**DIRECCION GENERAL DE AERONAUTICA CIVIL**
**DIRECCION DE PLANIFICACION**
**SUBDIRECCION DE PLANIFICACION DE NAVEGACION AEREA**

**11TH INTERNATIONAL FLIGHT INSPECTION SYMPOSIUM**
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*.*.*.*.*.*.*

*SANTIAGO DE CHILE, 24 AGOSTO 2000*

*ES UN ALTO HONOR PARA EL DIRECTOR EJECUTIVO DEL 11° SIMPOSIO INTERNACIONAL DE INSPECCION EN VUELO SALUDAR A LA COMUNIDAD AERONAUTICA INTERNACIONAL Y PRESENTAR LA PUBLICACION FINAL DE LAS SESIONES TECNICAS DEL SIMPOSIO INTERMACIONAL IFIS2000 REALIZADO EN SANTIAGO DE CHILE ENTRE EL 05 Y EL 09 DE JUNIO DE 2000, AUSPICIADO POR LA* ***"DIRECCION GENERAL DE AERONAUTICA CIVIL - D.G.A.C."*** .

*IT IS A GREAT HONOR FOR 11TH INTERNATIONAL FLIGHT INSPECTION SYMPOSIUM CHAIRMAN TO GREET THE INTERNATIONAL AERONAUTICAL COMMUNITY AND IS PROUD TO PRESENT THE FINAL PROCEEDINGS CORRESPONDING TO THE TECHNICAL SESSIONS FROM TEH INTERNATIONAL SYMPOSIUM - IFIS2000, THAT WAS HELD IN SANTIAGO-CHILE FROM 05 TO 08 JUNE 2000, UNDER THE AUSPICES OF THE* ***"DIRECCION GENERAL DE AERONAUTICA CIVIL-G.G.A.C.".***

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***JULIO SANTOS***
***11TH IFIS CHAIRMAN***

# PRE-SYMPOSIUM WORKSHOP

IFIS 2000
CHILE

# 11TH INTERNATIONAL FLIGHT INSPECTION SYMPOSIUM

*From earth to space: The millennium challenge*

JUNE 5-9, 2000    SANTIAGO, CHILE

# ELEVENTH INTERNATIONAL FLIGHT INSPECTION SYMPOSIUM

## GPS WORKSHOP PROGRAM

## A G E N D A

**SANTIAGO CROWNE PLAZA HOTEL**

**SALON CONSTITUCION**

**JUNE 05, 2000 - SANTIAGO, CHILE**

**MONDAY, JUNE 05**

| | |
|---|---|
| 08:00 - 08:45 | Registration |
| 08:45 - 09:00 | Introduction |
| 09:00 - 09:35 | GNSS Basics |
| 09:35 - 10:10 | Augmentation (SBAS/GBAS) |
| 10:10 - 10:40 | Break |
| 10:40 - 11:15 | GNSS Augmentation - Basic Suitability/Limits for Aviation |
| 11:15 - 11:50 | WGS-84 and its application to GNSS |
| 11:50 - 13:00 | GNSS - Real and proposed Systems |
| | GNSS - GPS and NAS Implementation<br>GNSS - Galileo |
| 13:00 - 14:00 | Lunch |
| 14:00 - 15:45 | SBAS Augmentation Systems |
| | SBAS - WAAS<br>SBAS - EGNOS<br>SBAS - MTSAT |
| 15:45 - 16:20 | Break |
| 16:20 - 16:55 | GBAS Augmentation systems |
| | GBAS Standardized system (ICAO) |
| 16:55 - 17:30 | Future enhancements |

# ELEVENTH INTERNATIONAL FLIGHT INSPECTION SYMPOSIUM

## GPS WORKSHOP PROGRAM

## A G E N D A

**SANTIAGO CROWNE PLAZA HOTEL**
**JUNE 05, 2000 - SANTIAGO, CHILE**

**MONDAY, JUNE 05**

1.- GNSS Basics
Speaker: **Prof. DAVE POWELL** - Stanford University

2.- Augmentation (SBAS/GBAS)
Speaker: **Dr. TODD WALTER** - Stanford University

3.- GNSS and Augmentation - Basic Suitability/Limits for Aviation
Speaker: **Mr. DAN HANLON** - FAA

4.- WGS-84 and its application to GNSS
Speaker: **Mr. MICHAEL MORGAN** - NIMA

5.- GNSS - Real and Proposed Systems

GNSS - GPS and NAS Implementation
Speaker: **Mr. JIMMY R. SNOW** - FAA AVN GPS Program

GNSS - Galileo
Speaker: **Mr. STEFAN NAERLICH** - DFS Deutsche Flugsicherung GmbH

6.- SBAS Augmentation Systems

SBAS - WAAS
Speaker: **Mr. JOHN BRITIGAN** - Raytheon WAAS Leader).

SBAS - EGNOS
Speaker: **Mr. STEFAN NAERLICH** - DFS Deutsche Flugsicherung GmbH

SBAS - MTSAT
Speaker: **Dr. ROBERT LOH** - Innovative Solutions International
**Mr. NAOTO ASADA** - Japanese Flight Inspection Unit

7.- GBAS Augmentation Systems

GBAS Standardized system (ICAO)
Speaker: **Ms. MARIA DIPASQUANTONIO** - FAA LAAS IPT Lead

8.- Future Enhancements
Speaker: **Mr. CURT KEEDY** - Flight Inspection Policy and Standards -FAA

# GPS WORKSHOP

## Brief description of Topics

1.- **GNSS Basic**
Satellite constellation, how CDMA ranging works, position calculation, concept of DOP, control segment. and any other relevant information related to GNSS.

2.- **Augmentation (SBAS/GBAS)**
Description of error sources, difference in correction quality, effect of time and distance. Report on the experiments that have been performed and the accuracy obtained from the test bed that has been operating up to day.

3.- **GNSS and augmentation - Basic Suitability/Limits for aviation**
Updates to GPS and future plans. Status and future of WAAS. What are the present capabilities and what the aviation community expects in the next 20 years for WAAS. Limitations if any, and its potential solution.

4.- **WGS-84 and its application to GNSS**
The presentation describes the generation of data sets, which are based on a single geodetic system (WGS-84).

5.- **GNSS - Real and proposed Systems**
GNSS - GPS
GNSS - Galileo
Description of the improvements to GPS that can be made by onboard equipment. What GPS implementation is and and what its capabilities are. Updates for GLONASS and its future advancements. Current status of the GNSS possibilities worldwide, including a description of the proposed system, if available

6.- **SBAS Augmentation Systems**
WAAS
EGNOS
MTSAT
Description of each SBAS being designed and built in the different regions of the world. What the aviation community could expect in the immediate and middle future.

7.- **GBAS Augmentation Systems**
GBAS standardized system (ICAO)
Description of the various local differential systems being designed and built. Status and future of LAAS. What are the present capabilities and what the community expect in the next 20 years for LAAS.

8.- **Future GPS enhancements**
Description of the new civil frequencies and their effect on interference robustness and ability to carry out carrier tracking. Future of GPS.

# GNSS Basics

**Prof. DAVE POWELL**

**Stanford University**

# GNSS Basics


Prof. Dave Powell

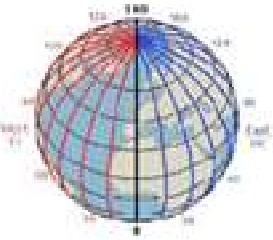
Stanford University

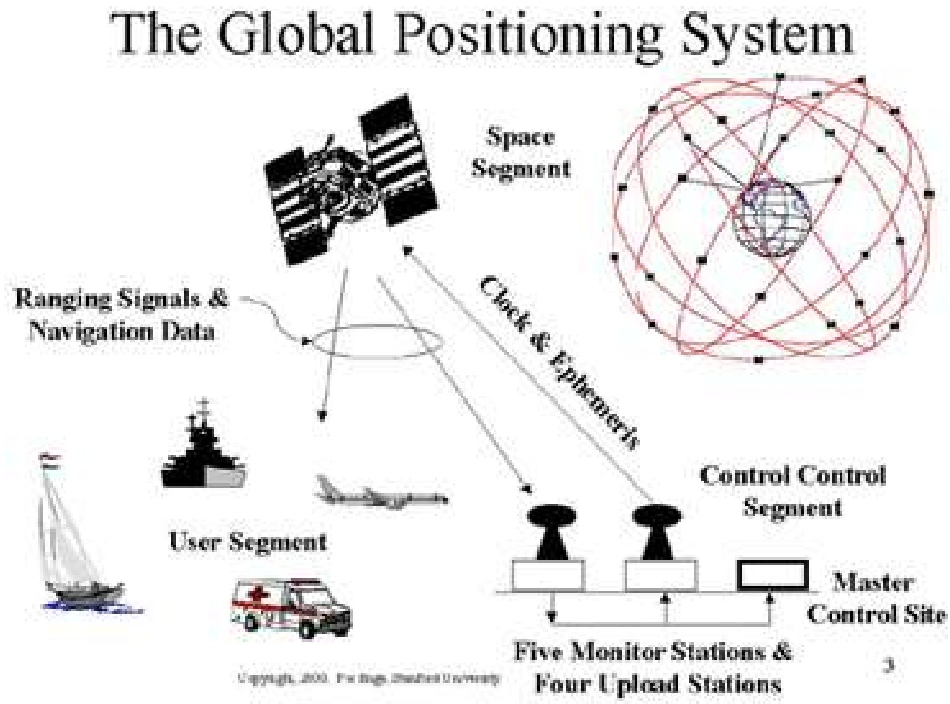

11th IFIS GPS Workshop

June 5, 2000

## Brief History of Navigation

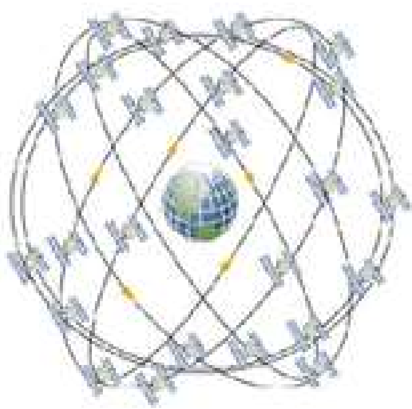
- Celestial sightings
- Magnetic compass ~1200
- Harrison's clock 1773
- Ground radio (VOR,ILS…)
- Satellites
  - Transit
  - GPS
  - Glonass




The Global Positioning System
Space Segment
Ranging Signals & Navigation Data
Clock & Ephemeris
Control Control Segment
User Segment
Master Control Site
Five Monitor Stations & Four Upload Stations
3

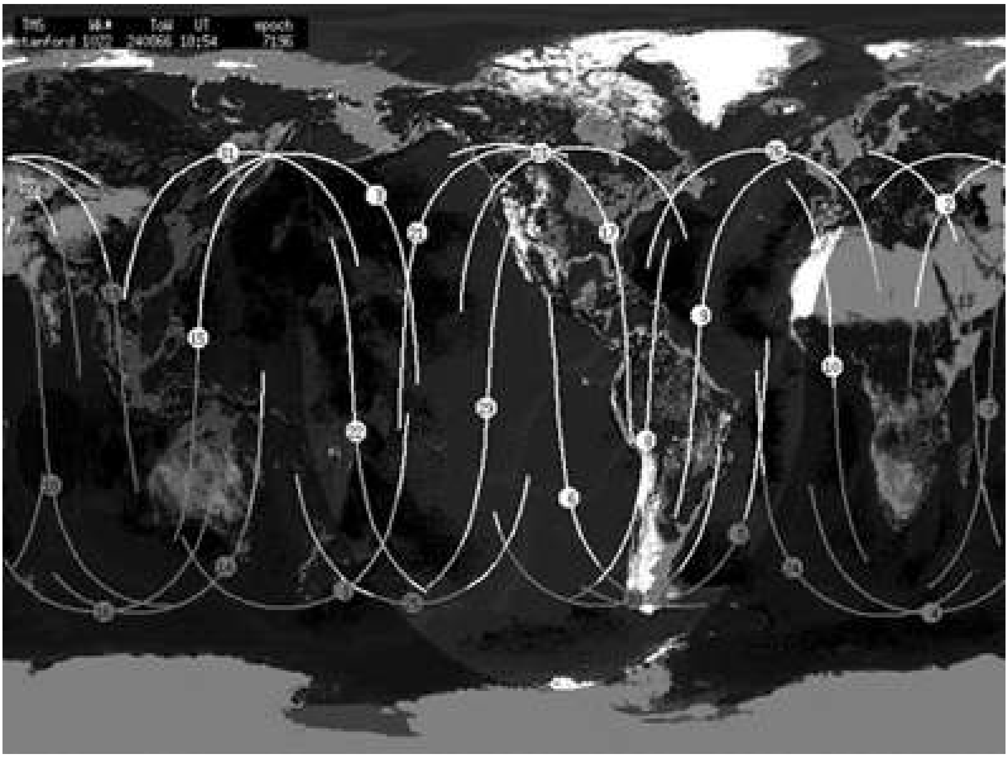
# Space Segment

- 6 orbit planes
- 55 Deg. Inclination
- Nominally 4 satellites (SV) per plane
- Currently 4 extra (total=28 satellites)
- 12 hour orbit period (26,560 km orbit radius)
- All transmit at same frequency (1575.42 MHz ) but each SV has a unique code (CDMA)





5



# Ground Control Segment


Global Positioning System (GPS) Master Control and Monitor Station Network

7

# Ground Control Segment

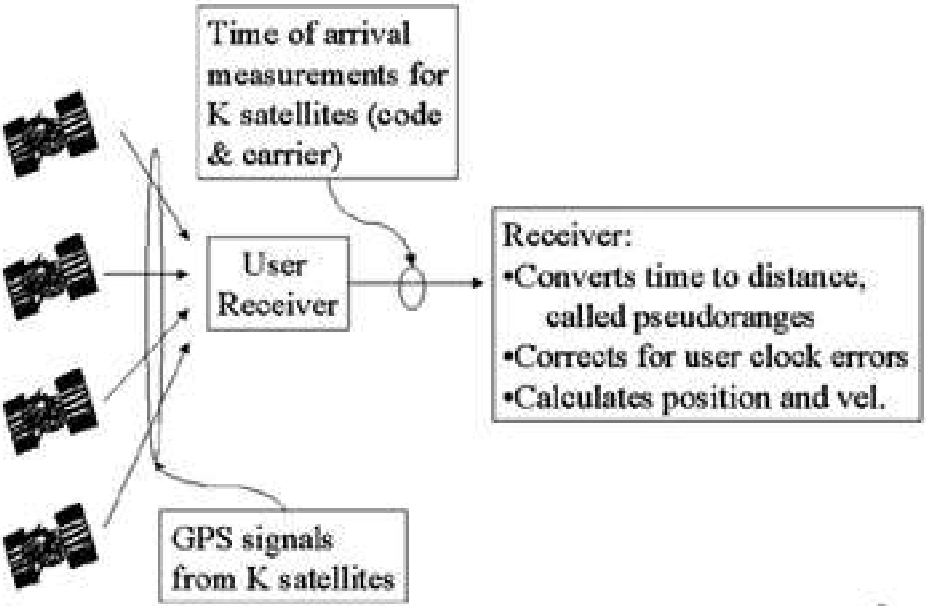
Functions:

- command infrequent small maneuvers to maintain orbit
- keep GPS time
- command infrequent small clock corrections
- track GPS satellite & estimate clock and orbit
- upload navigation data that describes clock & orbit for each sv
- command major relocations to compensate for any sv failures



8

# User Segment



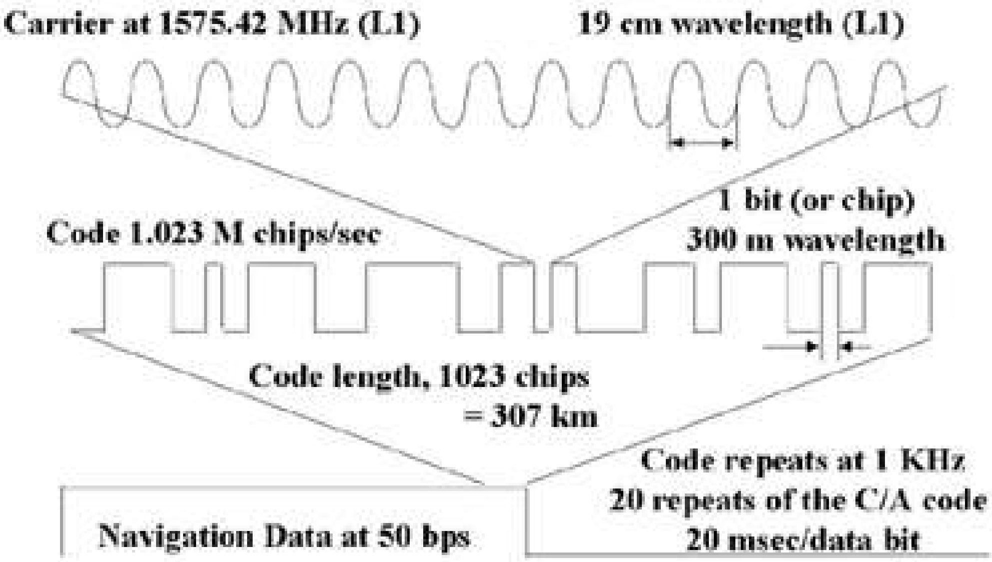





# User Segment

- Determines pseudorange to each satellite by
  - Identifying code associated with each SV
  - Finding phase of each code, thus time and distance to each satellite
- Calculates position and user clock error by combining range data from 4 or more satellites

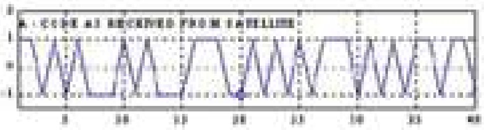
# GPS Signals



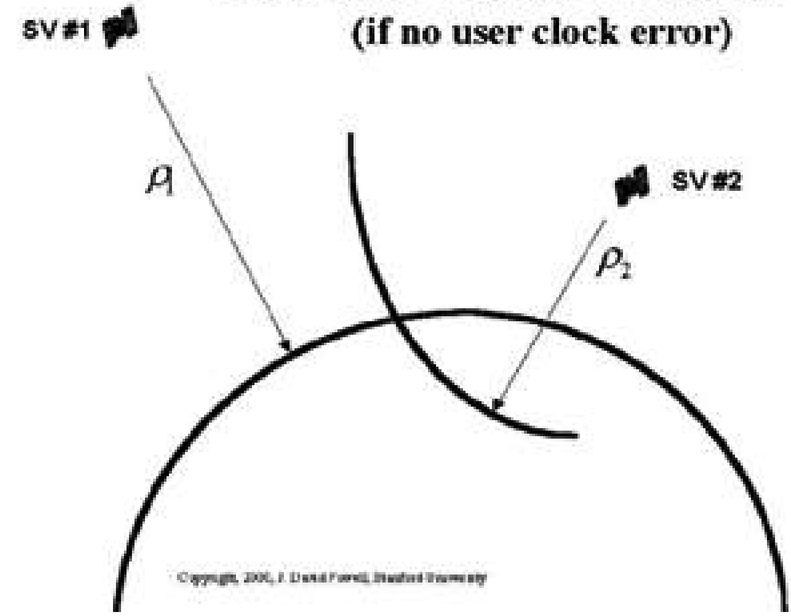





# Determine phase by correlation



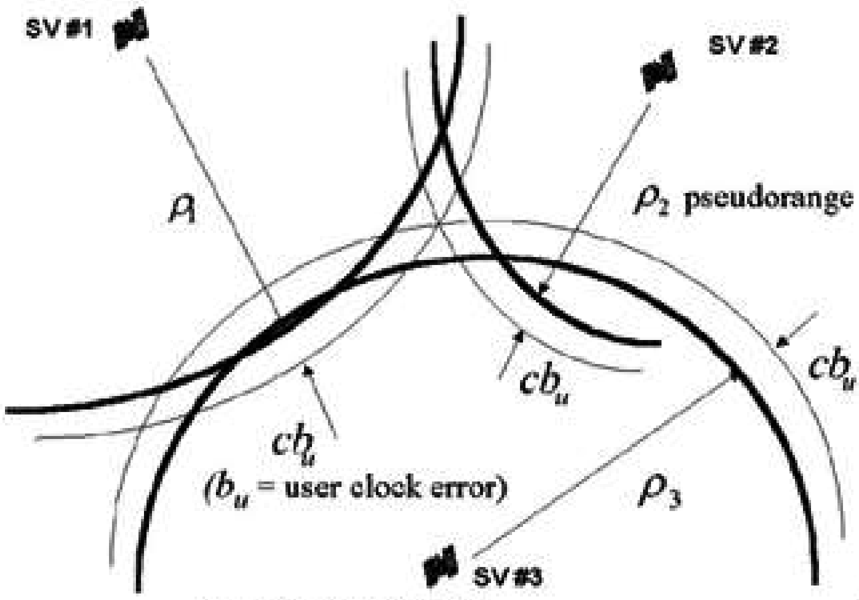
## Position Determination
(if no user clock error)



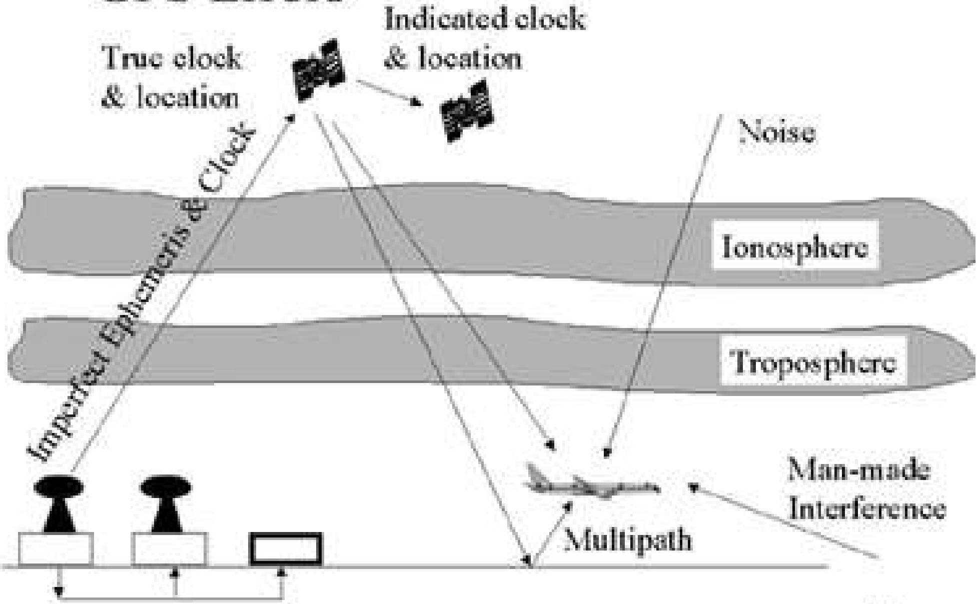





## Position and clock error determination



# GPS Errors






15

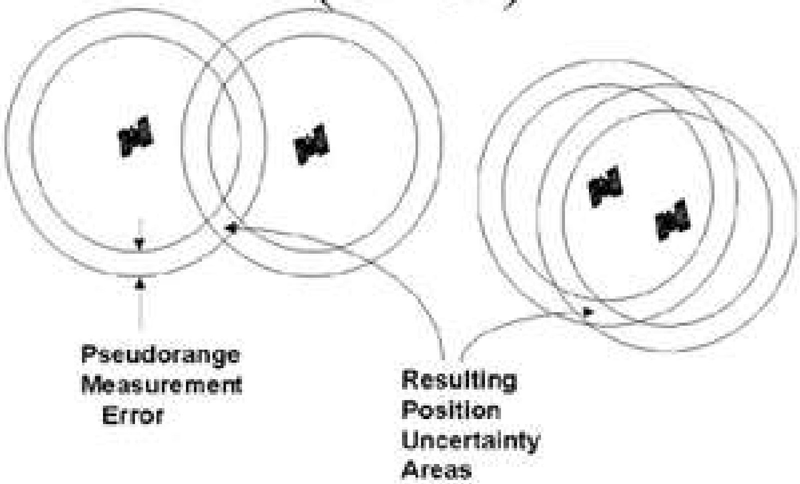
# GPS PseudoRange (PR)
# 1σ Error Budget

| Error Source | SA ON | SA OFF |
|---|---|---|
| Ephemeris | 2.1 m | 2.1 m |
| SV Clock | 20.0 | 2.1 |
| Ionosphere | 4.0 | 4.0 |
| Troposphere | 0.5 | 0.5 |
| Multipath | 1.0 | 1.0 |
| Receiver | 0.5 | 0.5 |
| **PR Error (RMS)** | **20.5 m** | **5.3 m** |



16

# Geometric Dilution of Precision (GDOP)








# Dilution of Precision Components

- Effect of geometry on precision is called Dilution of Precision or DOP
  - East component = EDOP
  - North component = NDOP
  - Vertical component = VDOP
  - Time component = TDOP
- PDOP = RSS of EDOP, NDOP & VDOP
- GDOP = RSS of PDOP & TDOP

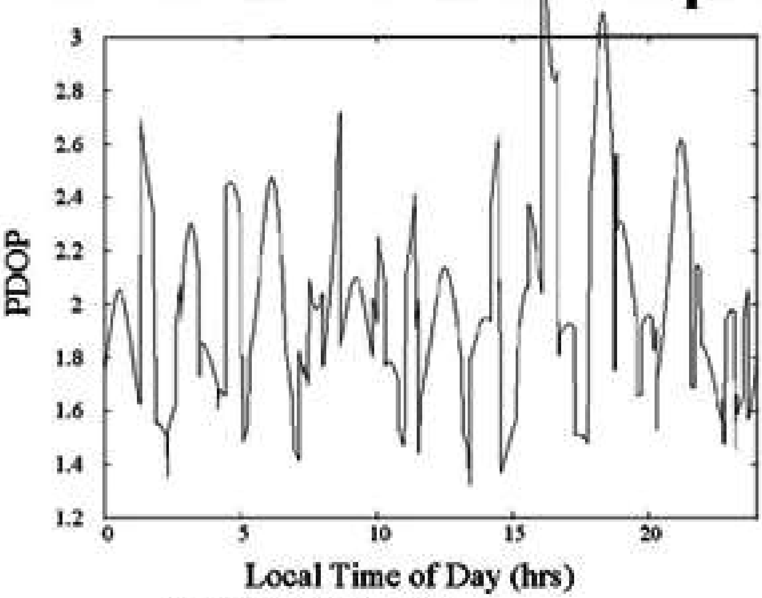
# The Power of the GDOP Concept

- Positioning ranging accuracy can be estimated as the ranging accuracy multiplied by a dilution factor (DOP) which depends solely on geometry.
- Typically, variations in geometry are far greater than variations in ranging accuracy.
- GDOP concept also quantizes the effect when nominal satellites are not in view.
  - local terrain shading
  - satellite outages
  - blockage by user platform





# PDOP at De Gaulle Airport

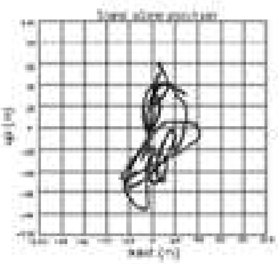


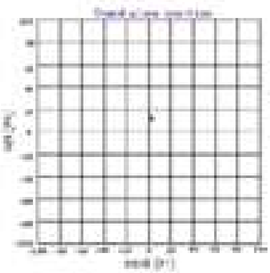
# Example of Position Errors

- Errors depend on time of day due to PDOP

$\sigma_P = (PDOP)\sigma_{PR}$

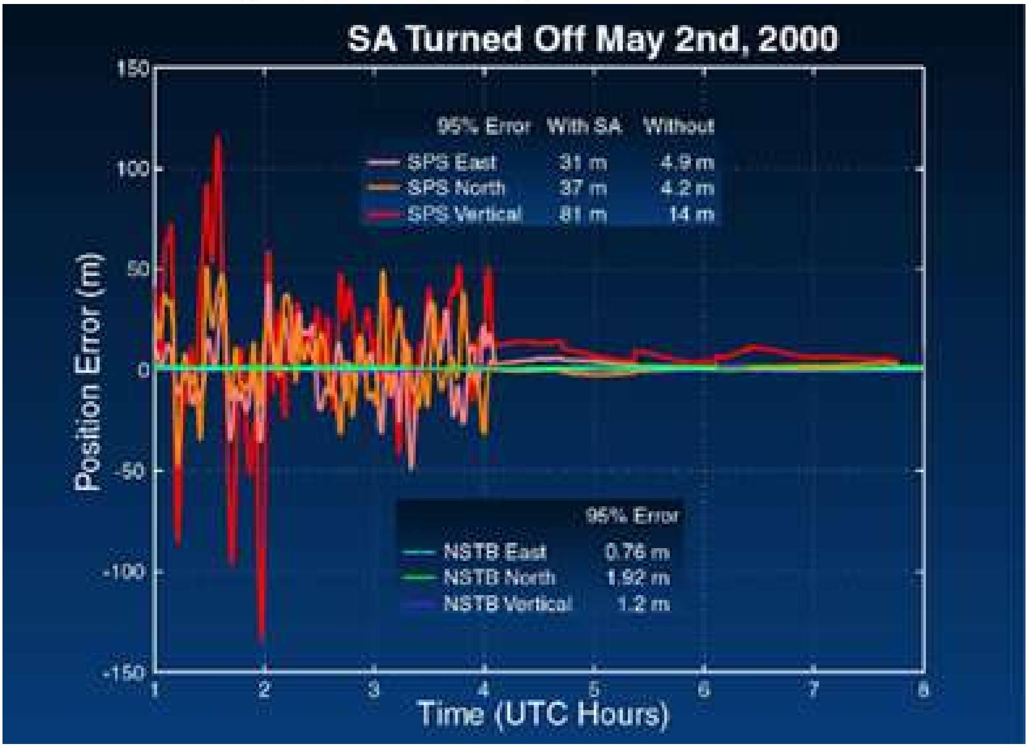
Where –
$\sigma_P$ = position rms error
$\sigma_{PR}$ = pseudorange rms error (from slide 16)


SA on


SA off



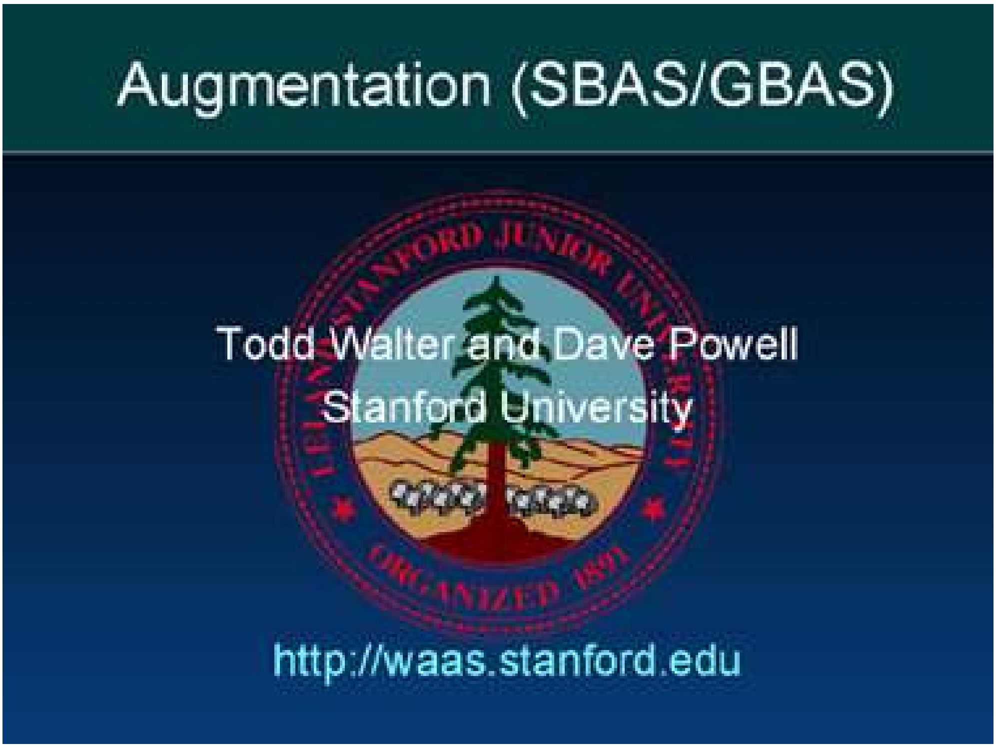


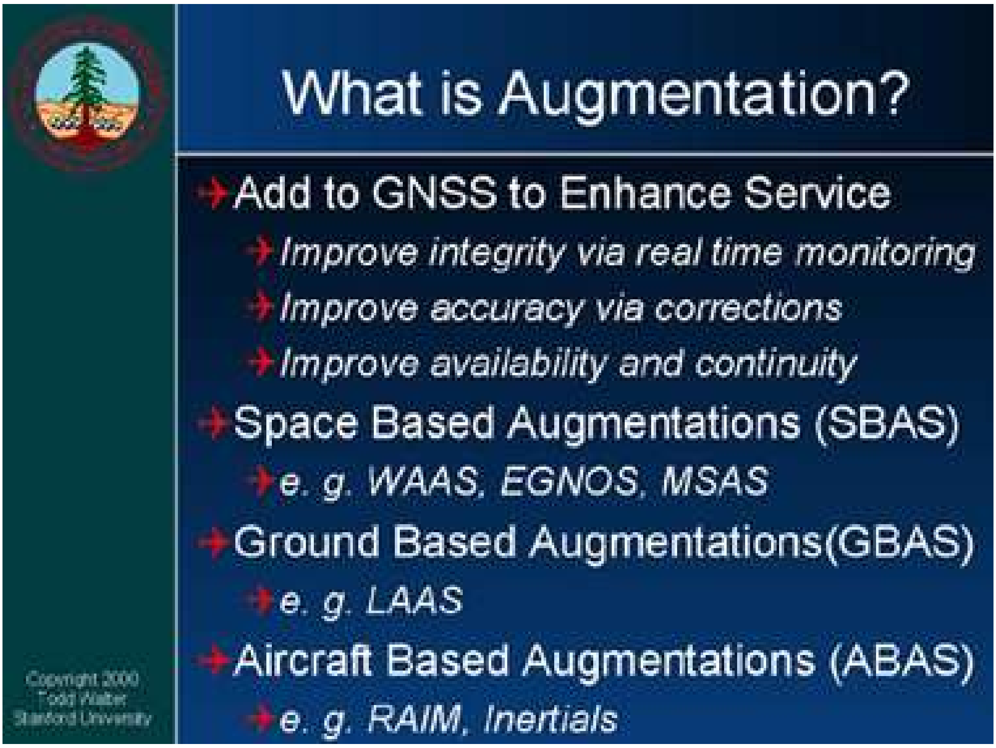


# Augmentation (SBAS/GBAS)

Dr. TODD WALTER

Stanford University


Augmentation (SBAS/GBAS)
LELAND STANFORD JUNIOR UNIVERSITY
ORGANIZED 1891
Todd Walter and Dave Powell
Stanford University
http://waas.stanford.edu


What is Augmentation?
Add to GNSS to Enhance Service
Improve integrity via real time monitoring
Improve accuracy via corrections
Improve availability and continuity
Space Based Augmentations (SBAS)
e. g. WAAS, EGNOS, MSAS
Ground Based Augmentations(GBAS)
e. g. LAAS
Aircraft Based Augmentations (ABAS)
e. g. RAIM, Inertials
Copyright 2000
Todd Walter
Stanford University


Why Augmentation?
Current GPS and GLONASS Constelations Cannot Support Requirements For All Phases of Flight
Integrity is Not Guaranteed
All satellites are not monitored at all times
Time-to-alarm is from minutes to hours
No indication of quality of service
Accuracy is Not Sufficient
Even with SA off, vertical accuracy > 10 m
Availability and Continuity Must Meet Requirements
Copyright 2000
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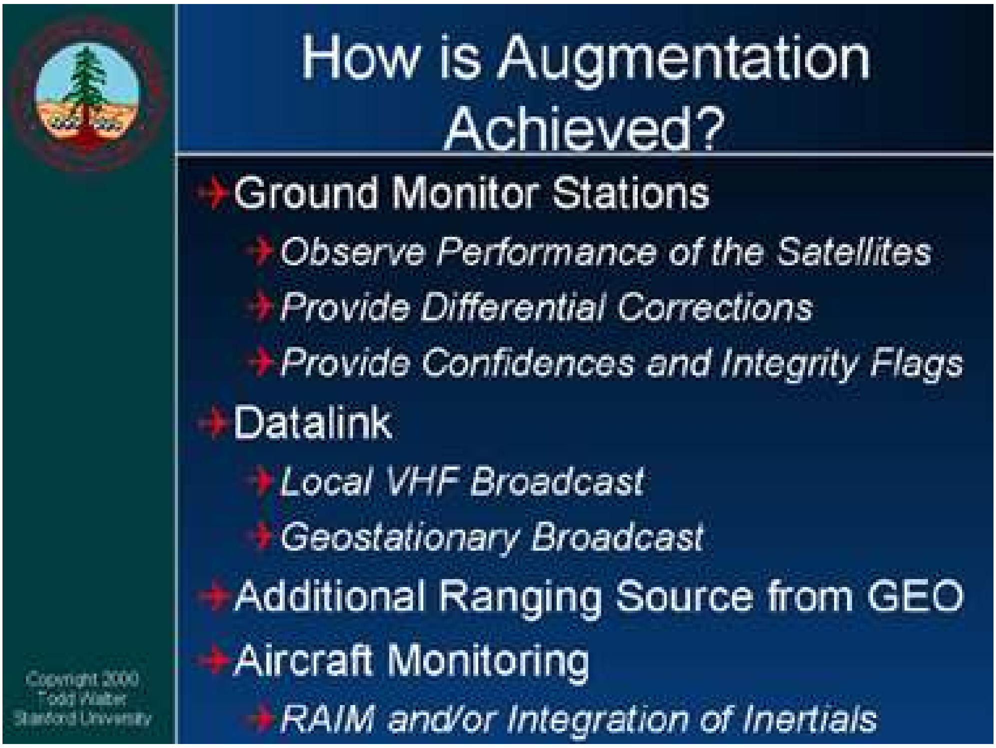
How is Augmentation Achieved?
Ground Monitor Stations
Observe Performance of the Satellites
Provide Differential Corrections
Provide Confidences and Integrity Flags
Datalink
Local VHF Broadcast
Geostationary Broadcast
Additional Ranging Source from GEO
Aircraft Monitoring
RAIM and/or Integration of Inertials
Copyright 2000
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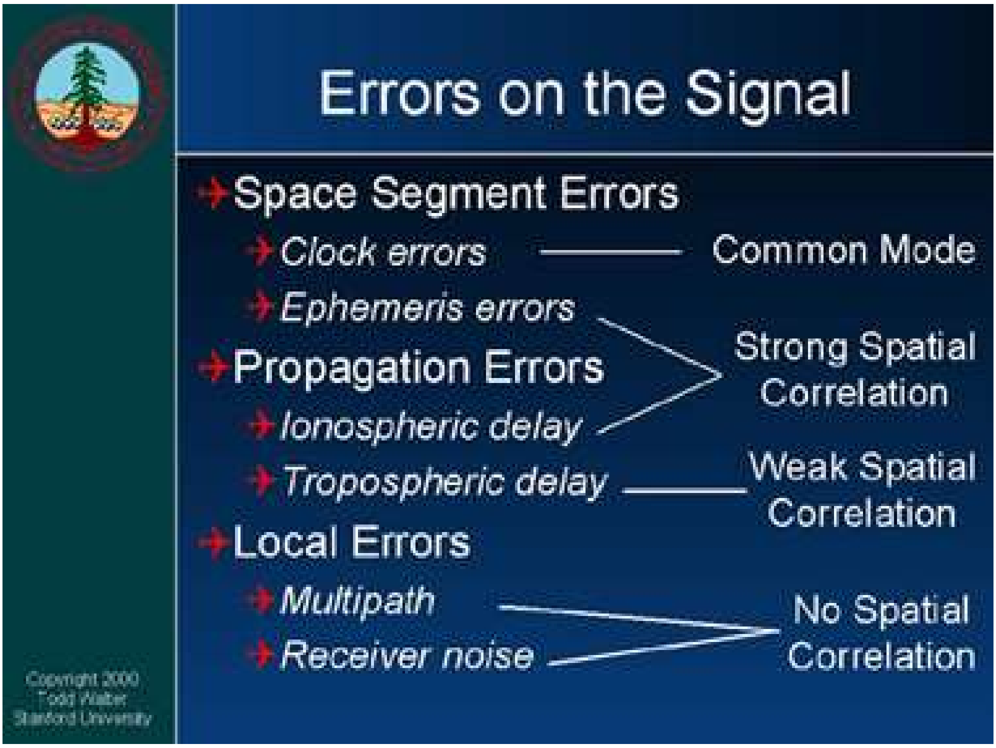
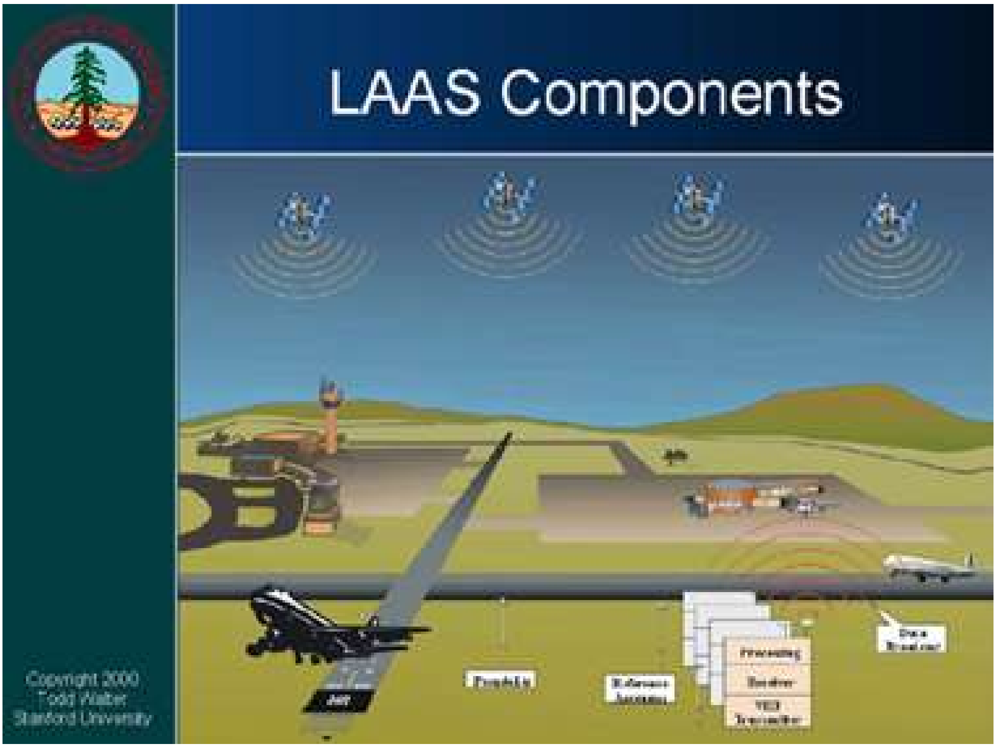
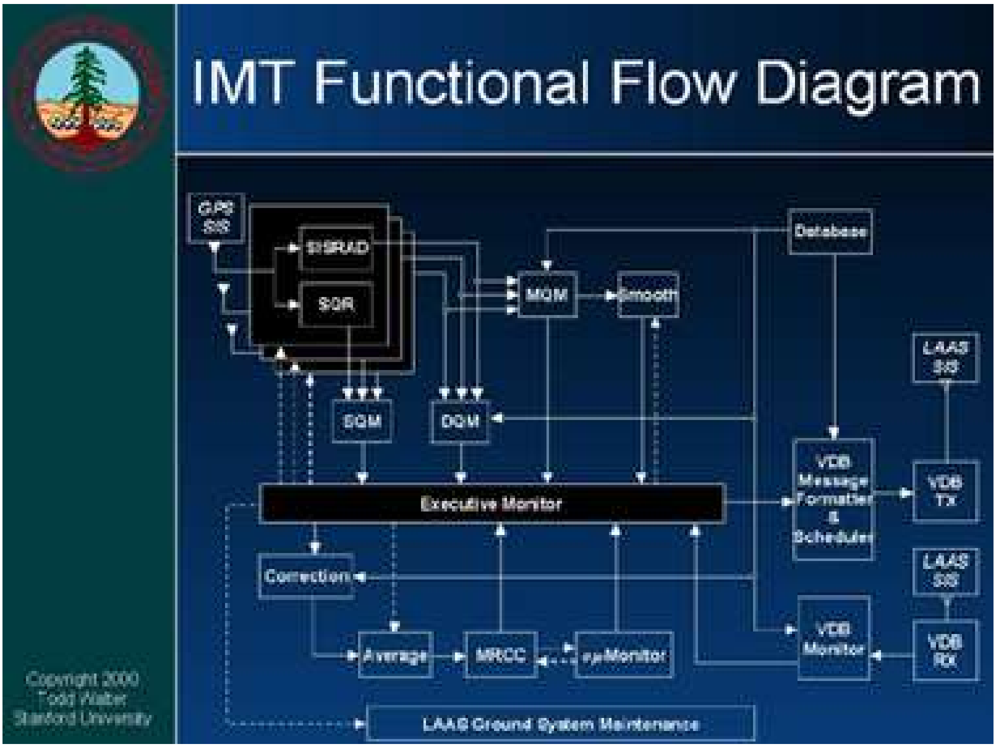
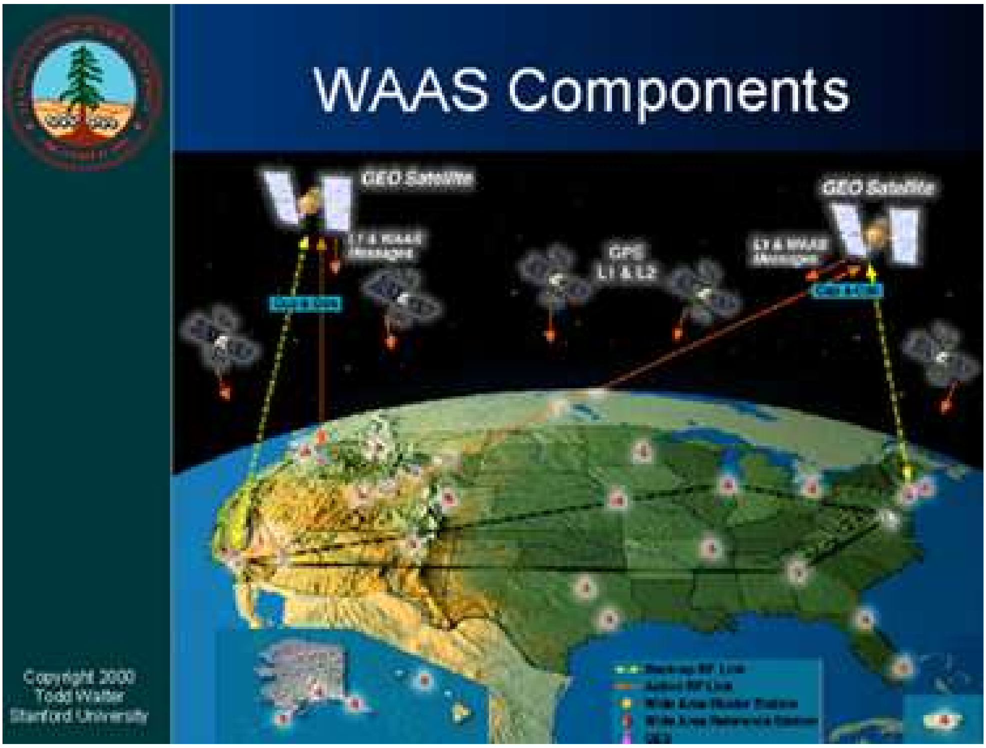
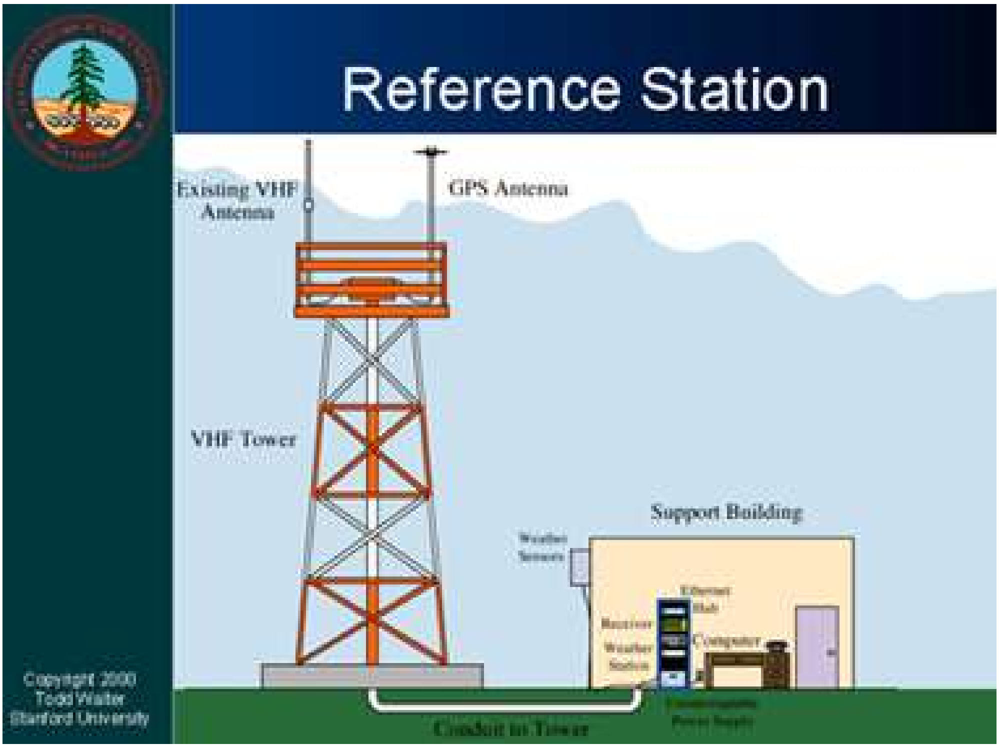
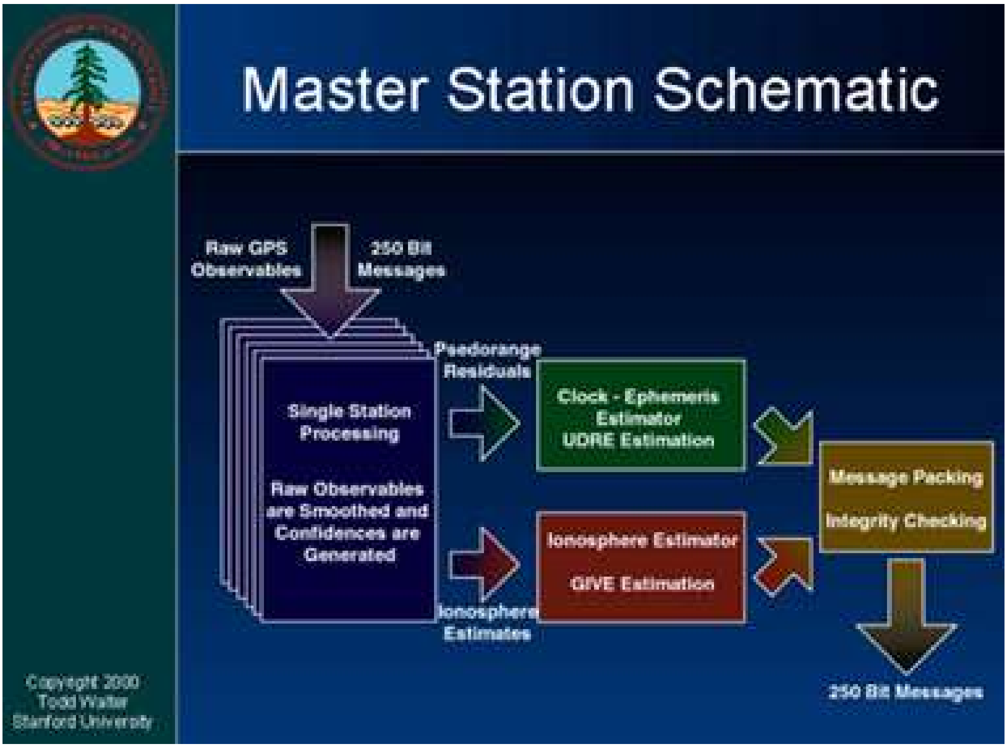

Errors on the Signal
Space Segment Errors
Clock errors
Common Mode
Ephemeris errors
Strong Spatial Correlation
Propagation Errors
Ionospheric delay
Tropospheric delay
Weak Spatial Correlation
Local Errors
Multipath
Receiver noise
No Spatial Correlation
Copyright 2000 Todd Walter Stanford University


LAAS Components
Copyright 2000 Todd Walter Stanford University


IMT Functional Flow Diagram
GPS SIS
SISRAD
SQR
MQM
Smooth
Database
LAAS SIS
SQM
DQM
VDB Message Formatter & Scheduler
VDB TX
Executive Monitor
Correction
LAAS SIS
VDB Monitor
VDB RX
Average
MRCC
Monitor
LAAS Ground System Maintenance
Copyright 2000
Todd Walter
Stanford University


WAAS Components
GEO Satellite
L1 & WAAS Messages
GPS L1 & L2
GEO Satellite
L1 & WAAS Messages
Copyright 2000
Todd Walter
Stanford University


Reference Station
Existing VHF Antenna
GPS Antenna
VHF Tower
Support Building
Computer
Conduit to Tower
Copyright 2000
Todd Walter
Stanford University

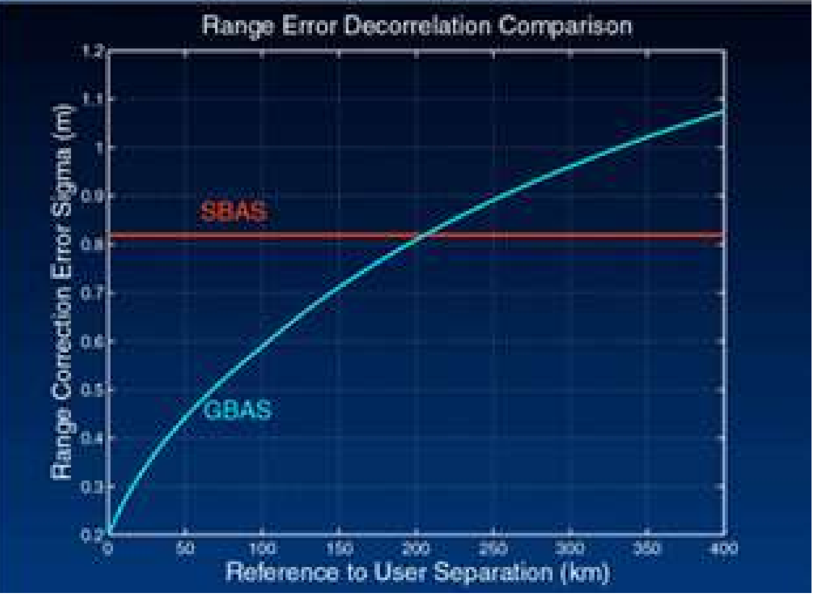

Master Station Schematic
Raw GPS Observables
250 Bit Messages
Psedorange Residuals
Single Station Processing
Raw Observables are Smoothed and Confidences are Generated
Clock - Ephemeris Estimator
UDRE Estimation
Ionosphere Estimator
GIVE Estimation
Ionosphere Estimates
Message Packing
Integrity Checking
250 Bit Messages
Copyright 2000
Todd Walter
Stanford University

# Error Mitigation

| Error Componant | GBAS | SBAS |
|---|---|---|
| Satellite Clock | Common Mode Differencing | Estimation and Removal |
| Ephemeris | Common Mode Differencing | |
| Ionosphere | Common Mode Differencing | Estimation and Removal |
| Troposphere | Common Mode Differencing | Fixed Model |
| Multipath and Receiver Noise | Carrier Smoothing by User | |



# Range Error Decorrelation



# Observation Equations

Code and Carrier Error Sources at $L_1$

$$PR_i^j = \rho_i^j + \Delta\mathbf{r}^j \cdot \mathbf{1}_i^j + B^j - b_i + I_i^j + T_i^j + M_i^j + \nu_i^j$$

$$\phi_i^j = \rho_i^j + \Delta\mathbf{r}^j \cdot \mathbf{1}_i^j + B^j - b_i - I_i^j + T_i^j + N_i^j \lambda_{L1} + m_i^j + \varepsilon_i^j$$

Code and Carrier Error Sources at $L_2$

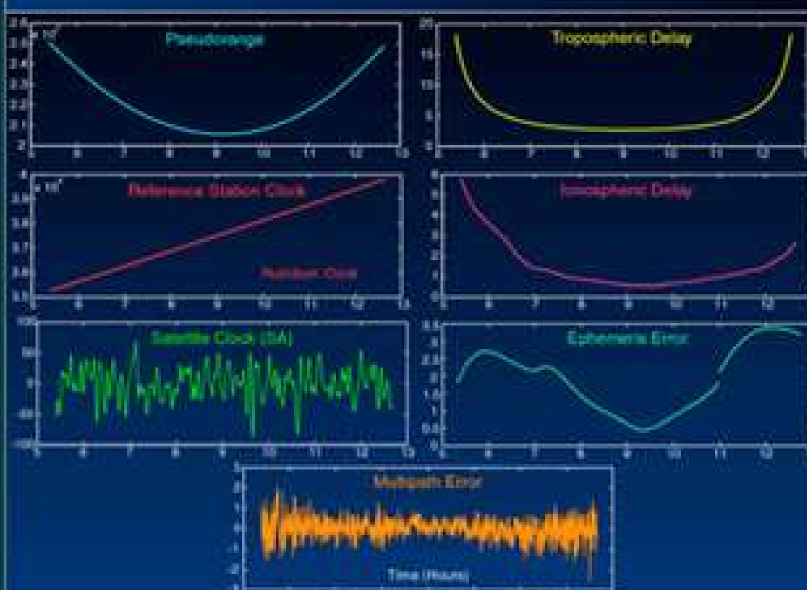
$$PR_i^j = \rho_i^j + \Delta\mathbf{r}^j \cdot \mathbf{1}_i^j + B^j - b_i + \gamma I_i^j + T_i^j + M_i^j + \nu_i^j$$

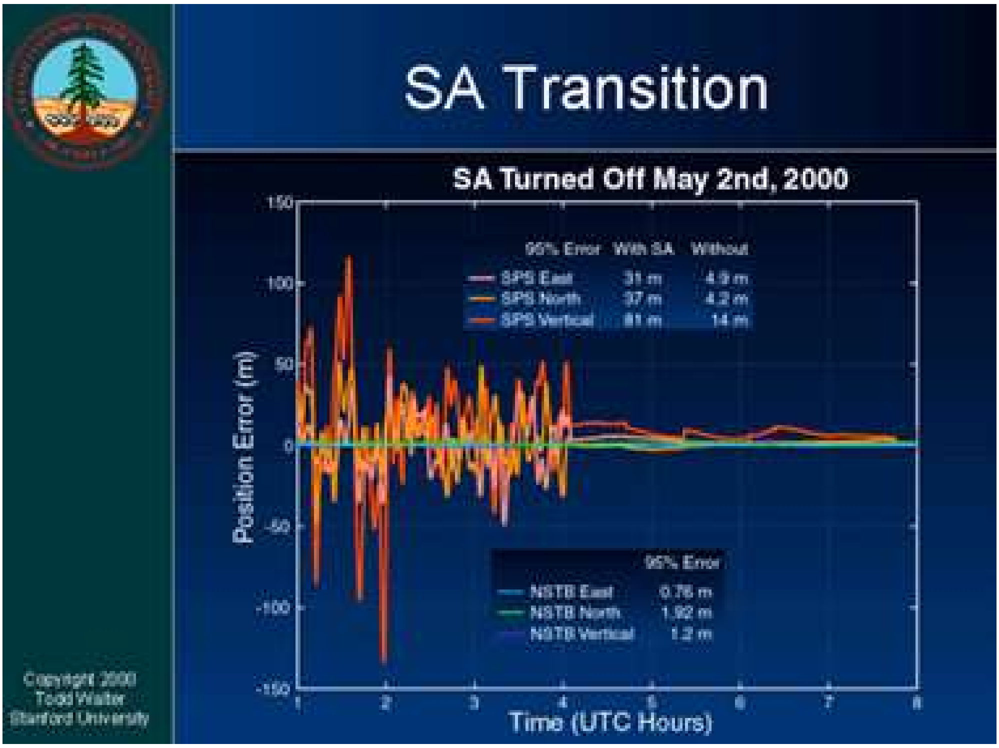
$$\phi_i^j = \rho_i^j + \Delta\mathbf{r}^j \cdot \mathbf{1}_i^j + B^j - b_i - \gamma I_i^j + T_i^j + N_i^j \lambda_{L2} + m_i^j + \varepsilon_i^j$$

$$\gamma \equiv \left(\frac{f_1}{f_2}\right)^2$$

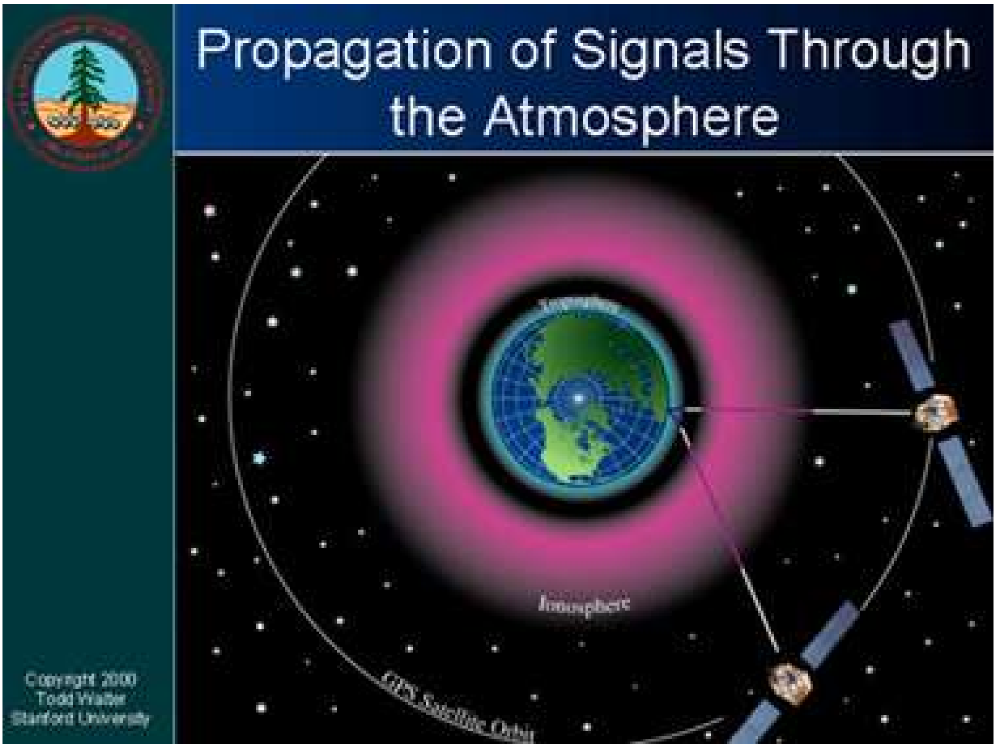


# Ranging Errors

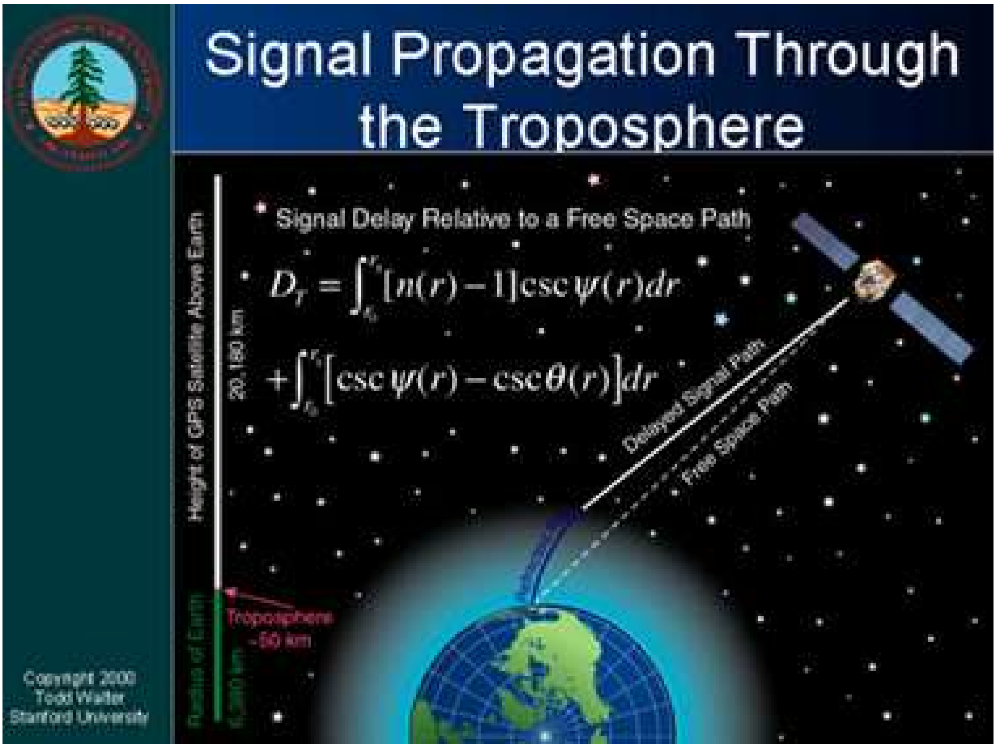


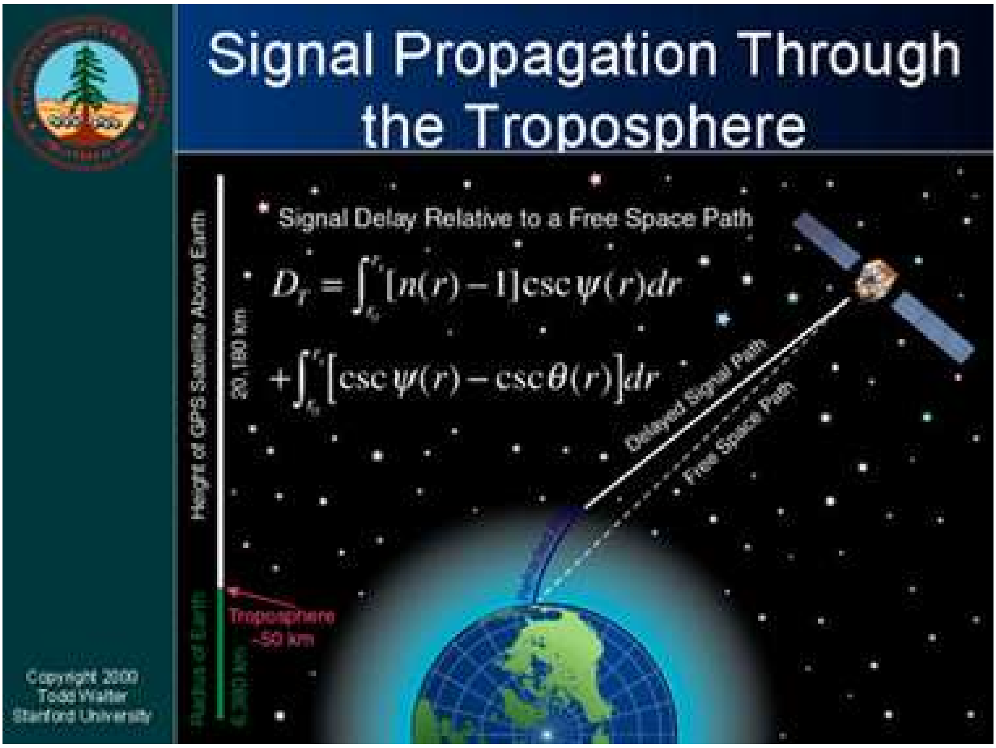


SA Transition
SA Turned Off May 2nd, 2000
95% Error With SA Without
SPS East 31 m 4.9 m
SPS North 37 m 4.2 m
SPS Vertical 81 m 14 m
95% Error
NSTB East 0.76 m
NSTB North 1.92 m
NSTB Vertical 1.2 m
Position Error (m)
Time (UTC Hours)
Copyright 2000
Todd Walter
Stanford University

Propagation of Signals Through the Atmosphere
Troposphere
Ionosphere
GPS Satellite Orbit
Copyright 2000
Todd Walter
Stanford University


Signal Propagation Through the Troposphere
Signal Delay Relative to a Free Space Path
$D_T = \int_{r_0}^{r_t} [n(r) - 1] \csc \psi(r) dr + \int_{r_0}^{r_t} [\csc \psi(r) - \csc \theta(r)] dr$
Height of GPS Satellite Above Earth
20,180 km
Delayed Signal Path
Free Space Path
Troposphere
~50 km
Radius of Earth
6,380 km
Copyright 2000
Todd Walter
Stanford University


Signal Propagation Through the Troposphere
Signal Delay Relative to a Free Space Path
$D_T = \int_{r_0}^{r_t} [n(r) - 1] \csc \psi(r) dr + \int_{r_0}^{r_t} [\csc \psi(r) - \csc \theta(r)] dr$
Height of GPS Satellite Above Earth
20,180 km
Delayed Signal Path
Free Space Path
Troposphere
~50 km
Radius of Earth
6,380 km
Copyright 2000
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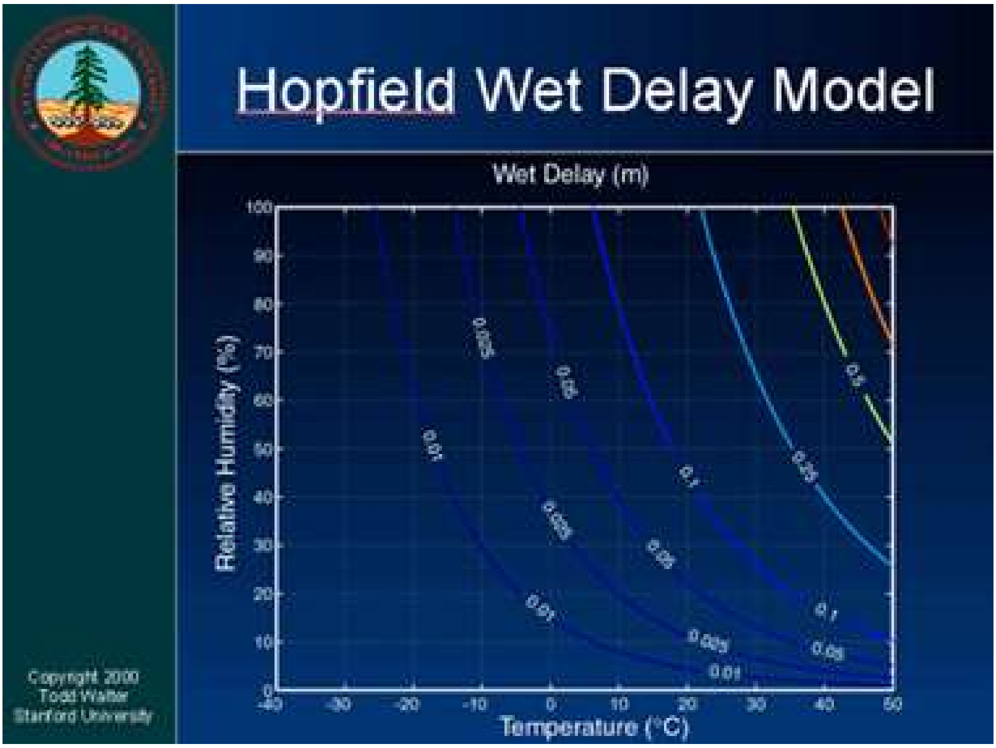
Stanford University


Hopfield Wet Delay Model
Wet Delay (m)
Relative Humidity (%)
Temperature (°C)
0.005
0.01
0.025
0.05
0.1
0.25
0.5
Copyright 2000
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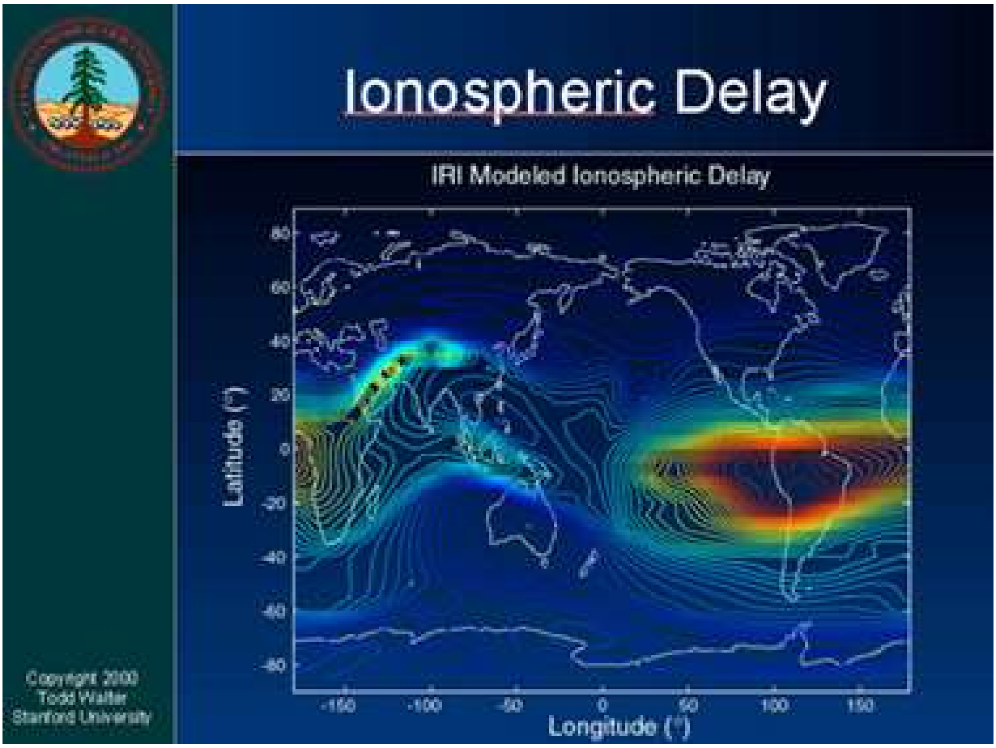
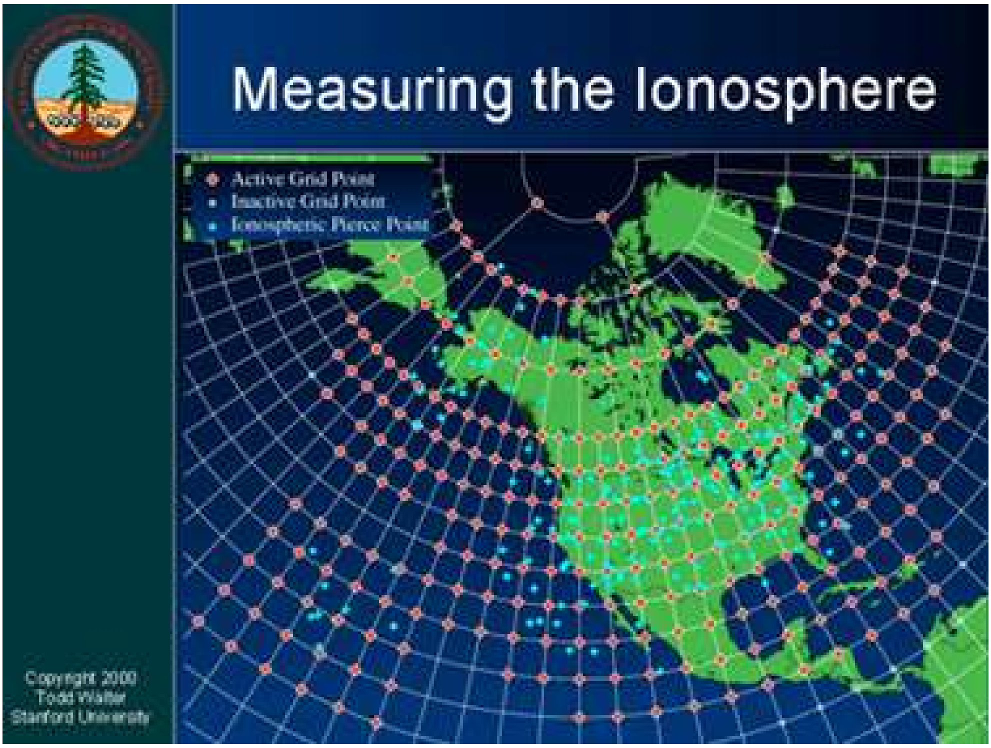

Ionospheric Delay
IRI Modeled Ionospheric Delay
Latitude (°)
Longitude (°)
Copyright 2000
Todd Walter
Stanford University


Measuring the Ionosphere
Active Grid Point
Inactive Grid Point
Ionospheric Pierce Point
Copyright 2000
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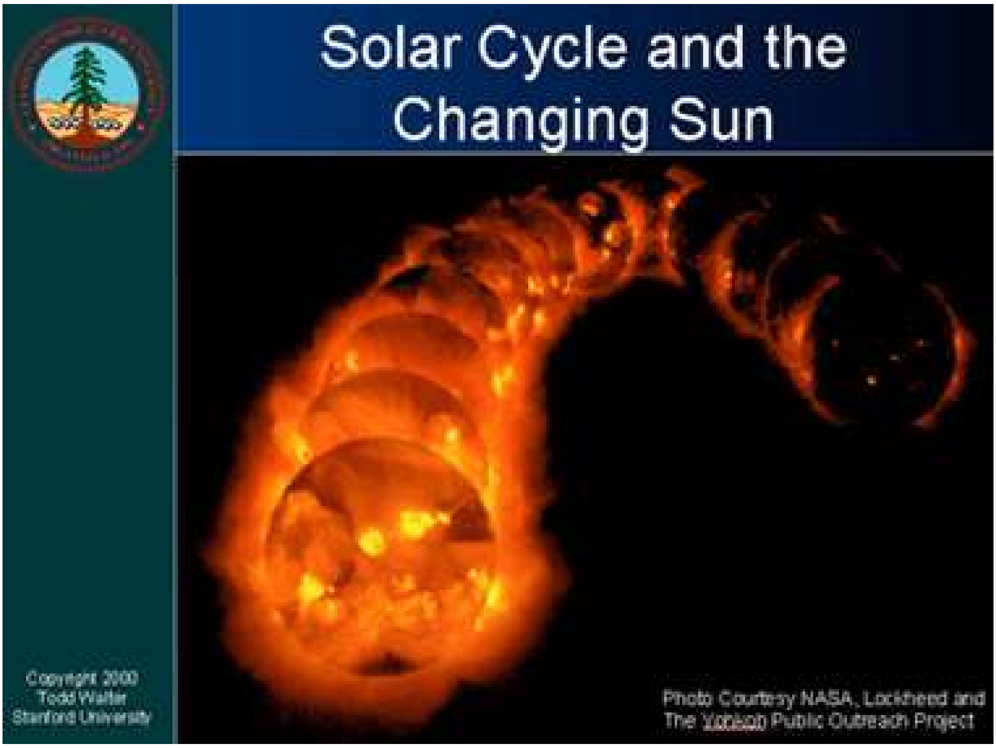
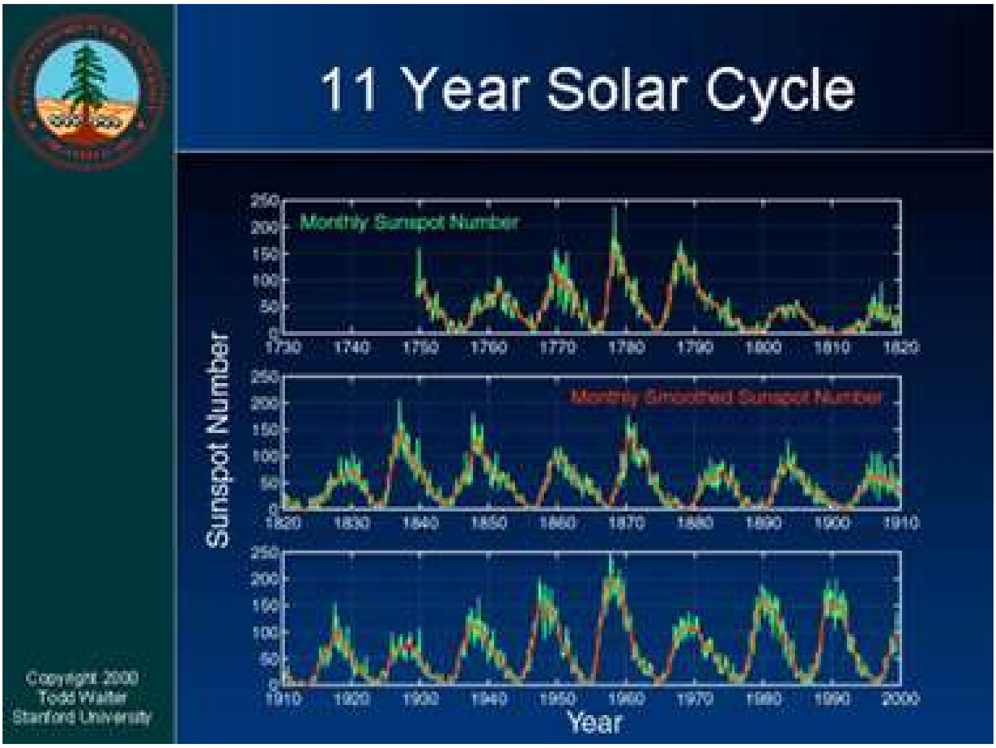

Solar Cycle and the Changing Sun
Copyright 2000
Todd Walter
Stanford University
Photo Courtesy NASA, Lockheed and
The Yohkoh Public Outreach Project


11 Year Solar Cycle
Monthly Sunspot Number
Monthly Smoothed Sunspot Number
Sunspot Number
Year
Copyright 2000
Todd Walter
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NSTB
Gander
Kotzebue
Fairbanks
Bethel
Bangor
Ottawa
Sitka
Cold Bay
Atlantic City
Winnipeg
Green Bay
Grand Forks
Dayton
Columbus
Seattle
Great Falls
Anderson
Denver
Greenwood
Elko
Arcata
Oklahoma City
Miami
Prescott
Stanford
San Angelo
Riverside
Honolulu
Mauna Loa
Copyright 2000
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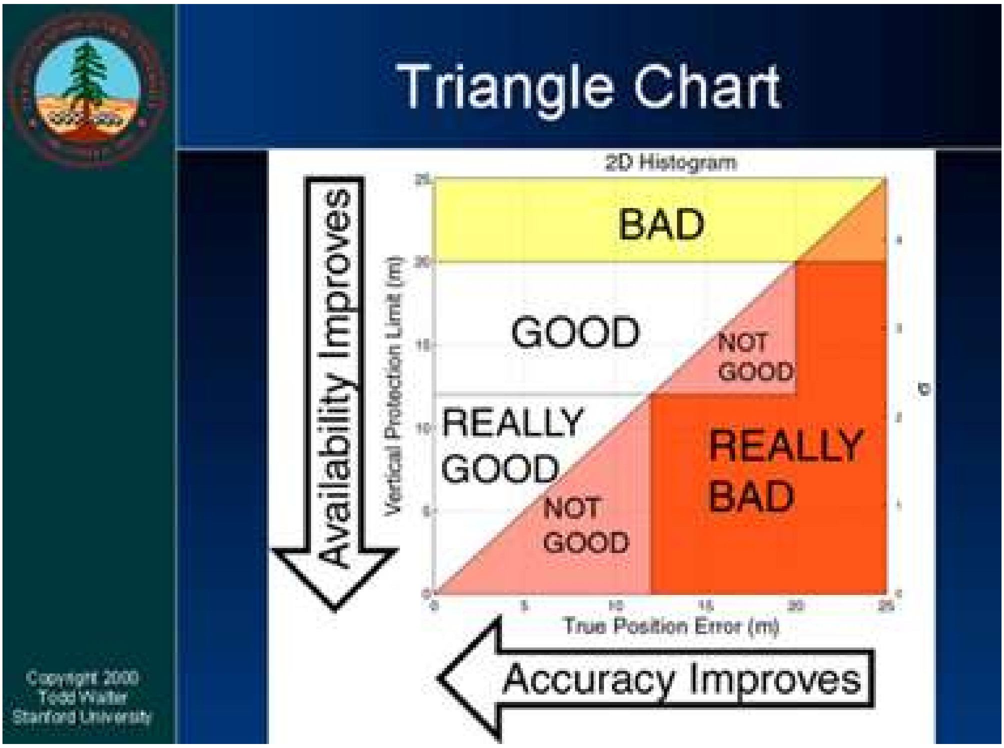
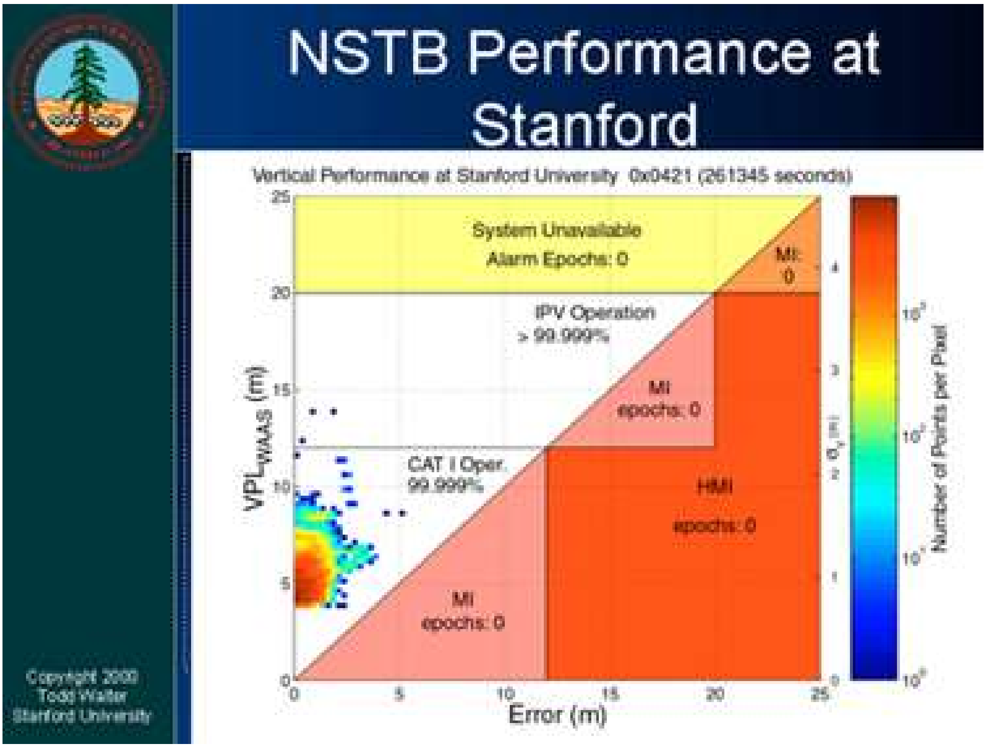

Triangle Chart
2D Histogram
BAD
GOOD
NOT GOOD
REALLY GOOD
NOT GOOD
REALLY BAD
Vertical Protection Limit (m)
True Position Error (m)
Availability Improves
Accuracy Improves
Copyright 2000
Todd Walter
Stanford University


NSTB Performance at Stanford
Vertical Performance at Stanford University 0x0421 (261345 seconds)
System Unavailable
Alarm Epochs: 0
MI: 0
IPV Operation
> 99.999%
MI
epochs: 0
CAT I Oper.
99.999%
HMI
epochs: 0
MI
epochs: 0
VPL_WAAS (m)
Error (m)
Number of Points per Pixel
Copyright 2000
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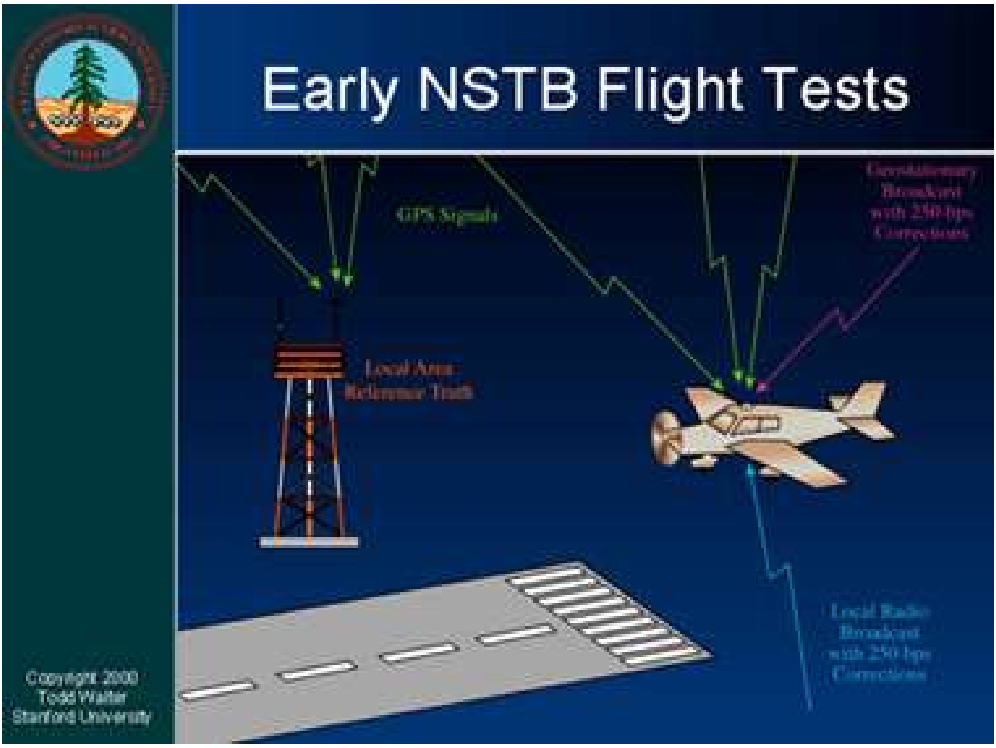
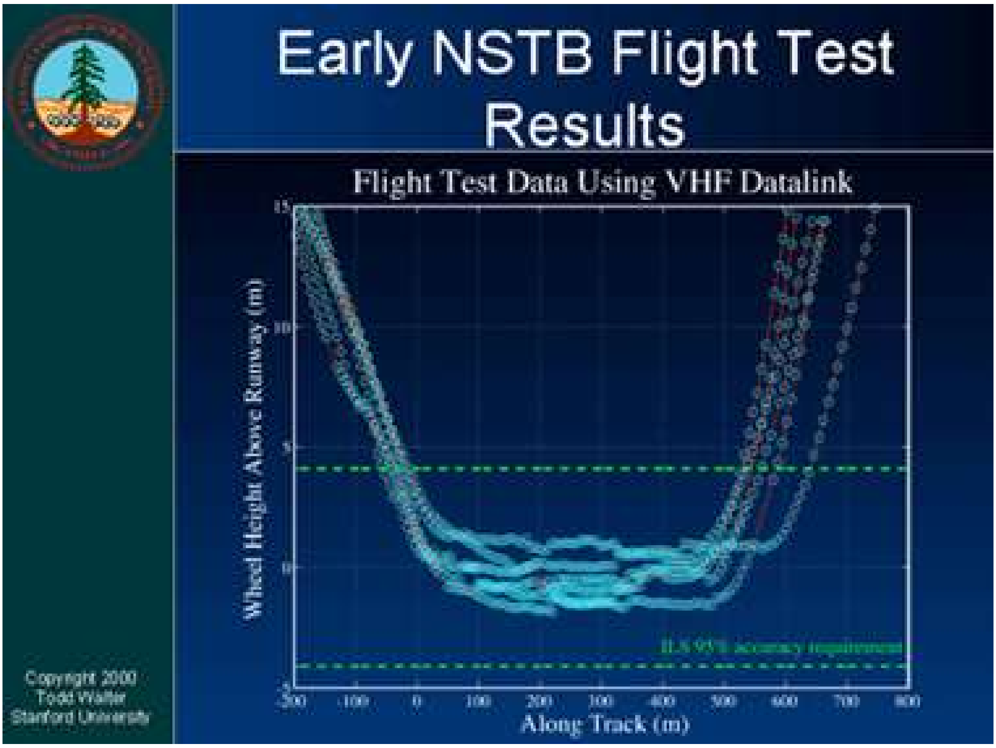
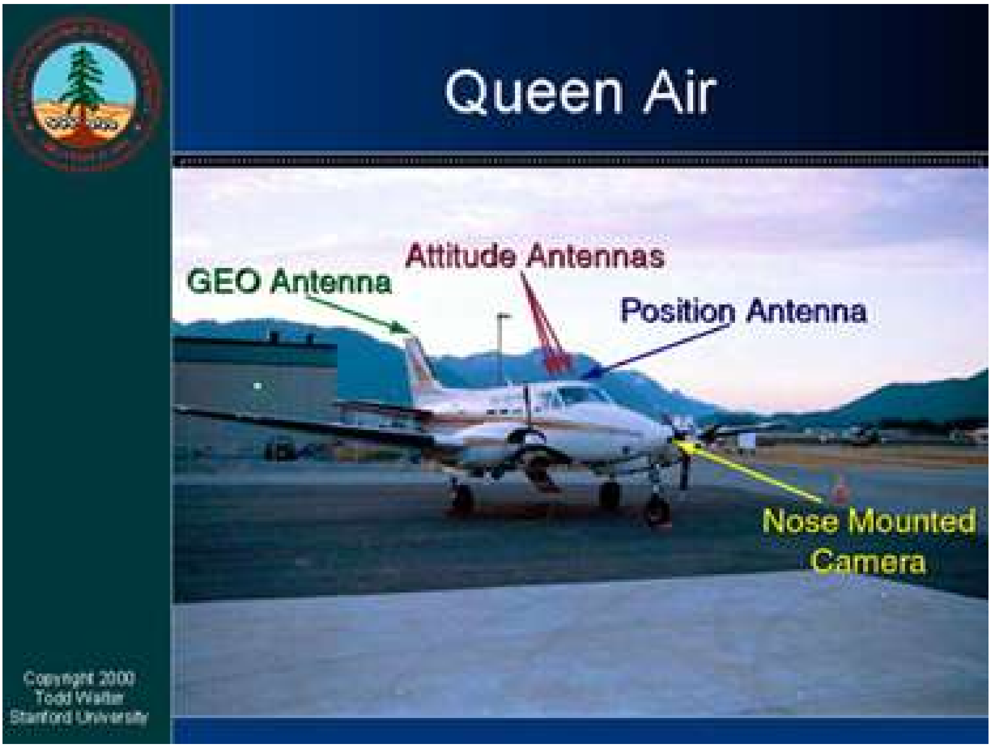
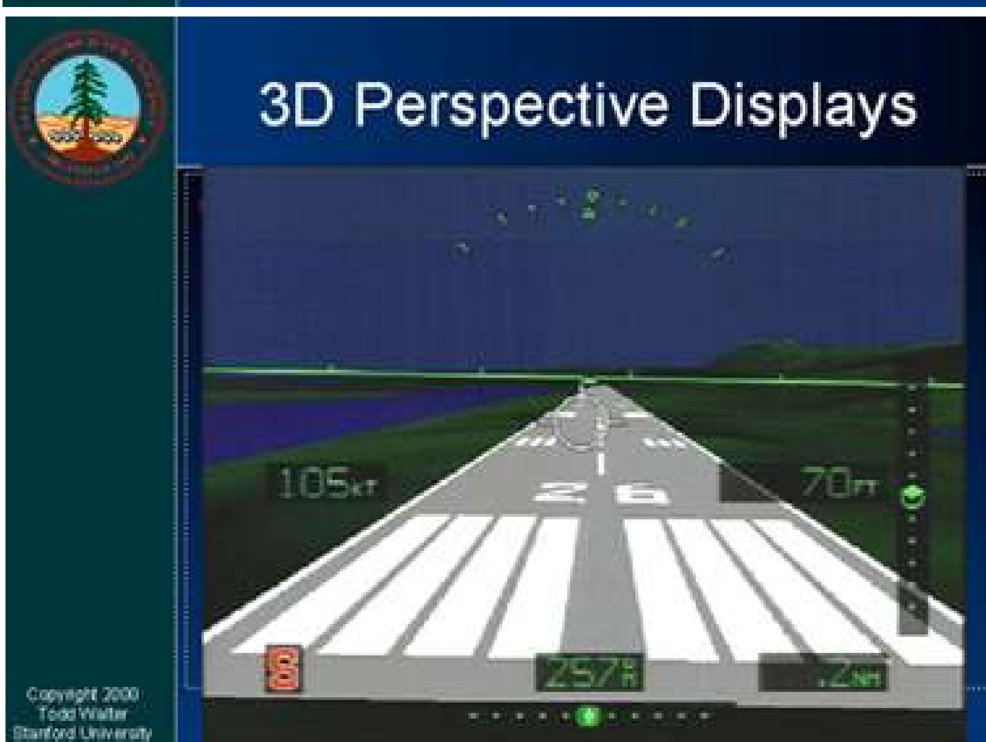

Early NSTB Flight Tests
GPS Signals
Geostationary Broadcast with 250 bps Corrections
Local Area Reference Truth
Local Radio Broadcast with 250 bps Corrections
Copyright 2000
Todd Walter
Stanford University

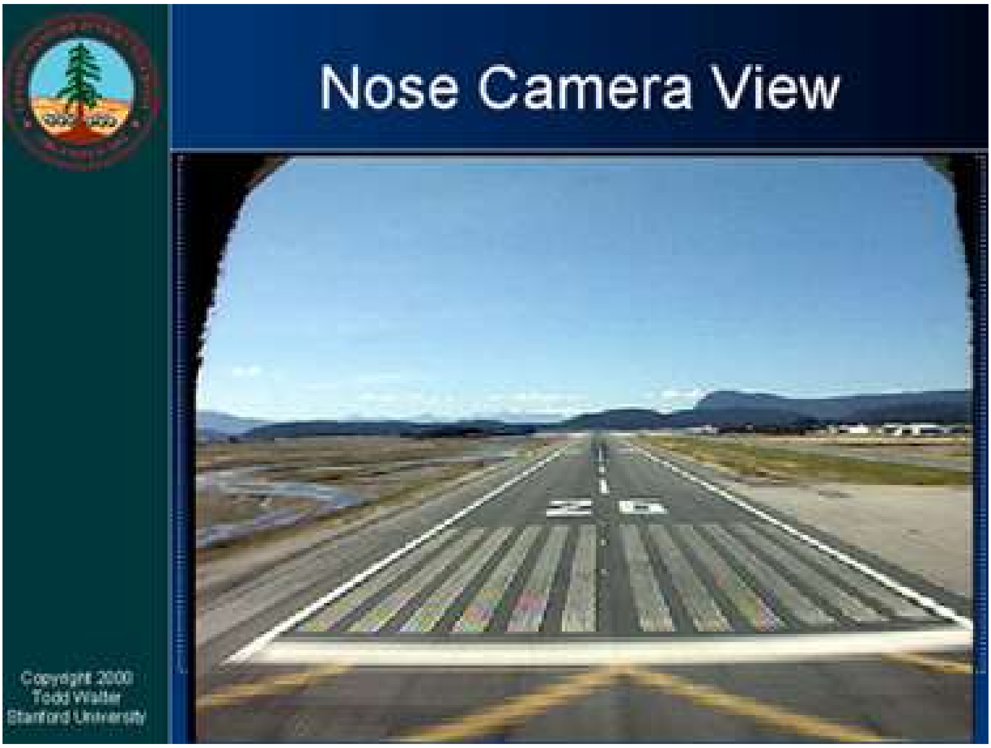

Early NSTB Flight Test Results
Flight Test Data Using VHF Datalink
Wheel Height Above Runway (m)
Along Track (m)
Copyright 2000
Todd Walter
Stanford University

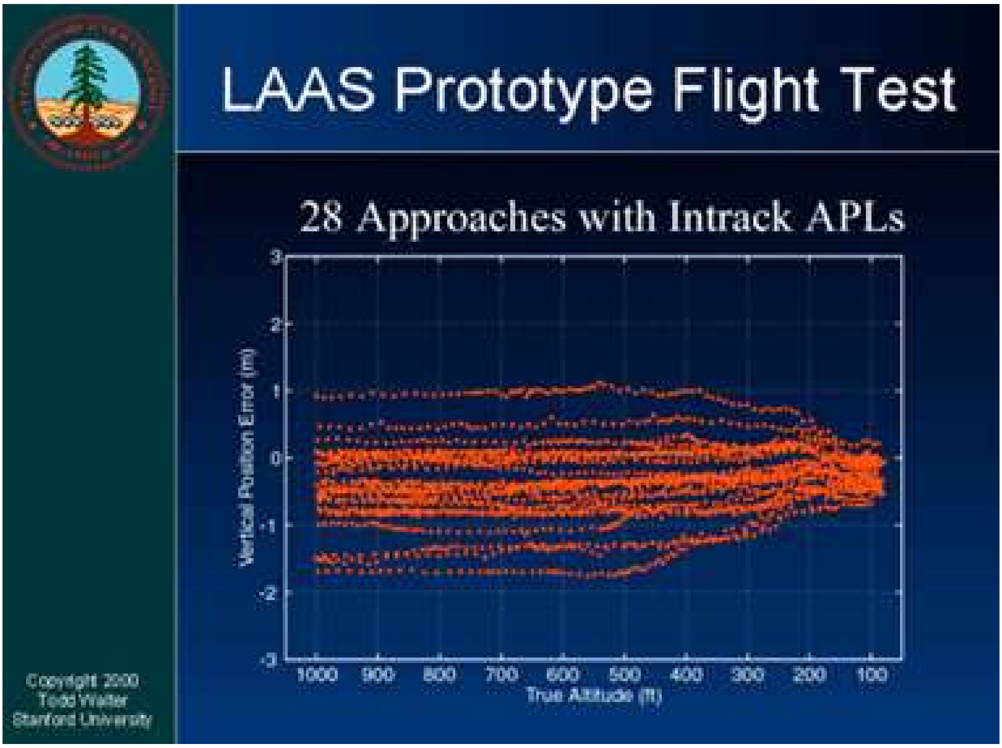

Queen Air
GEO Antenna
Attitude Antennas
Position Antenna
Nose Mounted
Camera
Copyright 2000
Todd Walter
Stanford University


Avionics
Attitude & Display Rack
Video Recorder
WAAS Receiver
Radio Modem
WAAS Rack
Reference INS
Copyright 2000
Todd Walter
Stanford University


Juneau Airport
Copyright 2000
Todd Walter
Stanford University


3D Perspective Displays
105KT
70FT
26
257
.2NM
Copyright 2000
Todd Walter
Stanford University


Nose Camera View
Copyright 2000
Todd Walter
Stanford University


LAAS Prototype Flight Test
28 Approaches with Intrack APLs
Vertical Position Error (m)
True Altitude (ft)
3
2
1
0
-1
-2
-3
1000 900 800 700 600 500 400 300 200 100
Copyright 2000
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Stanford University


Summary
Augmentation is Necessary to Meet Aviation Requirements
Both SBAS and GBAS Improve Integrity and Provide Extremely Accurate Positioning
GBAS
Higher performance in a local region
Well suited for precision approach
SBAS
Broad coverage area
Well suited for en route - precision approach
Copyright 2000
Todd Walter
Stanford University

# GNSS and Augmentation

# Basic Suitability/Limits for Aviation


## Mr. DAN HANLON

## FAA

# Program Update for 11th International Flight Inspection Symposium

## Wide Area Augmentation System

June 5, 2000
Santiago, Chile

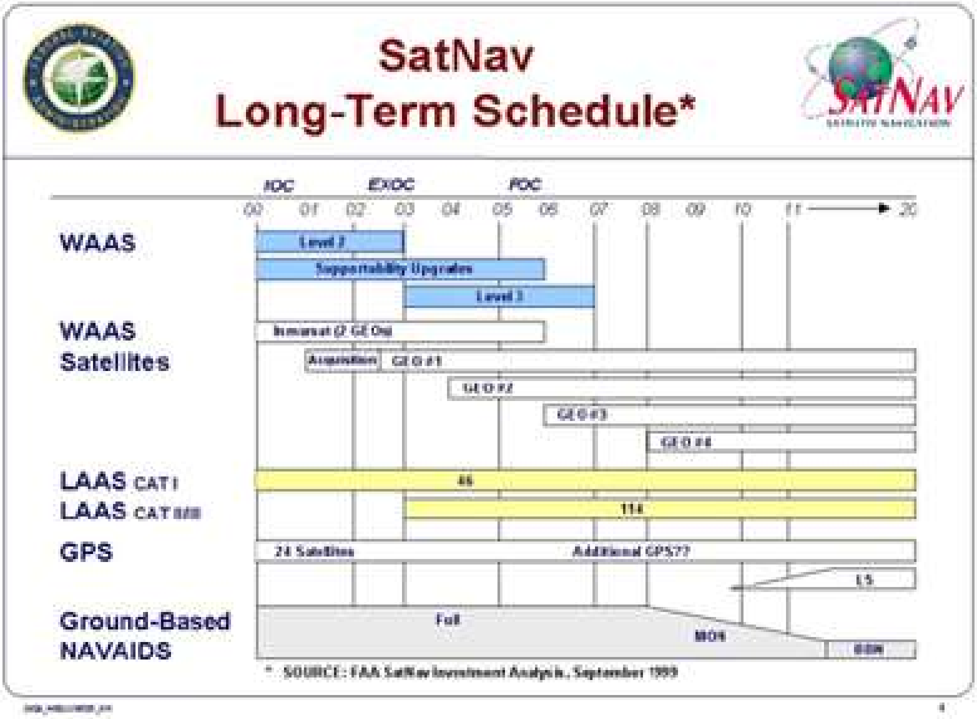
Dan Hanlon
FAA WAAS Program Manager

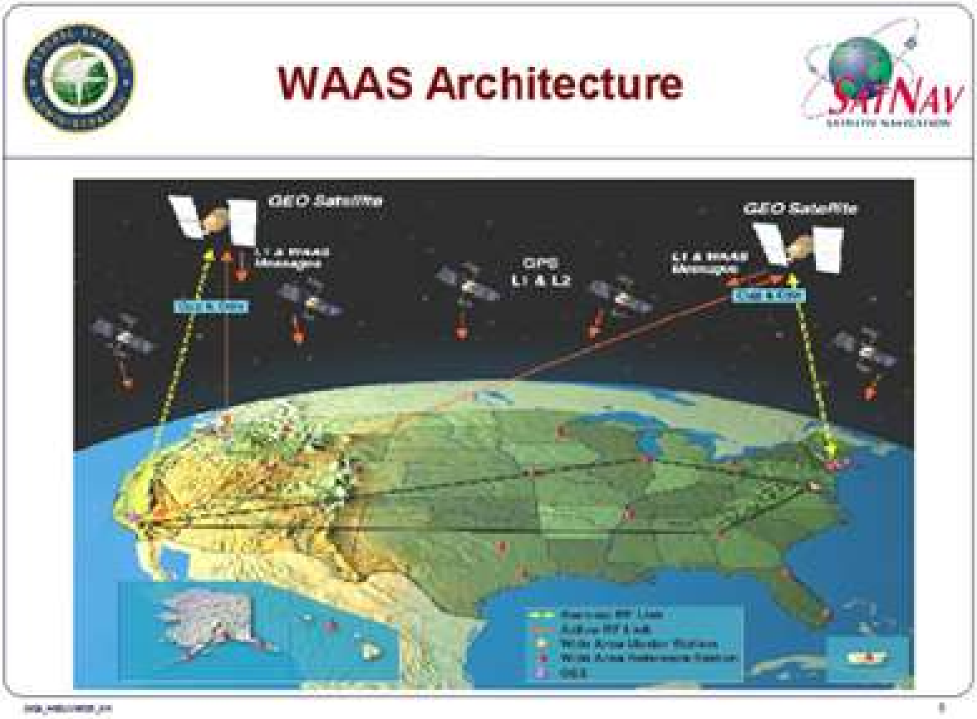


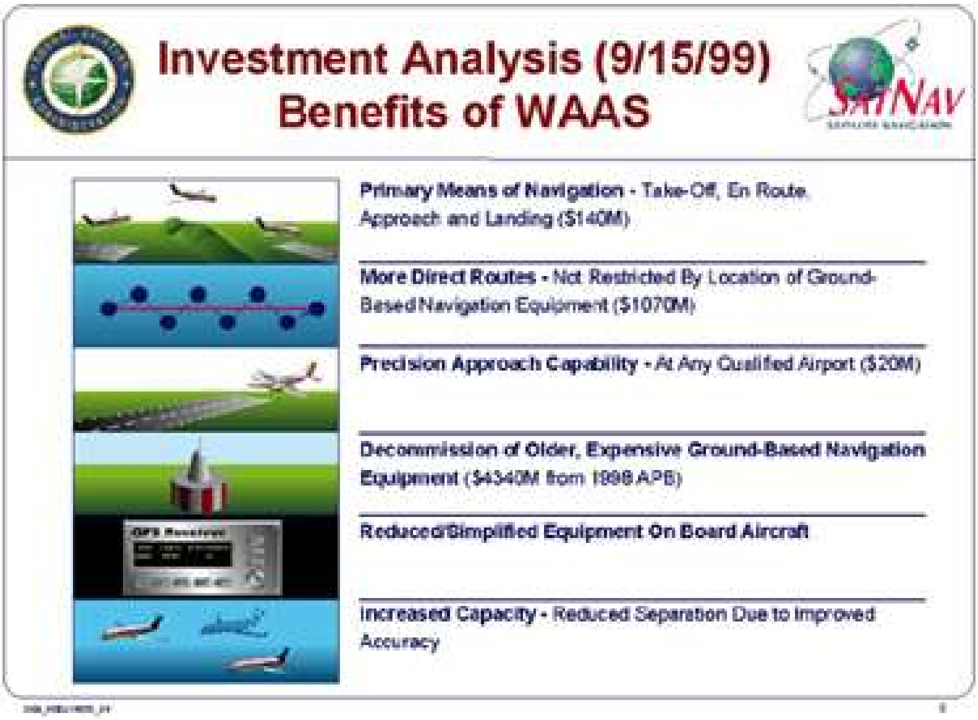
## Overview

- SatNav Mission/Schedule
- WAAS Architecture
- Program Status
- Recent Events


Satellite Navigation's Mission
WAAS/LAAS Implementation
SATNAV
WAAS
Enroute Oceanic
Enroute Domestic
Terminal
Approach
Surface
LAAS
3


SatNav
Long-Term Schedule*
SATNAV
IOC
EXOC
FOC
00 01 02 03 04 05 06 07 08 09 10 11 20
WAAS
Level 2
Supportability Upgrades
Level 3
WAAS Satellites
Inmarsat (2 GEOs)
Acquisition
GEO #1
GEO #2
GEO #3
GEO #4
LAAS CAT I
46
LAAS CAT II/III
114
GPS
24 Satellites
Additional GPS??
L5
Ground-Based NAVAIDS
Full
MON
* SOURCE: FAA SatNav Investment Analysis, September 1999
4


WAAS Architecture
GEO Satellite
L1 & WAAS Messages
GPS
L1 & L2
GEO Satellite
L1 & WAAS Messages
Wide Area Master Station
Wide Area Reference Station


Investment Analysis (9/15/99)
Benefits of WAAS
Primary Means of Navigation - Take-Off, En Route, Approach and Landing ($140M)
More Direct Routes - Not Restricted By Location of Ground-Based Navigation Equipment ($1070M)
Precision Approach Capability - At Any Qualified Airport ($20M)
Decommission of Older, Expensive Ground-Based Navigation Equipment ($4340M from 1998 APB)
Reduced/Simplified Equipment On Board Aircraft
Increased Capacity - Reduced Separation Due to Improved Accuracy
GPS Receiver

# Phase 1 Accomplishments

Jan 97 INMARSAT Lease Signed

Jun 98 Hardware & Communications Installed and Tested

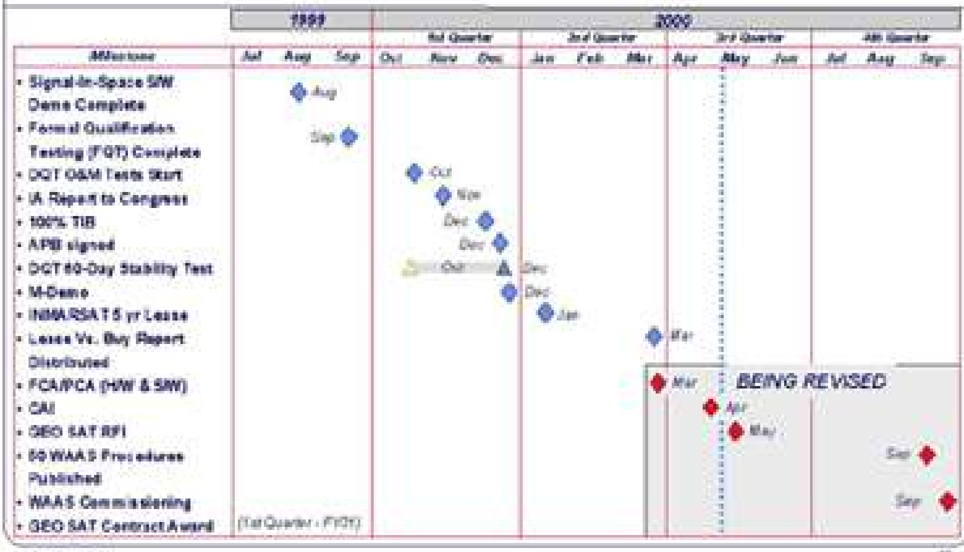
- 25 WAAS Reference Stations (WRS)
- 2 WAAS Master Stations (WMS)
- 2 INMARSAT Satellites
- Terrestrial Communications Network

# Wide Area Augmentation System
## Phase 1 Locations

## Phase 1 Accomplishments

| | |
|---|---|
| Aug 99 | Completed 3 Signal-in-Space Demos<br>- Stable Signal/Better Accuracy |
| Sep 99 | Completed Formal Qualification Testing |
| Nov 99 | Completed 7 of 8 Formal System Tests |
| Dec 99 | GEO Satellite Lease Vs Buy Study Complete<br>- Confirms Lease Best Option |
| Dec 99 | Completed Maintainability Demonstration |
| Jan 00 | Exercised Additional 5-Year INMARSAT Lease<br>- $1.5 M Cost Savings FY00<br>- $2.2 M Cost Savings Over Life of Lease |

## WAAS Near-Term Milestone Schedule



## Recent Developments

- Progress Has Been Made in the Development of WAAS
  - System Integration Has Been Accomplished
  - Accuracy/GPS Differential Correction Performance
    - Accuracy Required: 7.6 Meters
    - Accuracy Demonstrated: 2-3 Meters
- Two Issues Have Been Identified
  - Stability
    - Activities to Resolve Expected to Be Completed by September 00
  - Integrity
    - Near-term Options Have Been Identified, Long-term Under Development
- Issues Preclude CY00 Commissioning of Any Level of Service



## WAAS Stability Issue

- Commenced 60-day Stability Test on Dec 13, 1999
  - Accuracy Required: 7.6 Meters
  - Accuracy Demonstrated: 2-3 Meters
- Test Halted After 30 Days Due To 100 Minute Signal Loss
  - Problems with Backup Geostationary Uplink Station (GUS) Transition Function
  - Software Problem in C&V Processor
  - Excessive Alarms
- Raytheon Working Corrections
  - 21-Day Stability Test to Begin June 20, 2000

## WAAS System Integrity Issue

- Meeting FAA Safety Integrity Requirement is Most Significant Schedule Driver
  - No Greater Than One in 10 Million Chance of Failure for a Given Approach (Hazardously Misleading Information - HMI)
- Problem Identified Meeting This Requirement
  - Analysis Indicates Integrity Monitors Do Not Work Correctly
  - HMI Event in Dec 99 - Monitor Did Not Detect



## WAAS System Integrity Issue (cont.)

- WAAS Integrity Performance Panel (WIPP)
  - FAA Established Team of Experts in January 2000 to Work Closely With Raytheon to Identify Most Cost-Effective and Expedient Solution
  - Team Includes FAA, MITRE, Stanford University, Ohio University, JPL
  - Will Provide Technical Strategy for the Foreseeable Future
- Recent WIPP Activities
  - Identified Solution for Enroute and Non-Precision Integrity
  - Identify a Path to Achieve LNAV/VNAV Integrity
- WAAS Phase 1 IOC (LNAV/VNAV) Projected in CY2002
- WIPP Will Identify Solution and Migration Path to GLS Within 9 Months
  - Results Used to Refine Detailed Cost and Schedule for Future Program

## RNAV Procedures

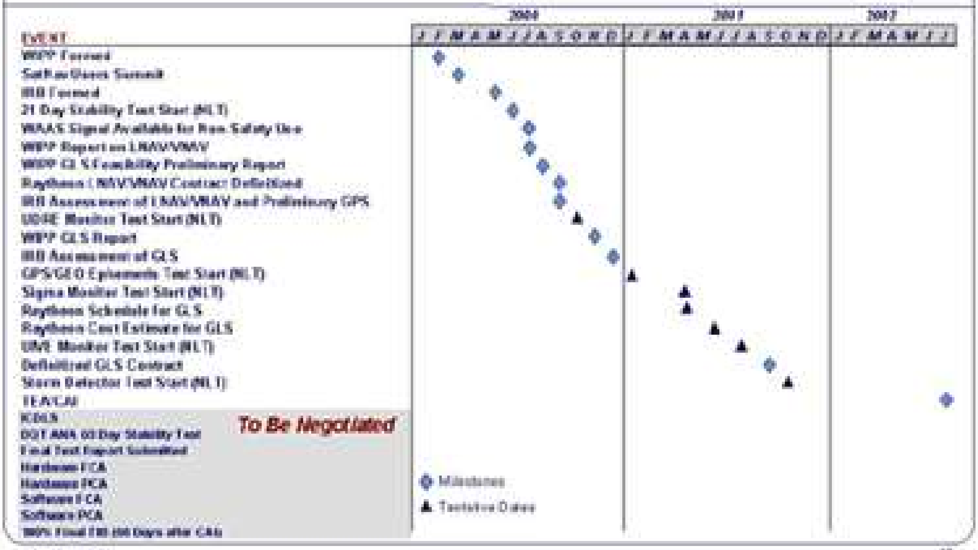
| | |
|---|---|
| LNAV | Non-Precision Approach With 250ft ROC, Smaller Protected Area Than VOR, No Vertical Guidance |
| LNAV/VNAV | Vertically Guided Approach With Decreasing Vertical Obstruction Clearance, HAT 350 and Up |
| GLS | ILS Look-Alike With Decreasing Vertical Obstruction Clearance and Smallest Lateral Protection |
| (with PA Designator) | HAT 200 and Up, with Precision Airport Infrastructure Requirements Met |
| (without PA Designator) | ILS Look-Alike, Except with Higher DA Due to Limited Airport Infrastructure |

## Levels of Service

- Goal of WAAS Is to Provide Precision Approach Capability at All Runway Ends in the Service Volume
  - CONUS
  - Portions of Alaska
  - Hawaii
  - Portions of Caribbean
- WAAS Will Provide 3 Levels of Approach Service
  - Non-Precision
  - LNAV/VNAV
  - GLS

*ILS-Equivalent Precision Approach Can Be Achieved With WAAS*

# WAAS Interim Schedule

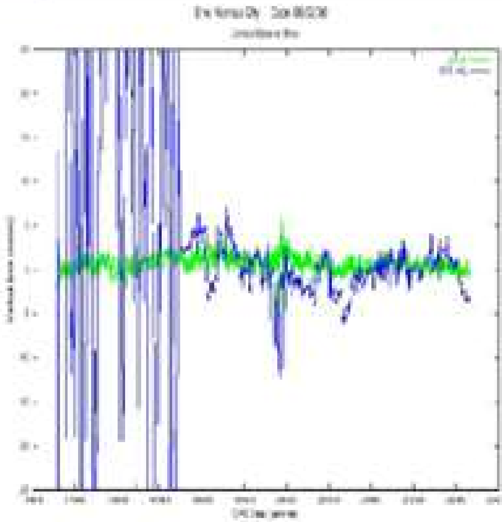



# Recent Events

- SatNav Summit Meeting (March 15, 2000)
  - Attendees Included US Domestic Users, Satellite Navigation Users Group (SNUG), FAA, DOT, DoD, etc.
  - LNAV/VNAV Capability Agreed
  - IOC in Calendar Year 2002
- Selective Availability (SA) Set to Zero (May 1, 2000)
  - Civil Users will Realize Immediate Improvement in GPS Accuracy
  - GPS Still Requires Integrity Augmentation
  - No Change to WAAS or LAAS Architecture Planned

# WAAS and SA

- Primary Mission of WAAS Is to Provide Accuracy and Integrity
- Removal of SA Improves Accuracy, Does Not Affect Integrity
- Even Without SA, GPS Alone Does Not Meet GLS Requirements





# FAA GPS Product Team Website

- For further information on the FAA's Satellite Navigation Program, please visit our website at:

## http://gps.faa.gov

# WGS-84 and its application to GNSS

**Mr. MICHAEL MORGAN**

**NIMA**

# Why WGS 84?

**Building GPS approaches**

**From a Geodesy and Surveying perspective**

## Overview

- **Geodesy**
  - Definition
  - History
  - Why is it important?
- **GPS** (GNSS)
  - Basic concepts
- **Surveying the airfield**
  - What and how?
  - Accuracy

# Geodesy

- **Describing the earth**
  - Shape of earth (big potato)
  - Spheroid or ellipsoid
    - Latitude and longitude
  - **Geoid**
    - Gravity field
    - MSL
  - **Visual presentation** (maps and charts)
    - Projections

# Ellipsoids

- Mathematical model of the earth's shape
- Improved accuracy over time
- Great variety
- Mathematically described by
  - Semi major axis (a)
  - Semi minor axis (b)
  - Flattening (f), f=(a-b)/a
  - Eccentricity (e), e^2 = f * (2-f)

# Geodesy

- **History**
  - Many Ellipsoids
    - Scientific and political reasons
  - Much disagreement
    - Scientific and political reasons
  - GPS navigation requires agreement
    - Common Ellipsoid and height reference (horizontal and vertical Datum)

# Only 1 Datum

- Current system
  - Relative references
  - At the airport
    - NAVAIDS, runway, and planes are linked
    - No need for global reference
  - Enroute problems / increased spacing
- GPS (GNSS)
  - All references to the satellites
- ICAO, FAA, & US DoD agree

## Datums

- A Datum is a combination of Ellipsoid with an orientation
- A Datum is valid for the area it is designed for
- One Ellipsoid can be used for several Datums
- With our present ability of looking at the world as a whole, not only local but also global Datums are in use: e.g. WGS-84

## WGS 84

- ECEF (global) Datum
  - The Ellipsoid definition
    - Vlbi-quasars-satellite laser ranging
    - Fixed ground stations
    - Precise satellite orbits (Ephemerides)
    - Cartesian system x, y, z, rotational values and scale
  - The Geoid definition
    - + 50 million land gravity stations
    - Satellite Altimetry, underwater, shipborne, SRTM
    - Orthometric height ±0.5m / ±1.0m, 1s

# Co-ordinates

- Geodetic latitude / longitude / height and astronomic latitude / longitude
- Cartesian (ECEF) X, Y and Z
- Projection X and Y or Easting and Northing

# Geodetic Co-ordinates

- Latitude = angle from Equator plane. Equator plane defined by orientation of Ellipsoid
- Longitude = angle from Greenwich
- Height = perpendicular height above Ellipsoid

## Cartesian Co-ordinates

- Simple X-Y-Z model makes easy computations
- X-Y-Z axis coincide with main axis of Ellipsoid (Datum)
- Each geodetic co-ordinate has Cartesian ECEF equivalent

## Summary: Datums and Co-ordinates

- A Datum consists of an Ellipsoid with an orientation and origin
- On a Datum both Geodetic and Cartesian co-ordinates can be used
- On top of a Datum, a Projection can be defined to convert 3D co-ordinates to 2D co-ordinates

# Datum Transformations

**•To change from Datum A to Datum B:**

❶ Origin of Ellipsoid A needs to be shifted to position origin of Ellipsoid B

❷ Ellipsoid A needs to be rotated such that the main axis of Ellipsoid A coincide with Ellipsoid B

❸ Ellipsoid A needs to be scaled to make it same size as Ellipsoid B

# Datum Transformations

- Co-ordinates in Datum A can be transformed to Datum B using transformation parameters:
  - **Delta x(m) rotation X(")**
  - **Delta y(m) rotation Y(")**
  - **Delta z(m) rotation Z(")**
  - **Scalefactor (ppm)**
- Often only delta X-Y-Z are used
- Datum transformations should only be used with great care

# Geoid

- Difference between Geoid (MSL) and Ellipsoid is called Undulation (N) and is maximally 100 meters
- Global and local Geoid Undulation models available
- When doing leveling the traditional way, one observes on the Geoid
- $H_{MSL} = h_{ellipsoid} - N$

**Summary**: Datum Transformations and Geoid

- Transfomations between two Datums are performed by applying a 3D datum shift, a 3D rotation and a scale factor
- Geoid is an earth model describing the Gravity Potential and equals Mean Sea Level

# Projection Co-ordinates

- 3D co-ordinate is projected on 2D surface (projection)
- Conversion 3D > 2D means loss of information
- 2D projection required for cartography and traditional surveying
- $E = f(\varphi_g, \lambda_g, H_G$, model parameters)
- $N = f(\varphi_g, \lambda_g, H_G$, model parameters)

Universal Transverse Mercator Projection

- 60 zones over whole earth
- Conform cylinder projection
- Zones of 6 degrees longitude
- Eastings and Northings
- Defined on various different Datums
- Attempt to make them all world wide equal on WGS-84 Datum

## GPS

- **Earth segment**
  - Monitor and control
- **Space segment**
  - 24 SV's
    - Broadcasting position and time information on 2 frequencies
- **User**
  - Ranging system based on wave length count & Ephemerides

## GPS (Continued)

- **User positioning** (continued)
  - Point positioning (absolute)
    - Precise Ephemerides
    - Relative (differential) positioning
    - Post processing
    - Real time Kinematic (RTK)

# Alternatives

- Status quo
- GNSS (Glonass and GPS)
- New systems

# Surveying

- PACS and SACS
- Features
- Navaids
- Obstacles
- Photo control

# PACS and SACS

- **Why?**
- **How?**
  - WGS 84
  - Monuments
  - Visibility
  - Horizon
  - Interference / multi-path

# Runway Features

- **Why?**
- **What?**
  - Ends
  - Vertical profile
  - Corners
- **How?**

# Navaids

- **Why?**
  - Transition
- **What?**
  - Electronic devices
- **How?**

# Obstacles

- **Why?**
- **What?**
  - Obstacle ID surfaces
- **How?**
  - Surveys vs. Imagery
  - Economy vs. Utility

# Photo Control

- Sharply defined corners
- Bigger is better
- High contrast
- Ideal distribution

# GNSS - Real and Proposed Systems

## GNSS - GPS and NAS Implementation


Mr. JIMMY R. SNOW

FAA AVN GPS Program

Department of Transportation
Federal Aviation Administration

# NAS GNSS IMPLEMENTATION

Jimmy R. Snow
AVN GPS Program Manager
June 5, 2000

## OVERVIEW

- GPS Procedures Status
- WAAS Phase I Activities
- WAAS Problem Areas
- RNAV Procedures
- NAS Major Activities
- LAAS Status
- Aeronautical Database Development
- ICAO GNSS Guidance

## U.S. COMMITMENT TO GPS

- **U.S. has Pledged to Provide GPS Signals to the International Community Free of Direct User Charges**
  - Reaffirmed in March 1996 Presidential Directive
  - Signed into Law by an Act of Congress in 1997
- **FAA is Firmly Committed to the Use of Satellite Navigation**
  - As a "Sole Means" of Navigation Within the NAS
  - As the "Cornerstone" of a Modernized U.S. NAS
    - Pace and extent of SatNav transition will depend on many factors, all centering on system performance and *user acceptance*
- **FAA is Firmly Committed to Assist ICAO in the Development of a Seamless Global Navigation Satellite System (GNSS)**

## GPS TSO-C129

- **Feb 1995 FAA Declared GPS Operational**
- **Approved IFR Operations: (AC9094)**
  - **Oceanic En Route/NAS En Route**
  - **Overlay/Stand Alone Approaches**
- **AVN Asked to Develop and Flight Inspect 500 GPS Approaches Annually**

# STATUS OF GPS PROCEDURES
## (5/01/00)

| | FY 97 | 98 | 99 | 00 |
|---|---|---|---|---|
| GPS Proc Developed | 500 | 531 | 581 | 267 |
| GPS Proc Flt Inspected | 540 | 528 | 585 | 228 |
| GPS Proc Published | 573 | 516 | 531 | 304 |

**TOTAL**

| | |
|---|---|
| GPS Proc Developed | 2,792 |
| GPS New Capability | 1,036 |
| GPS Proc Flt Inspected | 2,542 |
| GPS Proc Published | 2,319 |

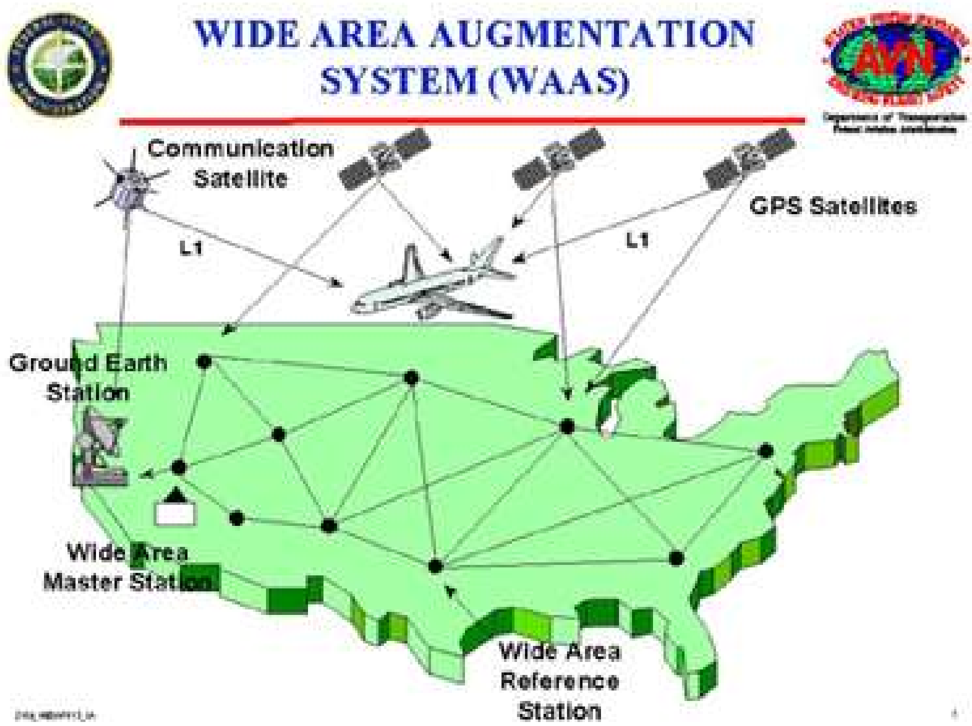
# NAS Implementation Major Activities

### Receiver Development
- Minimum Operational Performance Standards (MOPS)
- Technical Standard Order (TSO)
- 17 Prototype WAAS Receivers

### Flight Standards & Procedures
- Satellite Operational Implementation Team (SOIT)
- Terminal Procedures (TERPS) Criteria
- Airport Surveys
- Airport Standards
- Instrument Approach Procedures
- Flight Inspection

### Air Traffic Airway Facilities
- Ops Concept
- Direct Routing
- Air Traffic Satellite Operational Implementation Team (ATSOIT)
- Regional System Enhancements
- Notices to Airmen (NOTAMS)
- GPS Database

### Operational Integration
- GPS Interference Mitigation
- Second and Third Civil Frequencies
- DoD/DOT Coordination
- Performance Monitoring


WIDE AREA AUGMENTATION SYSTEM (WAAS)
Communication Satellite
GPS Satellites
L1
L1
Ground Earth Station
Wide Area Master Station
Wide Area Reference Station

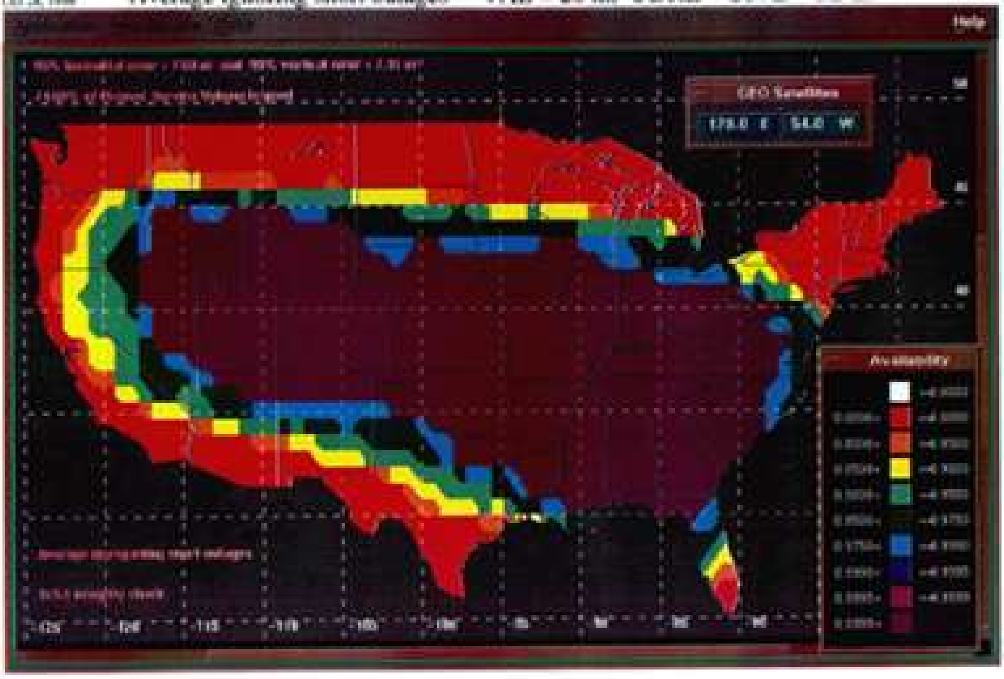

WIDE AREA AUGMENTATION SYSTEM
Phase 1 Locations
Communication Satellite
GPS Satellite
Key

# WAAS PHASE 1 ACCOMPLISHMENTS

- **Nationwide Network of Diverse Components Has Been Successfully Integrated**
  - Data Collection Processing (25 Ground Stations)
  - Master Stations (2 Ground Stations)
  - GEO Uplink Stations (4 Ground Stations)
  - GEOs (2 Satellites)
  - Nationwide Telecommunications System

- **Three Major System Builds Confirmed Validity of WAAS Design (April-August 1999)**
  - System Stability
  - Full System Functionality
  - System Performance

Average ignoring short outages VAL = 20 m, UDRE = UIVE = 1.5 m



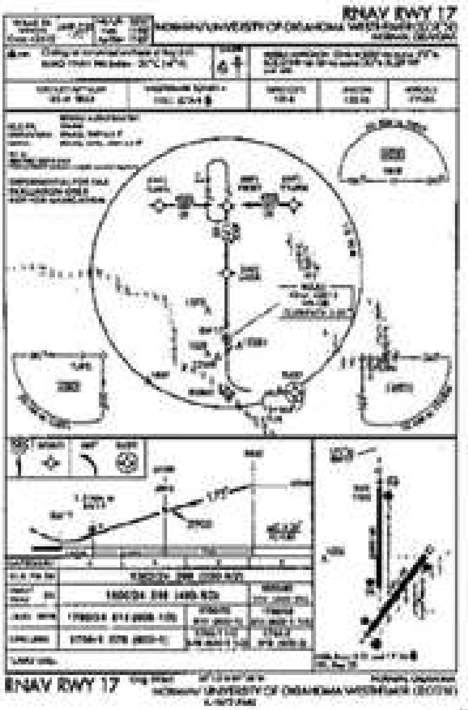
## WAAS PROBLEM AREAS

- Two Problems Have Been Identified
  - Stability
  - Integrity

- Problems Preclude FAA Commissioning of Any Level of Service in FY00

## WAAS SYSTEM INTEGRITY

- Problem Identified Meeting This Requirement
  - Analysis Indicates Integrity Monitors Do Not Work Correctly
  - HMI Event in Dec 99 - Monitor Did Not Detect
- Meeting FAA Safety Integrity Requirement is Most Significant Schedule Driver
  - No Greater Than One in 10 Million Chance of Failure for a Given Approach (Hazardously Misleading Information - HMI)
- WAAS Phase 1 IOC Projected in CY2002




| CATEGORY | A | B | C | D |
|---|---|---|---|---|
| GLS PA DA | 1383/24 200 (200-1/2) | | | |
| LNAV/VNAV DA | 1500/24 318 (400-1/2) | | | 1500/40 318 (400-3/4) |
| LNAV MDA | 1700/24 518 (600-1/2) | | 1700/50 518 (600-1) | 1700/60 518 (600-1 1/4) |
| CIRCLING | 1760-1 578 (600-1) | | 1760-1 1/2 578 (600-1 1/2) | 1760-2 578 (600-2) |

# RNAV PROCEDURES

| | |
|---|---|
| **LNAV** | **Non-Precision Approach With 250ft ROC, Smaller TERPS Protected Area Than VOR, No Vertical Guidance** |
| **LNAV/VNAV** | **Vertically Guided Approach With Precision like Vertical Obstruction Clearance, HAT 350 and Up** |
| **GLS PA** | **ILS Look-Alike With Decreasing Vertical Obstruction Clearance and Smallest Lateral Protection** |
| **(with PA Designator)** | **HAT 200 and Up, with Precision Airport Infrastructure Requirements Met** |
| **(without PA Designator)** | **ILS Look-Alike, Except with Higher DH Due to Limited Airport Infrastructure** |

## PROCEDURE PUBLICATION STRATEGY

- Develop RNAV Procedures with LNAV/VNAV, LNAV, & Circling Minima
  - First 6 Published on Feb 24
- Flight Inspect WAAS LNAV/VNAV when Available
- Add Vertical Angle to All Approaches

## AIRPORT STANDARDS

- Old Definition of "Precision" and "Non-Precision" Not Adequate for Satellite Navigation Technology
- New LNAV/VNAV Airport Standards More Flexible Than Old ILS "Precision" Requirements, Due to Varying DH Based on Airport Infrastructure
- FAA Advisory Circular 150/5300-13 Appendix 16, Change 6 Addresses Requirements in Terms of Desired Decision Height and Visibility

## AIRPORT STANDARDS
### (continued)

- 1100 ILS "PA" Runways in NAS
- 3000 "NPA" Runways in NAS
  - Without Improvement, Limited to LNAV/VNAV and GLS (without PA designator) ~350' & 1 Mile
  - Lower Minima Will Require Airport Improvements Via AIP Program

## AIRPORT SURVEYS

- Airport Survey Production is Divided into the Following Phases:
  - Phase I
    - Establish Primary and Secondary Airport Control Stations (PACS & SACS)
    - Referenced to WGS-84
  - Phase II
    - Survey Runway Points, NAVAIDS, and Elevations
  - Phase III
    - Survey Obstructions out to 50,000 ft
    - Required for Approach Procedure Development

# OPERATIONAL INTEGRATION

- **Interference Mitigation**
  - SOIT Interference Working Group
  - 5 Commercial Vendors have Presented Mitigation Concepts / Products to FAA
  - Threat Assessment Underway Through IGEB

- **Operational Activities**
  - GPS Interference Mitigation Efforts Managed by FAA Spectrum Office (ASR)
  - Three-year Interference Resolution Plan
  - Airborne RFI DF, Vans, Portable DF, Handheld Locators

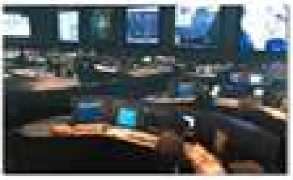
# FLIGHT STANDARDS SUPPORT TERPS

- **WAAS TERPS Criteria Complete**
  - FAA Order 8260.48 (RNAV)
    - GLS
    - LNAV/VNAV
    - LNAV

- **Final Criteria Still Requires Raytheon Signal-in-Space Validation**
- **New Airport Standards Support SatNav TERPS**

## Instrument Flight Procedures Development

- Aviation System Standards (AVN)
  - Develop and Flight Inspect 500 GPS Procedures Annually
  - Equip Lears with Prototype WAAS Receivers
  - Instrument Approach Procedure Automation (IAPA)
  - Develop Flight Inspection Criteria and Software



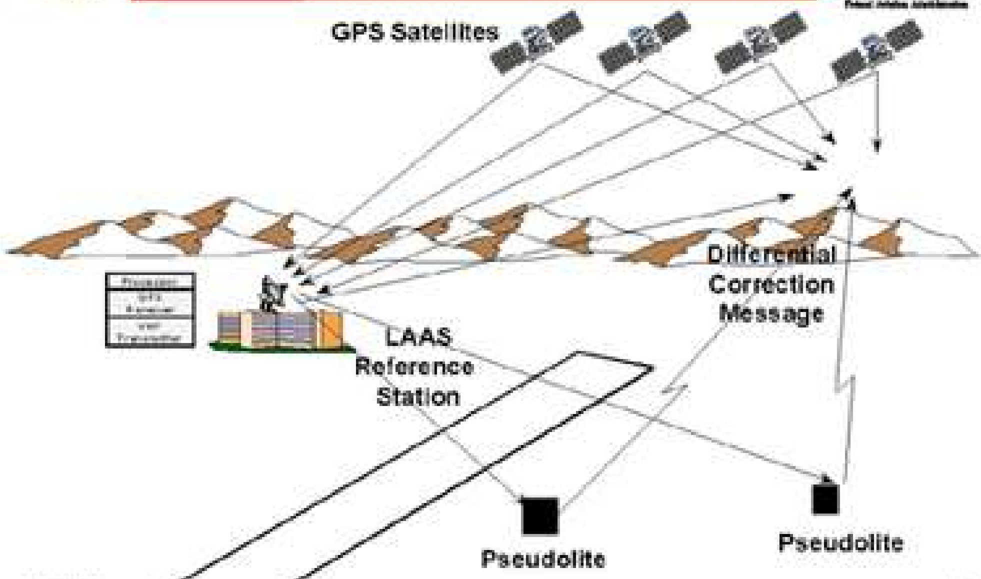
## Receiver Development

- Prototype WAAS Receivers
  - Managed by U.S. Navy with Rockwell Collins
  - Minimum Operational Performance Standards Compliant
  - 17 Receivers for Initial WAAS Validation, Flight Tests, and Flight Inspection
  - Limited to VFR Weather Conditions
  - Will be Replaced When TSOed Receivers are Available

# Flight Standards Support

- **Design Operational Guidance Material**
  - Aviation System Performance Restriction
  - Operational Approvals for Pilots
  - Guidance and Training Documentation for Pilots
  - Safety Inspector Training
  - Aeronautical Information Manual (AIM)
  - Satellite Operational Implementation Team (SOIT)

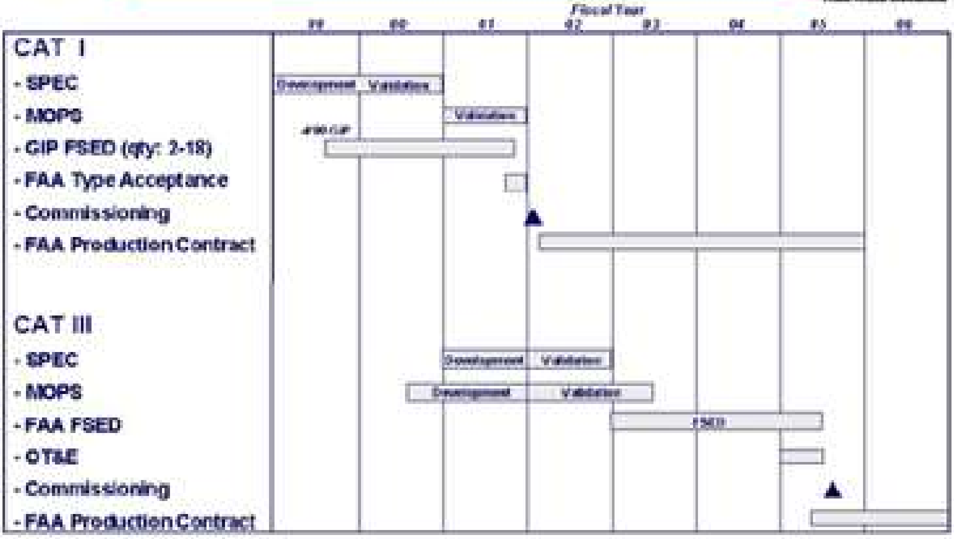
# LOCAL AREA AUGMENTATION SYSTEM (LAAS)



# LAAS STATUS

- Two Government-Industry Partnerships (GIP) Formed for LAAS CAT I Development- April '99
- LAAS Spec (CAT I) Completed and Approved- September '99
- CAT II/III R&D Efforts
  - Delivery of Pseudolite Antenna
  - Wide Body Flight Testing- Fall '99
- RTCA DO-253, LAAS MOPS Approved, February '00

# LAAS Program Schedule



## AERONAUTICAL DATABASE DEVELOPMENT

- Purpose
  - Develop and Maintain a Low Cost Government Developed/Maintained, Aeronautical Database for Use in GPS and RNAV Operations
- Joint NOAA/FAA Initiative
- Feasibility Study Completed, March '99
- NOAA Developed ARINC 424-Compliant Structure
  - Currently Developing Software for Population of En-route Data
- Funding Required for IAP Population/Distribution

## DATABASE STUDY

- Current Receiver Database Expensive
  - (User Group Interest)
- AVN Accepted Lead to Develop Study
  - Support from AND NFDC AIR NOS
  - Feasibility of Providing Low-Cost Receiver Data
  - Study Completed March 3, 1999

# DATABASE STUDY CONCLUSIONS

- Government Produced Database is Feasible
  - NIMA Willing to Provide DAFIF (Digital Aeronautical Flight Information File)
  - Standard Coding Format Required
  - AVN/NFDC/NOAA Continue Current Responsibilities (Different Product)
  - Product Would be Generic & Require Manipulation for Specific Receivers

# ICAO GUIDANCE

- PANS-OPS, Doc 8168, Vol II, Construction of Visual and Instrument Flight Procedures, 4th Edition 1993
- Doc 8071, Vol I & II, Manual on Testing of Radio Navigation Aids, 3rd Edition 1972
- Annex 10, Aeronautical Telecommunications, Vol I (Radio Navigation Aids) 5th Edition 1996, GBAS & SBAS SARPS Completed With Approval Expected Nov 2000

# FAA GPS PRODUCT TEAM WEBSITE

- For further information on the FAA's Satellite Navigation Program, please visit our website at:

**http://gps.faa.gov**

# GNSS - Real and Proposed Systems

## GNSS - Galileo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# THE DEFINITION PHASE OF THE GALILEO GLOBAL NAVIGATION SATELLITE SYSTEM

March 23rd, 2000

## ABSTRACT

**The Definition Phase of the Galileo Global Navigation Satellite System**

In June 1999, the Council of the Transport Ministers of the European Union decided to enter into the Definition Phase for a European Global Navigation Satellite System "Galileo".

Galileo, as a joint programme of the European Commission and ESA, will be composed of a global constellation of MEO (Medium Earth Orbit) satellites complemented with regional (i.e. geostationary satellites) and local segments. Two types of signals will be made available to the Galileo users: Open Access Service (OAS) signals and Controlled Access Service (CAS) signals each of them with their own specific requirements and characteristics. Galileo will be designed to be fully interoperable with GPS and integrates elements from the Space-based Augmentation System EGNOS.

This paper presents the status of the current activities in the definition phase and addresses the perceived user requirements and anticipated system architecture.

## INTRODUCTION

GPS NAVSTAR declared full operational capability on July 17th, 1995; GLONASS declared full operational capability on February 5th, 1996 but has since fallen back behind this capability.
Both of these systems are Global Navigation Satellite Systems (GNSS) owned by sovereign states and operated by their military forces. Confirmations are given that a part of their signals remain available for civil use for the foreseeable future.
On January 10th, 1999, the European Commission issued a Communication inviting the European Union states to consider the development of a civil-controlled GNSS under the name of "Galileo". Since then, a Definition Phase was launched to determine the financial and technical feasibility of such a development and to prepare the required political decisions. This paper details the background of the development and described the current status of the activities in the Definition Phase.

## OBJECTIVES

The existing GPS and GLONASS Navigation Systems deliver a word-wide homogeneous navigation capability which was previously unavailable to many users. Which benefits can be expected from the launch of another GNSS? The expectations can be grouped in three distinctive areas:

**User Objectives:**
User demand is directed at increased availability and integrity for the signals obtained from a satellite navigation system. Such increased performance may help to support existing applications for GNSS as well as open up new opportunities in areas so far denied to satellite navigation services. Users will also be attracted by a guarantee for an uninterrupted level of service at a high degree of performance.

**Political/Institutional Objectives:**
Civil users world-wide are striving to limit their reliance on signals from what can basically be described as military systems. The erection of a European system under civil control could serve the double purpose of (a) creating an independent satellite system in addition to the existing two constellations thus in itself reducing the dependency on any single one of them and (b) create the first system external to military control. In addition, it is desirable to create an operating entity which not only provides the navigation signals but also accepts a liability in case of their failure.

**Economical Objectives:**
From a European perspective, the markets for system infrastructure (satellites, control stations) and user equipment (receivers) have been served so far predominantly by foreign (mostly U.S.) industry. Although it is not to be disregarded that a major business can also be generated from offering value-added services building on existing hardware components (e.g. traffic guidance systems), it is also desirable for European economies to capture new markets in the design and manufacture of high-technology equipment (e.g. clocks).

## ACTIVITIES OF THE DEFINITION PHASE

The responsibility for activities of the Definition Phase is split between the European Space Agency ESA and the European Commission. The activities of the former are mainly governed through the activities in their Advanced Research in Telecommunication Systems programme, element 9 (ARTES-9). Details for this will be provided below.
The European Commission has grouped their endeavours within the research activities of the 5th Framework Programme which governs expenditures in the years 1998-2002. Several calls for tender have been issued to address various Galileo-related activities under the framework of the so-called "Dedicated Call on GNSS". Detailed work packages of this Dedicated Call will be addressed below.
Other than the activities mentioned

there, the European Commission also sponsors studies in the areas of search-and-rescue applications, market analysis (Questionnaire addressing 1000 market actors) and possible LORAN-C upgrades.

**User Requirements**

The user requirements as perceived by the European Commission and its selected contractors' analysis of this subject are manifold:

Improved performance, especially in the domains of integrity and availability

Increased robustness to interference

Guaranteed service secured by liability in case of failure

Continuity of Service even in times/near areas of crisis (as opposed to the Local Selective Denial Policy)

Increased robustness against efforts of spoofing.

A process has been started within the so-called GEMINUS programme to investigate the user needs and translate them into requirements for future Galileo services. Broad participation in discussion forums shall serve to validate the articulated user needs.

**System Architecture**

*Overall Architecture*

Based on the user requirements and service definition, this task will investigate the ensuing Galileo system requirements. Considered are trade-offs between various space constellation designs and the required redundancy level in face of the existing GPS and GLONASS systems is addressed. The main objective will be to avoid common-mode failures for GNSS which could for example arise if only identical frequencies were used for the various GNSS. The Overall Architecture task will also determine whether there is a need for signal encryption and - if so - how this encryption should be set up to respect all user requirements.

Within the Overall Architecture task a so-called "open architecture approach" is performed to establish the boundaries between Galileo and possible other systems outside GNSS that may provide additional services: LORAN, GSM and UMTS are candidates in this area.

From the beginning, non-space elements will be considered in the architecture, defining any regional and local augmentations as well as the future user equipment. Pilot projects will be defined to test critical technology elements and provide the potential users with an early view of the system's capabilities. The Overall Architecture study will also draft an operating concept for the future system, defining roles and responsibilities during the future service provision. A Cost-Benefit-Analysis is performed as a key element of a joint public/private funding of the programme.

All of these activities will support a Decision Recommendation to be provided to the Council of the EU by the end of the year 2000.

To date, two major candidate solutions for the Galileo architecture have emerged. Both have in common that a coherent approach is sought from the beginning to accommodate interoperability between the space constellation itself and the intended regional and local augmentations.

While the presence of SIS and local augmentation elements springs to the eye immediately, it is not so evident why a requirement exists for the provision of regional augmentations (or "SBAS"). In this context it is important to note that no attempt was made so far within the Galileo programme to achieve the intended accuracy, availability and integrity requirements through the erection of a space constellation alone. Although not beyond the technical capabilities of today, it is generally regarded as less complex and economically more viable to achieve this functionality and performance with the help of dedicated space and ground segments mainly tasked with providing the necessary integrity checks.

It is unclear today however, how complex such a system element should be constructed: Proposals range from dedicated elements WITHIN the Galileo structure to the creation of a truly independent "augmentation" system (an "SBAS"?).

Notwithstanding the options and under which name they appear: It comes as an accompanying justification for the development of the GPS (and GLONASS) augmentations WAAS, MSAS and EGNOS that even for a newly designed GNSS such elements seem to be the logical choice as far as a reliable, cost effective service provision is sought.

The two candidate scenarios which have attracted a wider attention for study so far are (a) a pure MEO constellation and (b) a combined MEO/GEO constellation.
As the detailed design for these implementations has not yet matured, an in-depth discussion of the relative merits of these options falls outside the scope of this document.

*Space Segment Design*
The name of this task performed by ESA hides the fact that not only the space segment itself is examined, but also all accompanying infrastructure such as operating centers, tracking stations and the layout of a communication network. A trade-off between various technical solutions is made and cost estimates are provided which will also provide input to the Cost-Benefit-Analysis performed under direction of the European Commission.

*Services*
As an outcome of the above activities, three service levels are currently foreseen for Galileo:
Open Access Service (OAS): Similar in quality to the existing GPS C/A Code but lacking this systems selective availability degradation, this service is foreseen for mass market applications not demanding any special degree of integrity. As is the case with GPS and GLONASS, this service shall be provided "free of direct user fees".

Controlled Access Service Level 1: This service is aimed at Commercial and Professional Applications which require an accurate, reliable service with a high degree of integrity. It is intended to provide CAS 1 through signal transmission over three carrier frequencies.

Controlled Access Service Level 2: This service will feature the added benefit of guaranteed availability of the service even in times and areas of crisis. CAS 2 is aimed to support so-called "safety-of-life" applications (which include the aviation sector) and "Governmental" use which covers civil duties (police, medical) as well as the military application.

*Frequencies*
Two contradicting requirements dominate the selection process for frequencies for the new satellite navigation system: "New" frequencies shall be located close enough to the existing GNSS frequencies to reduce receiver complexity. At the same time it is desirable to move the frequencies far enough apart from existing GNSS frequencies to capitalise from the independence of the signals and ensure adequate robustness. A third factor contributing to the selection process is the availability of sufficient bandwidth within the considered spectrum to permit the required service quality.

**SBAS Integration**
Three SBAS systems are being developed in the world. From the user and system perspective two complementing requirements emerge: (a) Even with the advent of a new Global Navigation Satellite System the continuity of service shall be guaranteed for the users of GNSS-1 SBAS systems. This mandates the continued provision of EGNOS functionality in Europe together with possible future upgrades to GPS-IIF standard and compatibility with ICAO-conforming WAAS and MSAS developments. (b) As shown above, Galileo will also be rely on ground integrity monitoring capability. Whether such a function shall be set up "internal" to Galileo relying on experience from EGNOS or whether this function shall also be provided "external" to the system in the sense of a true augmentation is the subject of a trade-off performed under the name of INTEG (EGNOS Integration into Galileo). As of now, three scenarios are conceivable to achieve such integration:
Integration at User Level
GPS/GLONASS/SBAS will perform independently from Galileo which has to secure adequate integrity through suitable means. Final "integration" and reasonability checking will be performed at the level of the user receiver.
Unified Augmentation
EGNOS provides (within Europe) Augmentation for GPS, GLONASS and Galileo. This configuration is simple in character but may lead to problems when considering that no interruption to the GNSS-1 augmentation is permitted during upgrade for Galileo. Full independence of the solutions is a risk.

Full independence
Based on the panned EGNOS configuration, a similar but independent "Channel" is developed which exclusively supports Galileo. The present paper cannot venture to anticipate the results of the corresponding studies on this subject.

**Standardisation**
It is the desire of the European Commission to foster at the earliest possible stage the development of future standards on the system and equipment levels. To this end, special attention is given to the aviation sector and the ICAO GNSS Panel. The standardisation activities for Galileo commence with an analysis of existing standards for signal in space, receivers and performance. One key element here is the analysis of the ICAO SARPs material. Building on this, the Standardisation task aims at meeting as many elements of the existing standards as possible, while at the same time starting out on the development of any new standards material which may be regarded necessary.
As such, also members of the aviation community are stimulated to enter into preparation of standards for the future European-provided GNSS. Standardisation activities within EUROCAE, RTCA, IMO and - last not least - ICAO will take place beginning in 2000 and are partially sponsored by the European Commission up to the year 2003.

It is a part of the standardisation activity to ensure a safe design of the satellite navigation system. Such a safe design in conjunction with a suitably shaped and authorised operations organisation shall permit the certification of Galileo for use in safety-critical applications. Such applications would be found predominantly in the transport sector, with aviation only playing one role in this wider view.

The objective of certification for safety-critical applications also demands a high level of security to be achieved by the future Galileo GNSS. The security shall be extended over the system elements (sound design and manufacture), operation and user signal (high degree of robustness).

**Public Private Partnership**
Interest to develop and use a new, civil-controlled GNSS comes both from the public sector (national States and the European Union itself) and from the private sector (future users and service providers).
Therefore, it is realistic to assume the financing of this undertaking to come from both of these sectors: The "Public-Private-Partnership". This concept is proposed by the European Commission for the financing of the system development, deployment and operation. It acknowledges that both "parties" share a common interest in this system and may not able to finance the costs alone.
The European Commission has already laid out a scenario where 50% of the development and deployment cost for Galileo would be borne by the public sector. This funding would be

dedicated mainly to the early phases of the programme prior to the provision of "sellable" services but at the same time would also assume that the private sector is willing and capable to provide the remaining funding at an appropriate time.

A significant amount of effort of the Definition Phase is directed at identifying exactly which (private) users and service providers would be interested in contributing to the financing of the Galileo system. Such funding is inconceivable without proper projections of customers and markets as well as a clear understanding of the potential return of investment.

It is therefore a not to be underestimated element of the Definition Phase to develop credible scenarios for a future funding of the system. As a consequence, potential users from all domains have been invited to influence and comment on the intended system services and performances with a view of attracting them as future revenue generating customers. Only a successful implementation of the PPP scheme will see the technical realisation of Galileo proceed in time.

## THE INSTITUTIONAL FRAMEWORK

Whenever a future operator provides world-wide GNSS service to both private and public (including possibly the military) users he will break into new ground concerning world-wide service level agreements, guaranteed availability and accepting the liability in case of failure. Politics is invited to create an environment where regulations are found in which national and international law actually permits the provision of such a service. The current definition phase also looks at those forthcoming issues and promotes the development of future organisational scenario.

## SCHEDULE AND UPCOMING DECISIONS

If the Definition Phase for Galileo establishes in 2000 that the implementation of this system is feasible, a System Design/Development Phase will follow up to the year 2003. In-orbit validation of the system can then be performed in 2005/06. After this period, all ground and space components of the systems need to be deployed until 2008 when operations of Galileo can commence.

## OUTLOOK

It is not so much the technical but rather the "institutional" and financial issues that have to be solved prior to the installation of a civil-controlled Global Navigation Satellite System. The advent of Galileo - if realised - will see the users benefit from increased accuracy, availability and robustness of navigation from space.

## REFERENCES


1.- Communication of the European Commission, Involving Europe in a New Generation of Satellite Navigation Services, Brussels, 10.01.1999


## ACRONYMS

| | |
|---|---|
| ARTES | Advanced Research in Telecommunications (ESA Programme) |
| CAS | Controlled Access Service |
| ESA | European Space Agency |
| EC | European Commission |
| EU | European Union |
| GEMINUS | A Project of the Galileo Definition Phase |
| GEO | Geostationary (satellite) |
| GLONASS | Global Navigation Satellite System (Russian Federation) |
| GNSS | Global Navigation Satellite System |
| GPS | Global Positioning System NavStar (USA) |
| IMO | International Maritime Organisation |
| INTEG | A Project of the Galileo Definition Phase |
| MEO | Medium Earth Orbit (satellite) |
| MSAS | MTSAT-based Satellite Augmentation System |
| OAS | Open Access Service |
| SARPs | Standards and Recommended Practices |
| SBAS | Space-Based Augmentation System |
| WAAS | Wide Area Augmentation System |

# SBAS Augmentation Systems

## SBAS - WAAS


Mr. JOHN BRITIGAN

Raytheon WAAS Leader

# FAA Wide Area Augmentation System

WAAS

John Britigan

June 2000





## Wide Area Augmentation System

Raytheon


SNS Program Office
Fullerton, CA

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## Installed WAAS Equipment

Satellite Navigation Systems

Raytheon

Reference Station Antenna

Reference Station Cabinets

Master Station Cabinet, Comm Nodes

Signal Generator Cabinets



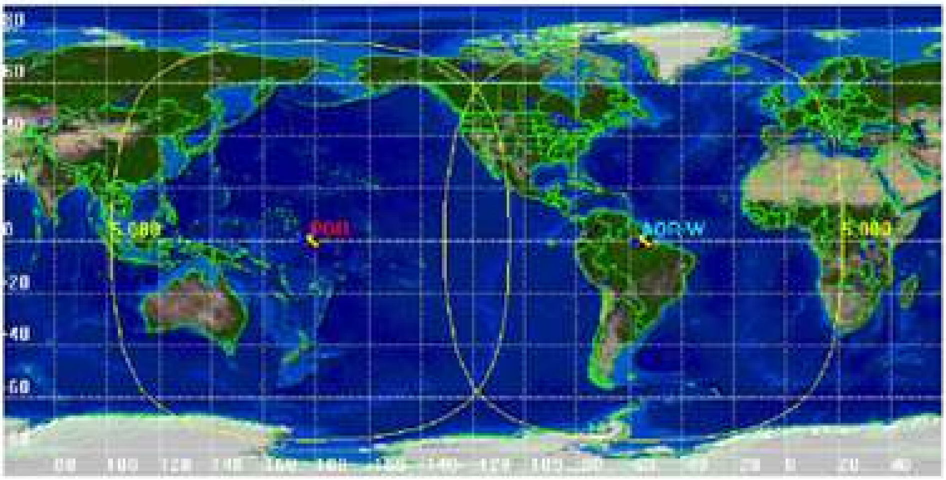




## Phase 1 WAAS Satellite Coverage

Satellite Navigation Systems

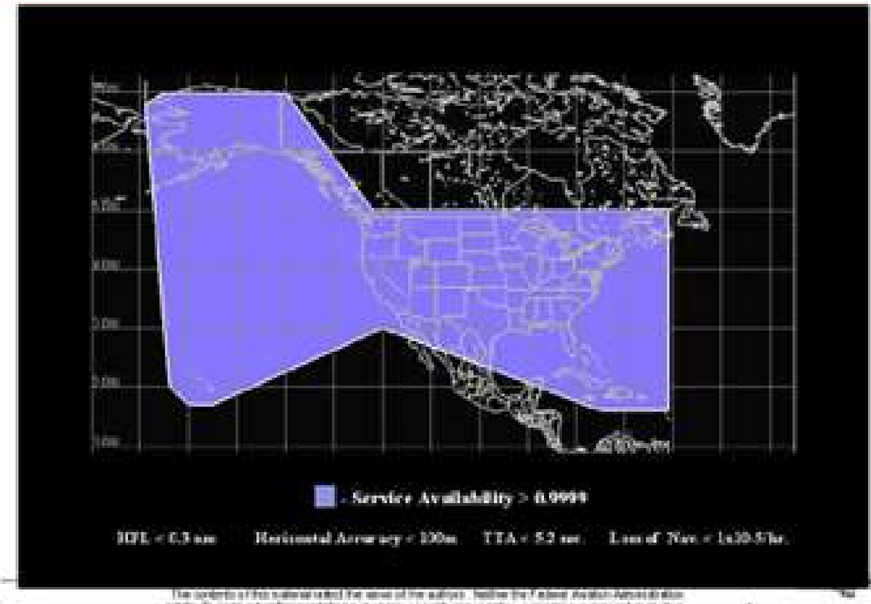
Raytheon



Satellite Navigation Systems

# En Route through Non-precision Approach Navigation Service

Raytheon



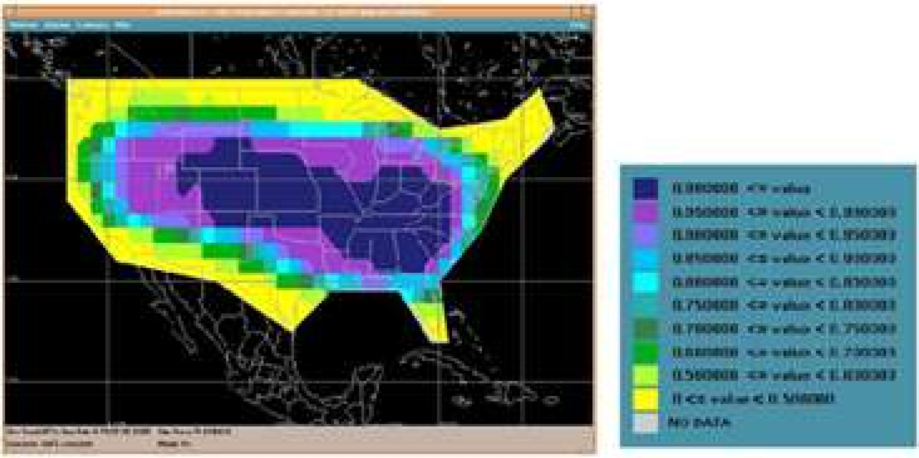

Satellite Navigation Systems

# Precision Approach Navigation Service

Raytheon

PA Coverage, Feb. 6, 2000

52.1% (glove fit), 95% contour (light purple)



Satellite Navigation Systems

## Current WAAS Status

Raytheon

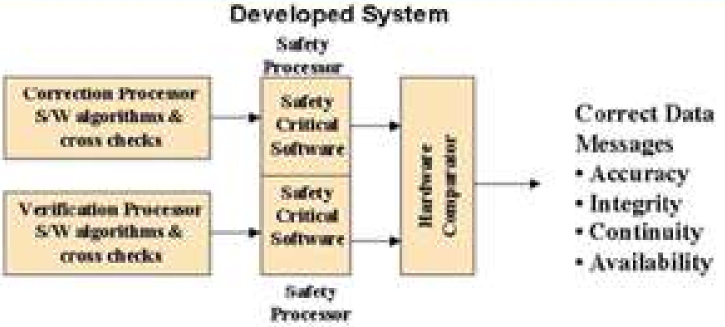
- All sites have been installed since summer of 1997
- All communication networks are in place and operating
- Two INMARSAT GEOs are in use
- All software development has been completed
- Acceptance testing stopped 30 days short of completion

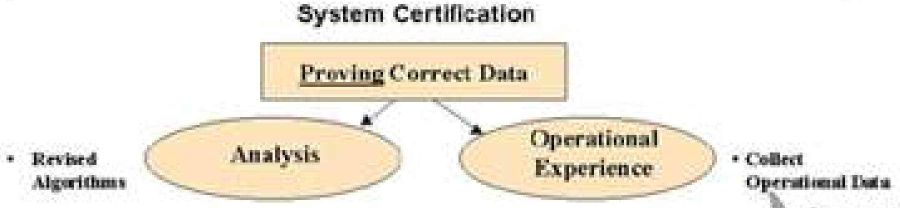


Satellite Navigation Systems

## WAAS and the Challenge

Raytheon



Satellite Navigation Systems

## WAAS Certification Issue

Raytheon

System certification must guarantee correct augmentation

- at every location
- 24 hours a day, 365 days a year
- year after year
- Northern Hemisphere, mid-Atlantic to mid-Pacific

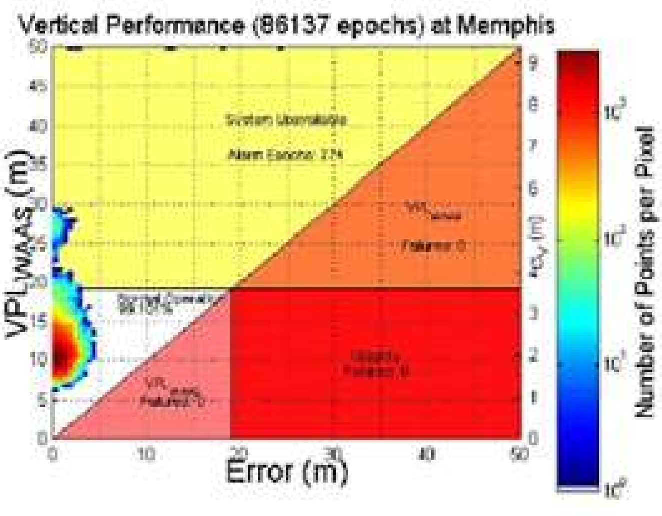
WAAS is the largest safety critical system to ever attempt certification



Satellite Navigation Systems

## Operational Tests Demonstrate Excellent WAAS Performance

Raytheon




VPE & HPE between 1M and 2M

Satellite Navigation Systems

# WAAS Plans

Raytheon

WAAS will be commissioned when certification efforts are completed -- June 2002

System expansion and enhancements are planned following commissioning

- Add additional GEOs to the constellation
- Add additional reference stations to achieve 100% PA throughout the continental United States
- Add Canadian and Mexican reference stations to achieve North American WAAS
- Refine algorithms for more efficient processing
- Replace aging hardware with new devices

# SBAS Augmentation Systems

## SBAS - EGNOS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# THE IMPLEMENTATION OF THE EUROPEAN GEOSTATIONARY NAVIGATION OVERLAY SERVICE (EGNOS)

**March 23rd, 2000**


## ABSTRACT

**The Implementation of the European Geostationary Navigation Overlay Service (EGNOS)**

EGNOS is an overlay augmentation to the current GPS and GLONASS systems, which provides independent integrity information and improved accuracy for GNSS-1 navigation users within Europe. EGNOS is intended to complement the United States' WAAS and Japanese MSAS systems within the European region and will offer the users a compatible service based on a common ICAO standard.
The Advanced Operational Capability of EGNOS will provide a service level equivalent to civil aviation primary means of navigation for En-route down to Category 1 precision approach. Setting up such a system for Europe requires the solution for a number of technical problems as well as institutional and legal problems.

The specifications for Space-Based Augmentation Systems were are developed with the assistance of the ICAO GNSS Panel and are published elsewhere. It is the intention of the present paper to focus on the programmatic background of the EGNOS programme and describe the roles of the various contributors.


## INTRODUCTION

Although GPS signals are used to support En-route and Non-Precision Approach/Departure operations in several countries in the world, GPS and GLONASS alone do not satisfy all aviation requirements for accuracy, availability and integrity. Satellite-, Aircraft- and Ground-based augmentation systems are therefore under development. The USA, Europe and Japan are developing Space-Based Augmentation Systems which shall meet aviation requirements for all phases of flight down to CAT-I precision approach. The SBAS augmentation in Europe will be provided by the European Geostationary Navigation Overlay Service (EGNOS). This system will improve the existing GPS/GLONASS capabilities by providing additional ranging signals from geostationary satellites, as well integrity information and wide-area differential correction obtained though a network of ground monitoring stations.

EGNOS is conceived as a positioning system to augment GNSS-1 and does not include communication elements for the user.

**THE REQUIRMENT**

In March 1999, the EUROCONTROL ATM/CNS Consultation Group endorsed the Navigation Strategy for ECAC which stipulates the introduction of an all Area-Navigation (RNAV) environment from 2005 onwards, with a further move towards RNP RNAV in en-route airspace and in all TMAs from 2010. In general, the higher performance requirements for en-route and terminal areas will have to be fulfilled with RNP 1 or even RNP 0.3 capability.
Three technologies are considered to be capable of providing this type of navigation service in the future: DME, inertial systems and GNSS.

The EGNOS system is designed from the outset for use in all areas of transportation and outside the transportation domain (e.g. for timing applications). This broad range of applications has been labelled "multi-modal" and satisfies the interests of aviation, maritime and land-based users. Civil aviation requirements are the most stringent of all user groups and through fostering by the appropriate ICAO bodies have matured very far. The coverage of the EGNOS system is defined to include the Flight Information Regions (FIR) under the responsibility of ECAC member states (most of European countries, Turkey, the North Sea and the eastern part of the Atlantic ocean).

EGNOS will have the technical capability to provide a primary means service of navigation for en-route oceanic and continental, non precision approach and CAT-I precision approach within the ECAC area.

**EGNOS FUNCTIONS**

*EGNOS will provide the following functions:*
GEO Ranging (R-GEO): Transmission of GPS-like signals from 3 GEO satellites (INMARSAT-III AOR-E, INMARSAT-III IOR and the ESA ARTEMIS satellite). This will augment the number of navigation satellites available to the users and the availability of satellite navigation using RAIM.
GNSS Integrity Channel (GIC): Broadcasting of integrity information. This will increase the availability of GPS / GLONASS / EGNOS safe navigation service up to the level required for civil aviation Non-Precision, Non-Precision with Vertical Guidance (NPV I, II) and CAT-I precision approaches.
Wide Area Differential (WAD): Broadcasting of differential corrections. This will increase the GPS / GLONASS / EGNOS navigation service performance, mainly its accuracy, up to the level required for precision approaches down to CAT-I landing.

## SYSTEM ARCHITECTURE

The EGNOS Ground Segment consists of GNSS (GPS, GLONASS, GEO) Ranging and Integrity Monitoring Stations (RIMS) which are connected to a set of four redundant control and processing facilities called Mission Control Center (MCC). The MCC determines the integrity, pseudorange differential corrections for each monitored satellite, ionospheric delays and generates GEO satellite ephemeris. This information is sent in a message to the Navigation Land Earth Station (NLES), to be uplinked along with the GEO Ranging Signal to GEO satellites. These GEO satellites downlink this data on the GPS Link 1 (L1) frequency with a modulation and coding scheme similar to the one from GPS. All ground Segment components are interconnected by the EGNOS Wide Area Communications Network (EWAN).

The EGNOS Space Segment is composed of transponders on board of the geostationary INMARSAT-III AOR-E and IOR, and the ESA ARTEMIS satellites.

The EGNOS User Segment will consist of SBAS compatible user receivers.

The EGNOS support facilities include the Development Verification Platform (DVP), the Application Specific Qualification Facility (ASQF) and the Performance Assessment and System Checkout Facility (PACF):

The DVP is the essential facility to validate and verify the EGNOS requirements during the design phase. It consists of simulation facilities, a real time EGNOS System Test Bed (ESTB) and Assembly, Integration and Verification Platform (AIVP) to perform system verification tests.

The PACF shall provide support to EGNOS system management in various areas necessary for the system operation and maintenance, such as system performance analysis and anomaly investigation.

The ASQF is the facility in charge to provide the Civil Aviation and Aeronautical Certification Authorities with tools to qualify, validate and certify the different EGNOS applications.

## EGNOS SYSTEM TEST BED

In order to obtain development support and facilitate early operational certification of the EGNOS system, a technology demonstrator system is developed under the overall control of ESA. This system is called EGNOS System Test Bed and uses several GPS monitoring sites within Europe which are tied into a Computing Centre at Honefoss in Norway. INMARSAT-III geostationary satellite AOR-East is mainly used for distribution of the augmentation signal.

ESTB is operational since early 2000 and will be used in the future to conduct a variety of system test activities both from manufacturers and future users.

## EGNOS ORGANISATION

### European Tri-Partite Group

Based on a decision of the Council of the European Union from 1997, the task of developing the EGNOS system has been entrusted to the European Commission (EC), the European Space Agency (ESA) and EUROCONTROL. In June 1998 these organisations signed the so-called Tri-Partite Agreement, detailing their respective roles and responsibilities within the programme. Since then, in the context of EGNOS implementation, these three organisations have come to be known collectively as the "European Tri-Partite Group" (ETG). Jointly, ETG oversee the definition of the "Mission Requirements" for EGNOS which address the performance requirements not only from aviation but also from maritime and land-based user groups. The individual tasks of ETG members are broken down as follows:

*European Commission*

The European Commission, through their Directorate General Transport and Energy (TREN), is responsible for overall implementation of the EGNOS programme as well as institutional and policy matters including political representation both internal (Member States) and external to the European Union. The European Commission is also directly financing certain elements of the system during the development phase (such as the lease for the transponders on board of the geostationary satellites.)

*European Space Agency*

The European Space Agency ESA is responsible for the design and development of the EGNOS Infrastructure. For this, they can rely on financial contributions from the participants to their Advanced Research in Telecommunications Systems Programme, Element 9 - GNSS. This programme (short form ARTES-9) serves to collect financial contributions from member states as well as from private institutions. To date, the states of Austria, Canada, France, Germany, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the UK contribute to this activity from their national budgets. In addition, the Air Traffic Service Organisations from France, Germany, Italy, Portugal, Spain, Switzerland and the UK are contributing to the development phase of the system (see EOIG below).

ESA has set up a GNSS-1/EGNOS Programme Office in Toulouse/France to oversee all industry contract activities of the design and development phase. This office receives the Mission Requirements developed under ETG coordination and translates them into system requirements applicable to the development contracts to industry. The industrial team performing these tasks is led by Alcatel Space Industries (France) with the participation of companies from Spain (GMV, INDRA), United Kingdom (Racal, Vega, Logica, MMS, British Telecom), France (Sextant Avionique, SRTI), Germany (DASA, Airsys ATM), Italy (Alenia, Laben, Vitrociset), Norway (Seatex) and Switzerland (CIR). Further industry companies contribute as subcontractors to these manufacturers. The ESA GNSS-1/EGNOS Programme Office is responsible for overseeing all day-to-day programme management activities involved in the development of the system. These efforts will culminate in the Operational Readiness Review where the technical compliance of the system with the specification is demonstrated.

**EUROCONTROL**

EUROCONTROL is defining the mission requirements for civil aviation, plays a major role in the operational validation phase of system deployment and is investigating system certification. EUROCONTROL is laying the foundation for the development of a system-wide safety case and has also been responsible for the compilation of a Cost-Benefit Analysis considering the impact of SBAS in the ECAC region. The objective of the Cost Benefit Analysis, completed in 1999, was to determine the relative merits, from the financial perspective, of alternative options for GNSS implementation and to compare the GNSS scenario against other, alternative implementations. One result of the Cost Benefit Analysis was a demonstration that the cost for introducing GNSS services is largely dependent of the cost of the associated avionics (through the large number of aircraft involved) and only to a lesser degree depending on implementation cost of the ground and space infrastructure. The analysis confirmed that operational benefits may be obtained from the introduction of GNSS services which are not available when conventional infrastructure is used (the benefits are mainly derived from the vertical guidance obtained from augmented GNSS). In conclusion, the benefits for SBAS introduction can outweigh the cost when appropriate conditions are taken during the implementation. As a consequence, the Cost Benefit Analysis provides valuable guidance during the programme implementation for both all programme participants.

**EGNOS Operators and Infrastructure Group**

In January 1999, the Air Traffic Service Organisations participating in the ARTES-9 programme of ESA signed a Memorandum of Co-operation to harmonise their activities within the frame of the GNSS-1/EGNOS programme. The Air Traffic Services Organisations Aena, DNA/STNA, DFS, ENAV, Swisscontrol, NATS and NAV_EP operating under this Memorandum are known as EGNOS Operators and Infrastructure Group (EOIG). The EOIG has defined its objectives as:

* Definition of technical and operational requirements for SBAS
* Securing the interests of aviation within the GNSS-1/EGNOS programme
* Support to the GNSS-1/EGNOS programme through participation in activities related to safety, certification, cost analysis and legal affairs
* Harmonisation of all activities concerning future GNSS service provision with the help of EGNOS
* Hosting of elements of the EGNOS infrastructure
* Preparation for operational use of EGNOS

EOIG intend to become the operators of the EGNOS infrastructure after completion of the development phase. Therefore, the group has embarked on intensive coordination with the members of ETG to permit a smooth transition to an operational service at completion of the technical development.

## PROGRAMME TASKS AND MILESTONES

So far, the preliminary design activity has been completed, yielding the system level specifications for all system elements. The currently ongoing activity is that of detailed design which will lead to a multitude of component Critical Design Reviews (CDRs) in the first half of 2001 with System CDR scheduled for June of that year.
Following this will be the equipment manufacture and deployment with the majority of activities in 2002. System integration, validation and qualification will follow in the year 2003. The conformity of the system to the technical specification shall be demonstrated during the Operational Readiness Review in December of 2003. By this time, the operating entities will already be in a position to operate and maintain the system with their own resources.

## OUTLOOK

With the EGNOS development phase now well underway, the system is expected to achieve its Advanced Operational Capability in 2003 with first operational use in the second half of 2004.

It was originally intended to complement the AOC development with the installation of further redundant ground elements and geostationary transponders to permit a Full Operational Capability (FOC) which secures full availability of the SBAS service.

With the emerging of plans to develop the GNSS constellation "Galileo" from Europe this intention is currently under review. While it is acknowledged that the continuity of the SBAS augmentation to GPS must be provided in Europe, it is currently under investigation how this objective can be fulfilled in the light of the development of the Galileo system. The European Union requires an "optimal integration of EGNOS into Galileo" and studies are currently underway to identify how this goal can be met in a most efficient way.

## REFERENCES

1.- EGNOS: the European Satellite Based Augmentation to GPS and GLONASS
J. Benedicto, P. Michel and J. Ventura-Traveset; European Space Agency, 18 avenue Edouard Belin, 31055 Toulouse, France, 1998
2.- The European Satellite Navigation Programme
A Steciw, European Space Agency; J Storey, EUROCONTROL; L Tytgat, European Commission, 1998
3.- EGNOS Multi-modal Costs and Benefits, EUROCONTROL, 1999

## ACRONYMS

| | |
|---|---|
| AIVP | Assembly, Integration and Verification Platform |
| AOR | Atlantic Ocean Region (INMARSAT III) |
| ARTES | Advanced Research in Telecommunications |
| ASQF | Application Specific Qualification Facility |
| ATM/CNS | Air Traffic Management / Communication Navigation & Surveillance |
| CAT-I | Category 1 Precision Approach |
| CDR | Critical Design Review |
| DVP | Development Verification Platform |
| EC | European Commission |
| ECAC | European Civil Aviation Conference |
| EGNOS | European Geostationary Navigation Overlay Service |
| EOIG | EGNOS Operators and Infrastructure Group |
| ESA | European Space Agency |
| ESTB | EGNOS System Test Bed |
| ETG | European Tri-Partite Group (EC, ESA, EUROCONTROL) |
| EWAN | EGNOS Wide-Area Network |
| FIR | Flight Information Region |
| GEO | Geostationary Satellite |
| GIC | GNSS Integrity Channel |
| GLONASS | Global Navigation Satellite System (Russian Federation) |
| GNSS | Global Navigation Satellite System |
| GPS | Global Positioning System NavStar (USA) |
| ICAO | International Civil Aviation Organisation |
| IOR | Indian Ocean Region (INMARSAT III) |
| MCC | Mission Control Center |
| NLES | Navigation Land Earth Station |
| NPV | Non-precision with Vertical Guidance |
| PACF | Performance Assessment and System Checkout Facility |
| RAIM | Receiver Autonomous Integrity Monitoring |
| RIMS | Ranging and Integrity Monitoring Station |
| RNAV | Area Navigation |
| RNP | Required Navigation Performance |
| SBAS | Space-Based Augmentation System |
| WAD | Wide Area Differential |

# SBAS Augmentation Systems

## SBAS - MTSAT


**Dr. ROBERT LOH**

**Innovative Solutions International**

**Mr. NAOTO ASADA**

**Japanese Flight Inspection Unit**

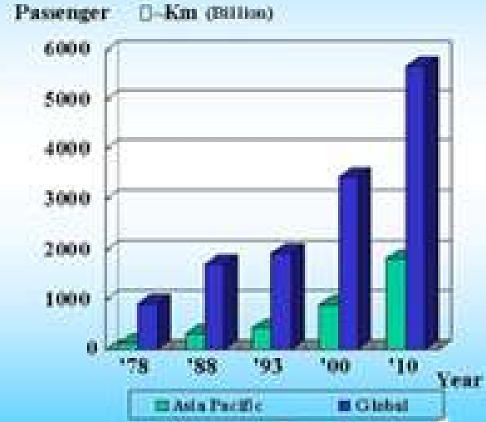

MTSAT Satellite-based Augmentation System
MTSAT/MSAS
Development
(MTSAT: Multi-functional Transport Satellite)
(MSAS: MTSAT Satellite-based Augmentation System)
Japan Civil Aviation Bureau
Ministry of Transport
Civil Aviation Bureau Ministry of Transport


MTSAT Satellite-based Augmentation System
Contents
• The Air Traffic Demand of Asia Pacific region
• ICAO CNS/ATM Concept
• MTSAT Overview
• MSAS Overview
– MSAS Architecture
– How MSAS Works etc.
• Expansion and Compatibility
• Present Program Status
• Conclusion
Civil Aviation Bureau Ministry of Transport

*MTSAT Satellite-based Augmentation System*

# The Air Traffic Demand of Asia Pacific Region

- The rapid increase of air traffic demand in Asia Pacific region
- Peculiarity of Asia Pacific region




*Civil Aviation Bureau Ministry of Transport*

*MTSAT Satellite-based Augmentation System*

# *ICAO CNS/ATM Concept*

- *ICAO:*
  *International Civil Aviation Organization*
  - *Communication(C)*
  - *Navigation(N)*
  - *Surveillance(S)*
  - *Air Traffic Management(ATM)*

– ***New CNS/ATM Concept***

*Civil Aviation Bureau Ministry of Transport*

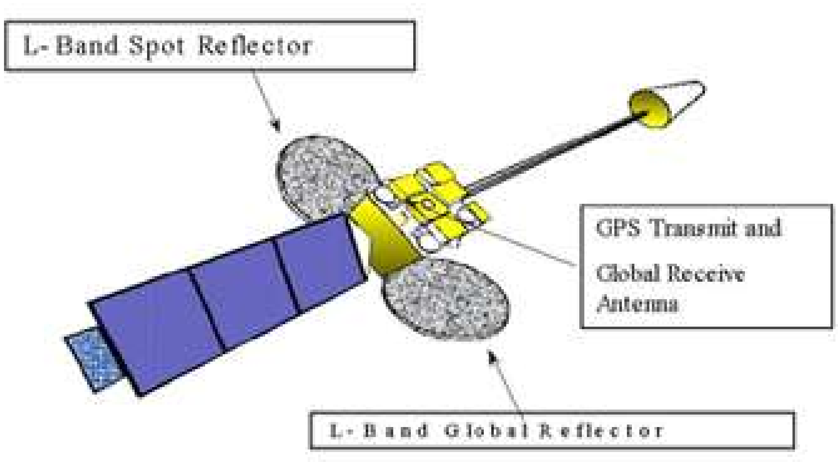
# MTSAT Overview

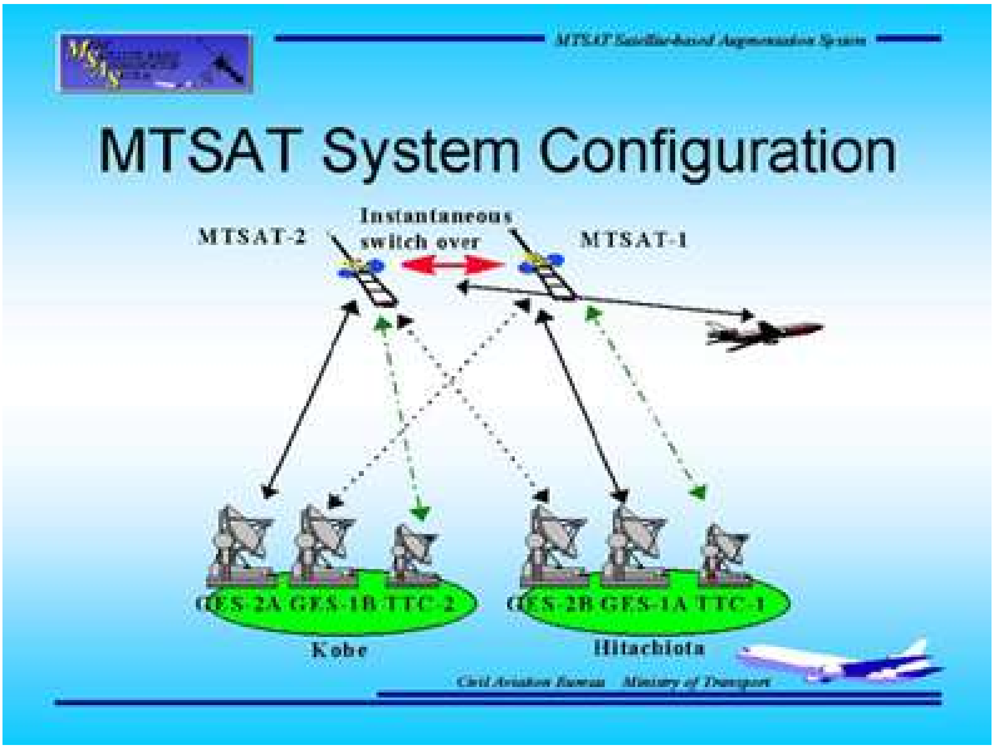
- ***Multi-functional Transport Satellite***
  - *Aeronautical Mission*
    - *Communication*
    - *Navigation*
  - *Meteorological Mission*
- ***Geo-stationary Earth Obit Satellite***
  - *140 deg. East (the first satellite)*
  - *135 or 145 deg. East (the second satellite)*

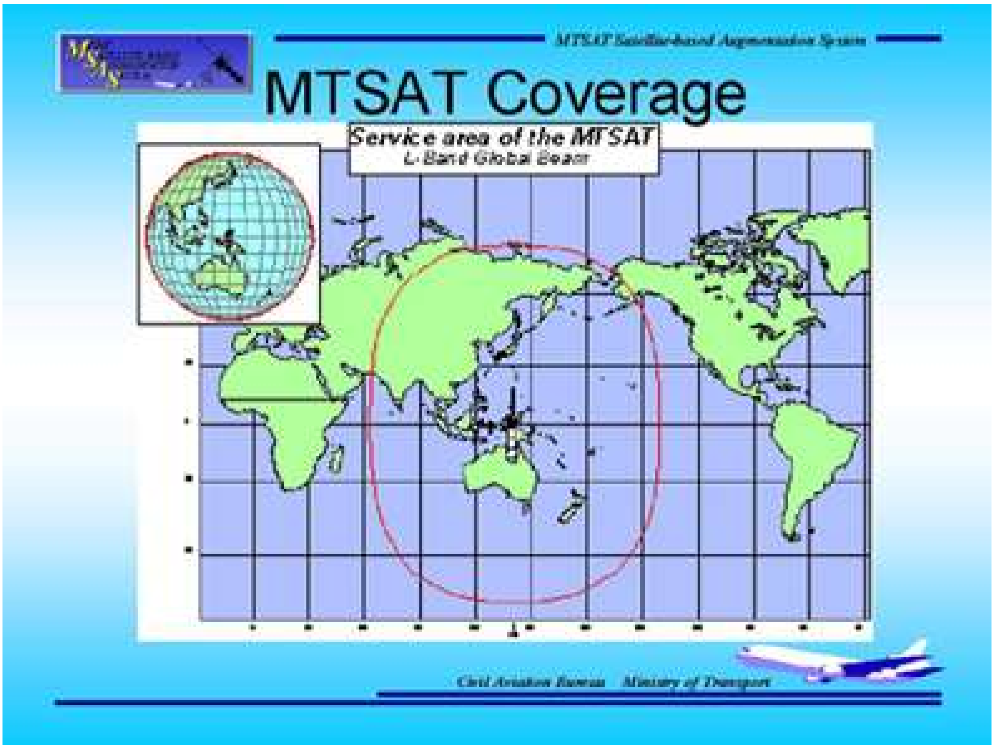


MTSAT Satellite-based Augmentation System

# MTSAT Satellite




MTSAT Satellite-based Augmentation System
MTSAT System Configuration
Instantaneous switch over
MTSAT-2
MTSAT-1
GES-2A GES-1B TTC-2
GES-2B GES-1A TTC-1
Kobe
Hitachiota
Civil Aviation Bureau Ministry of Transport


MTSAT Satellite-based Augmentation System
MTSAT Coverage
Service area of the MTSAT
L-Band Global Beam
Civil Aviation Bureau Ministry of Transport

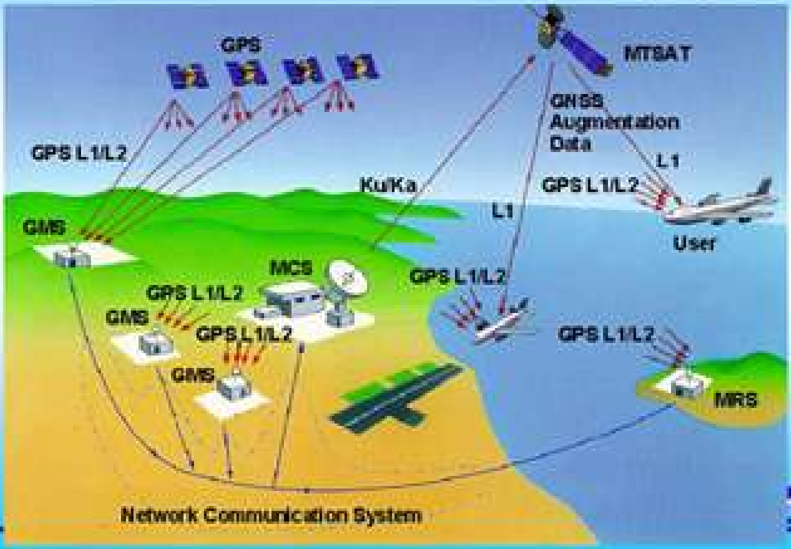
# MSAS Overview (1)

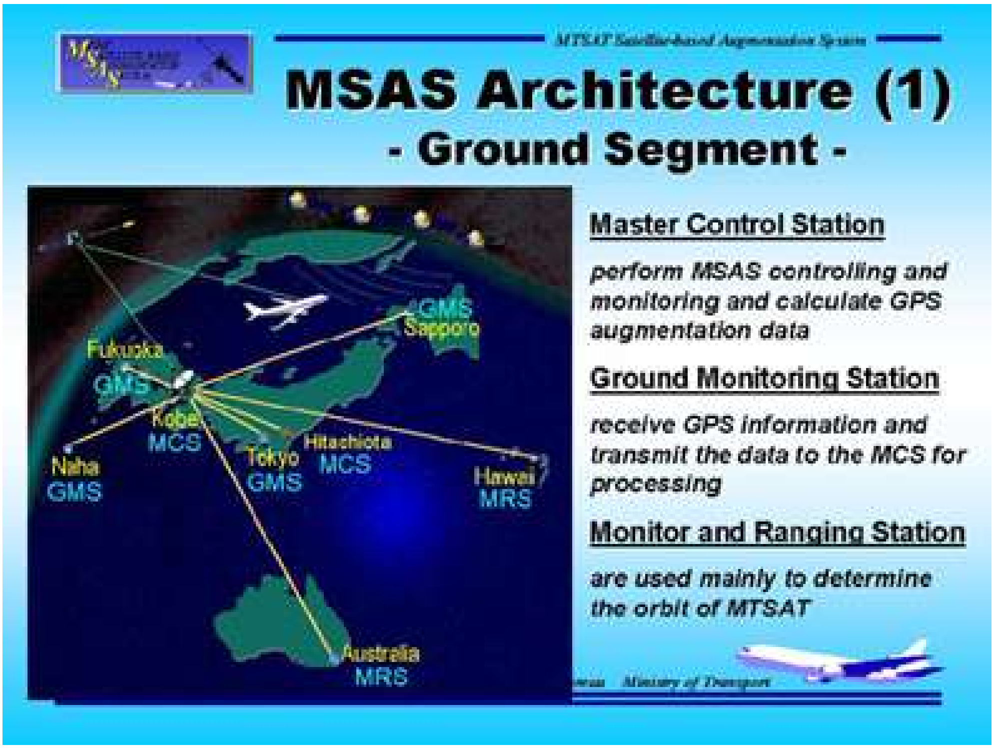
- ICAO CNS/ATM: Global Navigation Satellite System (GNSS)
  - GPS/GLONASS/ABAS/SBAS/GBAS
- MSAS is one of SBAS (Satellite Based Augmentation System) which augments GPS to support air navigation
- Augmentation improves GPS performance and completely satisfies all civil aviation requirements for integrity, accuracy, availability, and continuity

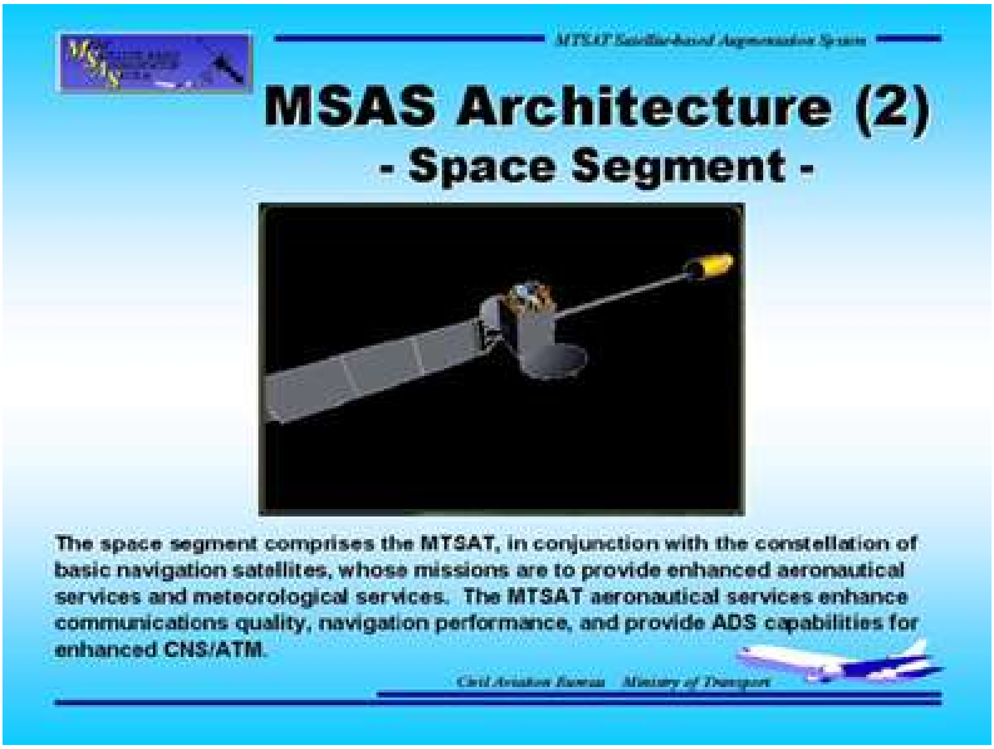


MTSAT Satellite-based Augmentation System

# MSAS Overview (2)




MTSAT Satellite-based Augmentation System
MSAS Architecture (1)
- Ground Segment -
Fukuoka
GMS
Kobe
MCS
Naha
GMS
Tokyo
GMS
Hitachiota
MCS
GMS
Sapporo
Hawaii
MRS
Australia
MRS
Master Control Station
perform MSAS controlling and monitoring and calculate GPS augmentation data
Ground Monitoring Station
receive GPS information and transmit the data to the MCS for processing
Monitor and Ranging Station
are used mainly to determine the orbit of MTSAT
Ministry of Transport


MTSAT Satellite-based Augmentation System
MSAS Architecture (2)
- Space Segment -
The space segment comprises the MTSAT, in conjunction with the constellation of basic navigation satellites, whose missions are to provide enhanced aeronautical services and meteorological services. The MTSAT aeronautical services enhance communications quality, navigation performance, and provide ADS capabilities for enhanced CNS/ATM.
Civil Aviation Bureau Ministry of Transport

# MSAS Architecture (3)

## - User Segment -

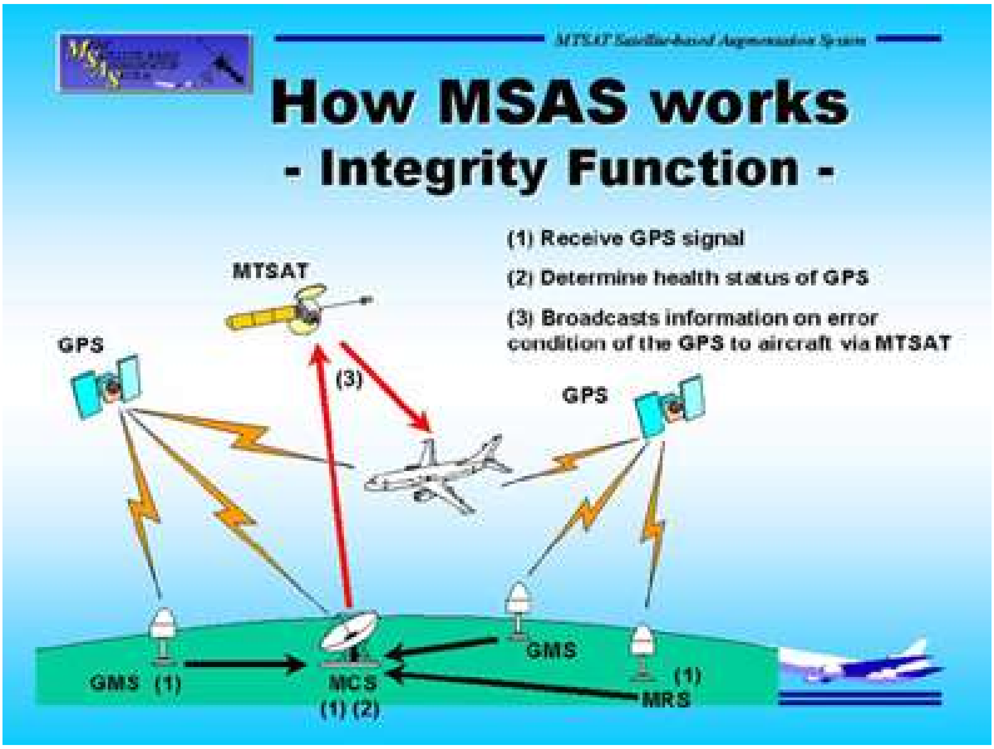

GPS receivers can be upgraded to also receive the MSAS correction messages so that GPS/MSAS can satisfy all the critical requirements for a navigation system in oceanic, domestic, and terminal airspace, as well as non-precision and Category I precision approaches.

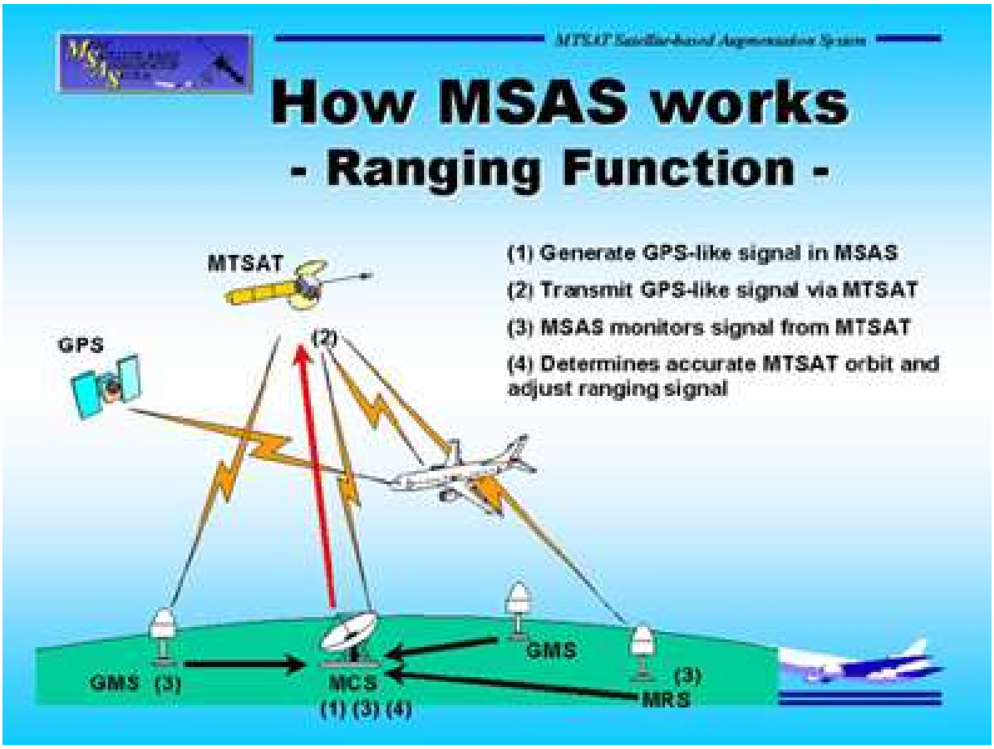


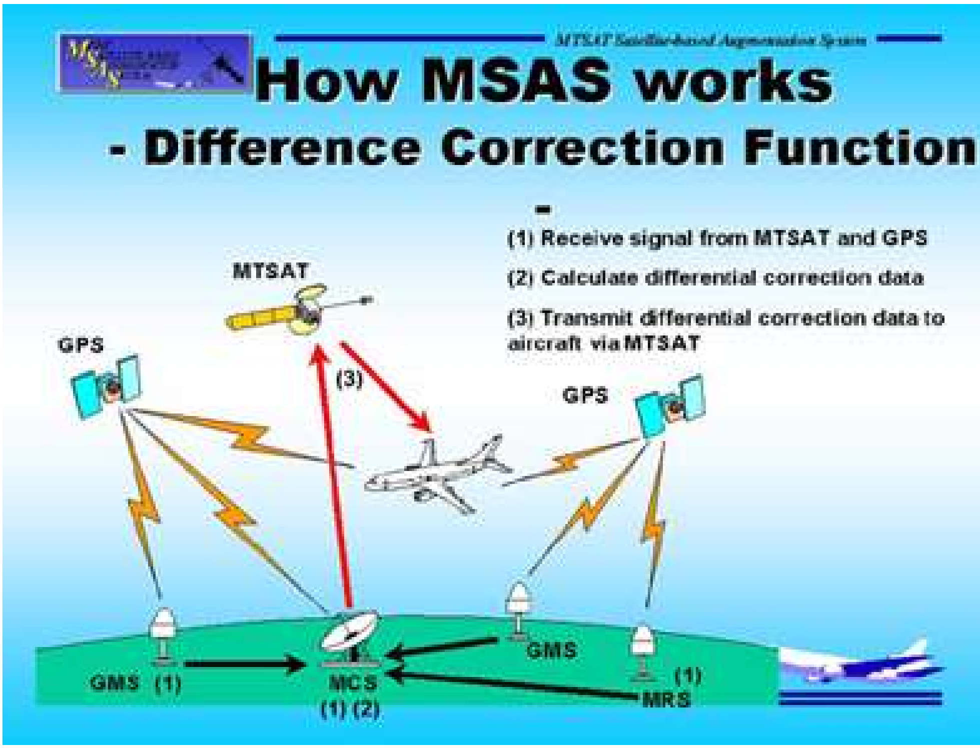


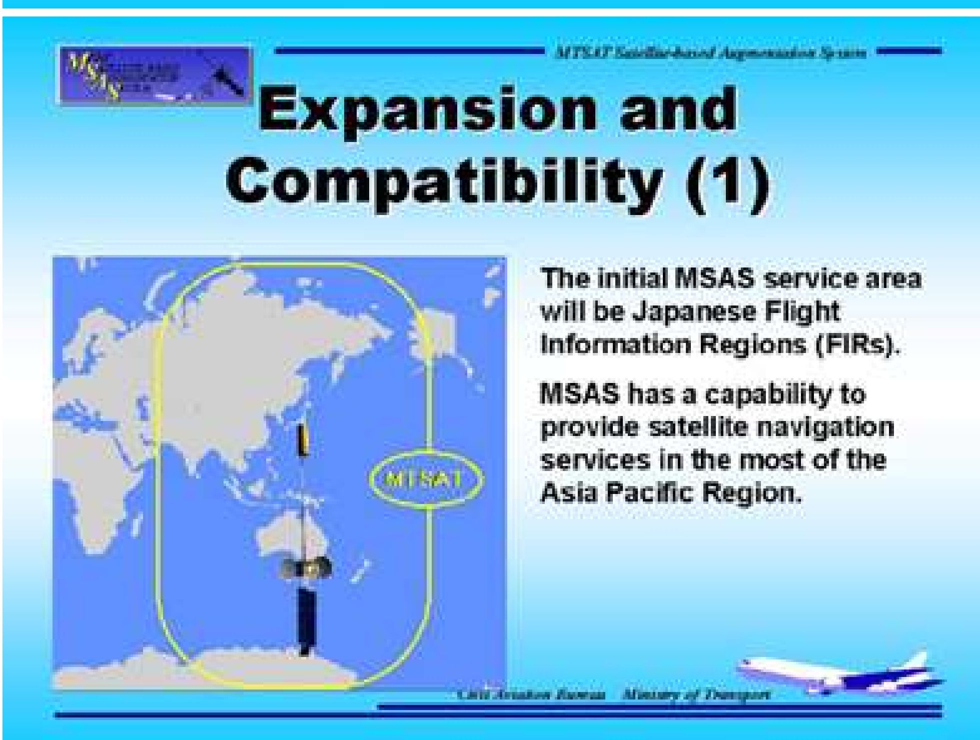
# MSAS Services

- **Integrity Function**
  - provides information on health status and error level of GPS. (Aircraft determines GPS availability)
- **Ranging Function**
  - allows MTSAT to function as another available GPS
- **Differential Correction Function**
  - provides information on error corrections to aircraft


MTSAT Satellite-based Augmentation System
How MSAS works
- Integrity Function -
(1) Receive GPS signal
(2) Determine health status of GPS
(3) Broadcasts information on error condition of the GPS to aircraft via MTSAT
MTSAT
GPS
(3)
GPS
GMS
GMS (1)
MCS
(1) (2)
(1)
MRS


MTSAT Satellite-based Augmentation System
How MSAS works
- Ranging Function -
(1) Generate GPS-like signal in MSAS
(2) Transmit GPS-like signal via MTSAT
(3) MSAS monitors signal from MTSAT
(4) Determines accurate MTSAT orbit and adjust ranging signal
MTSAT
GPS
(2)
GMS
GMS (3)
MCS
(1) (3) (4)
(3)
MRS


MTSAT Satellite-based Augmentation System
How MSAS works
- Difference Correction Function
-
(1) Receive signal from MTSAT and GPS
(2) Calculate differential correction data
(3) Transmit differential correction data to aircraft via MTSAT
MTSAT
GPS
(3)
GPS
GMS
GMS (1)
MCS
(1) (2)
(1)
MRS


MTSAT Satellite-based Augmentation System
Expansion and Compatibility (1)
MTSAT
The initial MSAS service area will be Japanese Flight Information Regions (FIRs).
MSAS has a capability to provide satellite navigation services in the most of the Asia Pacific Region.
Civil Aviation Bureau Ministry of Transport

*MTSAT Satellite-based Augmentation System*

# Expansion and Compatibility (2)


*MTSAT Satellite-based Augmentation System*

# Project Status

- MTSAT Launch Failure
  - MTSAT-1 Satellite was launched by the Japanese H-2 rocket on 15 November, 1999.
  - Rocket went out of the planned flight path due to the abnormal stoppage of the combustion of the first stage engine.
  - Command for destruction was sent to the rocket.
  - NASDA(National Space Development Agency of Japan) has investigated the causes.


*Civil Aviation Bureau Ministry of Transport*

# MTSAT Plan Rescheduling

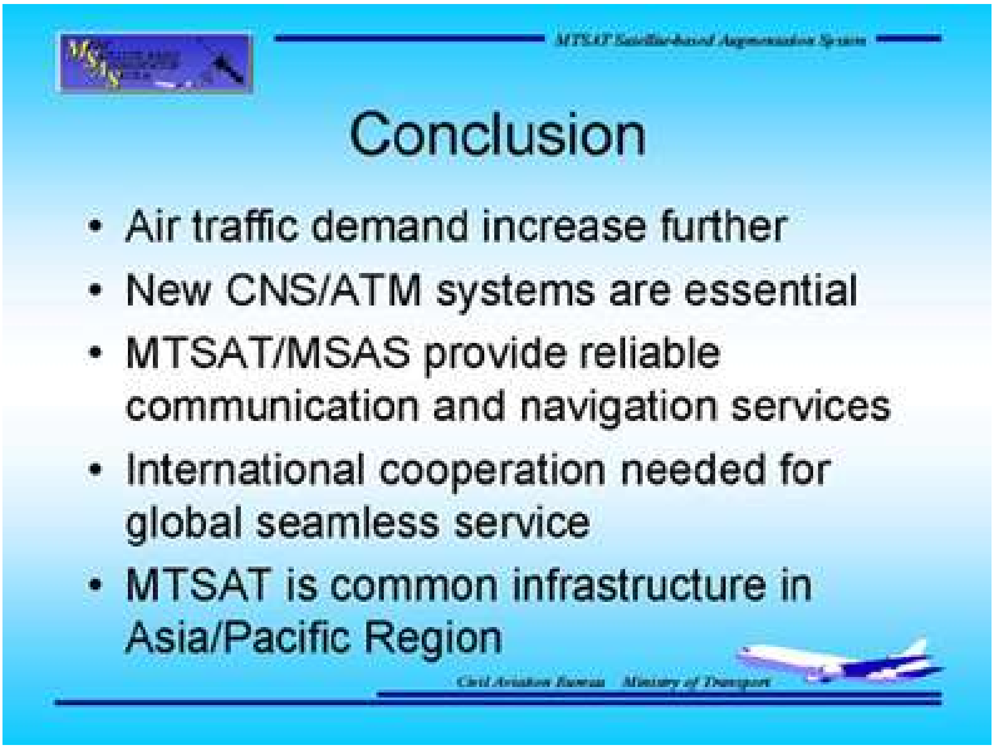
- Alternative satellite of MTSAT-1 has been procured.
  - Satellite is expected to be launched in 2003.
- MTSAT-2
  - The second satellite of MTSAT.
  - JCAB would like to keep the schedule of MSAS operation with two satellites which was planned to start from 2006.





# MTSAT/MSAS Operation

- MSAS
  - MSAS operation will start around 2004.
  - Data collection and analysis using MSAS and MSAS Analysis System(MAS).


MTSAT Satellite-based Augmentation System
Conclusion
• Air traffic demand increase further
• New CNS/ATM systems are essential
• MTSAT/MSAS provide reliable communication and navigation services
• International cooperation needed for global seamless service
• MTSAT is common infrastructure in Asia/Pacific Region
Civil Aviation Bureau Ministry of Transport

# GBAS Augmentation Systems

## GBAS Standardized system (ICAO)


## Ms. MARIA DIPASQUANTONIO

## FAA LAAS IPT Lead

# Program Update for 11th International Flight Inspection Symposium

## Local Area Augmentation System

June 5, 2000
Santiago, Chile

Maria DiPasquantonio
FAA LAAS Program Manager

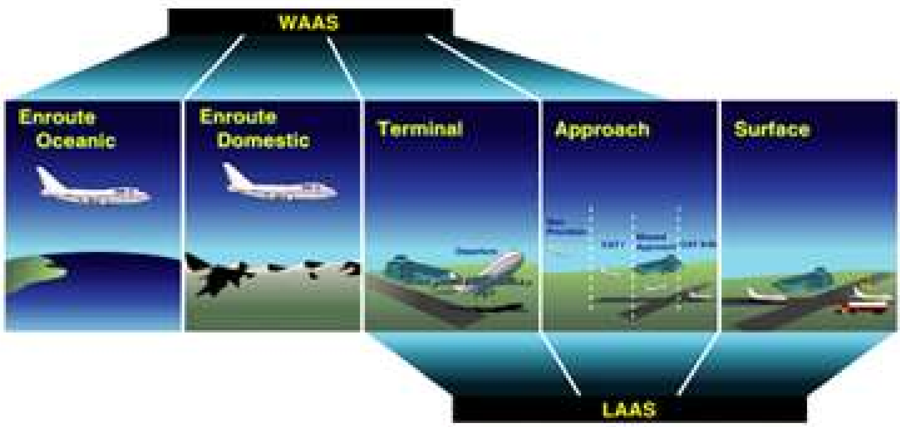


# Overview

## Local Area Augmentation System

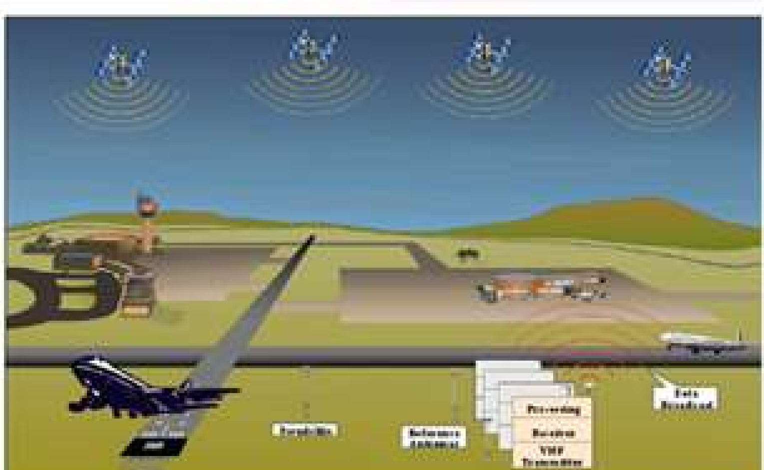
- LAAS Architecture/Requirements
- LAAS Benefits
- LAAS Development
- LAAS Program Status/Future Plans
- LAAS NAS Implementation

# GPS Augmentation
# Phases of Flight




3

# Local Area Augmentation System (LAAS)
# Ground Segment

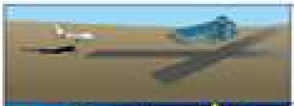


4

## LAAS Requirements

- To Provide a Signal Suitable for CAT I Precision Approach at Those Airports Where Either WAAS Does Not Provide Adequate Availability or Airport Is Outside WAAS Coverage Area
- To Provide a Signal Suitable for Precision Approach Capability for CAT II/III Airports
  - Existing (72)
  - Newly Qualifying (42)
- End State LAAS Quantities
  - CAT I -- 46
  - CAT II/III -- 114

## Benefits of LAAS

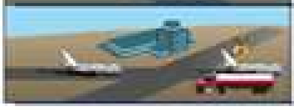


**Category I, II & III** - Provides Precision Approach Capability Within System Range

**Remote Coverage** - Augments Wide Area System in Various Locations (Terrain Traffic Volume)

**Tailored Approaches** - To Avoid Obstacles, Noise Sensitive Areas, or Congested Airspace (Helicopter Urban Access)

**Multiple Runway Coverage** - One LAAS May Serve the Entire Airport (Reduced Equipment and Maintenance Costs)



**Aircraft Surface Navigation** - Aircraft Use as a Guide When Taxiing in Inclement Weather

# LAAS Development

- Full Scale Development (FSD) of LAAS CAT I Ground Facility Accomplished Through Government-Industry Partnership (GIP)
  - Apr 1999 FAA Signed Partnerships With Honeywell and Raytheon
  - Industry Teams Consist of Ground Facility Vendor, Avionics Manufacturer, Airline or Manufacturer, and Airport
  - FAA Provides Test and Evaluation, Flight Testing, Development of Procedures and Certification for Non-Federal Systems
  - Innovative Approach to Production, Fielding, Testing, Evaluation and Approval for Public Use
  - Industry and Government Benefit by Sharing Expertise and Cost, Resulting in Timely Certification and Operational Approvals
  - Joint Development of Specification, Related Documentation and Concept of Operations



# LAAS Significant Milestones

- Sep '99 LAAS CAT I Specification Completed and Approved
- Fall '99 Conducted 2 Wide Body A/C Flight Tests-CAT II/III R&D
  - UPS (Boeing 767) at Atlantic City–35 of 35 Successful Flight Trials
  - FedEx (MD-10) at Memphis–39 of 39 Successful Flight Trials
  - Demonstrated/ Verified Reception of a Pseudolite Signal by Wide Body Aircraft and Ability to Accurately Range from Signal
- Jan '00 RTCA DO-253, LAAS MOPS Approved and DO-246A, LAAS ICD Approved

# FY 00 Program Goals

- Support Government Industry Partnership:
  - CAT I Specification Validation
  - Type Acceptance Activities for CAT I LAAS
- NAS Implementation Activities
- Acquisition Planning and Program Support Activities
- Minimal LAAS CAT II/III Development

# FY 00 Program Status

- CAT I Spec Validation Activities On-Going
  - Supported by Ohio University, Stanford University, MITRE, FAA Tech Center, FAA Aeronautical Center, Dept of Navy, FAA HQ
- Type Acceptance Activities On-Going
  - Type Acceptance T&E Plan and Preliminary Systems Review Plan, Guidelines and Procedures Developed
  - Preliminary Systems Review Held with GIP Vendors - Feb '00

## FY 00 Program Status (Con't)

- Established LAAS Siting Working Group
  - Develop Siting Guidelines and Criteria to Support FAA Fielding of LAAS CAT I
- RTCA/ICAO Harmonization
  - RTCA Has Released a New LAAS ICD
  - ICAO Validation Has Produced Additional Changes
  - RTCA Will Wait to Release Changes to Either MOPS, MASPS, or ICD Until CY 2001



## FY 00 Program Status (Con't)

- LAAS CAT I Specification Changes Coordination Underway
- LAAS CAT II/III Specification Development Efforts Initiated May'00
  - Incorporate "Lessons Learned" from CAT I Spec Development
  - Primary Issues for CAT III Spec Development:
    - Airport Pseudolite Requirements
    - Integrity Requirements
    - VHF Data Broadcast Coverage/Operational Considerations

## Goals/Proposed Work
## FY 01

- Complete Activities on GIP CAT I/Type Acceptance
- Acquisition Planning/Develop Request for Proposal for CAT I Production Contract
- CAT II/III Specification Development and Validation
- CAT II/III FSD MOPS Development and Validation
- NAS Implementation/Fielding Prep
  - Airport Surveys
  - Complex Procedures
  - TERPS
  - CBI Training
  - Receiver Development
  - Procedures/Flight Inspection

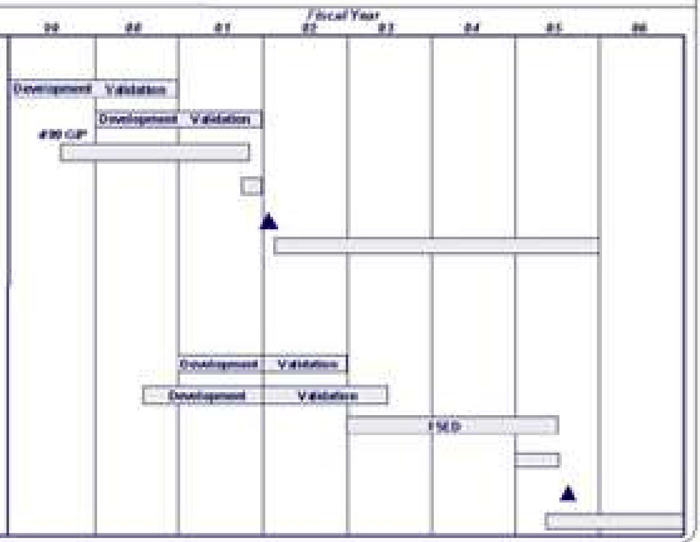
## Goals/Proposed Work
## FY 02

- CAT I LAAS Production and Fielding (20 Systems)
- Complete and Validate CAT II/III Specification
- Complete CAT II/III MOPS Validation
- Develop Request for Procurement for CAT II/III Full Scale Development
- NAS Implementation

# LAAS Program Schedule

CAT I
- SPEC
- MOPS
- GIP FSED (qty: 2-18)
- FAA Type Acceptance
- Commissioning
- FAA Production Contract

CAT III
- SPEC
- MOPS
- FAA FSED
- OT&E
- Commissioning
- FAA Production Contract

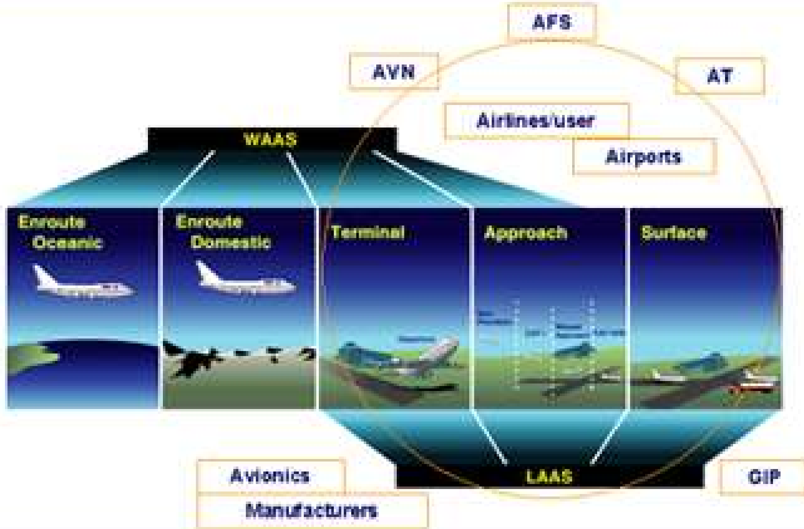





# LAAS Implementation Major Projects

| Flight Standards | ACT 360 | AVN | AOP/AOS 1000 | Air Traffic |
|---|---|---|---|---|
| • Terminal Procedures (TERPS) Criteria<br>• Flight Testing<br>• ICAO Support<br>• TSE Model<br>• Complex Procedures | • Minimum Operational Performance Standards (MOPS)<br>• MMR Development/ Integration for Validation and Flight Inspection | • LAAS FMS Integration<br>• Procedure Development<br>• Flight Inspection | • Part 171 (Non-Fed Program Documentation<br>• AF Documentation | • Computer-Based Instruction Development for AT Controller<br>• Air Traffic Control Unit Design/ Integration<br>• Airspace Integration |

## LAAS Implementation Integration






## FAA GPS Product Team Website

- For Further Information/Updates on the FAA's Satellite Navigation Program, Please Visit Our Website At:

**http://gps.faa.gov**

# GBAS Augmentation Systems

## Future Enhancements


## Mr. CURT KEEDY

## Flight Inspection Policy and Standards -FAA

# GPS MODERNIZATION

Curt Keedy
FAA Flight Inspection Operations
Policy and Standards

## SYSTEM EVOLUTION

1973 - DoD approved GPS for development
1978 - launched first of 10 Block I (first generation) satellites for test and evaluation
1985 - DoD approved implementation of an operational system
1985 - DoD contract with Rockwell Space Division for 28 satellites
1989 - launch of first Block II (second-generation) satellite. Modified Block IIA (third generation) with additional onboard data memory, launched after ninth Block II.
1995 - GPS declared operational (ground segment and between 24 and 27 operational satellites since)
1989 - DoD contract with Lockheed-Martin Astro-Space for 21 Block IIR (third generation) satellites.
1997 - first successful launch of Block IIR
1996 - DoD contract with Boeing Space Division for 30 satellites. First six will be Block IIF (fourth generation) with option for six more to sustain the constellation. Remaining 24 await final determination of new capabilities/modernization (GPS III).

## SIGNAL TRANSMISSION

Spacecraft to earth transmissions on L1 and L2.

- L1 - 1575.42 MHz - modulated by two pseudorandom noise (PRN) codes
  - coarse acquisition - C/A-code - at a bit (chipping) rate of 1,023 Mcps
  - precision/secure - P/(Y)-code - at a chipping rate of 10.23 Mcps.

- L2 - 1227.6 MHz - modulated with P/(Y)-code.
  - L2 primarily used for ionospheric group delay corrections, which can cause ranging errors of as much as 40 meters
  - transmitted power is -6 dB lower than L1

## CONSTELLATION STATUS

- 29 Healthy Satellites
  - 26 Block II/IIA on orbit (life expectancy extended another two years to 10.6)
  - 3 Block IIR satellites on orbit (last launch May 2000) - 21 Block IIR procured

- First six Block IIF satellites on contract - options for 27 additional

- Four launches likely over next two years

**PRESIDENTIAL DECISION DIRECTIVE - 1996**

- Free to peaceful use worldwide
- Dual civil/military system
- Turn off SA by 2006
- Military/civil Interagency GPS Executive Board (IGEB) to manage GPS
- DoD must:
  - Protect friendly use
  - Prevent adversary use
  - Preserve civil use outside area of operations

**WHY MODERNIZE?**

- Support to civil users:
  - new civil signals for improved accuracy, integrity and continuity - robustness
  - compatibility with civil aviation systems
- Support for defense operations:
  - more signal power - anti-jam
  - more secure military code structure
  - more user equipment anti-jam
  - able to deny enemy use of GPS

**GPS USER "WANTS"**

- Defense wants:
  - more jam resistance
  - more security
  - shorter time to first fix
  - backward compatibility
- Defense Solution - M-code (L1/L2)
  - higher power
  - spectral separation from civil signals
  - faster signal acquisition
  - improved security codes
- Civil wants:
  - accuracy
  - availability
  - coverage
  - integrity
  - robustness (more power and redundant signals)

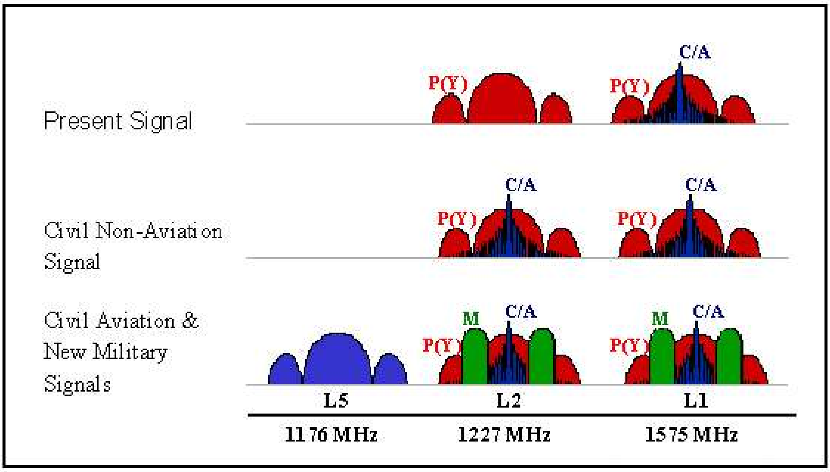
- Civil Solution - C/A-code (L2) and L5
  - SA off
  - Second civil signals for ionospheric correction and redundancy
  - Third civil signal for improved accuracy and real-time applications
  - Spectrum protection for safety-of-life applications

**SELECTIVE AVAILABILITY - May 2000**

- Selective Availability (SA) set to zero (0) in May 2000.

**SIGNAL EVOLUTION**

- Second Non-Aviation Civil Signal on L2. FAA opposes the use of L2 for aviation safety applications because ITU has authorized this band for use on a co-primary basis with radiolocation services (high power radars) which may cause unacceptable levels of interference.
- Third Civil Signal on L5 (1176.45 MHz) in the Aeronautical Radio Navigation Service (ARNS) band. ITU must designate a satellite-to-earth transmission classification for this band (currently ground-to-air).




- Existing C/A-codes on L1 and P/(Y)-codes on L1 and L2 will be retained for backward compatibility. Continuation of these codes is necessary until modernized spacecraft transmitting the new signals for civil and military users are deployed and user equipment is available. (10 - 25 years).
- Plans are to continue C/A-codes on L1 and transmit C/A-codes on L2 from replenishment satellites.

- New L5 signal will consist of a 10.23 Mcps code rate with a code length of 10,230 bits. This high-rate code sequence will provide improved ranging accuracy, lower code-noise floor, better cross-correlation properties, acceptable acquisition times, better isolation between codes and reduced multipath interference.
- L5 will transmit two signals in phase quadrature. One will not carry data modulation and will provide advantages for accurate phase tracking and more precise carrier-phase measurements.
- P/(Y)-code on L1 and L2 have an extremely long sequence (~1013 bits) with a period of seven days. Acquisition of this code is difficult without some knowledge of the code timing. P/(Y)-code acquisition involves acquiring the C/A-codes on L1 (short sequence - 1 millisecond) first. The C/A-code message contains timing data that provides an authorized user with information for acquiring the P/(Y)-code. DoD wants to acquire their secure signals without using the civil codes first.
- M-Code is "split spectrum" secure code on L1 and L2. Code will have a bit rate of 3-8 Mbps modulated on dual carriers spaced 6-9 MHz above and below the center of L1 and L2 bands.
- DoD will retain P/(Y)-codes until the M-code signals are generally available. Phase-over is expected to take until 2020, based on the current rate of spacecraft replacement.

**POWER**

- In general - a 3 to 6 dB increase in power for all civil signals
- C/A-code on L1 and L2 = -160 dBw
- P/(Y)-code on L2 (normally used for ionospheric corrections in past) will increase by 6 dB
- L5 signal in ARNS band will require a power level 6 dB greater that the CA-code on L1 to compensate for higher levels of interference and noise in this band.
- Military signals on L1 and L2 will be 6-10 dB higher than they are now.

**MODERNIZATION PROGRAM**

- Modify Block IIR (up to 12 satellites)
  - Second civil signal - C/A-code on L2
  - M-code on L1 and L2
  - Continue military P/(Y)-code on L1 and L2
  - More power for all signal services
  - Provide 14 days of operation without contact from control and up to 180 days of operation when operating in the autonomous navigation (AUTONAV) mode. Spacecraft maintain their accuracy by communicating with other IIR satellites in orbit (cross-link ranging).
- Modify Block IIF (6 already under development)
  - Second civil signal - C/A-code on L2
  - Third civil signal - new civil code on L5

- M-code on L1 and L2
- Continue military P/(Y)-code on L1 and L2
- More power for all signal services

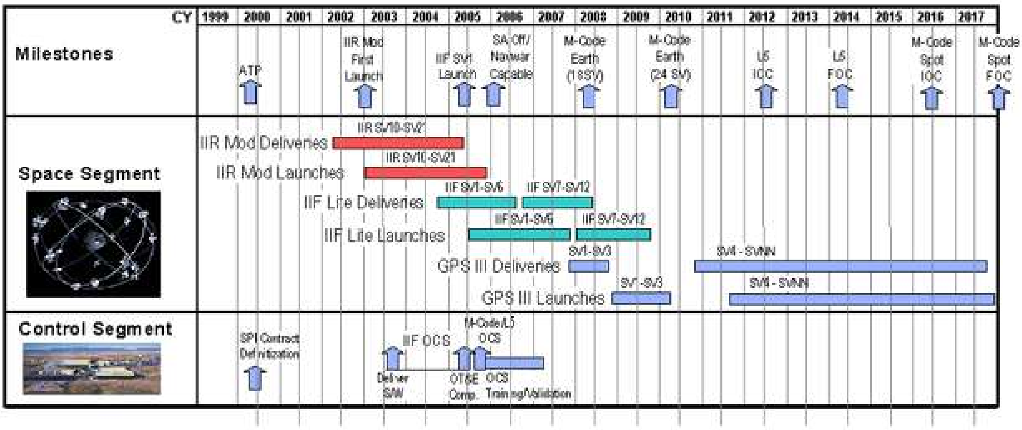
• GPS III
  - Assess future system level requirements to 2030
  - System Architecture/Requirements Phase
  - Program Definition/Risk Reduction Phase
  - Engineering/Manufacturing/Development Phase

• Operational Ground Control Segment
  - Support Block IIR, IIF testing and operational capability
  - Addition of six National Imagery and Mapping Administration (NIMA) ground stations to the tracking network
  - improve quality and timeliness of (latency) of tracking measurements and computed parameters
  - 2000-2010 - submeter ephemeris accuracy that will improve to decimeter range.
  - System Test Bed to validate signals and prototype user equipment

**SCHEDULE**

• Last 12 Block IIRs - add second civil signal (C/A on L2) - new military signal (M-code) - more signal power
• First 6 Block IIFs - all of above capabilities plus new third civil signal in protected band (L5).
• Next [nominally] 6 Block IIFs - procured as necessary to sustain the constellation.
• GPS III (Full Modernization) - meets future requirements through 2030 - more M-code signal power
• First modernized launch (Block IIR) - 2003
  - First Block IIF launch - 2005
• M-code (earth coverage) IOC (18 satellites) 2008
• Full Performance IOC 2016
• OCS - evolutionary incremental development

## TIMELINE




## IMPACT

- More anti-jam for defense
  - GPS accuracy maintained closer to the target in a high jamming environment
- More secure, robust military signal service
  - assured acquisition of the GPS signal when needed in a hostile electronic environment
- Deny enemy the military advantage of GPS
  - Protect friendly force operations
  - Preserve peaceful GPS use outside Area of Operations
- Availability of additional civil GPS signals
  - compatibility with GPS signals for civil aviation