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**
Timing Techniques

- Problem with calibrating power
- Time of flight
  - Tor = 2Rc + transponder relay time
- Multi-lateration
  - GDOP, HDOP, VDOP
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

- Expanded ACARS use (PDC, Oceanic Clearances, Taxi)
- FANS 1 / FANS A
- VDL Mode 2 (Petal)
- ATN
- VDL Mode 3?
- VDL Mode 4?

Source: Tom Imrich, Boeing
NAS Architecture Elements
Communication 1

Aeronautical Telecommunication Network Air to Ground 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
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)
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 Telecommunication 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 Network (NADIN)

NWS INTERFACE DESIGN
FAA X.25 Packet switch Network
Connectivity to the Pacific Area Islands, ARINC in Annapolis, FAA/AFTN, and FAA Leesburg & FAA New York

The Concurrent virtual channel queues
multiple virtual circuits x one virtual circuit

The NWS transmitted data is duplicated on each virtual circuit on the outbound port to NADIN II. The NWS receive will be on one line queue in the Gateway.
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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LORAN

- Master Slave Architecture
- Low Frequency (100khz) Center Freq
- Hyperbolic Coordinates
- Geometric Dilution of Precision
• * 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
• **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)**
• Requirements
  - Accuracy (RNP)
  - Availability
  - Integrity

• Differential GPS
  - SBAS Satellite Base Augmentation Systems
    - Wide Area Augmentation System (WAAS)
      - Non-Precision Approaches (GPS Overlay)
      - RNAV Approach
      - 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

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

Increased Airspace Efficiency

Optimized Use of Airspace

Containment
Seamless Vertical Path
"curved" paths
Performance-Based NAS Approaches

RNP-x (SAAAR)

xLS

Default

(Notional figure)
WAAS Fielding Status

Figure by MIT OCW.
• **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

US Local Area Augmentation System (LAAS)

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.
• Path Indications - Common

• Autoflight Status - Common

• Mode Annunciation - Common

• NAV Source Clearly Shown
  (ILS; GLS; FMS; ID; WP Distance)
Potential GNSS Services

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th>2015</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLS(200)</td>
<td>GPS &amp; Galileo OS dual-frequency &amp; IRU</td>
<td>GPS &amp; SBAS &amp; Galileo OS dual frequency</td>
<td>GPS &amp; GBAS (where necessary)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GPS &amp; SBAS dual frequency (&amp; Galileo OS)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>GPS &amp; GBAS (where necessary)</td>
<td></td>
</tr>
<tr>
<td>LPV</td>
<td>GPS &amp; SBAS</td>
<td>GPS &amp; Galileo SOL dual-frequency</td>
<td></td>
</tr>
<tr>
<td>RNP-0.1</td>
<td>GPS &amp; SBAS</td>
<td>GPS &amp; Galileo OS dual-frequency</td>
<td>GPS dual-frequency</td>
</tr>
</tbody>
</table>

Source: Bruce Declean (FAA)
Navigation & Communication

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

UAT Top and Bottom Antennas

GPS antenna

UAT Data Link Unit
- GPS RX
- UAT Data Link and Processor
- Power Supply

Discrete Panel
Altitude Encoder Input
DC Power In
Traffic Symbology
Bill Kaliardos (FAA)

Figure 1 Basic Traffic Symbol Set
## Maintenance Costs (1995 Dollar Estimates)

<table>
<thead>
<tr>
<th>System</th>
<th>Cost</th>
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<tbody>
<tr>
<td>HF Voice</td>
<td>$5,000</td>
</tr>
<tr>
<td>NDB</td>
<td>$30,000</td>
</tr>
<tr>
<td>VOR</td>
<td>$200,000</td>
</tr>
<tr>
<td>DVOR/DME</td>
<td>$450,000</td>
</tr>
<tr>
<td>ILS Cat 1</td>
<td>$500,000</td>
</tr>
<tr>
<td>ILS Cat II</td>
<td>$550,000</td>
</tr>
<tr>
<td>Primary Radar</td>
<td>$6 million</td>
</tr>
<tr>
<td>SSR</td>
<td>$2 million</td>
</tr>
</tbody>
</table>

Source: ICAO FANS Investment Plan for India
• 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/