach Projects

- Delta MD88/90 – establish GIP to provide a demonstration project using Delta aircraft operating in the NY Metro area utilizing WAAS capability
- Gulfstream – demonstrate the effectiveness of guided visual departures, approaches at New York area airports and also validate oceanic track offsets inbound to the New York Metroplex;
- Maryland State Police Emergency Medical Services (EMS) - demonstrate how WAAS approaches permit EMS to operate during poor weather conditions and accomplish the FAA Mandate for Helicopter Safety
- Hudson River Corridor Project - demonstrate helicopters on flyable legs to RNP. 0.3 values.
- Porter Air - demonstrate de-coupling traffic at Newark for arrival/departure flow efficiency and demonstrating WAAS LPV procedures w/RF leg
- FAA/Insitu/ConocoPhillips Arctic Region UAS Project - Demonstrate the safe operation of small Unmanned Aircraft Systems (sUAS) beyond line of sight below 2000 feet above sea level per the FAA Reauthorization Act of 2012 through the integration of GPS/WAAS avionics

Future LPV-200 Coverage(Dual Frequency GPS)

WAAS
EGNOS
MSAS





Summary

- **WAAS-provided messages improve the accuracy, availability and safety of GPS-derived position information**
- **WAAS results in safety and capacity improvements in the National Airspace System (NAS)**
- **WAAS will reduce FAA operations costs by enabling the decommissioning of some ground-based navigation aids**
  - All new CAT I Approaches in the NAS shall be WAAS LPV Approaches
  - FAA committed to making a decision on the reduction of CAT I ILS in 2016
- **WAAS provides a cost-effective means of integrating a precision approach capability into the cockpit**
- **Nearly 4,000 WAAS procedures are available with half published at runways that previously had no precision approach capability**
- **Continued support of International expansion of SBAS and adoption of future standards**

Questions?