RAIM and ADS-B

RAIM & ADS-B PREDICTION FOR PBN OPERATIONS

-

JOHN WILDE, GLOBAL STRATEGIC SALES

12.09.2016

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What is GPS?

CHAPTER 01

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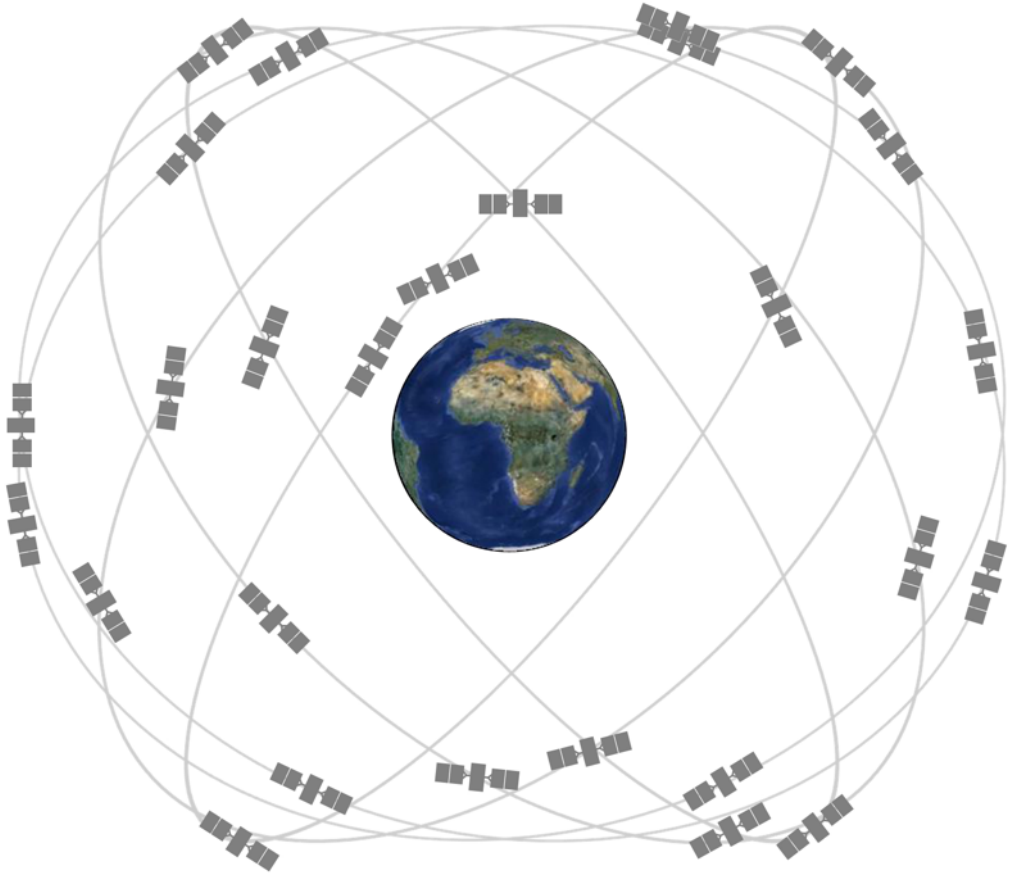
Basic GNSS Principles

- NAVSTAR = Navigation System using Timing and Ranging
- GPS = Global Positioning System
- Initiated by Department of Defence
- Project was started in 1973
- First satellites launched in the late 1970's
- Declared fully operational in 1995
- System has been improving ever since



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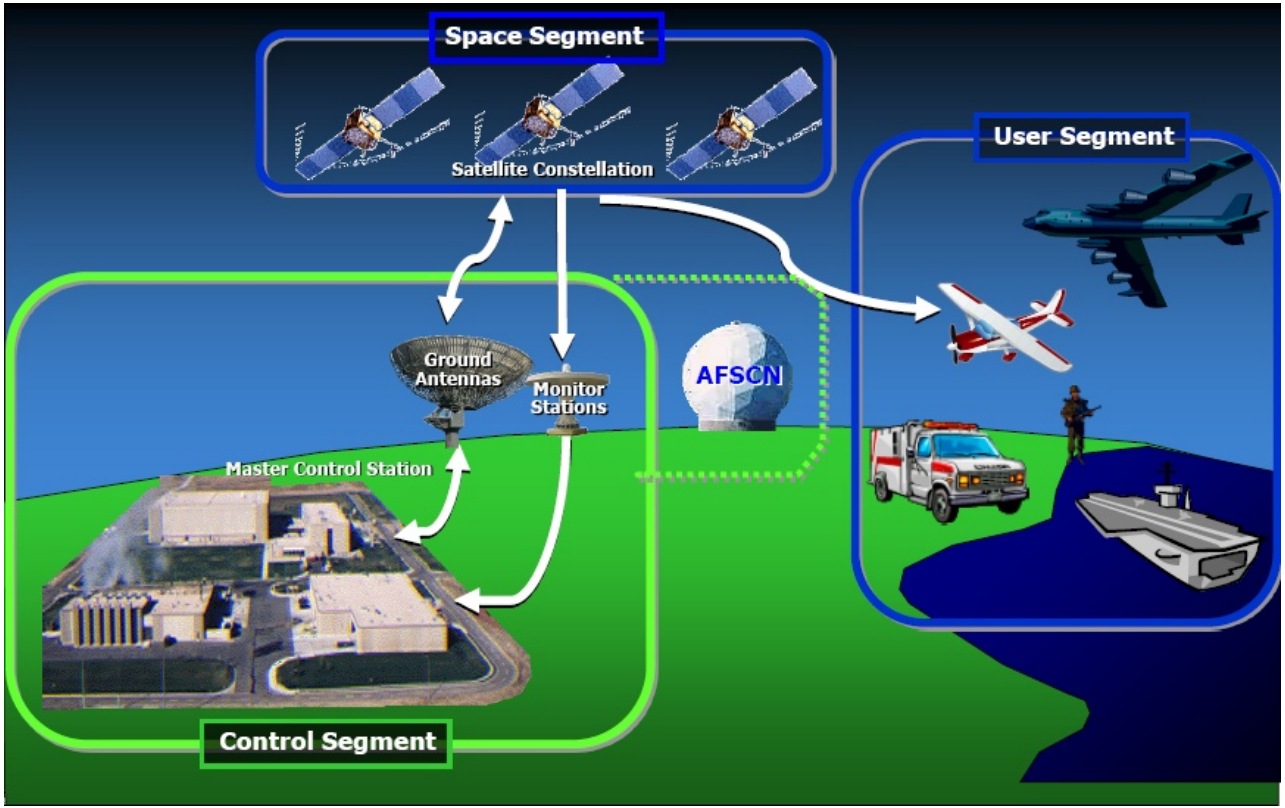
Basic GNSS Principles

- 3 Component Segments of GPS
  - Space
  - Control
  - User



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GPS
Space Segment

- Constellation of 32 satellites move in six orbital planes approximately 20,200 km above Earth
- Base constellation of 24 satellites in designated primary slots
- Increased to 27 operational satellites (June 2011) to improve availability, "The Expandable-24"
- GPS constellation has 31 operational satellites
- Zero Block IIA
- 12 Block IIR
- 7 Block IIR-M
- 12 Block IIF
- 3-5 residual satellites in a stand-by mode

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GPS
Space Segment

- 1 additional satellite set unhealthy (SVN49/PRN27 used for tests)
- “Residual” satellites are kept in a stand-by mode and can be set “healthy” if needed to replace a failed satellite
- The expanded constellation uses the additional satellites (24+3) to increase worldwide availability
- There are three expanded slots (one in the B, D and F planes)
- A "non-primary" satellite is typically located to back-up an older satellite and is not located in a primary or expanded slot

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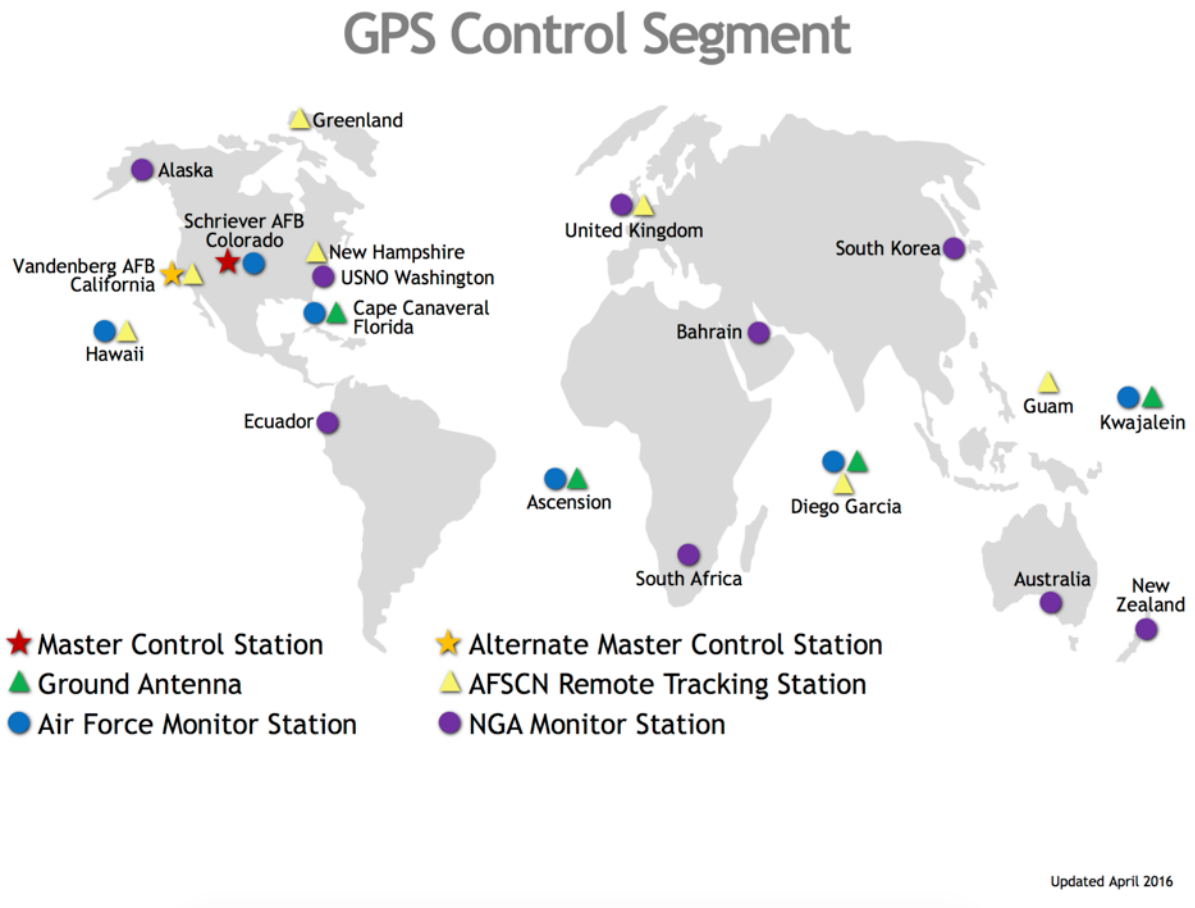
GPS
Control Segment

- Ground Control Segment is comprised of monitor stations and ground antennas with uplink capabilities. Monitor stations track all satellites in view
- Information from monitor stations is processed at Master Control Station (MCS) to determine satellite clock and orbit states and to update navigation message of each satellite. This updated information is transmitted to satellites via ground antennas



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GPS
User Segment

- Each satellite transmits its position and a time signal
- Signals travel to receiver delayed by distance travelled
- Differences in distance travelled make each satellite appear to have a different time
- Receiver calculates distance to each satellite and can then calculate its own position

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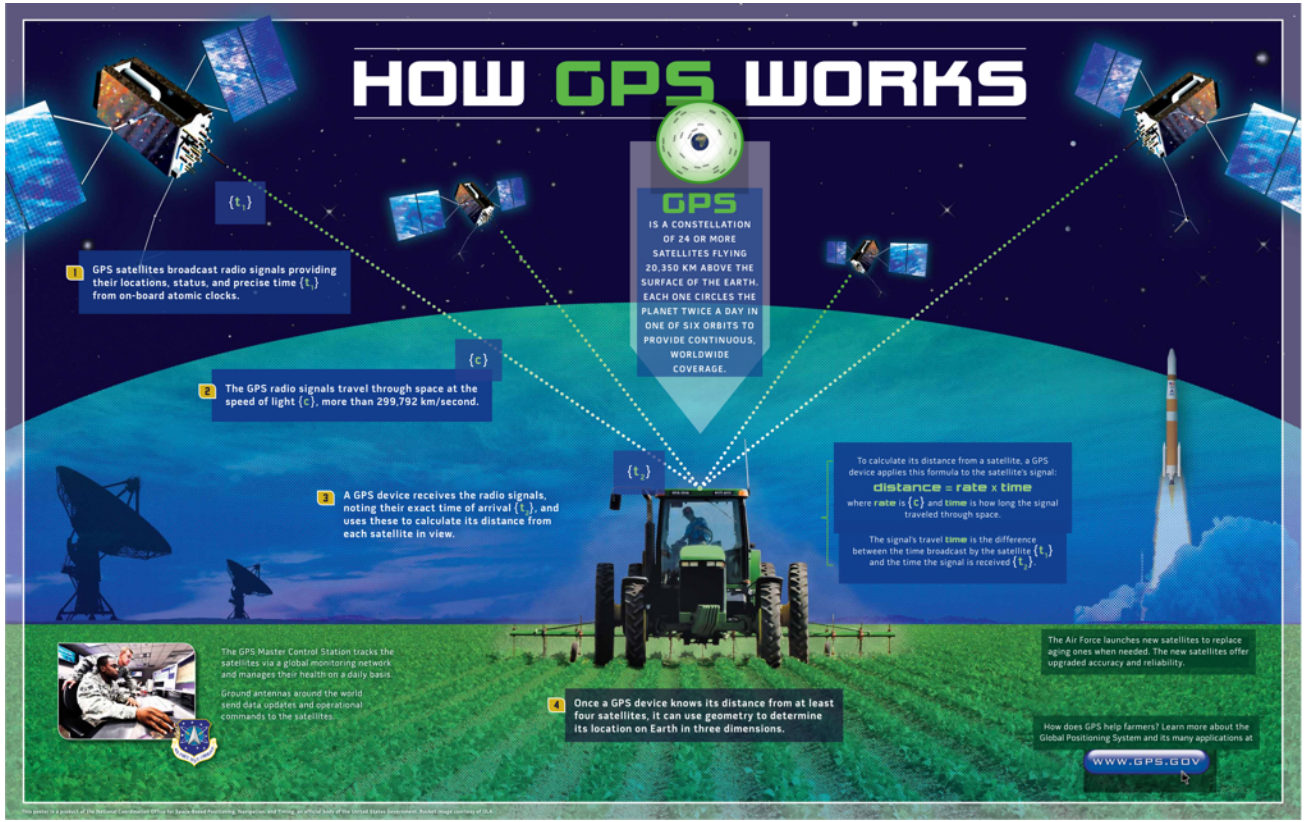
GPS
One-Way Ranging

- GPS satellites broadcast radio signals providing their locations, status, and precise time from on-board atomic clocks.
- The GPS radio signals travel through space at the speed of light, more than 299,792 km/second.
- A GPS device receives the radio signals, noting their exact time of arrival and uses these to calculate its distance from each satellite in view.
- Once a GPS device knows its distance from at least four satellites, it can use geometry to determine its location on Earth in three dimensions.



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Satellite Position: Almanac and Ephemeris

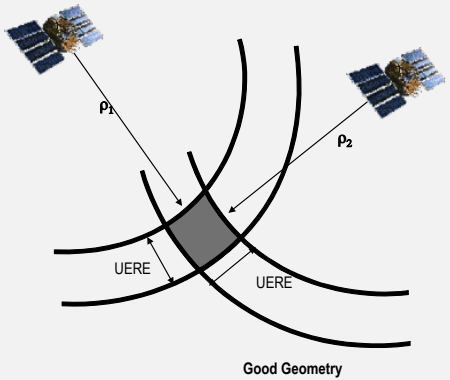
- GPS Navigation Message
  - Time
  - Almanac data
  - Ephemeris data

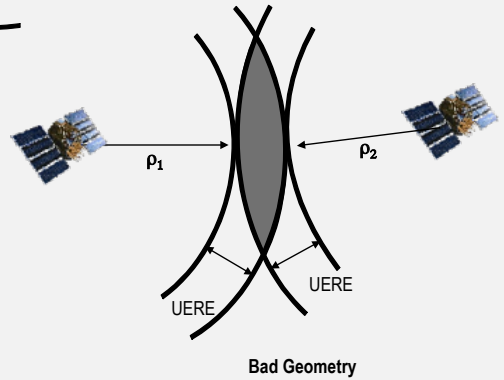
- Almanac data
  - Coarse orbital position of whole constellation
  - Valid for a long time

- Ephemeris data
  - Coarse orbital position for whole constellation
  - Valid for a few hours
  - Updated regularly

GNSS Principles: Error Sources

Error Source	GPS Error (m)
Almanac / Ephemeris	1 to 3
Ionosphere	1 to 7
Troposphere	0.1 to 0.5
Multi-path	0.5 to 1.5
Satellite Clock vs Receiver Clock	1 to 2
Receiver Noise	0.2 to 0.3





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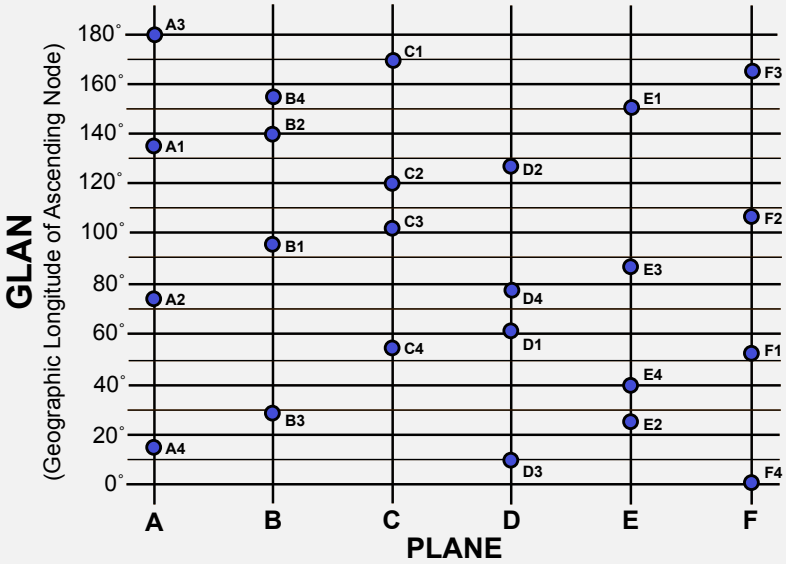
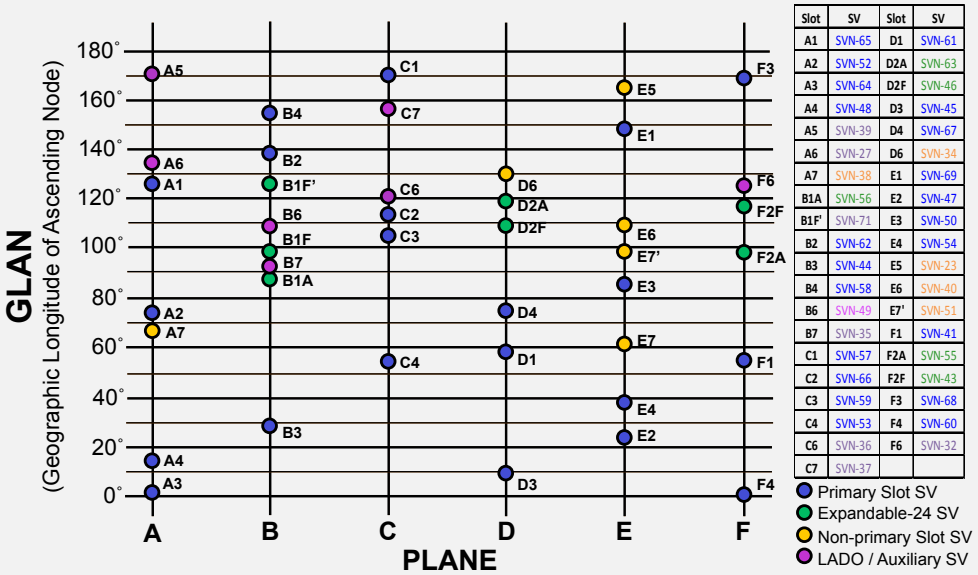
GNSS Principles: Navigation System Performance: Geometry



1st July 1993



Slot	SV	Slot	SV
A1	SVN-65	D1	SVN-61
A2	SVN-52	D2A	SVN-63
A3	SVN-64	D2F	SVN-46
A4	SVN-48	D3	SVN-45
A5	SVN-39	D4	SVN-67
A6	SVN-27	D6	SVN-34
A7	SVN-38	E1	SVN-69
B1A	SVN-56	E2	SVN-47
B1F'	SVN-71	E3	SVN-50
B2	SVN-62	E4	SVN-54
B3	SVN-44	E5	SVN-23
B4	SVN-58	E6	SVN-40
B6	SVN-49	E7'	SVN-51
B7	SVN-35	F1	SVN-41
C1	SVN-57	F2A	SVN-55
C2	SVN-66	F2F	SVN-43
C3	SVN-59	F3	SVN-68
C4	SVN-53	F4	SVN-60
C6	SVN-36	F6	SVN-32
C7	SVN-37		

Primary Slot SV
Expandable-24 SV
Non-primary Slot SV
LADO / Auxiliary SV

3rd April 2015

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Navigation System Performance - RNP

- Traditionally “box-based”
  - Mandatory Equipment
  - Performance not specified explicitly
- Move towards Required Navigation Performance or Performance-Based Navigation
  - Operator can meet requirements in ‘anyway he pleases’
  - e.g. with GPS
- Goal: Target Level of Safety
- Risk of leaving containment area distributed amongst:
  - Accuracy
  - Integrity
  - Continuity
  - Availability

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RAIM+

CHAPTER 02

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Introduction to RAIM+

OVERVIEW

- RAIM+ supports all RNAV and RNP operations supported by ICAO PBN
- Supports all PBN Navigation Specifications and regional / state AMCs and ACs
- From RNAV 10 to RNP AR down to **0.1 NM**
- Since DWI (now NAVBLUE) started to supply the RAIM+ to commercial customers (Scheduled 2007, On-Demand 2008, Web UI 2012) there has been zero downtime of the service
- Updated for
  - New Navigation Specifications
  - New Constellations (Galileo, Compass etc)

THREE MAIN DELIVERY CHANNELS

- RAIM+ Web User Interface
- RAIM+ On-Demand
- RAIM+ Scheduled

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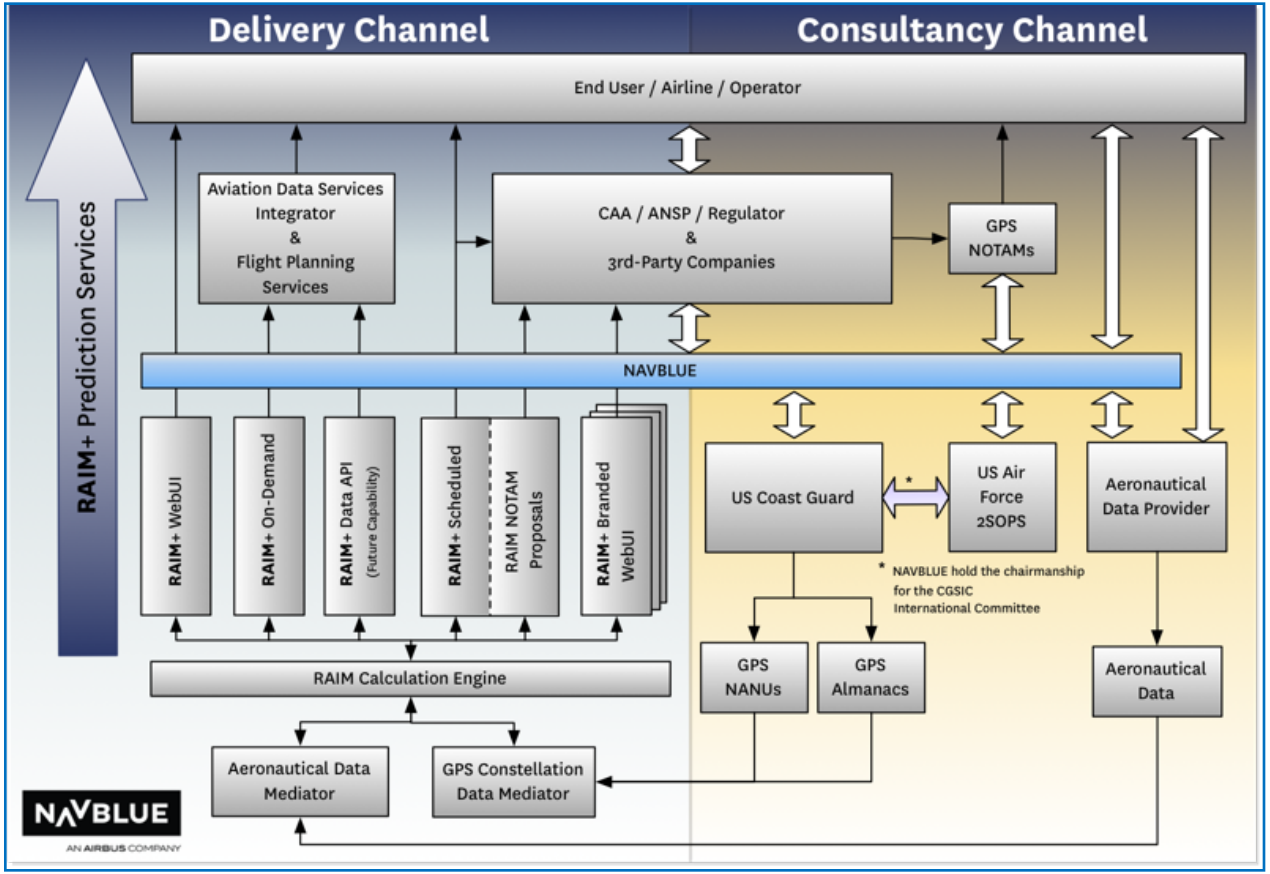
RAIM+ Delivery Channels

- Interfaces with USCG/USAF – official distributors of GPS Almanacs and NANUs

- NAVBLUE aeronautical data

- Same core engine for all services



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Standards Compliance

- Meets ICAO PBN guidance, FAA ACs and EASA AMCs

- Local variations on the above

	USA FAA	Europe EASA	Australia CASA	South America SVRSOP
RNAV				
RNAV 10 (aka RNP 10)	Order 8400.12	AMC 20-12	AC 91U-2(0)	AC 91-001
RNAV 5 (aka B-RNAV)	AC 90-96	AMC 20-4 (JAA TGL 2)	CAAP B-RNAV-1	AC 91-002
RNAV 2 (aka US RNAV Type A)	AC 90-100	JAA TGL 10 (AMC 20-16)	AC 91U-II-3-B	AC 91-003
RNAV 1 (aka US RNAV Type B; P-RNAV)	AC 90-100	JAA TGL 10 (AMC 20-16)	AC 91U-II-3-B	AC 91-003
RNP				
RNP 4	Order 8400.33		AC 91U-3(0)	AC 91-004
RNP 1	AC 90-105	JAA TGL 10 AMC 20-16)	AC 91U-II-C-3(0)	AC 91-006
RNP Approach	AC 90-105() (LNAV, LNAV/VNAV) AC 90-107() (LP, LPV)	AMC 20-27 (LNAV, LNAV/VNAV) AMC 20-28 (LP, LPV)	AC 91U- AC 91U-II-Attachment (LNAV/VNAV) II-C-5 (LNAV)	AC 91-008 (LNAV) AC 91-010 (LNAV/VNAV)
RNP AR (Authorisation Required) Approach	AC 90-101	AMC 20-26	AC 91U-II-C-5 (RNP AR) AC 91U-II-C-6	AC 91-009

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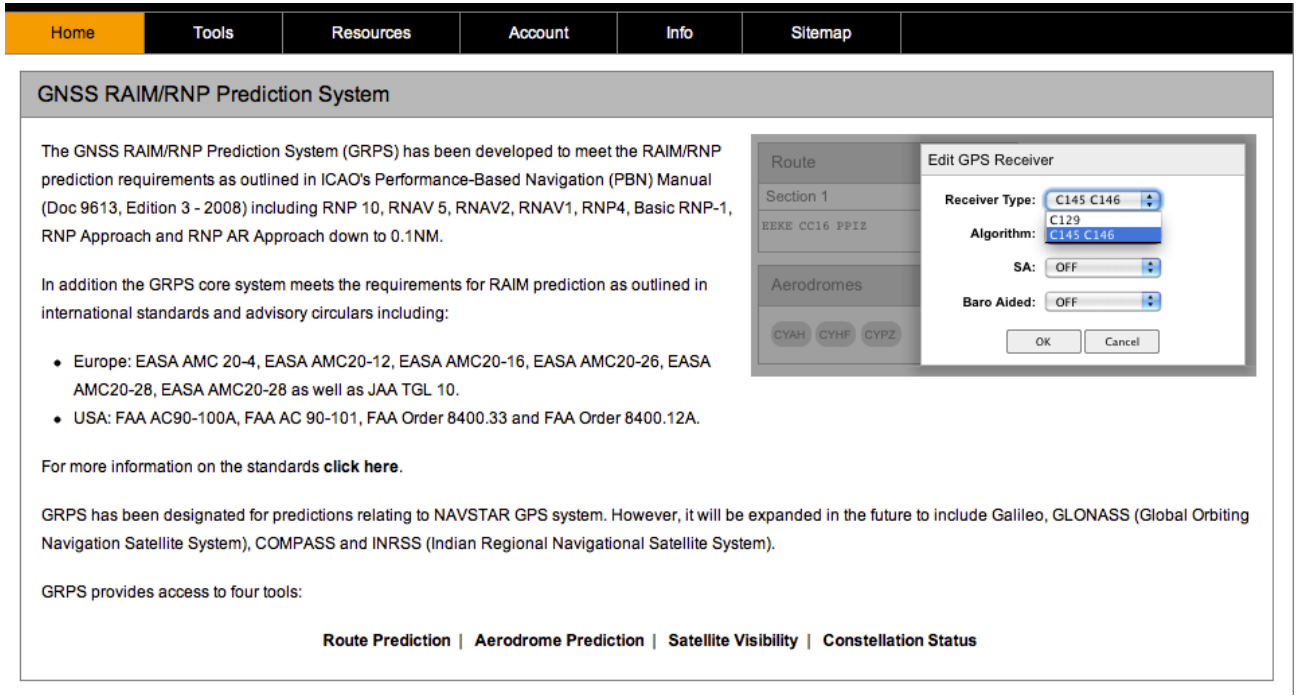
RAIM+ Web User Interface

- Self-service Web Portal
- Suite of tools to assist
- 3 hour training course
- Admin tools



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RAIM+ Scheduled

- Daily subscription service

- Emailed / AFTN or preferred delivery

- Aerodrome outages prioritised in message

Subject RAIM PREDICTION B772/B773 Cathay - New York
Date 2014-05-19 02:02:18 UTC
Message RAIM PREDICTION B772/B773 Cathay - New York
RUN AT 02:01Z 19/May/2014
VALID FROM 02:00Z 19/May/2014 FOR A 48 HOUR VALIDITY

B772/B773 KEWR RNP:0.3 RAIM Check
COVERAGE UNACCEPTABLE FOR OPERATION DURING GIVEN PERIOD
FROM (Z) TO (Z)
19/05/2014 17:39:30 - 19/05/2014 17:44:30

B772/B773 KEWR RNP:1.0 RAIM Check
GPS COVERAGE ACCEPTABLE FOR THIS OPERATION OVER THE NEXT 48 HOURS

B772/B773 KJFK RNP:0.3 RAIM Check
GPS COVERAGE ACCEPTABLE FOR THIS OPERATION OVER THE NEXT 48 HOURS

B772/B773 KJFK RNP:1.0 RAIM Check
GPS COVERAGE ACCEPTABLE FOR THIS OPERATION OVER THE NEXT 48 HOURS

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RAIM+ Scheduled

- GNSS RAIM Outages for Aerodromes

- NOTAM Proposals generated for State NOTAM Office

- Proposals issued in NOTAM format so no additional formatting required by NOTAM Office

NOTAM N example

A1234/09 NOTAMN
Q) LFBB/ QGAAU/ I/ NBO/ A/ 000/ 999/ 4100N00200E005
A) LFBO
B) 0908240145
C) 0908250225
D) 24 0145-0230 0630-0645 25 0155-0225
E) EGNOS NOT AVAILABLE FOR LPV

This NOTAM is a new NOTAM (NOTAMN). Its reference is A1234/09

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RAIM+ On-Demand

- Integrated with flight / trip planning systems

- Calculates RAIM predictions automatically as part of routine flight planning

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Future Developments

CHAPTER 03

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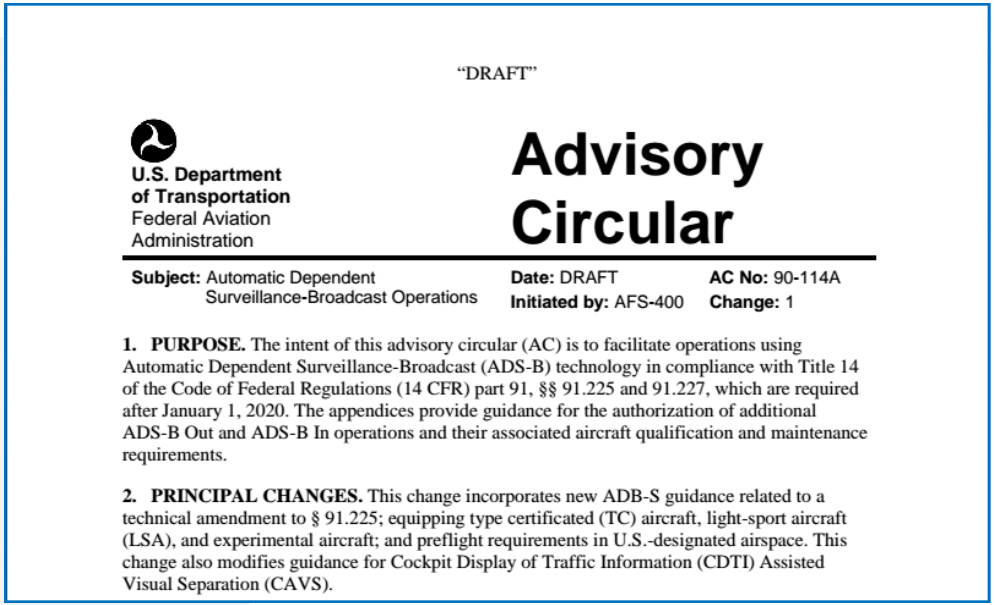
ADS-B Availabilty

ADS-B IN THE USA

- ADS-B Availability Predictions required for operations in USA from 2020

- If a similar mandate implemented in other ICAO regions this functionality will be available for SATDIS

- IPACG/38, para 2.1.2.11 “Operators may choose to use an alternative FAA-approved prediction tool”



“DRAFT”

U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: Automatic Dependent Surveillance-Broadcast Operations

Date: DRAFT **AC No:** 90-114A
Initiated by: AFS-400 **Change:** 1

1. PURPOSE. The intent of this advisory circular (AC) is to facilitate operations using Automatic Dependent Surveillance-Broadcast (ADS-B) technology in compliance with Title 14 of the Code of Federal Regulations (14 CFR) part 91, §§ 91.225 and 91.227, which are required after January 1, 2020. The appendices provide guidance for the authorization of additional ADS-B Out and ADS-B In operations and their associated aircraft qualification and maintenance requirements.

2. PRINCIPAL CHANGES. This change incorporates new ADB-S guidance related to a technical amendment to § 91.225; equipping type certificated (TC) aircraft, light-sport aircraft (LSA), and experimental aircraft; and preflight requirements in U.S.-designated airspace. This change also modifies guidance for Cockpit Display of Traffic Information (CDTI) Assisted Visual Separation (CAVS).

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ADS-B Service Availability Prediction

OVERVIEW

- Main message: very similar to RAIM prediction
- RAIM case: predict Horizontal Protection Limit **HPL**) (as observed by airborne equipment)
- ADS-B case: predict the observed position's Navigation Accuracy Category (**NACp**) and – Integrity category (**NIC**)
- Simple mapping exists: NIC is based on HPL, NACp on HFOM (introduced next)

SIMILARITIES

- In both cases: availability can be predicted based on predictable performance parameters
- RAIM availability based on horizontal alert limit (HAL) allowed in an operational environment:
  - HPL ≤ HAL system is available
- ADS-B availability is similarly based on minimum NIC and NACp values, e.g.:
  - NIC ≥ 7 and NACp ≥ 8 system is available

NIC ≈ HPL

MAPPING ONE TO ANOTHER

- NIC ≈ HPL: NIC represents a range of HPLs →

- Predicted HPL can be translated into NIC using a simple look-up table. Example:

  - HPL of 300 m falls in interval [185.2m,380.4m], hence NIC = 7

NIC	Containment Radius	Associated HPL range
0	Unknown	HPL unknown
1	RC < 37.04 km (20nm)	14816 m ≤ HPL < 37040 m
2	RC < 14.816 km (8nm)	7408 m ≤ HPL < 14816 m
…	..	…
7	RC < 370.4 m (0.2nm)	185.2 m ≤ HPL < 370.4 m
8	RC < 185.2 m (0.1nm)	75 m ≤ HPL < 185.2 m
…	…	…

Horizontal Figure of Merit (HFOM)

- HFOM: horizontal 95% containment value for position error

- Not used in RAIM prediction:
  - RAIM availability is driven by integrity, not accuracy

- Based on same computations as HPL using:
  - Predicted satellite geometry
  - Range error model, either:
    - SA-on model (TSO-C129)
    - SA-off model (TSO-C145/146/196)

- Adding HFOM to the RAIM prediction environment requires no significant architectural changes
  - HFOM can be derived from already computed results in few lines of code

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NACp ≈ HFOM

MAPPING ONE TO ANOTHER

- NACp ≈ HFOM: NACp represents a range of HFOMs →

- Predicted HFOM can be translated into NACp using a simple look-up table

NAC_p	Associated HFOM range	Comment
0	18520 m < HFOM	Unknown accuracy
1	7408 m ≤ HFOM < 18520 m	RNP-10 accuracy
…	…	.
6	185.2 m ≤ HFOM < 555.6 m	RNP-0.3 accuracy
7	92.6 m ≤ HFOM < 185.2 m	RNP-0.1 accuracy
…	…	…

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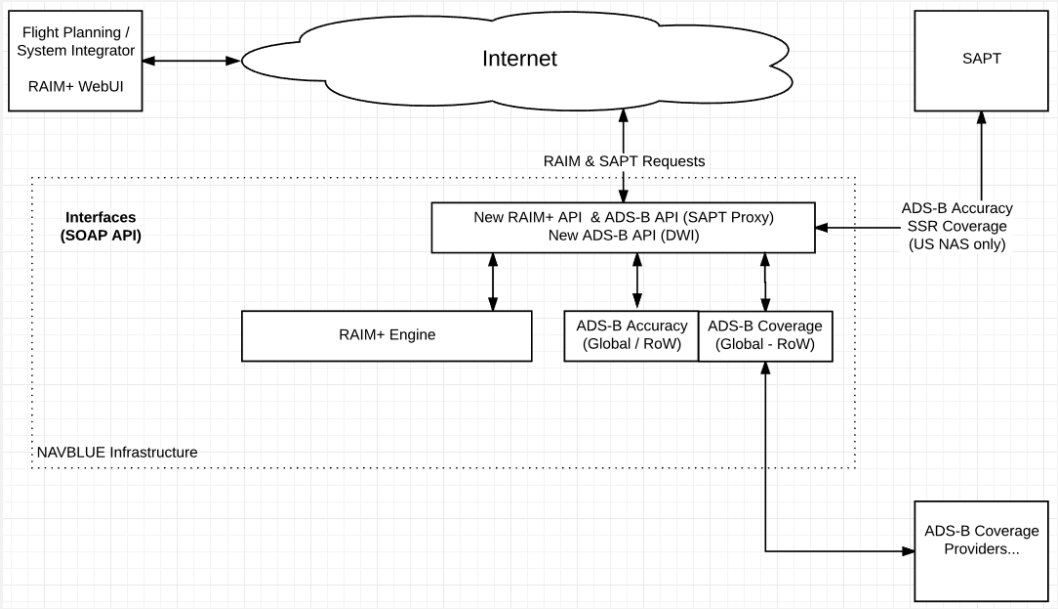
NAVBLUE ADS-B Solution

- Solution to be made available to the market by 2017
- Currently participating in FAA/Volpe testing
- Similar delivery channels to RAIM Prediction:
  - Web UI
  - On-Demand
- Scheduled not applicable for route predictions
- DWI actively participating in forums relating to ADS-B



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NAVBLUE and Worldwide RAIM Requirements

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Contact

JOHN WILDE
JOHN.WILDE@NAVBLUE.AERO
+44 (0) 118 324 0172

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