CNS

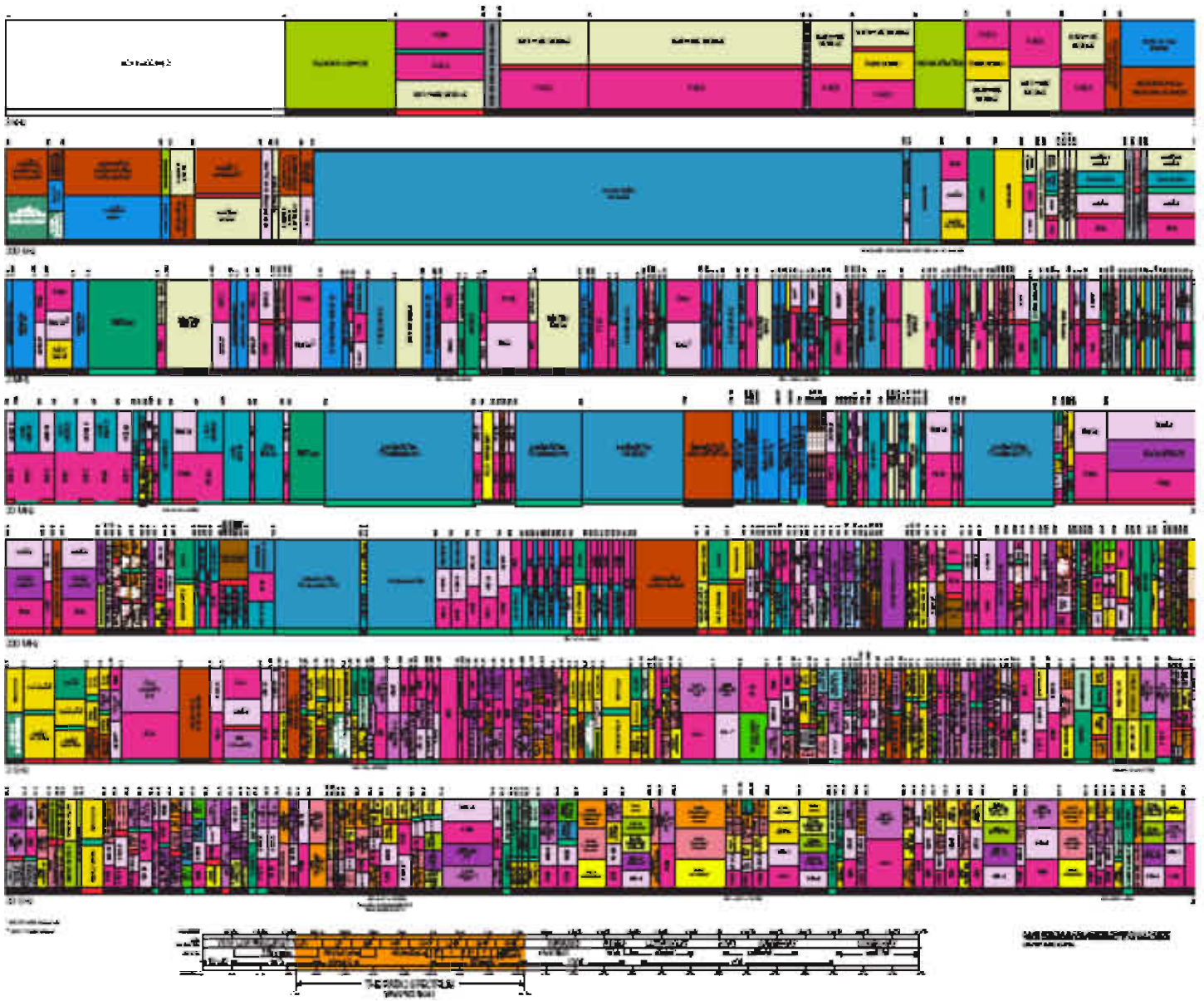
Prof. R. John Hansman, Director
MIT International Center for Air Transportation

COMPONENTS OF AIR TRANSPORTATION INFRASTRUCTURE

- **Airports**
  - ❑ Runways
  - ❑ Terminals
  - ❑ Ground transport interface
  - ❑ Servicing
  - ❑ Maintenance
- **Air traffic management**
  - ❑ Communications
  - ❑ Navigation
  - ❑ Surveillance
  - ❑ Control
- **Weather**
  - ❑ Observation
  - ❑ Forecasting
  - ❑ Dissemination
- **Skilled personnel**
- **Cost recovery**

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM



THE RADIO SPECTRUM

RADIO SERVICES COLOR LEGEND

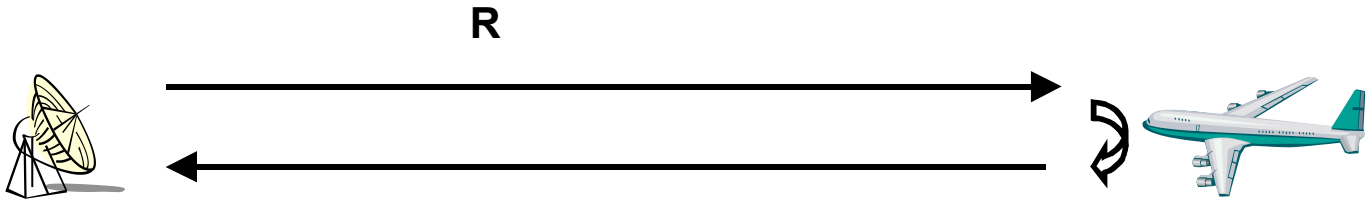
- AERONAUTICAL MOBILE
- AERONAUTICAL MOBILE SATELLITE
- AERONAUTICAL RADIONAVIGATION
- AMATEUR
- AMATEUR SATELLITE
- BROADCASTING
- BROADCASTING SATELLITE
- EARTH EXPLORATION SATELLITE
- FIXED
- FIXED SATELLITE
- INTER-SATELLITE
- LAND MOBILE
- LAND MOBILE SATELLITE
- MARITIME MOBILE
- MARITIME MOBILE SATELLITE
- MARITIME RADIONAVIGATION
- METEOROLOGICAL AIDS
- METEOROLOGICAL SATELLITE
- MOBILE
- MOBILE SATELLITE
- RADIO ASTRONOMY
- RADIODETERMINATION SATELLITE
- RADIOLOCATION
- RADIOLOCATION SATELLITE
- RADIONAVIGATION
- RADIONAVIGATION SATELLITE
- SPACE OPERATION
- SPACE RESEARCH
- STANDARD FREQUENCY AND TIME SIGNAL
- STANDARD FREQUENCY AND TIME SIGNAL SATELLITE

ACTIVITY CODE

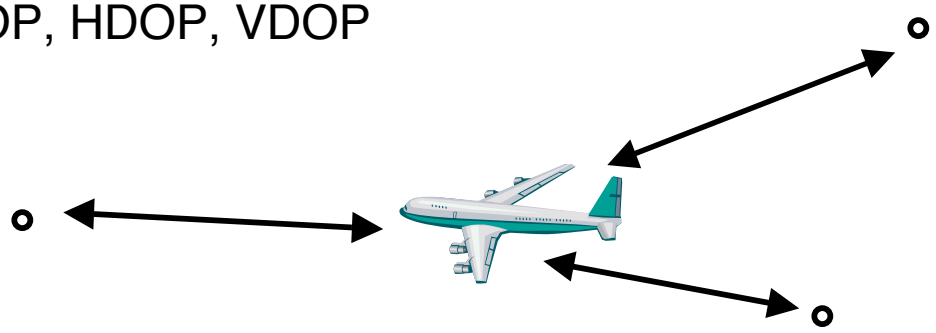
- GOVERNMENT EXCLUSIVE
- GOVERNMENT/ NON-GOVERNMENT SHARED
- NON-GOVERNMENT EXCLUSIVE

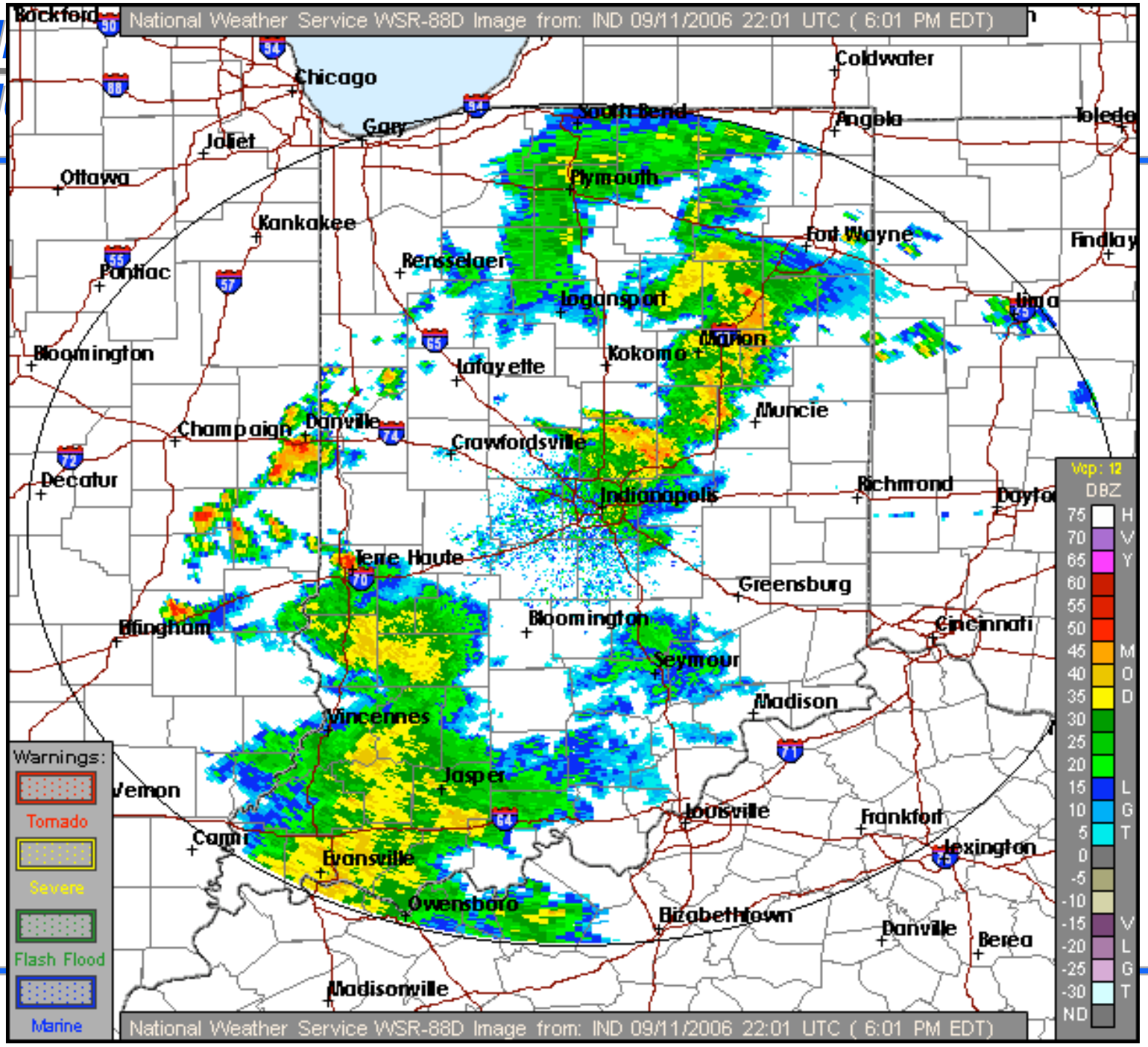
Timing Techniques

- **Problem with calibrating power**
- **Time of flight**
  - ❑ Tor = 2Rc + transponder relay time



- **Multi-lateration**
  - ❑ GDOP, HDOP, VDOP




National Weather Service WSR-88D Image from: IND 09/11/2006 22:01 UTC (6:01 PM EDT)
Rockford
Chicago
Gary
South Bend
Coldwater
Angola
Toledo
Joliet
Ottawa
Plymouth
Kankakee
Fort Wayne
Findlay
Pontiac
Rensselaer
Logansport
Lima
Bloomington
Marion
Kokomo
Lafayette
Champaign
Danville
Muncie
Crawfordsville
Decatur
Richmond
Indianapolis
Terre Haute
Greensburg
Bloomington
Cincinnati
Effingham
Seymour
Madison
Vincennes
Jasper
Louisville
Frankfort
Lexington
Evansville
Owensboro
Elizabethtown
Danville
Berea
Madisonville
Warnings:
Tornado
Severe
Flash Flood
Marine
Vcp: 12
DBZ
75 H
70 V
65 Y
60
55
50
45 M
40 O
35 D
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20
15 L
10 G
5 T
0
-5
-10
-15 V
-20 L
-25 G
-30 T
ND
National Weather Service WSR-88D Image from: IND 09/11/2006 22:01 UTC (6:01 PM EDT)

COMMUNICATION TRENDS

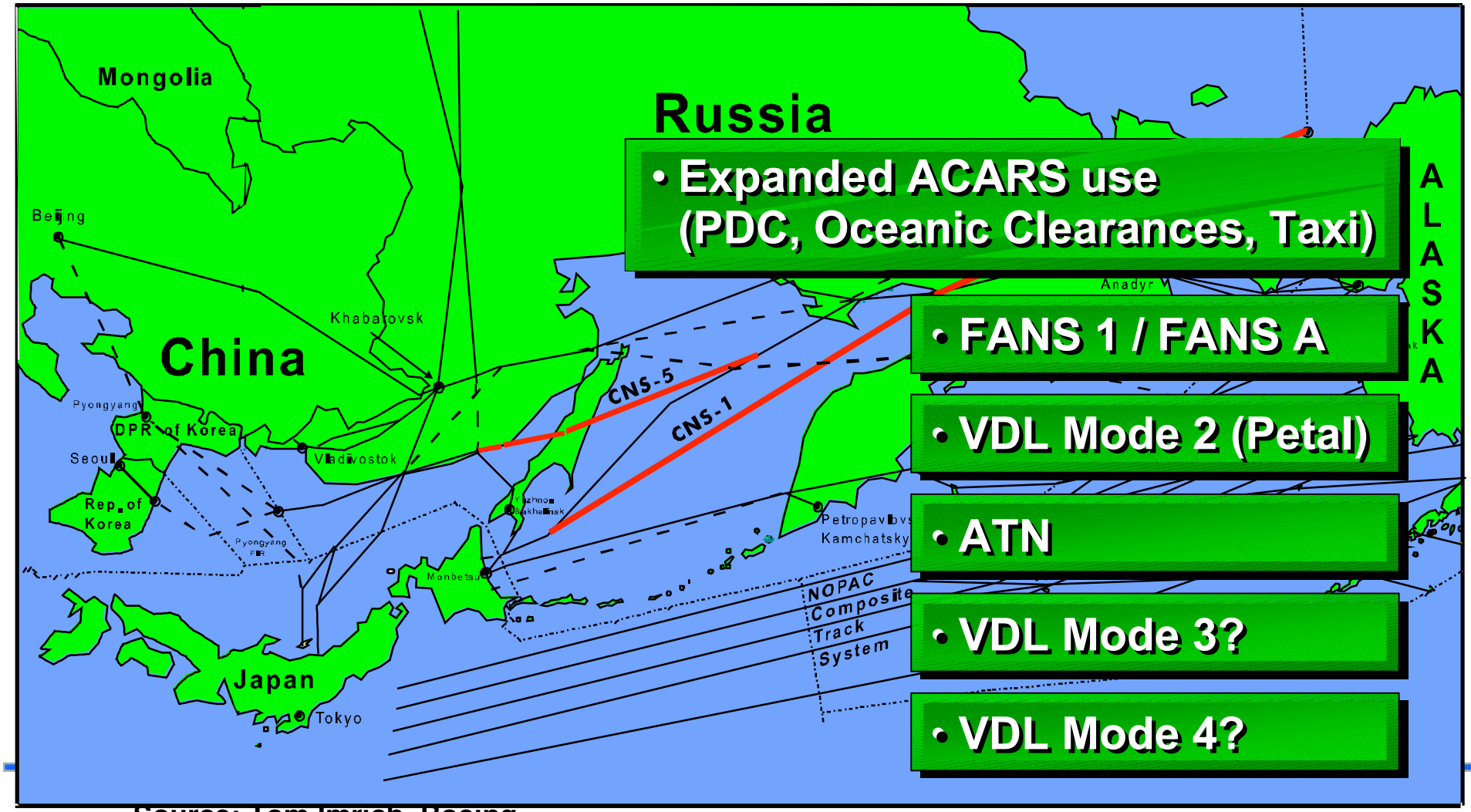
- **Voice**
  - ❑ VHF (line of sight), 25khz, spacing US, 8.33 khz Europe
  - ❑ HF (over the horizon)
  - ❑ Ground lines
- **Datalink (line of sight)**
  - ❑ ACARS (VHF)
  - ❑ VHF Data Link (VDL) Modes 2 (31.5kbps), Mode 4
  - ❑ CPDLC
- **Aeronautical Telecommunications Network (ATN)**
  - ❑ CDMA, TDMA
  - ❑ TCP/IP

COMMUNICATION TRENDS

- **Satellite**
  - ❑ Geosynchronous (data, voice, images)
    - ◆ Air-ground
    - ◆ Ground-ground
  - ❑ LEO and MEO Networks
    - ◆ (XM & Sirius Data Downlinks (WX)
- **Groundlines**
  - ❑ Switches

Communication Trend

Datalink Standardization Challenge



Source: Tom Imrich, Boeing

http://nas-architecture.faa.gov/nas/mechanism/mech_data.cfm?mid=100021

NAS Architecture Elements
Communication 1

Aeronautical Telecommunication Network Air to Ground Router (ATN A/G Router) (ATN A/G Router
Data Communication (Data Communication...
- Aeronautical Data Link (ADL) - Enhanced (ADL-E
- Aeronautical Data Link Decision Support System Services (ADL DSSS
- Aeronautical Data Link National Deployment (ADL National Deployment
- Alaskan NAS Interfacility Communications System Phase II (ANICS Phase II
- Commercial Weather Vendor (CWV
- Communications Management System (CMS
- Controller-Pilot Data Link Communications Build I (CPDLC Bld I
- Controller-Pilot Data Link Communications Build IA (CPDLC Bld IA
- Controller-Pilot Data Link Communications National Deployment (CPDLC National Deployment
- FAA Telecommunications Satellite (FAATSAT
- Flight Information Service - Data Link (FISDL
- High Frequency Data Link (HF Data Link
- Multi-Sector Oceanic Data Link (MSODL
- NGATS Data Communications (NGATS Data Comm
- NOTAM Distribution Program (NDP
- Satellite Telecommunications Data Link (SATCOM DL
- System Wide Information Management (SWIM
- System Wide Information Management Spiral 1 (SWIM Spiral 1
- System Wide Information Management Spiral 2 (SWIM Spiral 2
- System Wide Information Management Spiral 3 (SWIM Spiral 3
- Terminal Weather Information for Pilots (TWIP
- Tower Data Link System Refresh (TDLS Refresh

Video Communication (Video Communication...)

http://nas-architecture.faa.gov/nas/mechanism/mech_data.cfm?mid=100021

NAS Architecture Elements
Communication 2 (voice)

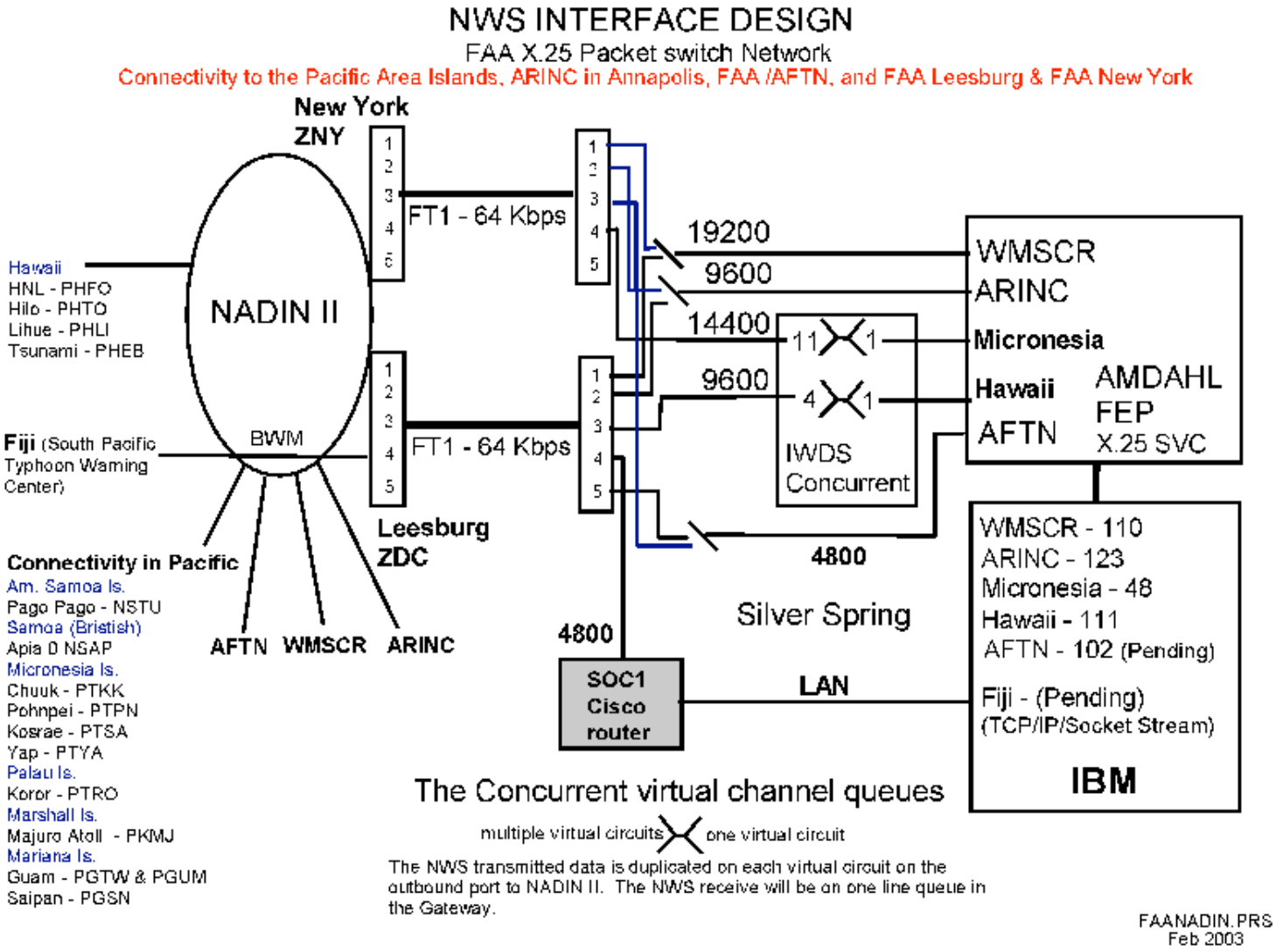
Voice Communication (Voice Communication...
- Air/Ground Communications RFI Elimination (RFI ELIM
- Backup Emergency Communications (BUEC
- Command and Control Communications (C3
- Conference Control System (CCS
- Digital Voice Recorder System (DVRS/DVR2
- Digital Voice Recorder System Replacement (DVRS Repl
- Emergency Transceiver Replacement (ETR
- Emergency Voice Communications System (EVCS
- Enhanced Terminal Voice Switch (ETVS
- Future Communications Infrastructure - Phase 1 (FCI-P1
- Future Radio System - Phase 1 (FRS-P1
- High Frequency Communications (HF Communications
- Integrated Communications Switching System Type I (ICSS I
- Multi-Channel Recording System (MCR
- Multi-Mode Digital Radios (MDR
- NAS Voice Switch (NVS
- Radio Control Equipment Sustainment (RCE Sustain
- Rapid Deployment Voice Switch Type I (RDVS I
- Satellite Communications (SATCOM
- Small Tower Voice Switch (STVS
- Ultra High Frequency Ground Radios (UHF Ground Radios
- Ultra High Frequency Ground Radios - Replacement (UHF Ground Radios - Relp
- Very High Frequency Ground Radios (VHF Ground Radios
- Very High Frequency/Ultra High Frequency Emergency Communications Transceivers - Term
- Voice Switching and Control System (VSCS
- Voice Switching and Control System Training and Backup Switches (VTABS)

http://nas-architecture.faa.gov/nas/mechanism/mech_data.cfm?mid=100021

NAS Architecture Elements
Communication 3 (WAN)

WAN Communication (WAN Communication...
- Aeronautical Telecommunication Network Ground to Ground Router (ATN G/G Router
- Agency Data Telecommunications Network 2000 (ADTN2000
- Alaskan National Airspace System Interfacility Communications System (ANICS
- Alaskan National Airspace System Interfacility Communications System Phase II (ANICS Phase II
- Bandwidth Manager (BWM
- Data Multiplexing Network (DMN
- En Route Communications Gateway (ECG
- En Route Communications Gateway Technology Refresh (ECG Tech Refresh
- FAA Bulk Weather Telecommunications Gateway (FBWTG
- FAA Telecommunications Infrastructure (FTI
- Federal Aviation Administration Telecommunications Satellite (FAATSAT
- Federal Telecommunications System 2001 (FTS 2001
- High Frequency Aeronautical Telecommuniction Network Data Link (HF ATN DL
- Interfacility Communications (Interfacility Comm
- Leased Inter-facility National Airspace System Communication System (LINCS
- Low-Density Radio Communications Link (LDRCL
- National Airspace Data Interchange Network Message-Switched Network (NADIN MSN
- National Airspace Data Interchange Network Packet-Switched Network (NADIN PSN
- Next Generation Messaging (NEXGEN Messaging
- Radio Communication Link (RCL
- Radio Control Equipment (RCE
- System Wide Information Management (SWIM
- Weather Message Switching Center Replacement (WMSCR
- Weather Message Switching Center Replacement (WMSCR) Sustain (WMSCR Sustain)

Federal Telecom Infrastructure (FTI National Aviation Data Integration Networ (NADIN)



NAVIGATION TRENDS (ENROUTE)

- **Radionavigation beacon**
  - ❑ VHF Omnidirectional Range (VOR)
  - ❑ Non-Directional Beacon (NDB)
  - ❑ Distance Measuring Equipment (DME)
  - ❑ TACAN
- **Aero navigation systems (ground based)**
  - ❑ Omega
  - ❑ LORAN
- **Inertial navigation systems**
- **Satellite navigation systems**
  - ❑ GPS (CA)
  - ❑ Glonass
  - ❑ GNSS

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  - ❑ Glonass
  - ❑ GNSS

LORAN

- Master Slave Architecture
- Low Frequencey (100khz) Center Freq
- Hyperbolic Coordinates
- Geometric Dilution of Precision

GPS Frequencies

- * L1 (1575.42 MHz):
- Carries a publicly usable coarse-acquisition (C/A) code as well as an encrypted precision P(Y) code.
- * L2 (1227.60 MHz):
- Usually carries only the P(Y) code, but will also carry a second C/A code on the Block III-R satellites.
- * L3 (1381.05 MHz):
- Carries the signal for the GPS constellation's alternative role of detecting missile/rocket launches (supplementing Defense Support Program satellites), nuclear detonations, and other high-energy infrared events.
- * L4 (1841.40 MHz):
- Being studied for additional ionospheric correction.
- * L5 (1176.45 MHz):
- Proposed for use as a civilian safety-of-life (SoL) signal. This frequency falls into an internationally protected range for aeronautical navigation, promising little or no interference under all circumstances. The first Block IIF satellite that would provide this signal is set to be launched in 2008.

http://en.wikipedia.org/wiki/GPS

GPS ISSUES

- **Requirements**
  - ❑ Accuracy
  - ❑ Integrity
  - ❑ Availability
- **Selective Availability (SA)**
  - ❑ Degraded to 100m accuracy
- **Control by US DoD**
  - ❑ International concerns
- **US guarantee of service free to world through 2005**
- **Vulnerability to jamming**
- **DGPS**
  - ❑ WAAS
  - ❑ EGNOS
  - ❑ LAAS

NAVIGATION TRENDS (APPROACH)

- **Instrument Landing System (ILS)**
  - ❑ Cat. I (200 ft; 1/4 mile)
  - ❑ Cat. II (50 ft; 800 RVR)
  - ❑ Cat. III (0,0)
- **Microwave Landing System (MLS)**
- **GPS (100m)**
  - ❑ Wide Areas Augmentation System (5m)
    - ◆ Cat. I, Cat. II
  - ❑ Local Areas Augmentation System (0.1m)
    - ◆ Cat. III
- **Change to Required Navigation Performance (RNP)**

GPS Approach Navigation

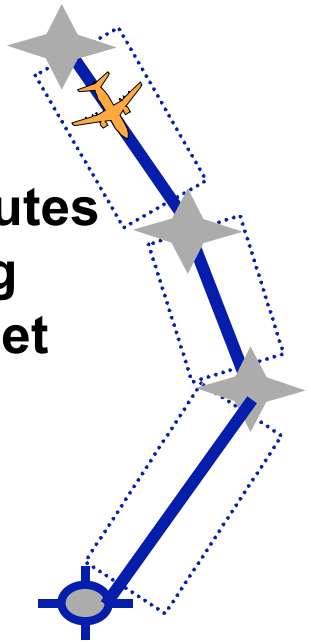
- **Requirements**
  - ❏ Accuracy (RNP) -
  - ❏ Availability
  - ❏ Integrity

- **Differential GPS**
  - ❏ SBAS Sattelite Base Augmentation Systems
    - ◆ Wide Area Augmentation System (WAAS)
      - ➪ Non-Precision Approaches (GPS Overlay)
      - ➪ RNAV Approachet
      - ➪ LPV Approaches (250 ft, 1/4 mile)
  - ❏ Ground Based Augmentation Systems
    - ◆ Local Area Augmentation System (LAAS)
      - ➪ GLS (Cat II+)

RNAV and RNP: Key Building Blocks of Performance-based Navigation

RNAV

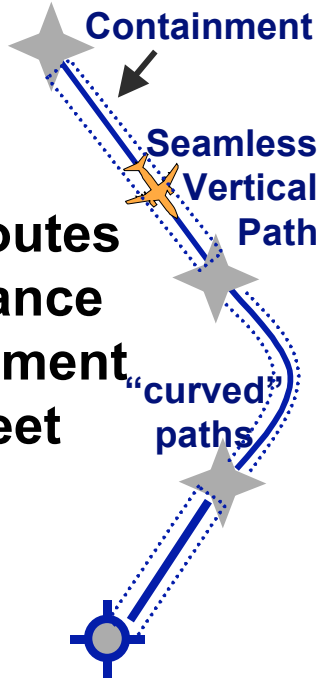
- Point-to-point routes
- Radar monitoring
- 90+% capable fleet



Increased Airspace Efficiency

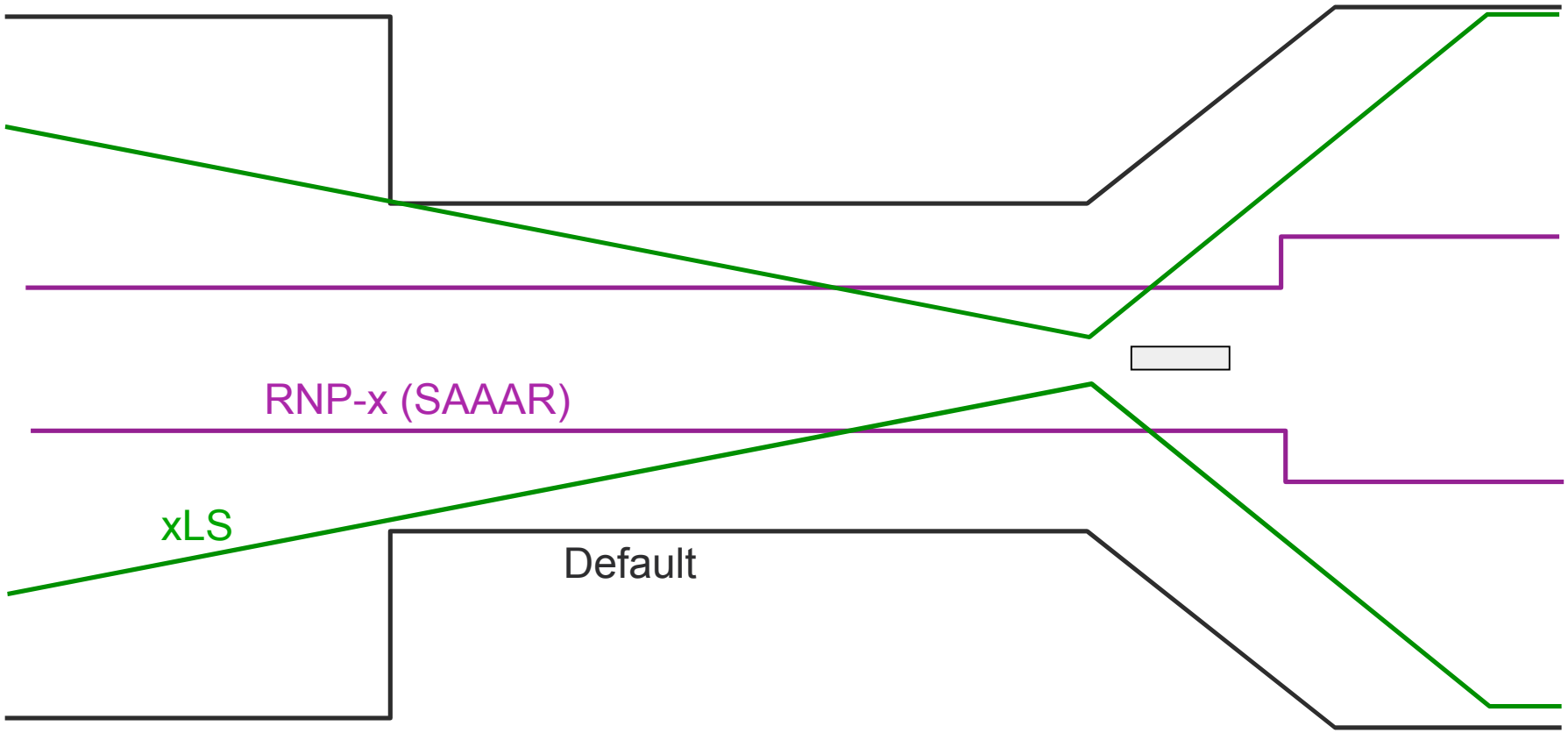
RNP

- More complex routes
- Tighter performance
- No radar requirement
- 30+% capable fleet



Optimized Use of Airspace

Performance-Based NAS Approaches



(Notional figure)

WAAS Fielding Status

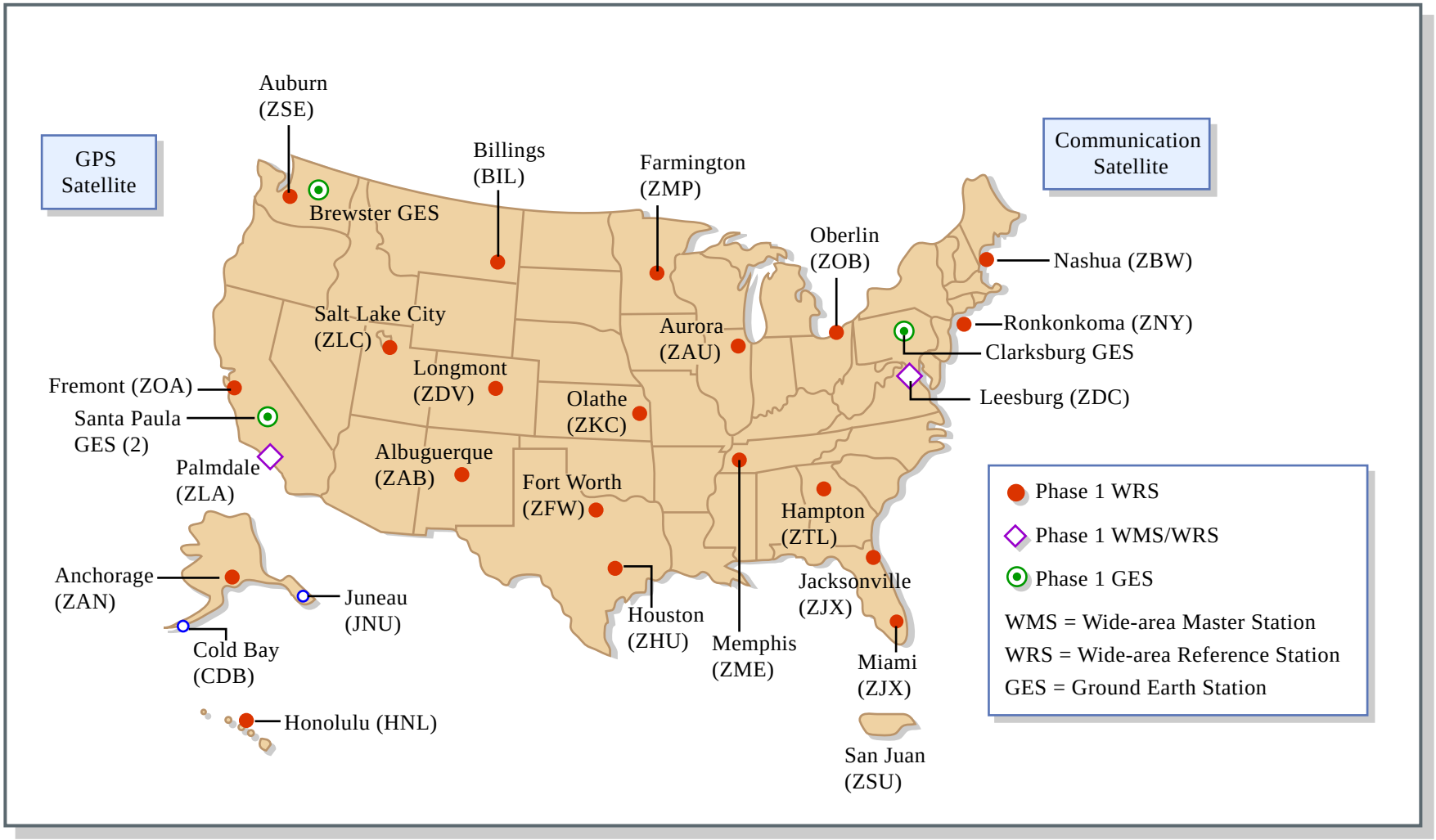
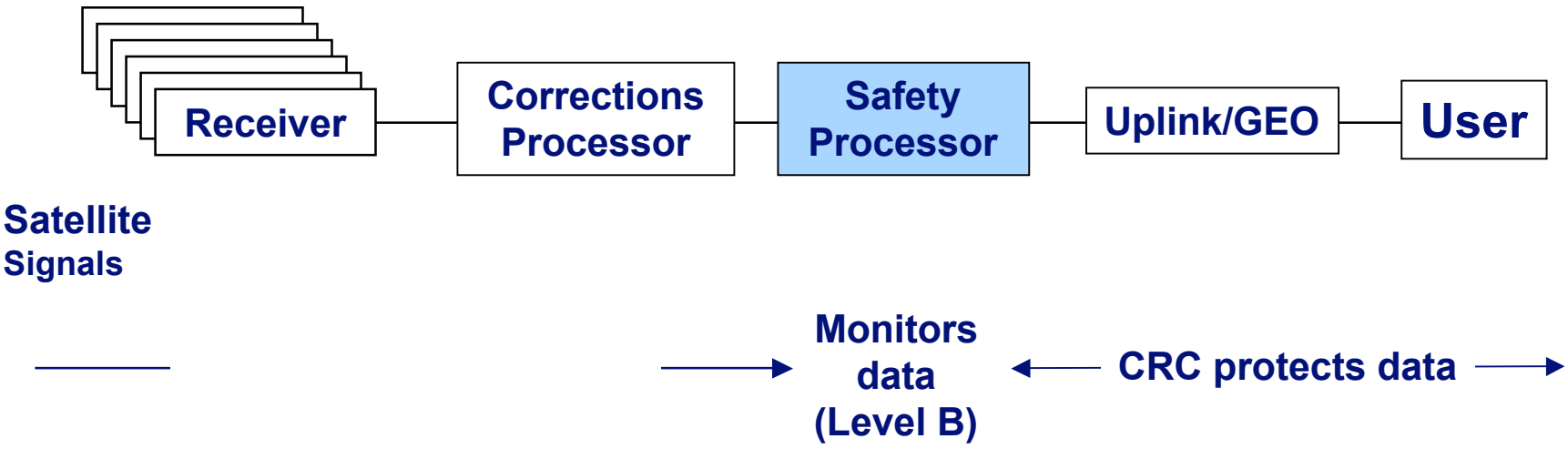


Figure by MIT OCW.

Safety Architecture



- **Weaknesses in Current System Monitor (Safety Processor)**
  - ❑ At Times Safety Processor Doesn't Monitor Data
- **Therefore, System Integrity Is Not Quantifiable**
  - ❑ Integrity Requirement Is No More Than One in 10 Million Chance of Hazardously Misleading Information (10^{-7})

GBAS Ground Based Augmentation System

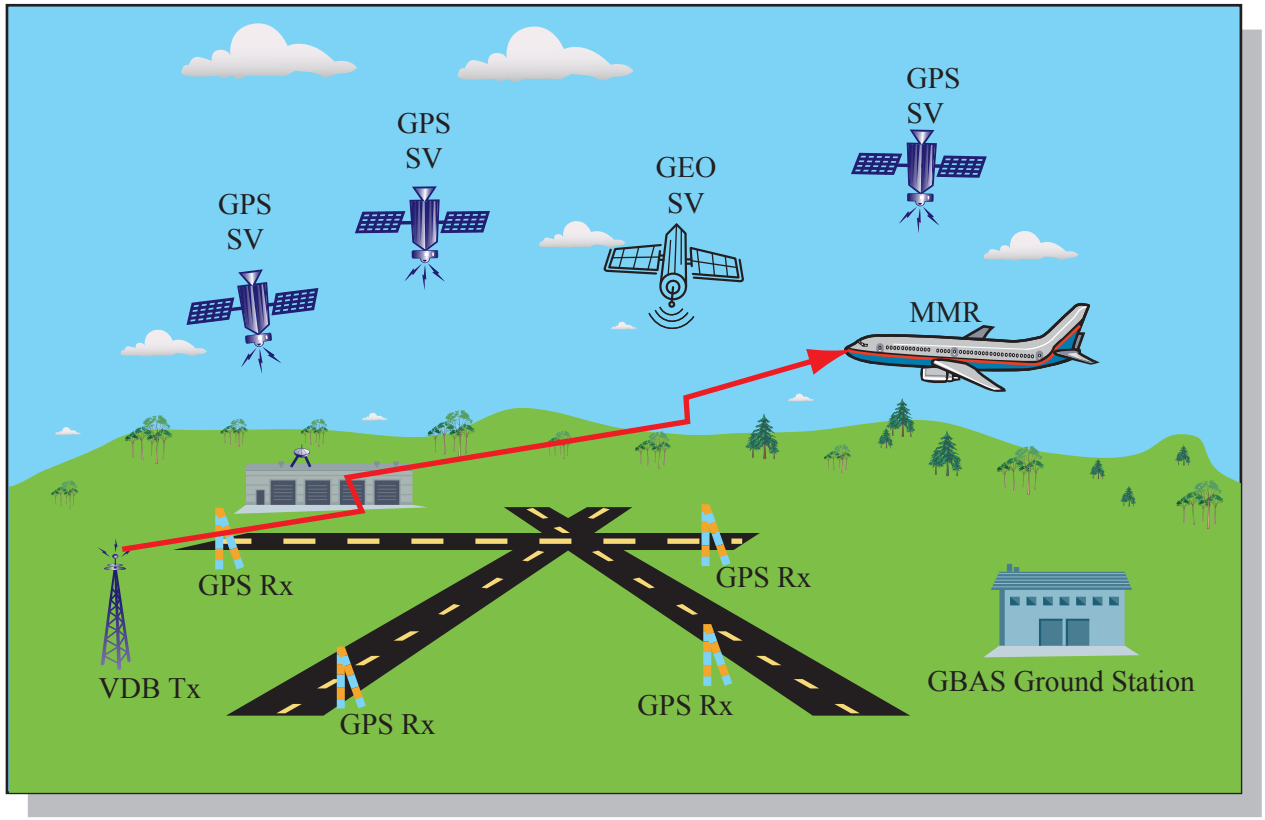


Figure by MIT OCW.

GLS - System Concept

- GPS based
- GBAS (e.g., LAAS)
- VHF Data Link
- MMR (ILS, GLS,)
- Uplinked WPs
- Multiple Paths
- Future Satellites
  (3rd Gen GPS; Galileo; Glonass)

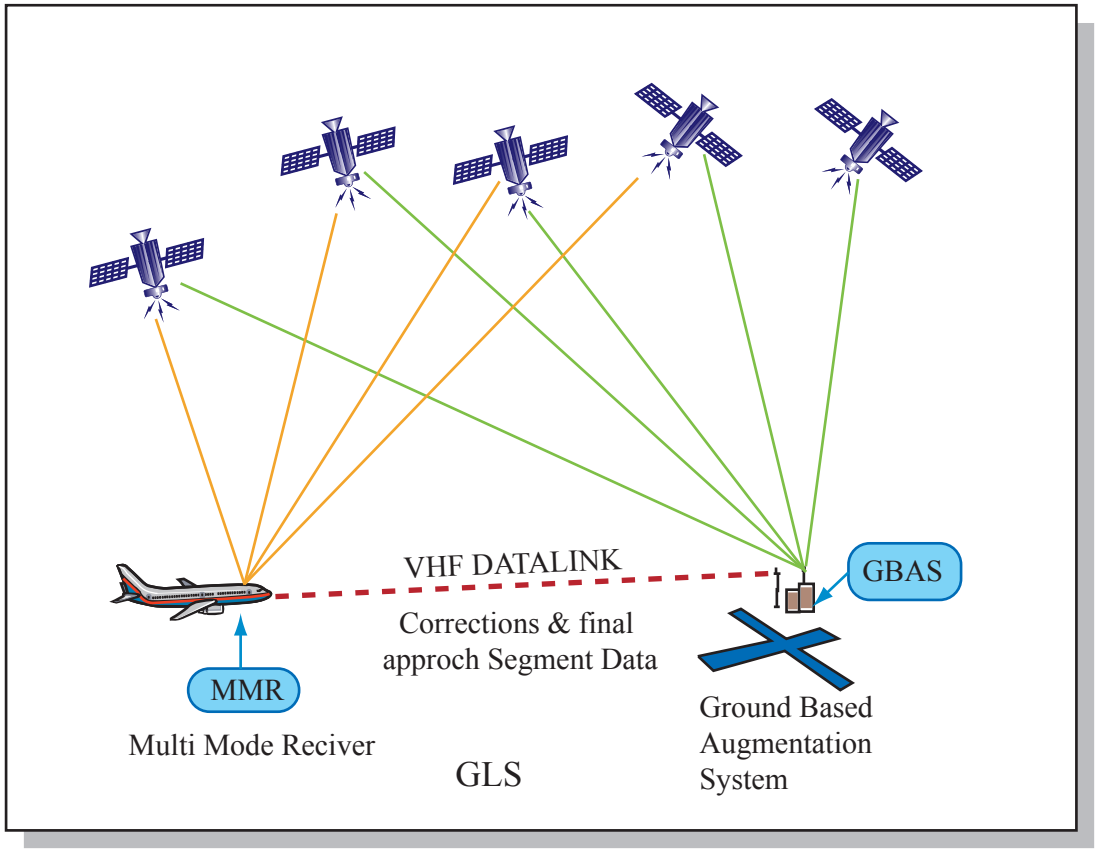
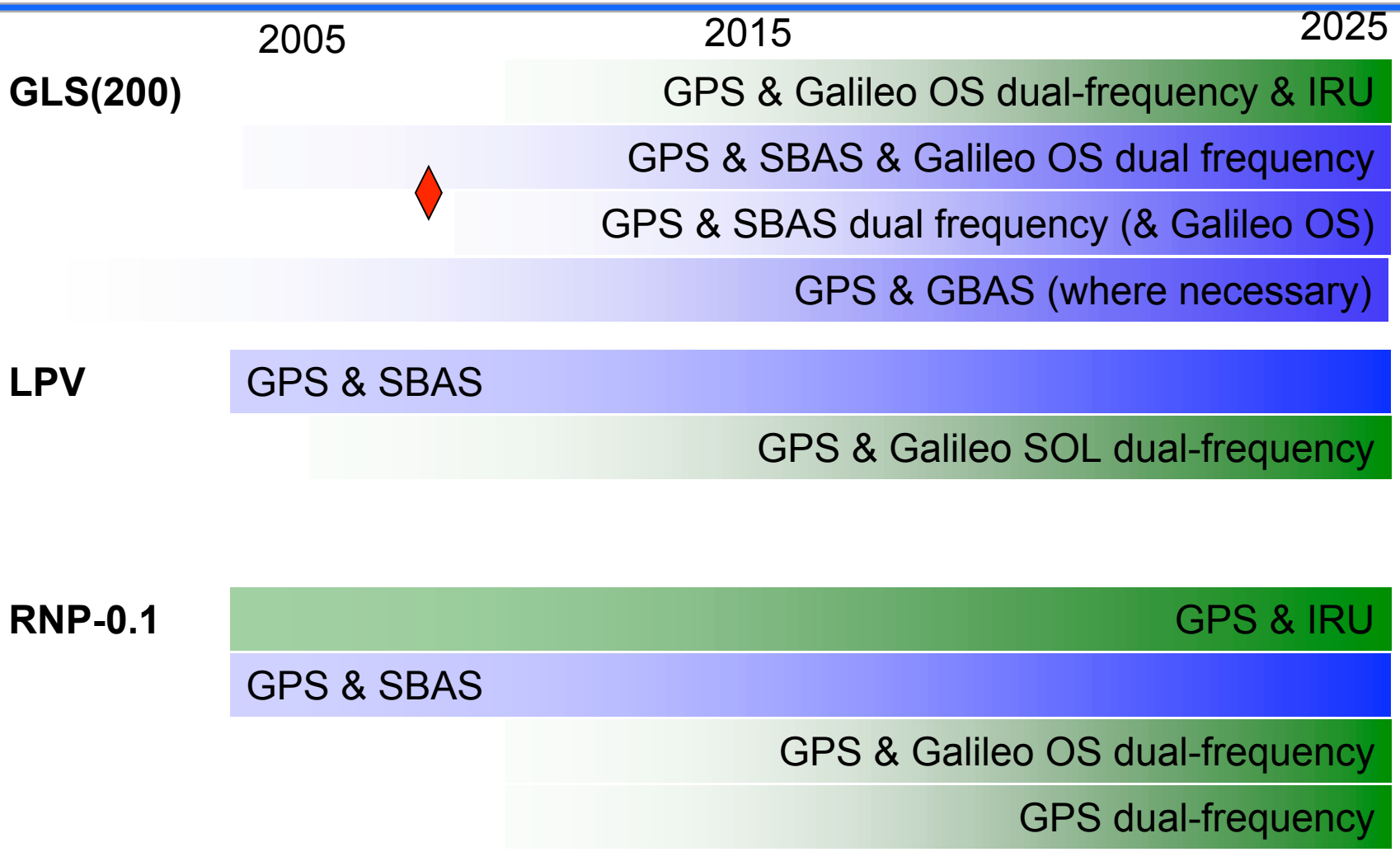


Figure by MIT OCW.

GLS - Primary Flight Display

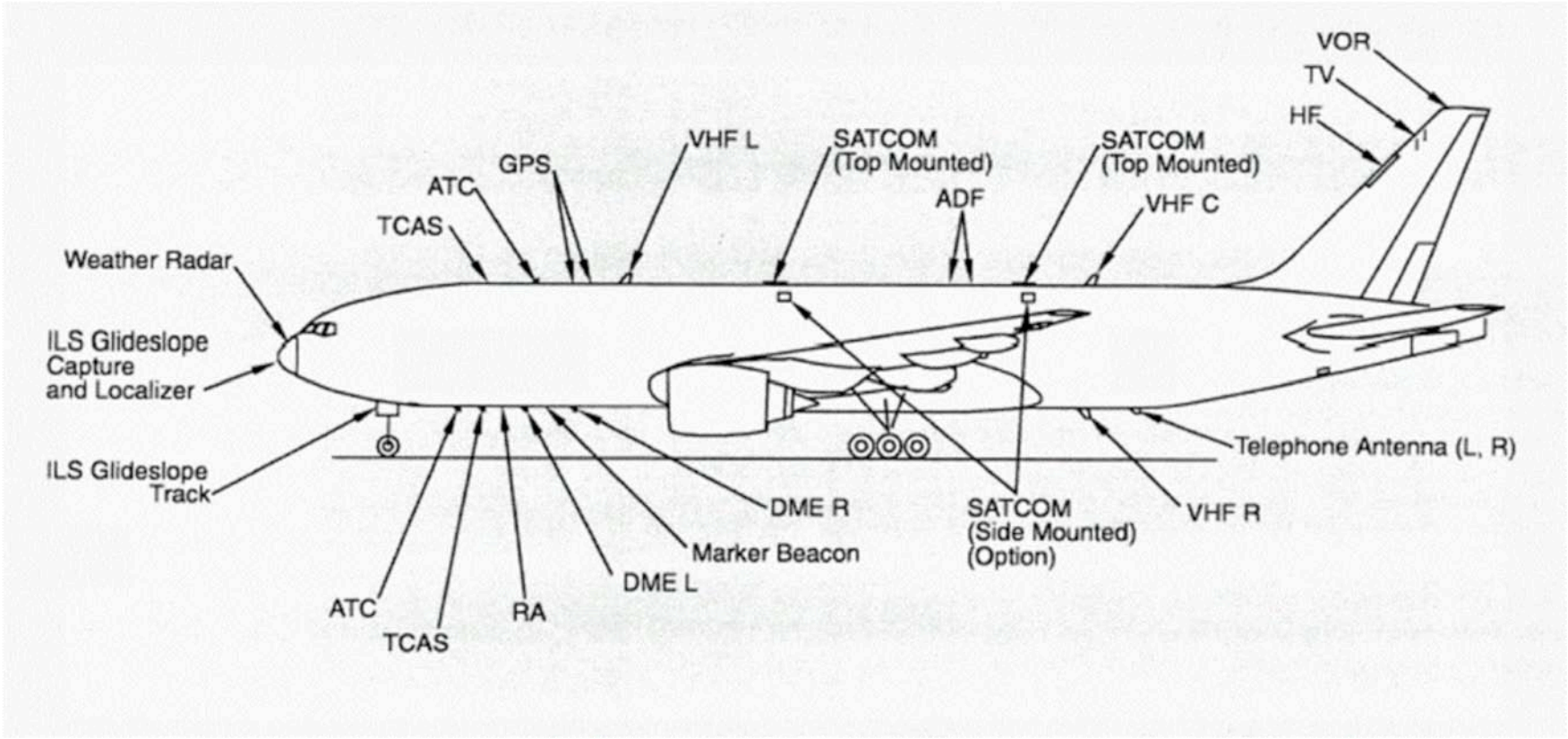
- **Path Indications - Common**
- **Autoflight Status - Common**
- **Mode Annunciation - Common**
- **NAV Source Clearly Shown**
  (ILS; GLS; FMS; ID; WP Distance)

Potential GNSS Services



Sourc: Bruce Declean (FAA)

Navigation & Communication

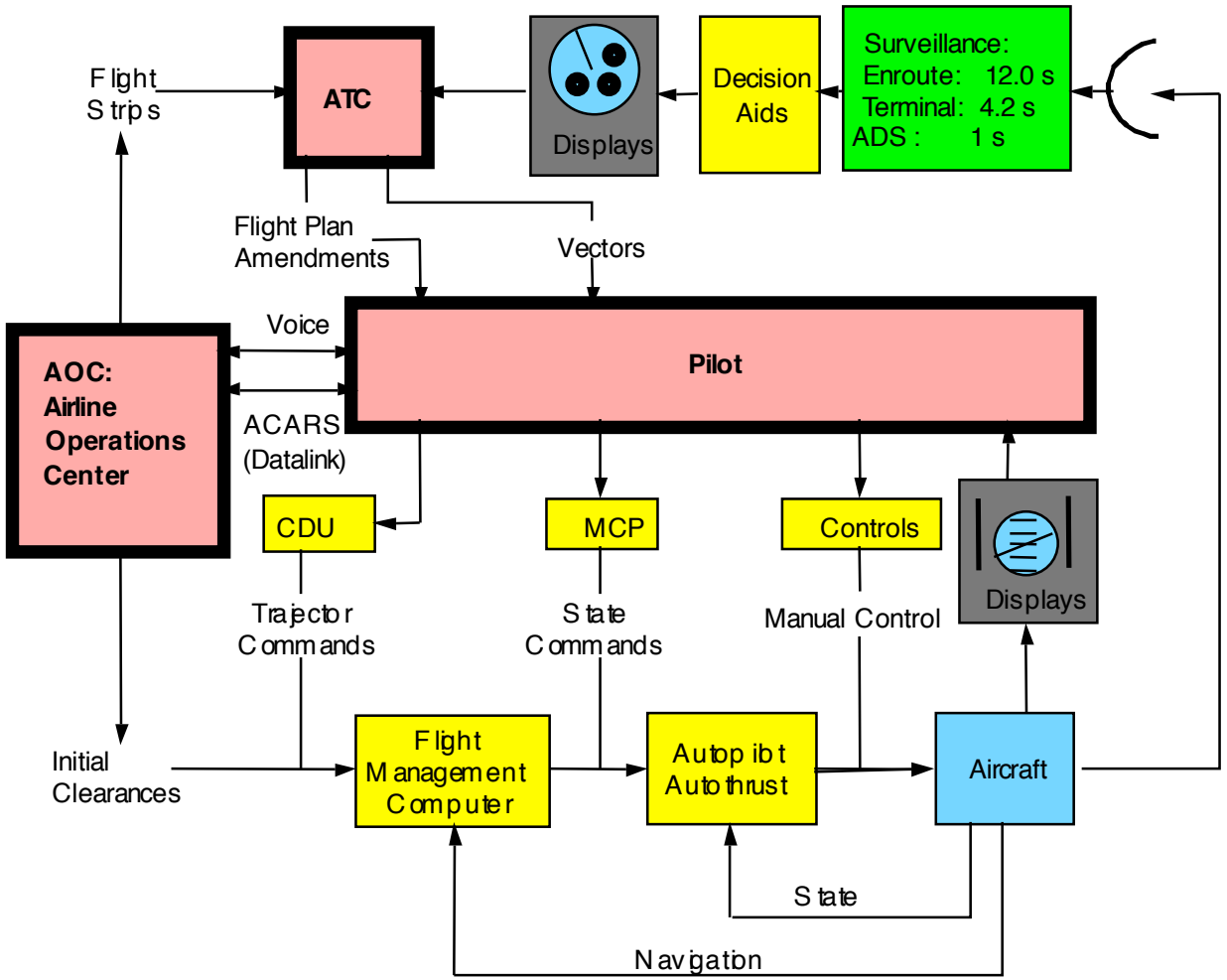


Source: Brian Kelly, Boeing

SURVEILLANCE TRENDS

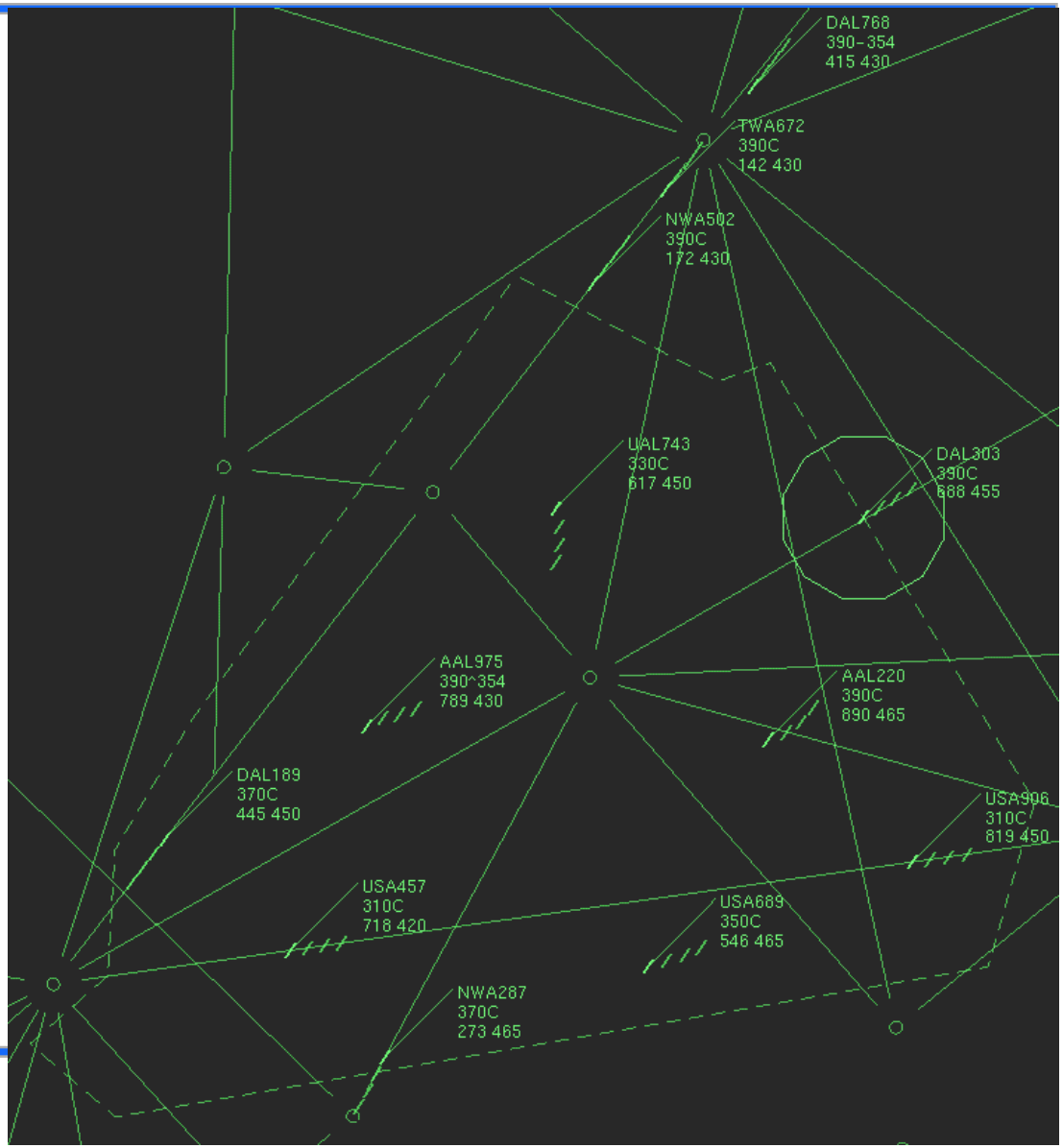
- **Primary radar**
  - ❑ Enroute (12 sec scan)
  - ❑ Terminal area (4.2 sec scan)
- **Secondary radar**
  - ❑ Transponders
    - ◆ Mode C (altitude)
    - ◆ Mode S (2-way data exchange)
- **Onboard surveillance**
  - ❑ TCAS
- **Automatic Dependent Surveillance (ADS)**
  - ❑ Oceanic (INS Based)
  - ❑ GPS squitter (Mode S)

ATC Control Loop
Radar Surveillance Limits

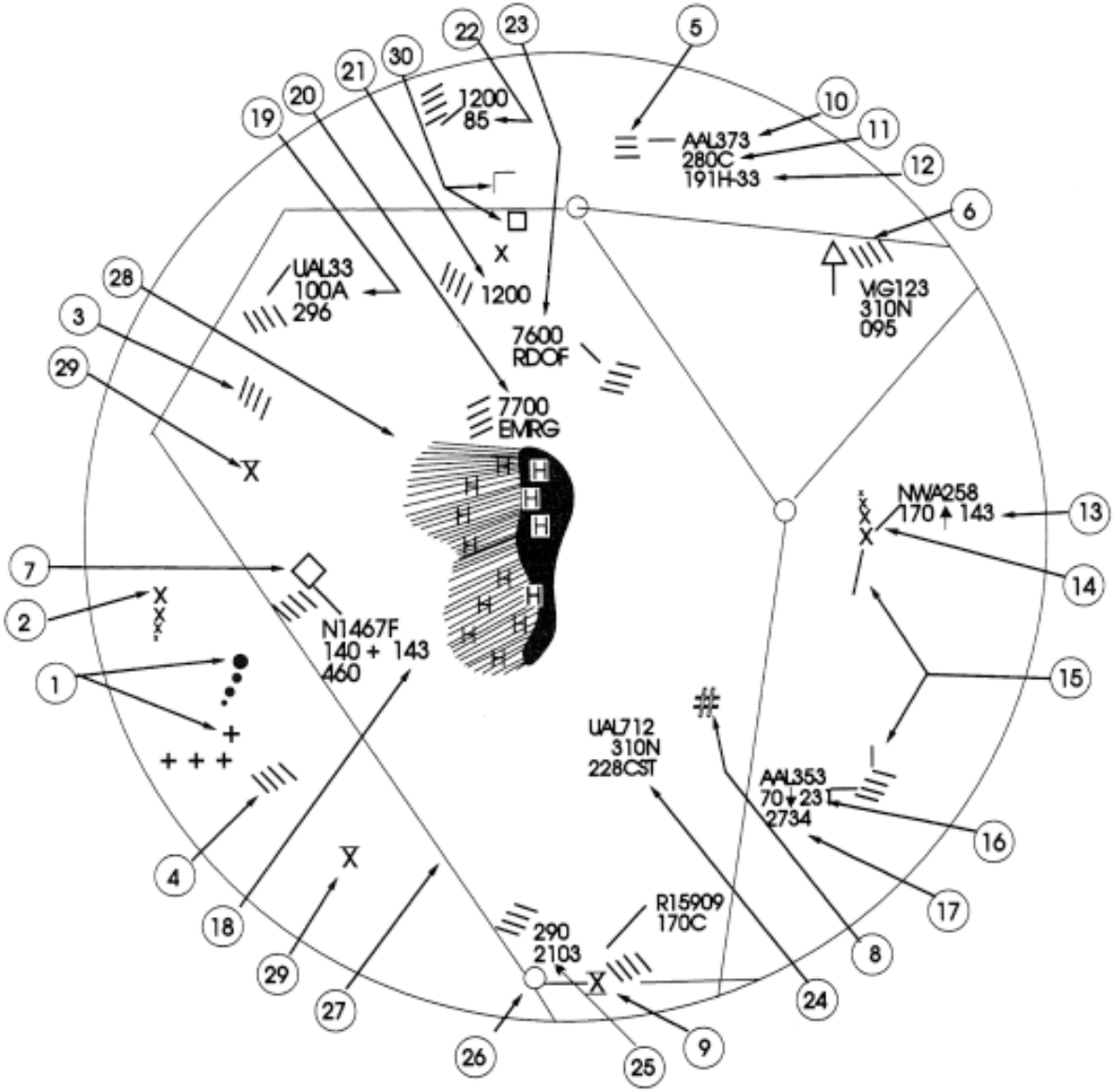


Radar Display Example

CO 123
350C
B757 310



Enroute Display



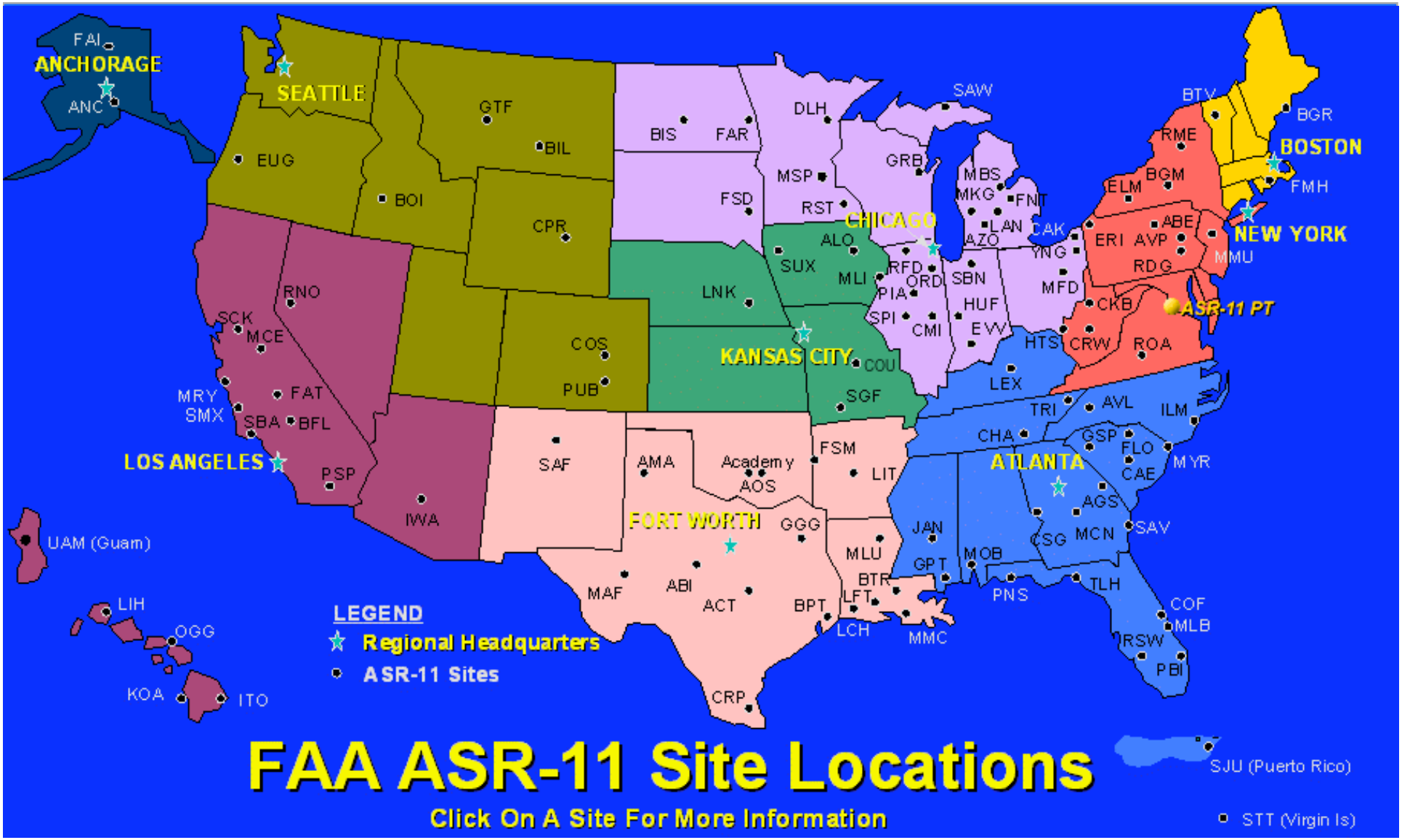
Enroute Display

1. *Uncorrelated primary radar target* [o] [+]
2. *Correlated primary radar target*
**See note below.*
3. *Uncorrelated beacon target* [/]
4. *Correlated beacon target* [\ ]
5. *Identing beacon target*
**Note: in Number 2 correlated means the association of radar data with the computer projected track of an identified aircraft.*
Position symbols:
6. *Free track (no flight plan tracking)*
7. *Flat track (flight plan tracking)*
8. *Coast (beacon target lost)* [#]
9. *Present position hold*
Data block information:
10. *Aircraft ident*
**See note below.*
11. *Assigned altitude FL 280, Mode C altitude same or within 200' of assigned altitude.*
**See note below.*
12. *Computer ID #191, handoff is to sector 33*
(0-33 would mean handoff accepted)
**See note below.*
13. *Assigned altitude 17,000', aircraft is climbing, Mode C readout was 14,300 when last beacon interrogation was received.*
14. *Leader line connecting target symbol and data block.*
15. *Track velocity and direction vector line (projected ahead of target)*
16. *Assigned altitude 7,000, aircraft is descending, last Mode C readout (or last reported altitude) was 100' above FL 230*
17. *Transponder code shows in full data block only when different than assigned code*
18. *Aircraft is 300' above assigned altitude*
19. *Reported altitude (no Mode C readout) same as assigned. (An "n" would indicate no reported altitude.)*

Enroute Display

20. *Transponder set on emergency Code 7700 (EMRG flashes to attract attention)*
21. *Transponder Code 1200 (VFR) with no Mode C*
22. *Code 1200 (VFR) with Mode C and last altitude readout*
23. *Transponder set on radio failure Code 7600 (RDOF flashes)*
24. *Computer ID #228, CST indicates target is in coast status*
25. *Assigned altitude FL 290, transponder code (these two items constitute a "limited data block")*
**Note: numbers 10, 11, and 12 constitute a "full data block"*
Other symbols:
26. *Navigational aid*
27. *Airway or jet route*
28. *Outline of weather returns based on primary radar. ”*
H" represents areas of high density precipitation which might be thunderstorms. Radial lines indicated lower density precipitation.
29. *Obstruction*
30. *Airports*

ASR-11 Sites


FAI
ANCHORAGE
ANC
SEATTLE
EUG
GTF
BIL
BOI
CPR
BIS
FAR
DLH
MSP
FSD
RST
GRB
SAW
MBS
MKG
FNT
LAN
AZO
CAK
CHICAGO
ALO
SUX
MLI
RFD
ORD
PIA
SPI
CMI
SBN
HUF
EVV
MFD
YNG
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SGF
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MCE
MRY
SMX
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SBA
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IWA
SAF
AMA
Academy
AOS
FSM
LIT
FORT WORTH
GGG
MLU
BTR
LFT
LCH
MMC
MAF
ABI
ACT
BPT
CRP
JAN
GPT
MOB
PNS
ATLANTA
LEX
TRI
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BOSTON
RME
BGM
ELM
FMH
NEW YORK
ABE
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AVP
RDG
MMU
CKB
ASR-11 PT
HTS
CRW
ROA
UAM (Guam)
LIH
OGG
KOA
ITO
LEGEND
Regional Headquarters
ASR-11 Sites
SJU (Puerto Rico)
STT (Virgin Is)
FAA ASR-11 Site Locations
Click On A Site For More Information

ARTS III Terminal Display

1. *Areas of precipitation (can be reduced by CP)*
2. *Arrival/departure tabular list*
3. *Trackball (control) position symbol (A)*
4. *Airway (lines are sometimes deleted in part)*
5. *Radar limit line for control*
6. *Obstruction (video map)*
7. *Primary radar returns of obstacles or terrain (can be removed by MTI)*
8. *Satellite airports*
9. *Runway centerlines (marks and spaces indicate miles)*
10. *Primary airport with parallel runways*
11. *Approach gates*
12. *Tracked target (primary and beacon target)*
13. *Control position symbol*
14. *Untracked target select code (monitored) with Mode C readout of 5,000'*
15. *Untracked target without Mode C*
16. *Primary target*
17. *Beacon target only (secondary radar) (transponder)*
18. *Primary and beacon target*
19. *Leader line*
20. *Altitude Mode C readout is 6,000'*
21. *Ground speed readout is 240 knots*
22. *Aircraft ID*
23. *Asterisk indicates a controller entry in Mode C block. In this case 5,000' is entered and "05" would alternate with Mode C readout.*
24. *Indicates heavy*
25. *"Low ALT" flashes to indicate when an aircraft's predicted descent places the aircraft in an unsafe proximity to terrain.*

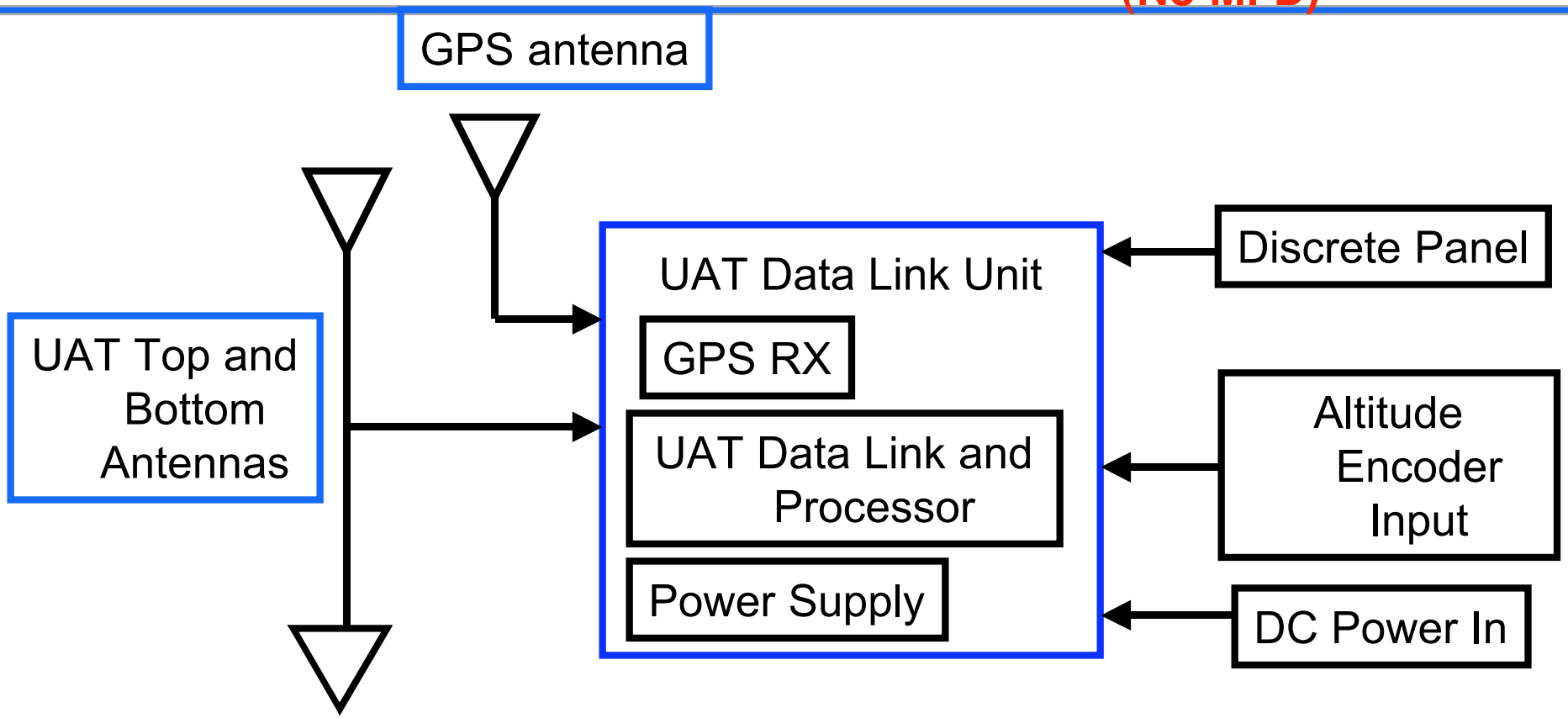
(Note: this feature does not function if the aircraft is not squawking Mode C.

ARTS III Terminal Display

26. *NAVAID's*
27. *Airways*
28. *Primary target only*
29. *Nonmonitored. No Mode C (an asterisk would indicate nonmonitored with Mode C)*
30. *Beacon target only (secondary radar based on aircraft transponder)*
31. *Tracked target (primary and beacon target) control position A*
32. *Aircraft is squawking emergency code 7700 and is nonmonitored, untracked, Mode C*
33. *Controller assigned runway 36 right alternates with Mode C readout*
(Note: a three letter identifier could also indicate the arrival is at specific airport)
34. *Ident flashes*
35. *Identing target blossoms*
36. *Untracked target identing on a selected code*
37. *Range marks (10 and 15 miles) (can be changed/offset)*
38. *Aircraft controlled by center*
39. *Targets in suspend status*
40. *Coast/suspend list (aircraft holding, temporary loss of beacon/target, etc.)*
41. *Radio failure (emergency information)*
42. *Select beacon codes (being monitored)*
43. *General information (ATIS, runway, approach in use)*
44. *Altimeter setting*
45. *Time*

MIT ICAT

ADS-B Simplified System (No MFD)



Traffic Symbology

Bill Kaliardos (FAA)

Directional	Selected	Non-Proximate	Proximate	ASA Caution	ASA Warning	TCAS TA	TCAS RA
					TBD		
	●				TBD		
●					TBD		
●	●				TBD		

Figure 1 Basic Traffic Symbol Set

Maintenance Costs (1995 Dollar Estimates)

• HF Voice	$5,000
• NDB	$30,000
• VOR	$200,000
• DVOR/DME	$450,000
• ILS Cat 1	$500,000
• ILS Cat II	$550,000
• Primary Radar	$6 million
• SSR	$2 million

Source: ICAO FANS Investment Plan for India

WEATHER TRENDS

- **Surface observations**
  - ❑ Human
  - ❑ Assisted
  - ❑ Automated (ASOS, AWS)
- **WX radar**
- **Satellite observations**
  - ❑ VIS
  - ❑ IR
  - ❑ Soundings
- **Pilot observations**
  - ❑ PIREPs (voice)
  - ❑ ACARs downlink
    - ◆ Winds, temperature
- **Forecasts**
  - ❑ Model based (ETA ➞ 20km grid)
  - ❑ Terminal
- **WX communications trend**
  - ❑ Teletype
  - ❑ Fax
  - ❑ WWW
  - ❑ Ground-air uplink

FAA
Dept of Commerce (NOAA)
Commercial Venders

Weather Information Distribution Examples

- http://adds.aviationweather.noaa.gov/
- http://www.aopa.org/members/wx/?
- http://www.duats.com/
- http://www.wsi.com/aviation/solutions/