Schedule change

Air Traffic Control Overview

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↑Color picture is better

A DAY IN THE LIFE OF
AIR TRAFFIC OVER
THE CONTINENTAL U. S.

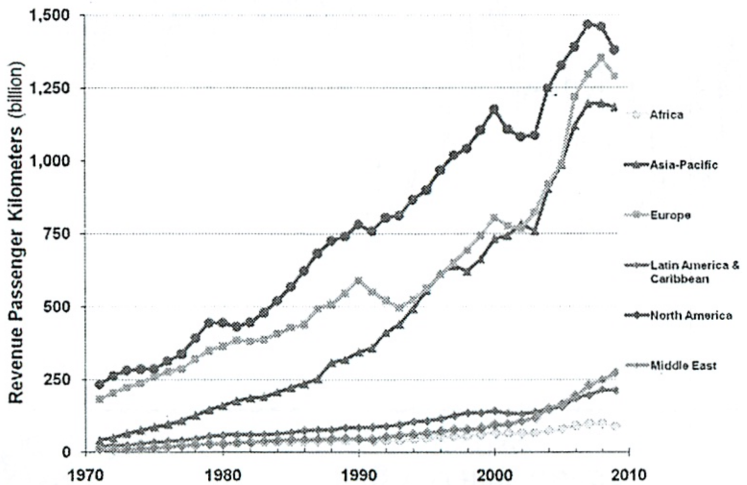
ANIMATION CREATED USING

FUTURE ATM CONCEPTS
EVALUATION TOOL
(FACET)

FOR
AVIATION SYSTEMS DIVISION
(AF)
NASA AMES RESEARCH CENTER

5,000 aircraft

Revenue Passenger Kilometers (RPK) by World Region

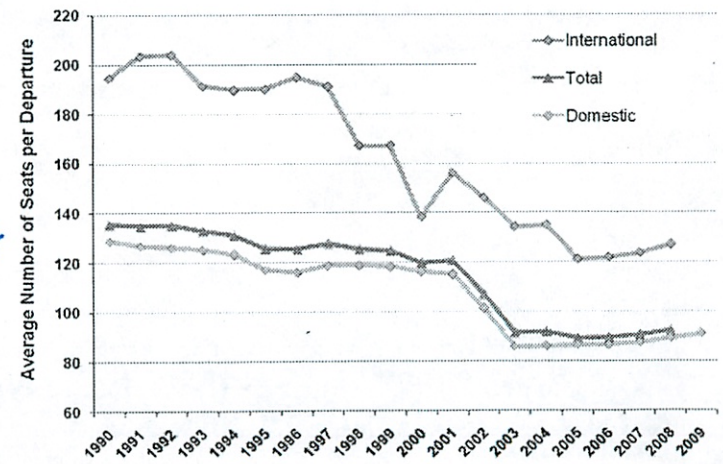


Data source: ICAO for 1970 to 2009

More people flying + smaller aircraft

Trends in Aircraft Size

U.S. Airlines



Data source: Form 41 Traffic data from Bureau of Transportation Statistics (US carriers)

1/22

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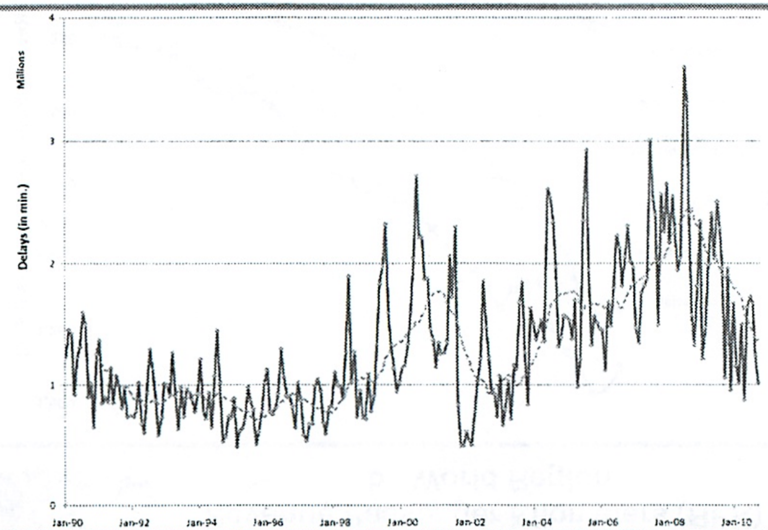
Flight Delay Trends
US Data



Data source: FAA Operational Network (OPSNET)

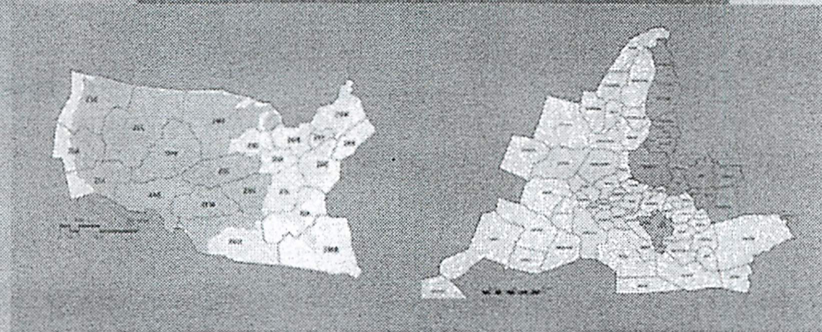
|→ voletality ↑
- capacity threshholds
esp in summer ~~w/~~ thunderstorms

Single European Sky Initiative

ATM Performance

EUROCONTROL

US and European ARTCCs



9.8 M km²	10.5 M km²
15.9 M flights	7.9 M flights
12700 M km	6300 M km

-slot restrictions
-teritorial restrictions

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Capacity Issue

- **The US, European and other Key Air Transportation Systems are approaching a critical saturation threshold where nominal interruptions (e.g. weather) result in a nonlinear amplification of delay**
- **National and Regional Economies highly dependant on Air Transportation**
  - Business travel (stimulated by info technology)
  - Air Freight
  - Personal travel
- **System is highly complex and interdependent**
- **Need better understanding of system dynamics and real constraints to guide and justify efforts to upgrade the system**
- **Current efforts will not provide capacity to meet future demand**
- **Impact of upcoming capacity crisis is not well understood**
  - Operational Impact
  - Economic Impact

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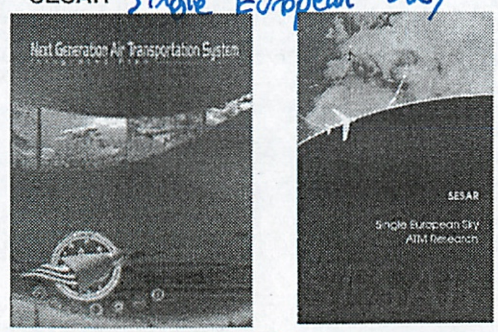
Long Term Plans for System Transformation

- **Common recognition that existing US and European ATM systems will not scale to meet future demand**
- **Reflected in major long term initiatives**
  - **US** NextGen
  - **Europe** SESAR Single European Sky

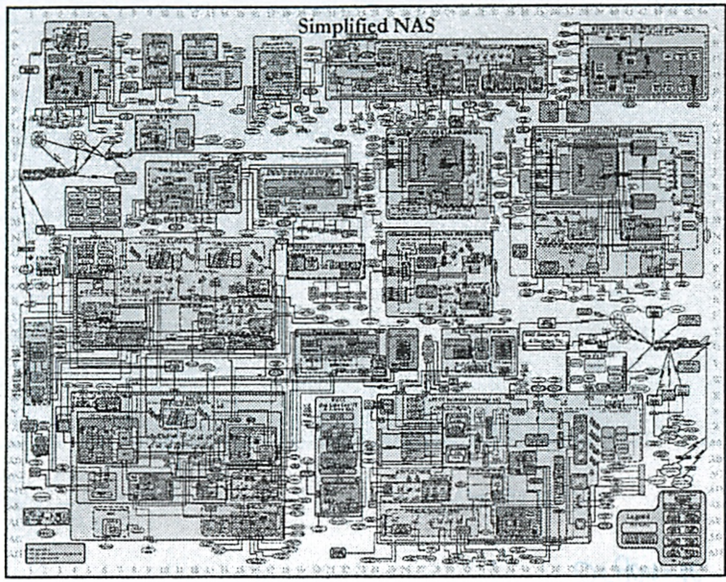
both in handwaving stage



System Complexity "Simplified" NAS Architecture

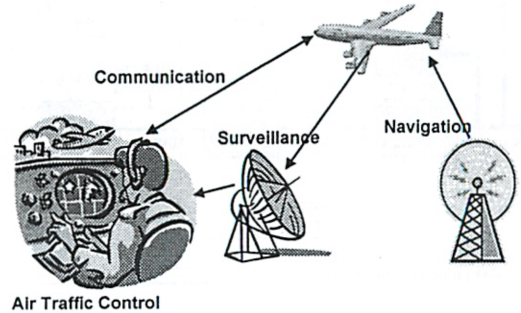
National Airspace Chart

FAA Chart



COMPONENTS OF AIR TRANSPORTATION INFRASTRUCTURE

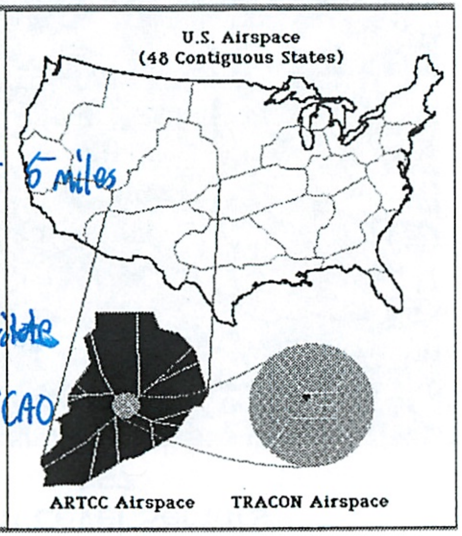
- **Airports**
  - Runways
  - Terminals
  - Ground transport interface
  - Servicing
  - Maintenance
- **Air Traffic Management**
  - Communications
  - Navigation
  - Surveillance
  - Control
- **Weather**
  - Observation
  - Forecasting
  - Dissemination
- **Skilled personnel**
- **Cost recovery mechanism**



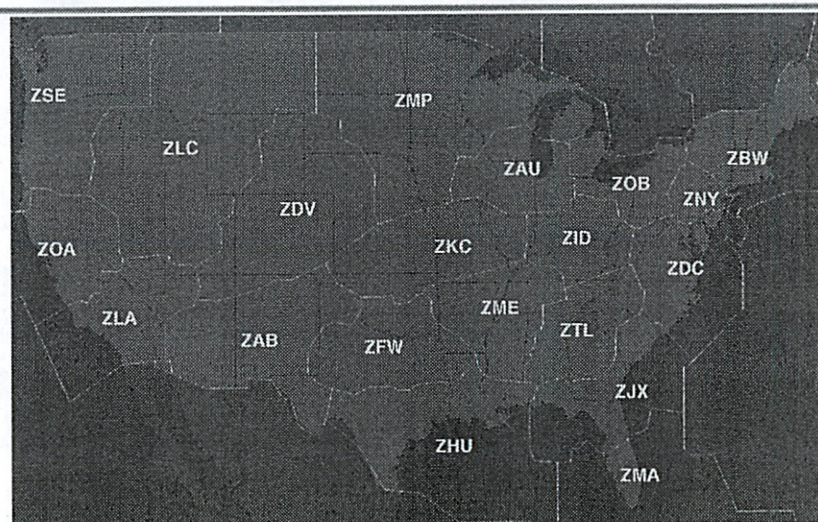
Current Control Structure

- **Surface Control**
  - "Ground" taxiways
- **Local Control**
  - "Tower" runways, 2000ft 5 miles
- **Terminal Area Control (TRACON)**
  - "Approach and "Departure"
- **Enroute Control (ARTCC)** 20 centers
  - "Center" medium + high altitude
- **Oceanic Control (FIR)**
  - "Oceanic" at boundries – ICAO
- **Flow Control (ATCSCC)**
  - "Central Flow"

manage resources

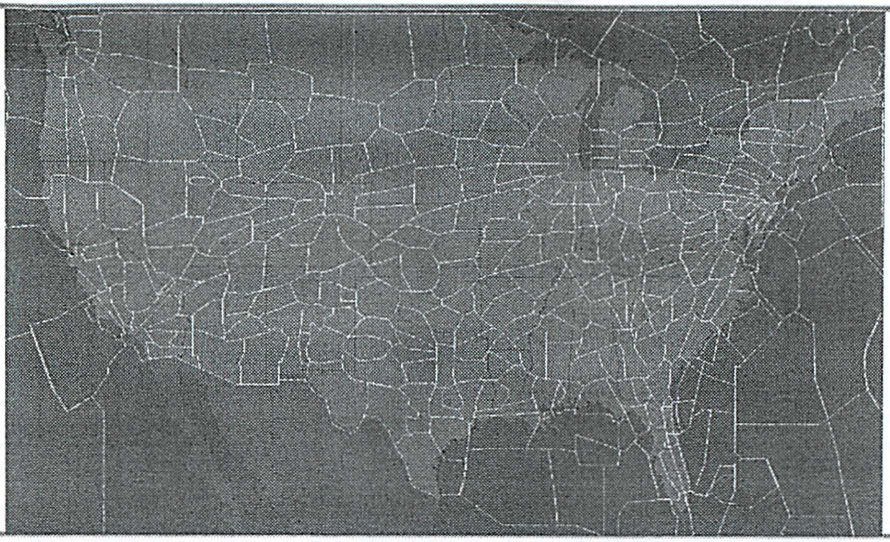


US Air Route Traffic Control Center (ATRCC) Airspace - 20 Centers



↑ from when done by teletype Z=center

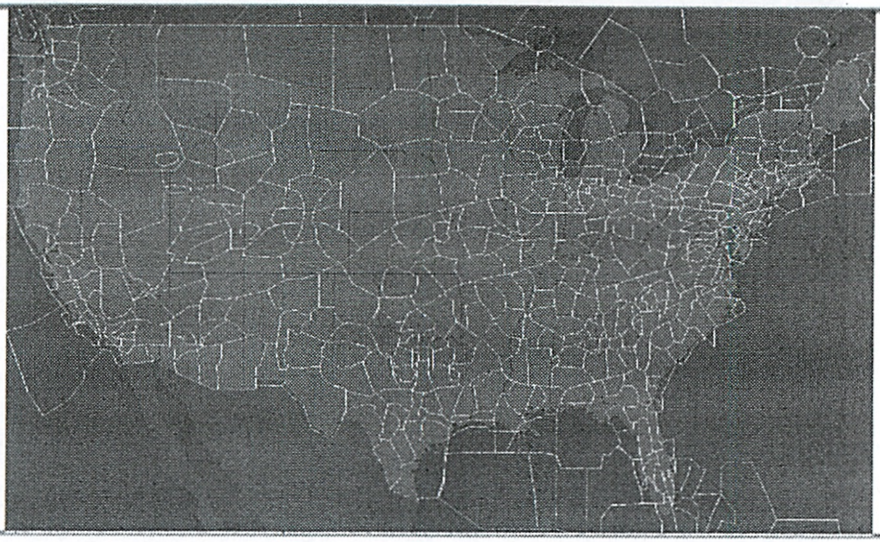
High Level Sectors
257



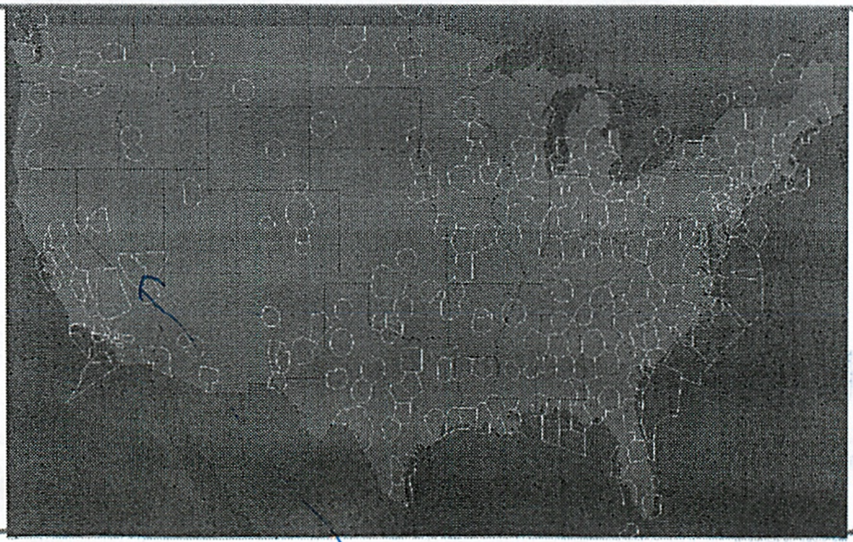
>34,000

Changes freq, organize around key nodes

Low Level Sectors
378



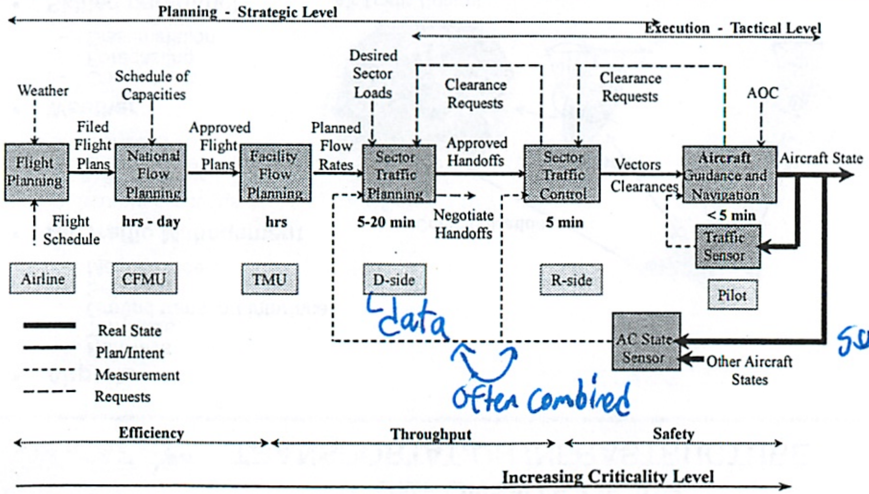
TRACONS



restricted areas

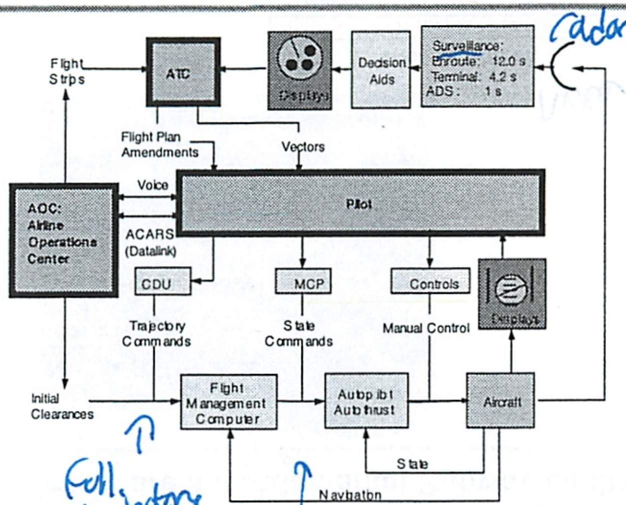
Strategic

ATM System Current Functional Structure



Source: A. Haraldsdottir Boeing

ATC Basic Control Loop

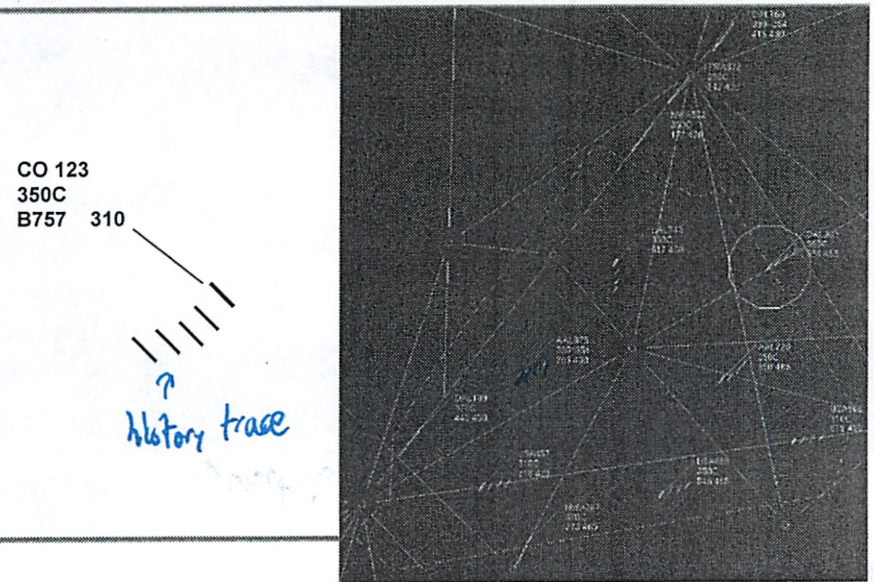


radar

full trajectory

tell it how to go

Radar Display Example



history trace

Older radar

takes a min to see if started to follow directions

Human Factors and Adaptation

- ATM is a human centered contract process for the allocation of airspace and airport surface resources.
- Current ATC system has evolved over 60 years
- The system has significant local adaptations resulting in nonhomogeneity
  - Airspace design
  - Local procedures
  - Letters of agreement
  - Noise restrictions
  - Site specific training (FPL = 3-5 years)
- Major operational changes were event driven, enabled by technical capability
  - Positive radar control - Grand Canyon 1956
  - TCAS - Los Cerritos 1982

adapted system

-weather
-terrain

6-7,000 letters of agreement in USA

full performance level

accidents

New York Arrival and Departure Tracks

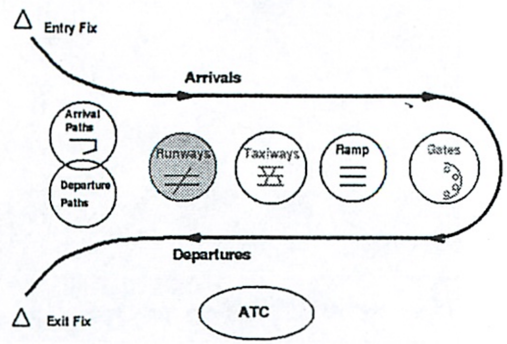
hard to change 1 w/o changing other

Capacity Limit Factors

- **Airport Capacity**
  - Runways
  - Gates
  - Landside Limits (including Security)
  - Weather
- **Airspace Capacity**
  - Airspace Design
  - Controller Workload
  - Balkanization — like in Europe
- **Demand**
  - Peak Demand
  - Hub & Spoke Networks
- **Environmental Limits**
  - Noise (relates to Airport)
  - Emissions (local, Ozone, NOX, CO_2)

Airport System
Capacity Limit Factors

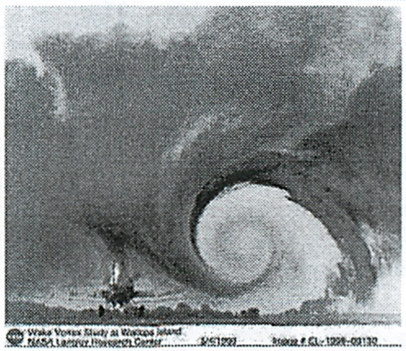
- Runways
- **Landside Limits**
  - Gates
  - Ramp Space
  - Terminals & Security
  - Road Access
- **Weather**
  - Capacity Variability
  - Convective Weather
- **Downstream Constraints**
- **Controller Workload**
- **Environmental**
  - Community Noise
  - Emissions
- **Safety**



Adaptive System - Impedance Matching

runway is the constraint
what taxiways + gates match runways

Wake Vortex Separation Requirements are a Fundamental Runway Limitation



need min separation b/w aircraft

		Trailing Aircraft		
		Heavy	Large	Small
Leading Aircraft	Heavy	4	5	5
	B757	4	4	5
	Large	3(2.5)	3(2.5)	4
	Small	3(2.5)	3(2.5)	3(2.5)

260 op/hr is max per runway

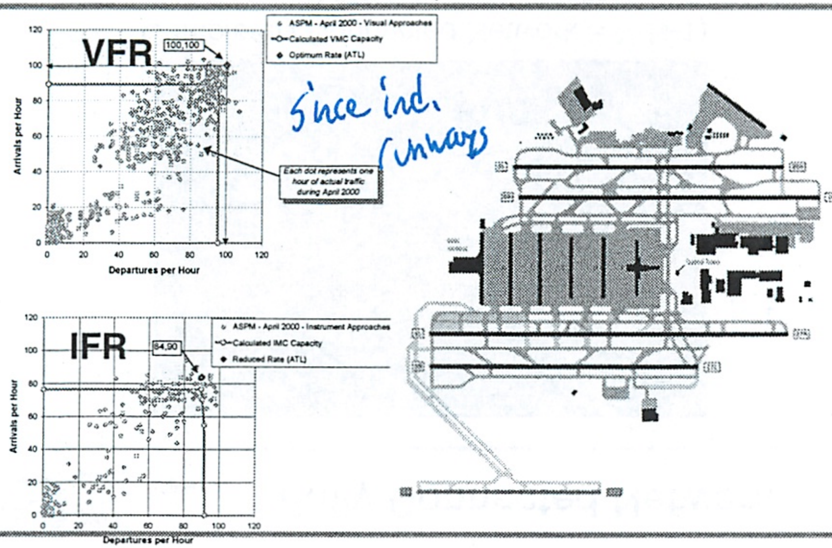
A-380

what is separation for this?

A380 - wash in airport throughput since add. seats offset by longer wake vortex

Airport Capacity Envelopes
Atlanta (ATL)

since incl. runways



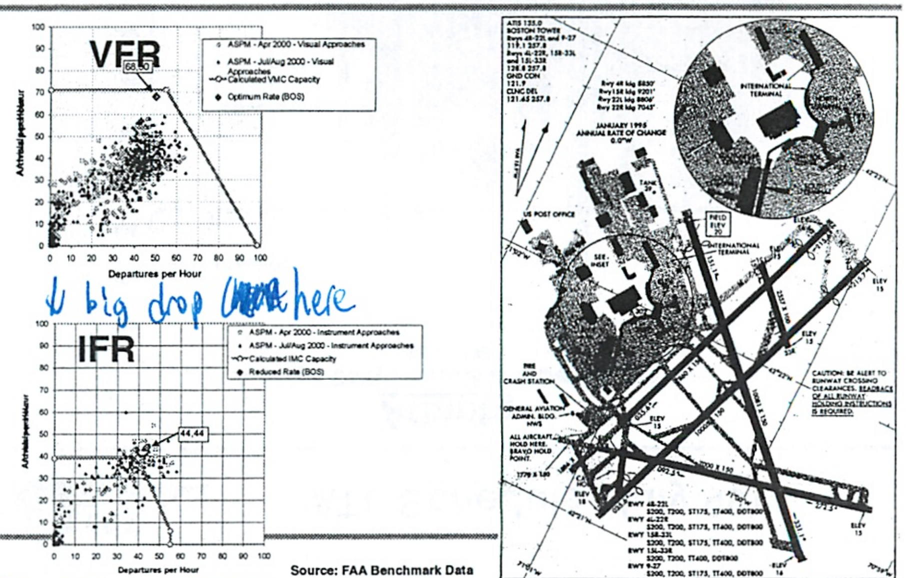
Source: FAA Benchmark Data

Airport Capacity Envelopes
Boston (BOS)

good weather

↓ big drop here

bad weather

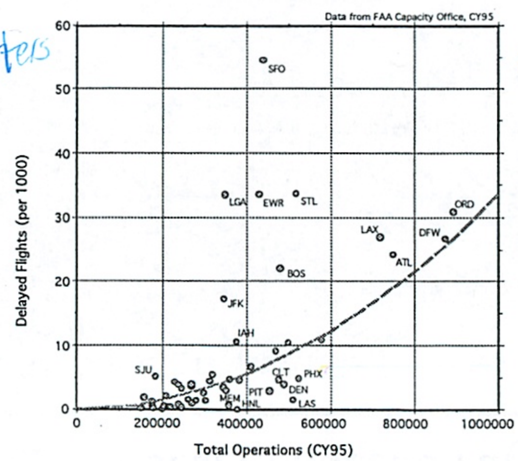


Source: FAA Benchmark Data

before new runway

Variable Capacity Effects
1995 Delays vs Operations

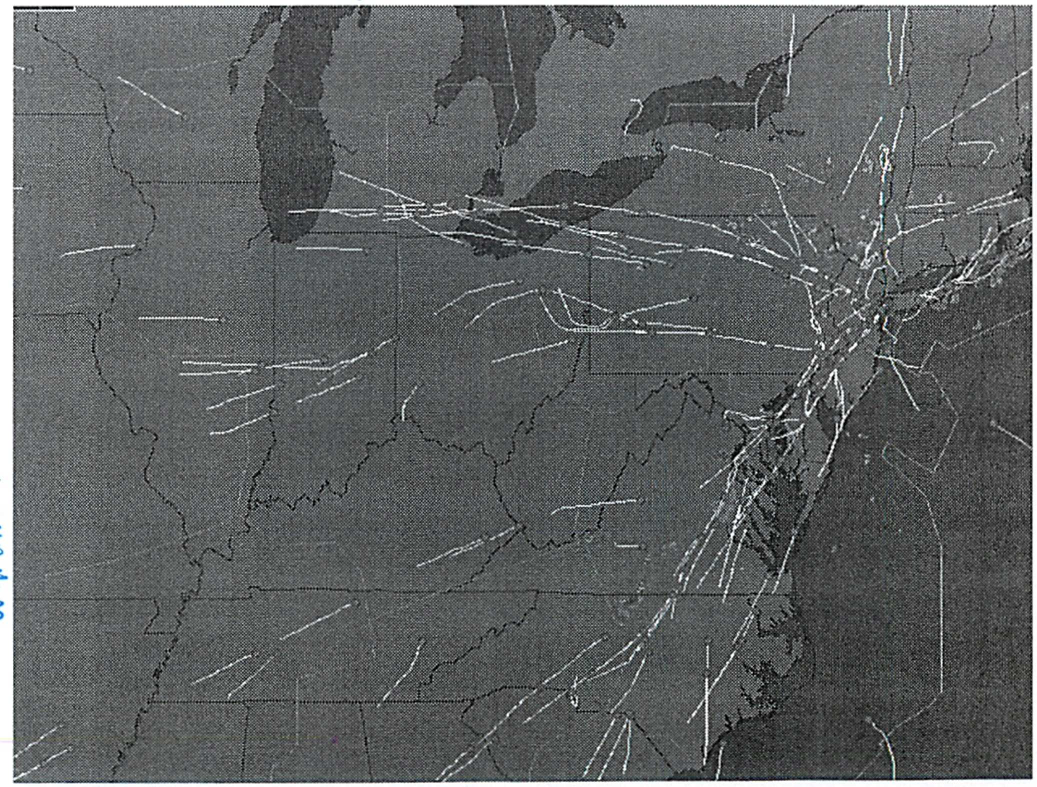
weather matters



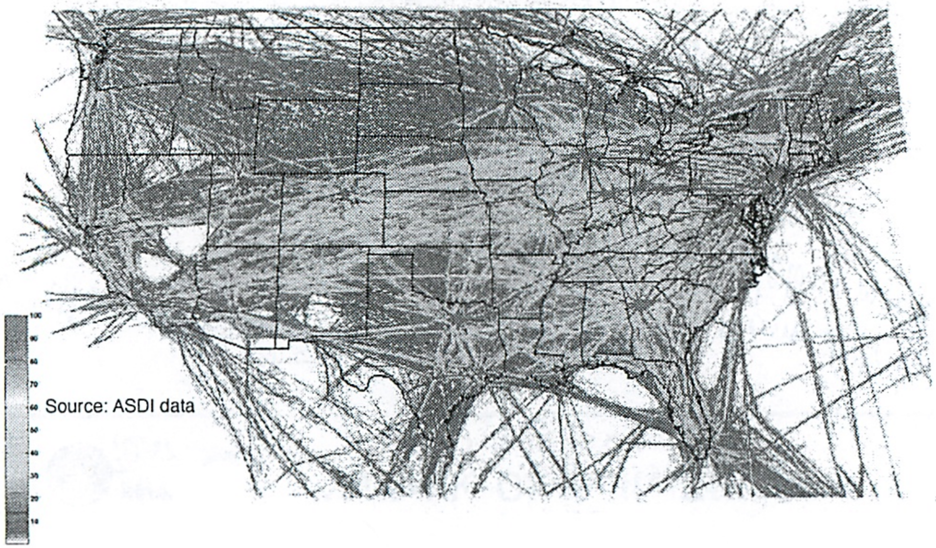
← some airports delays much worse

From John Andrews, MIT Lincoln Lab

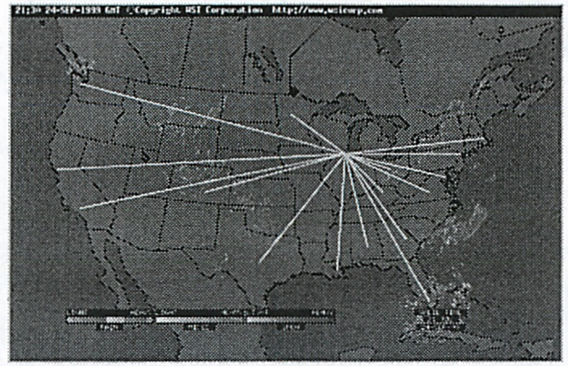
animation



Local Congestion at Hubs

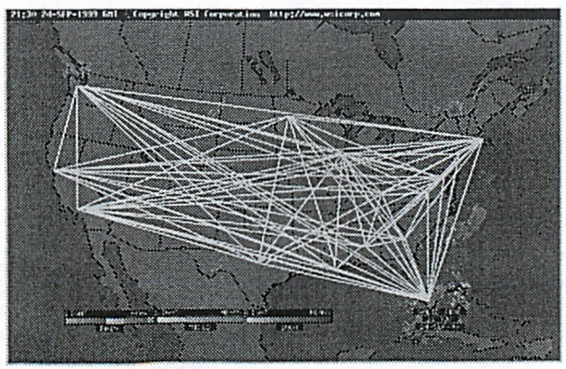


Hub and Spoke Network



Completely Connected Network = 2(N-1) Flights
(eg., 50 Airports, 98 Flights)

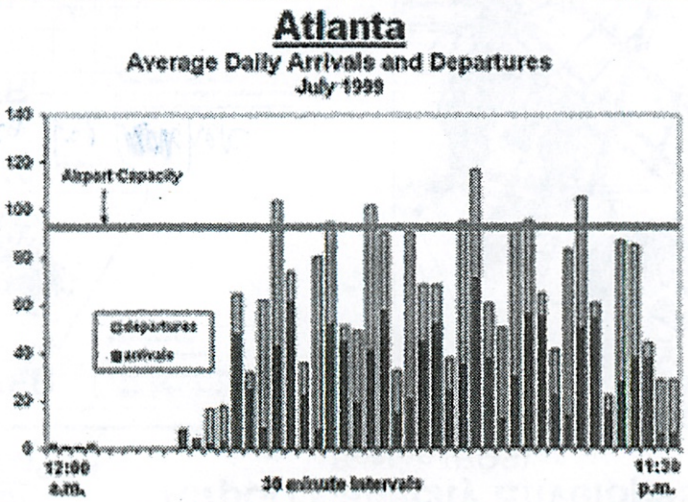
Fully Connected Network



Completely Connected Network = N(N-1)
(eg., 50 Airports, 2450 Flights)

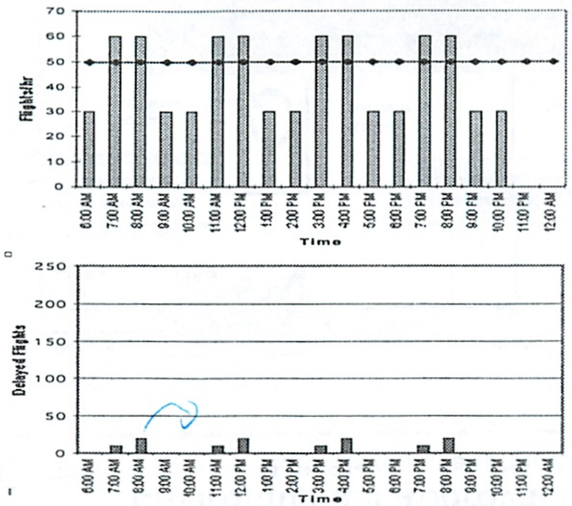
but need hubs

ATL Schedule (July 99)



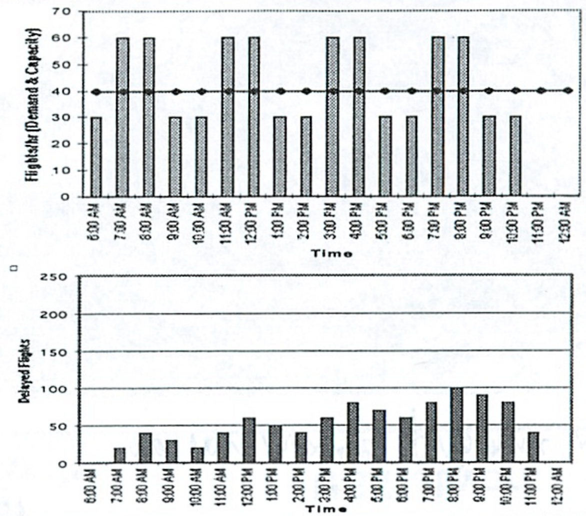
Source: ATA Website

Capacity Example
50 Flights/hr



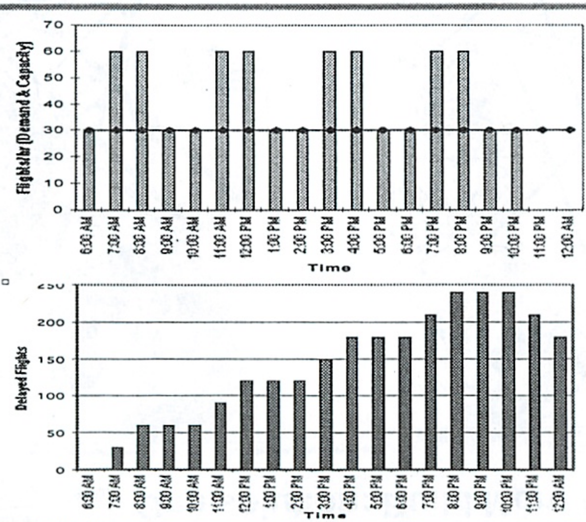
repair capacity throughout day

Capacity Example
40 Flights/hr



but not at this capacity

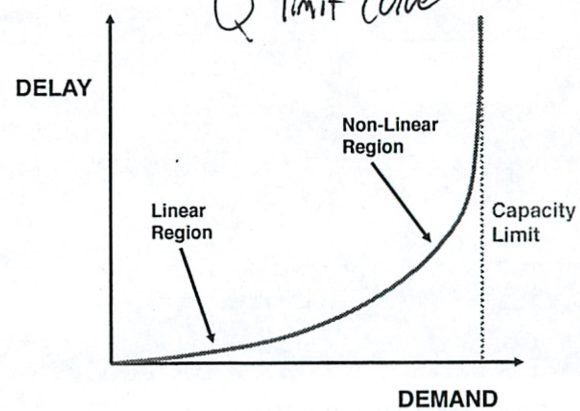
Capacity Example
30 Flights/hr



delays build up

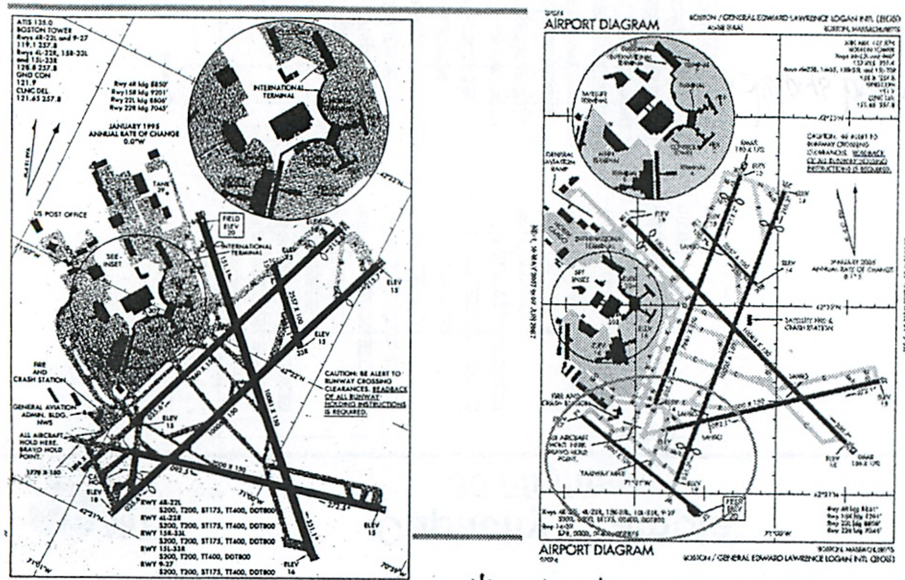
Classic Delay vs Demand Curve

Q limit curve



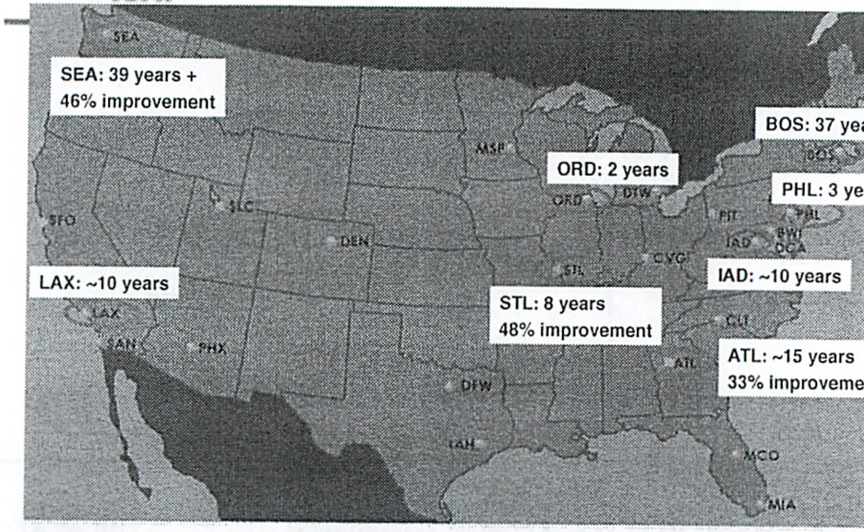
bad weather

One solution: Build More Runways



like to land into wind

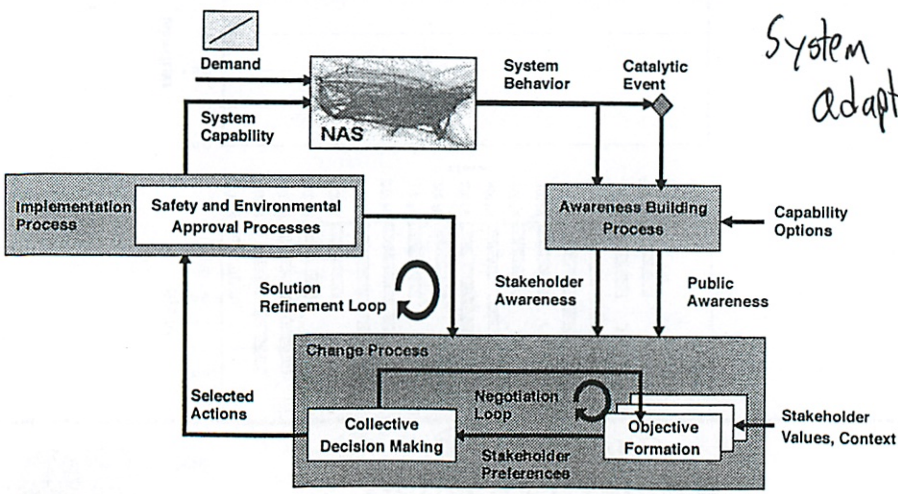
Current Airport Expansion Projects



Top 30 Congested Airports in 2005 — Expansion Projects

environmental impact law stopped airport building

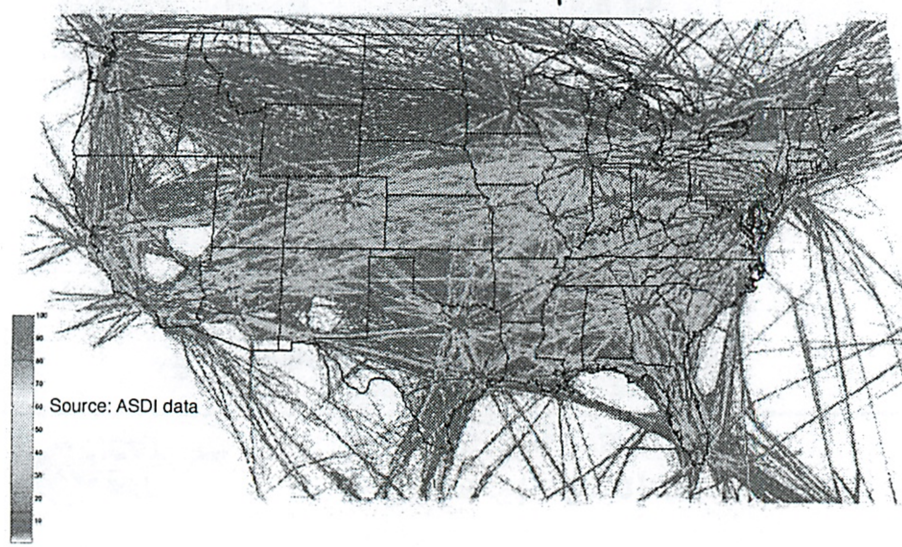
Environmental Approval Barriers
Multi-Stakeholder Effects



System adaptation

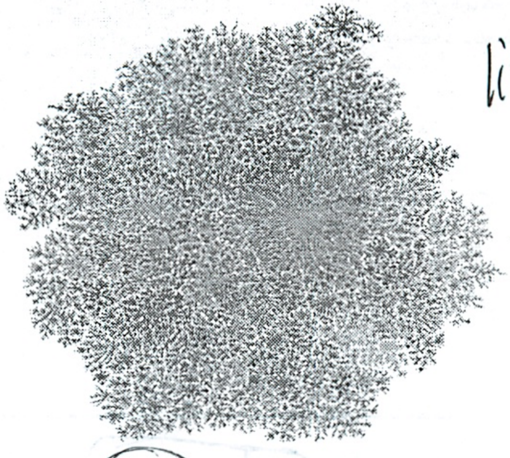
US Network

how maximize performance when can't build?



Scale Free Network

Growth Without Constraint



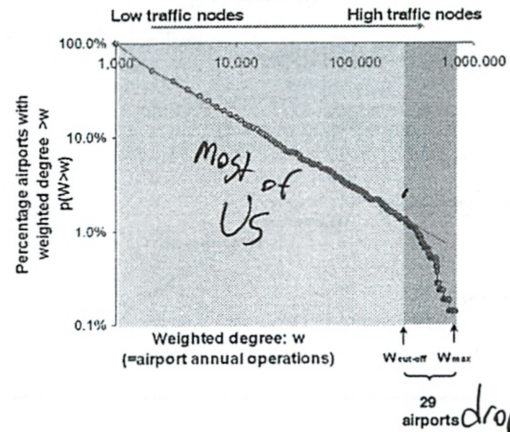
like fractiles

- internet

WWW in 1999

US Air Transportation System Not Quite a Scale Free Network

Flight Weighted Degree Distribution



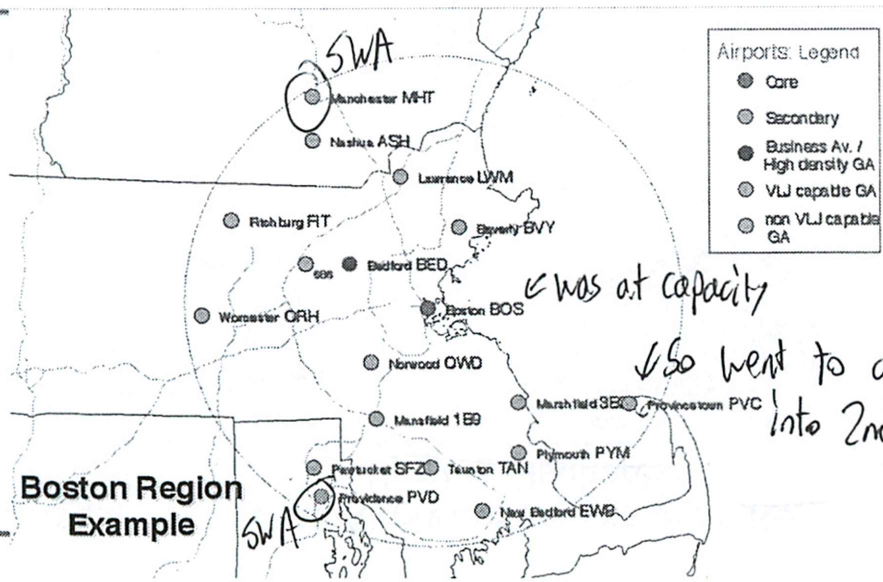
Most of US

drops off

- Capacity constraints limit connectivity at the highest density airport nodes

Emergence of Secondary Airports

"Southwest Effect"



SWA

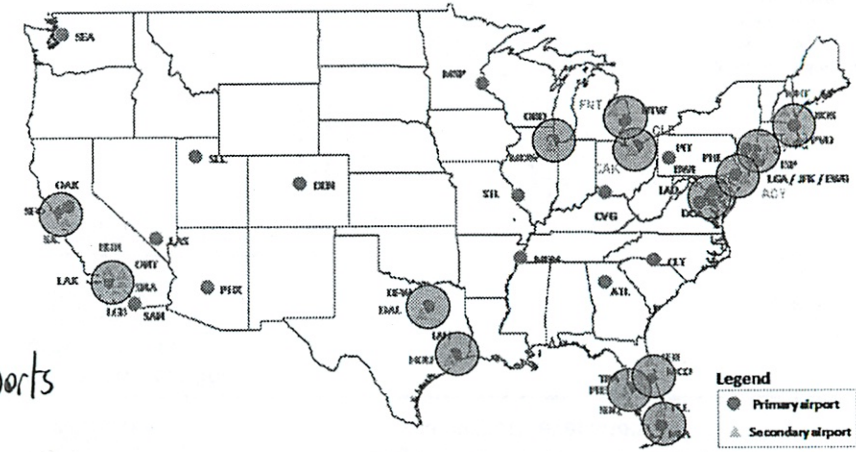
was at capacity

So went to airports into 2ndary airports

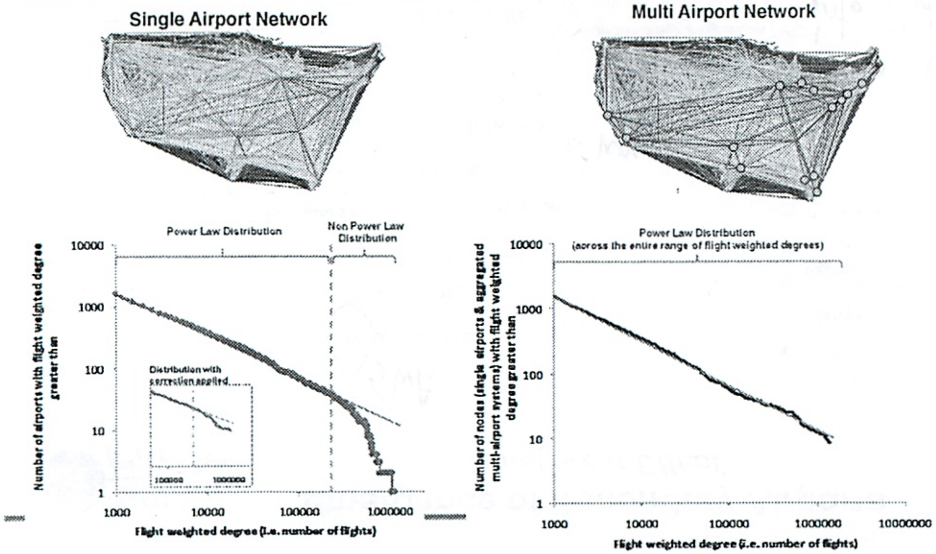
Boston Region Example

Multi-Airport system is how US adapted

Multi-Airport Systems in the United States



Multi Airports Systems are a Key Scaling Mechanism

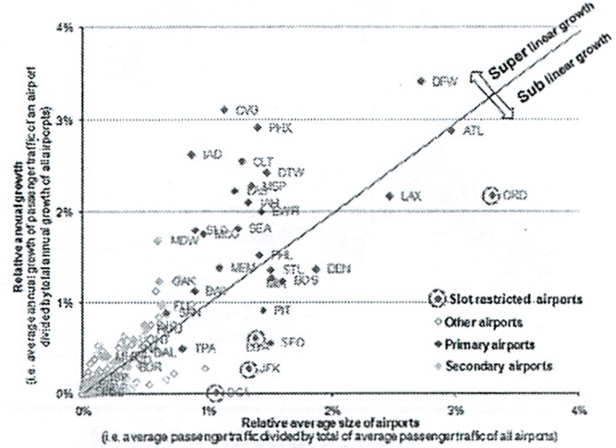


Single airports

Analysis of Airport Growth

(i.e. airport level analysis)

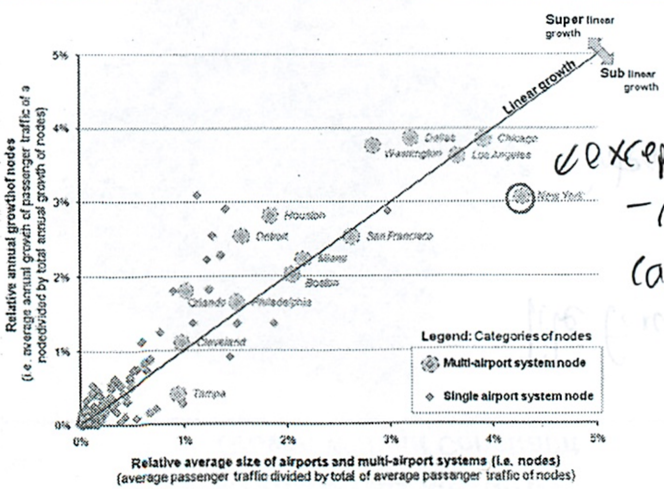
- **Deviation from linear growth due to:**
  - Sub linear: Capacity constrained airports (e.g. Washington/National DCA, New York/ Kennedy JFK, New York/LaGuardia LGA, Chicago O'Hare ORD)
  - Super linear: Connecting hub airports that emerged during the time period of analysis and secondary airports



Theory

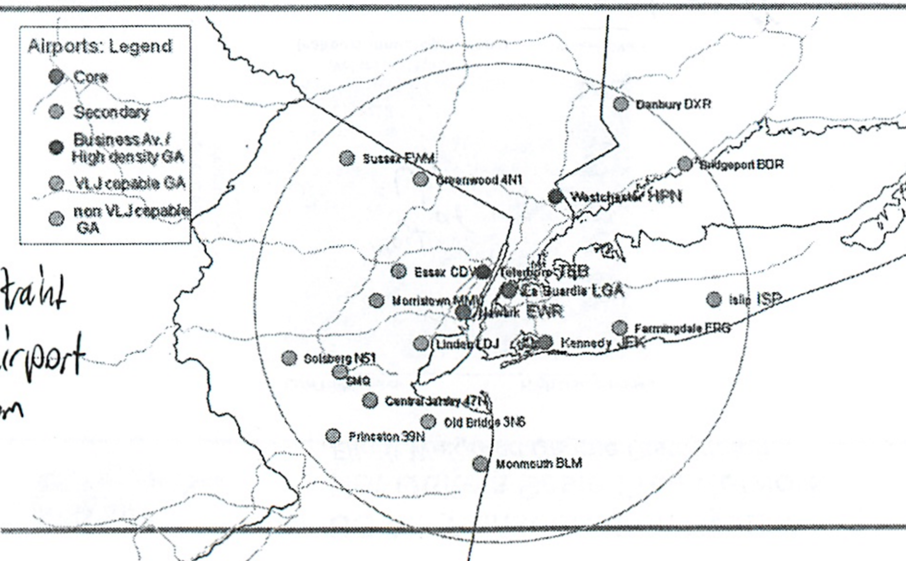
- growthrate should be proportional to size

Multi-Airport System Growth



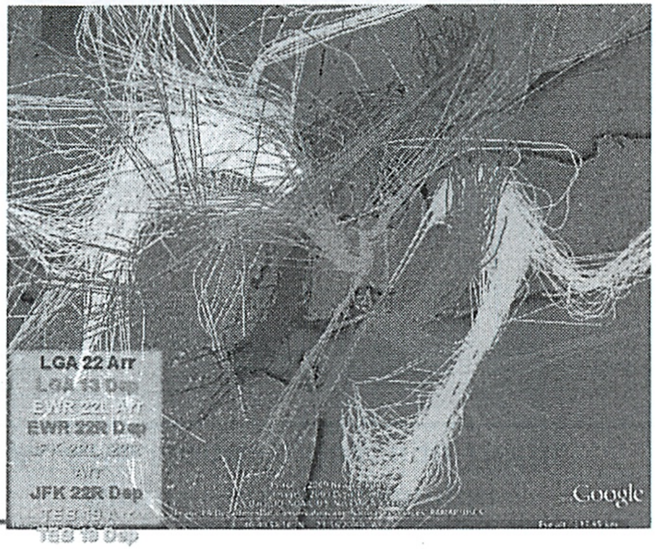
except
- reaching capacity constraint at multiairport system

New York Multi-Airport System



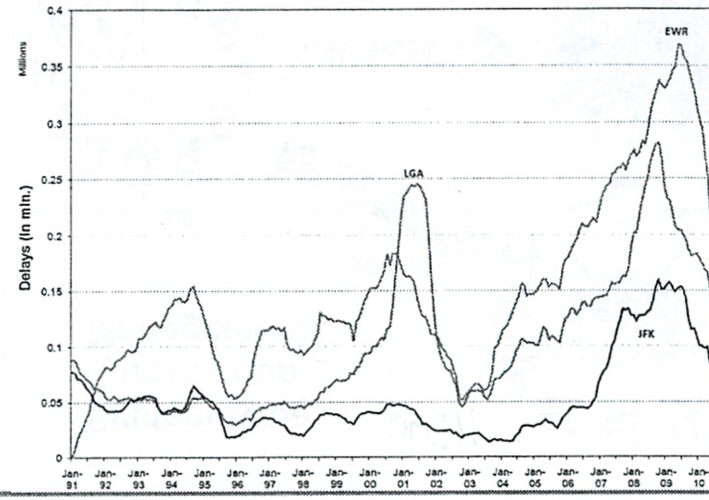
Example NY Configuration

- LGA 22 | 13
  EWR 22L | 22R
  JFK 22L, 22R | 22R
  TEB 19 | 24
- Used 2% of time
- 36% Capacity improvement potential
- Known Issue:
  EWR 22 Arr-
  TEB 24 Dep
- Other issues?
  - Merging departure flows from all airports?



New York Airport Flight Delays*

* Note: 12 month moving average



3 NY airports most delayed in US system

Data source: FAA Operational Network (OPSNET)

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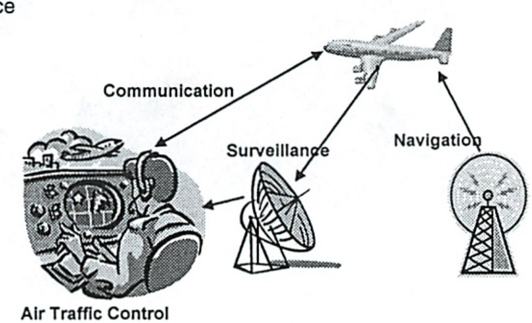
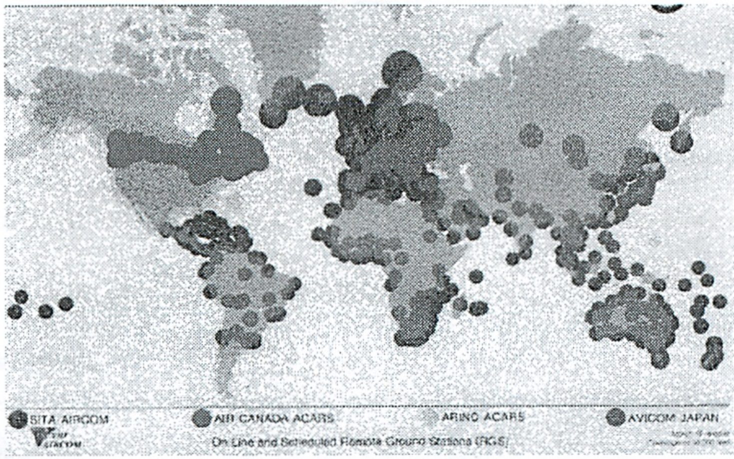


Very low bandwidth now

COMMUNICATION TRENDS

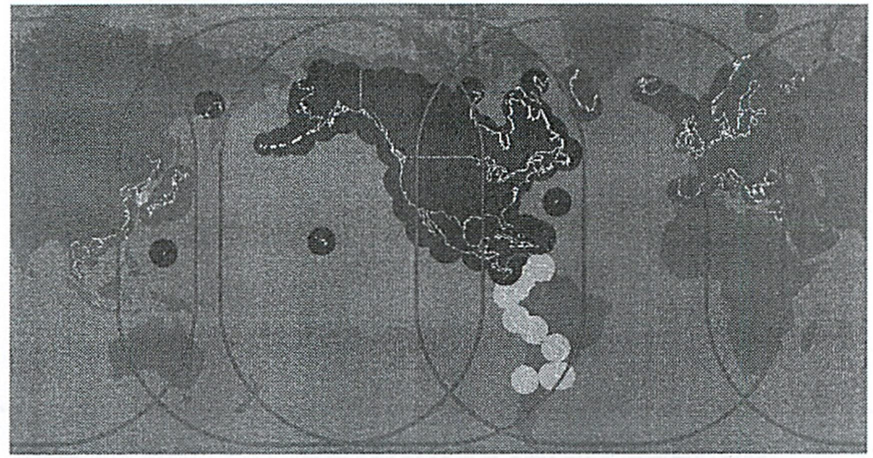
- **Voice**
  - VHF (line of sight)
  - HF (over the horizon) — not very reliable
  - Ground lines
- **Datalink (line of sight)**
  - ACARS (VHF)
  - Mode S (Obsolete?, 1090 Squitter) $.05/msg
  - CPDLC (VDL Mode 4)
- **Satellite**
  - Geosynchronous (data, voice, images) expensive $4-5/msg
    - Air-ground
    - Ground-ground
  - LEO and MEO Networks
  - XM Radio Downlink for Weather
- **Aeronautical Telecommunications Network (ATN)**
  - CDMA, TDMA
  - TCP/IP

Combined Datalink Networks ACARS



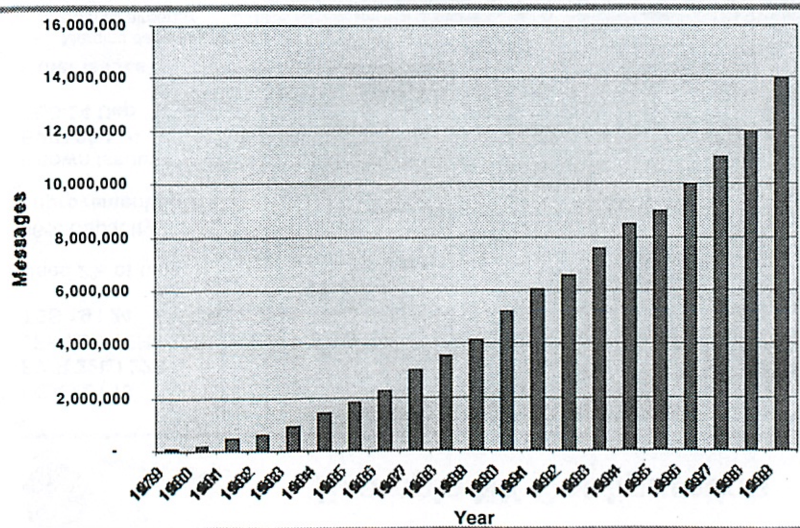
ACARS run by different companies

ARINC Datalink Network ACARS



satilight coverage

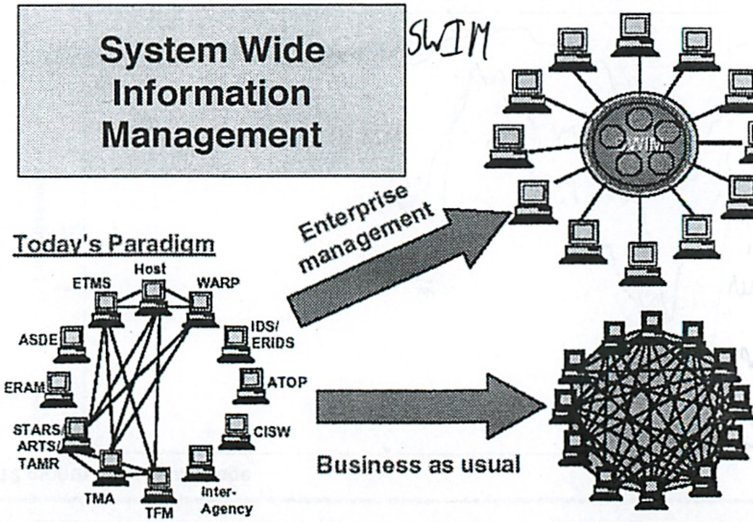
Airline-Aircraft Example ACARS Monthly Message Traffic



System Wide Information Management

SWIM

part of NextGen



Strategy Briefing to the Joint Resource Council April 26, 2006 | Federal Aviation Administration | 7

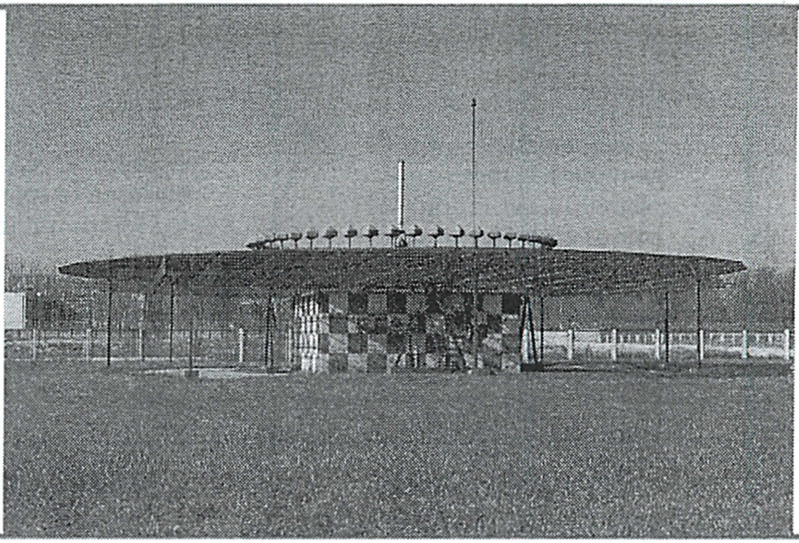
Source: Jim Eck Briefing, RTCA Technical Symp, May 2006

NAVIGATION TRENDS (ENROUTE)

before

- **Radionavigation beacon**
  - VHF Omnidirectional Range (VOR) — *to certain points*
  - Non-Directional Beacon (NDB)
  - Distance Measuring Equipment (DME)
  - TACAN
- **Area navigation systems (RNAV)**
  - Point to Point — *GPS nav*
- **Ground Based**
  - Omega
  - LORAN
- **Inertial navigation systems**
- **Satellite navigation systems**
  - GPS (CA)
  - Glonass
  - GNSS

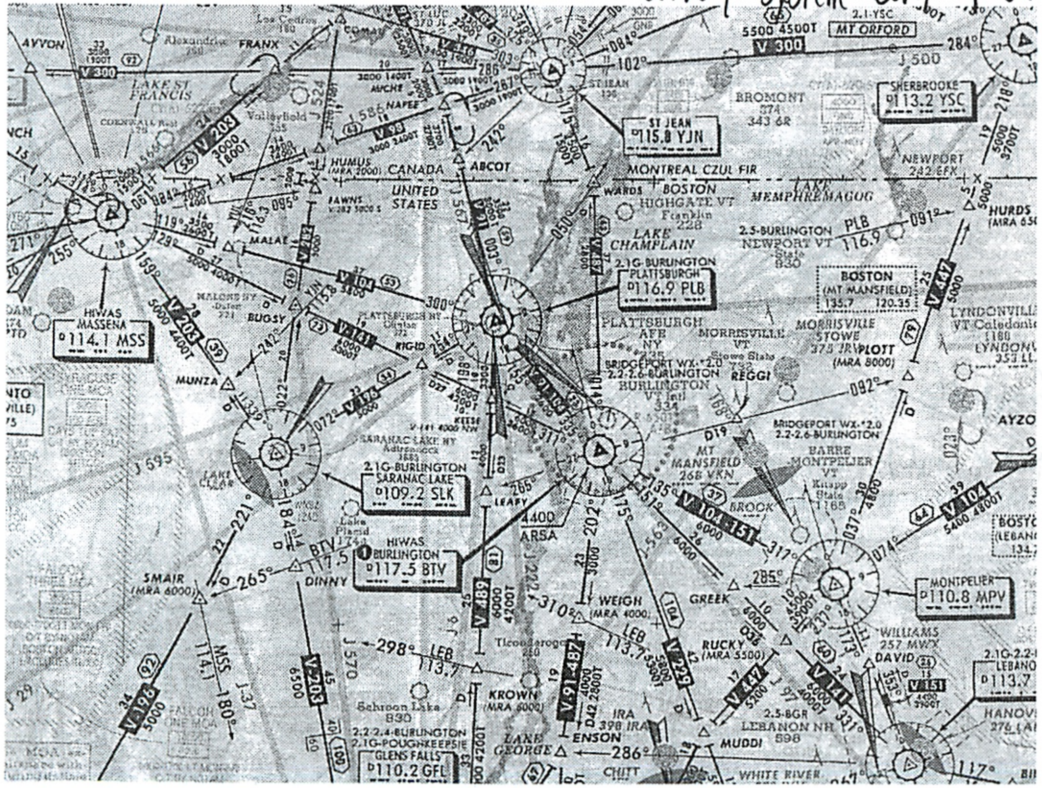
VOR



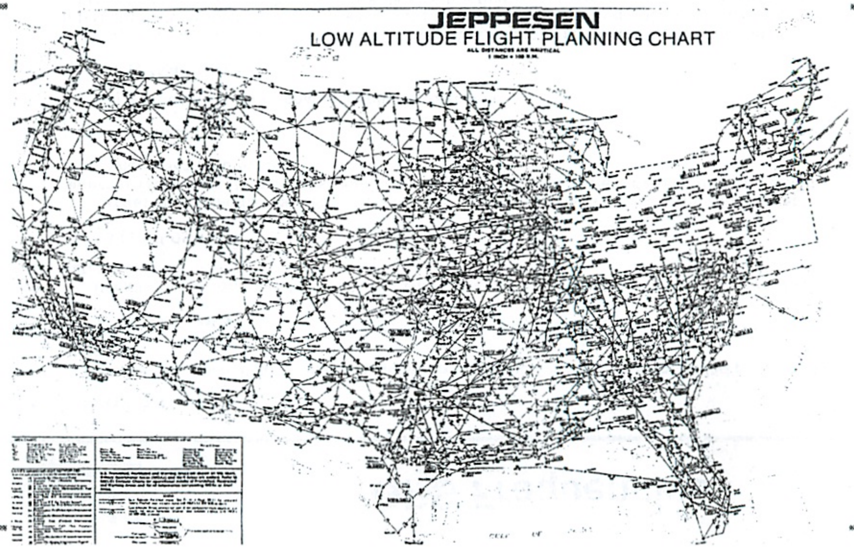
http://en.wikipedia.org/wiki/Image:D-VOR_PEK.JPG

? navigation beacons

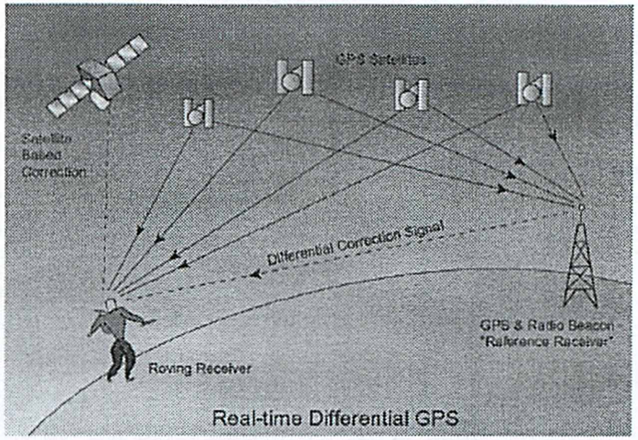
airway system built up around beacons



US Airway Structure



GPS



Signals need to go through ionsphere

fixed w/ diff. correction

Image source: The Fundamentals of GPS,Greg Pendleton , Leica Geosystems

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, No longer active
- **Differential GPS (Ionospheric Correction)**
  - Satellite Based Augmentation Systems (SBAS)
    - WAAS (US), EGNOS (EU), GAGAN (India)
  - Ground Based Augmentation Systems (GBAS)
    - LAAS
- **Second Civil Frequency**
- **Control by US DoD**
  - International concerns
- **Vulnerability to jamming**

5-10m - turned off in Gulf War

Europens building own

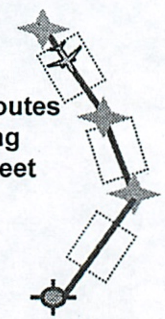
or radio problems

can't have it as only nav source

Performance Based Navigation RNAV and RNP

more precision

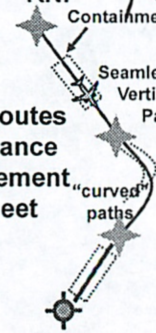
RNAV



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

Increased Airspace Efficiency

RNP - performance



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

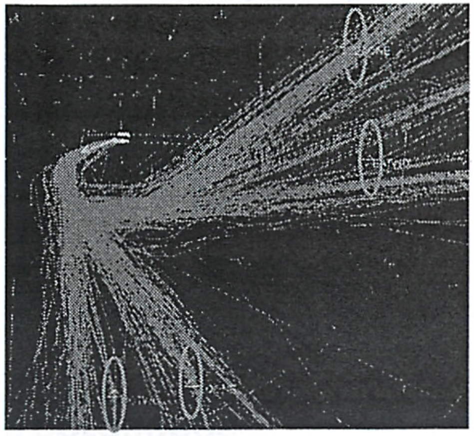
Optimized Use of Airspace

Source: Bruce DeCleene, FAA

MIT ICAT

ATL Departure Procedures Before RNAV

- Departures are vectored
  - **Headings, altitudes and speeds issued by controllers**
  - **Large number of voice transmissions required**
- Significant dispersion
  - **Tracks are inconsistent and inefficient**
- Limited exit points



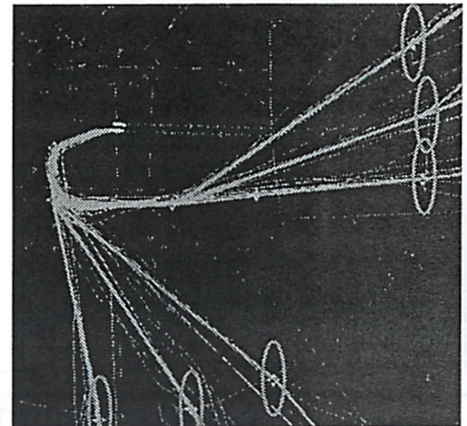
Source: Bruce DeCleene, FAA

∈ lots of error

MIT ICAT

ATL Departure Procedures After RNAV

- Departures fly RNAV tracks (not vectored)
  - **Headings, altitudes and speeds are automated (via avionics)**
  - **Voice transmissions reduced (30-50%)**
- Dispersions reduced
  - **Tracks are more consistent and more efficient**
- Additional exit points available



Source: Bruce DeCleene, FAA

more precise

– bad for people who live directly under

MIT ICAT

NAVIGATION TRENDS (APPROACH)

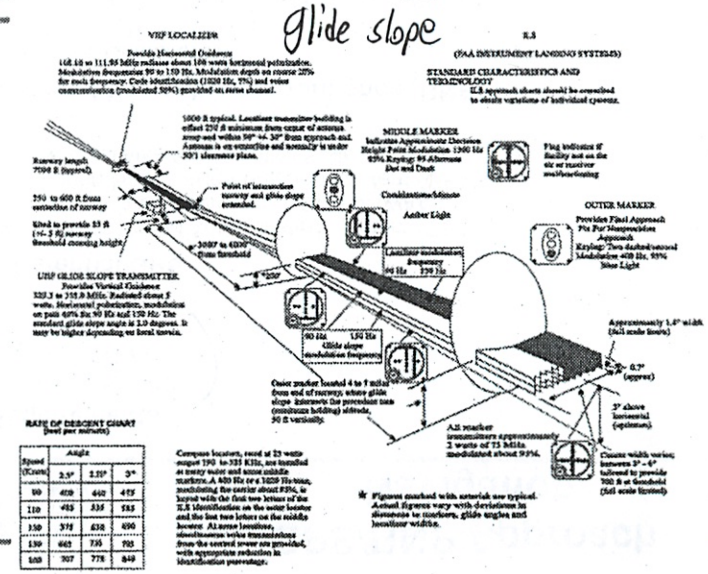
- **Instrument Landing System (ILS)**
  - Cat. I (200 ft; 1/4 mile)
  - Cat. II (50 ft; 800 RVR)
  - Cat. III (0,0) – LHR, Dallas → foggy
- **Microwave Landing System (MLS)**
- **GPS (100m)**
  - Wide Areas Augmentation System (5m)
    - Cat. I, Cat. II
  - Local Areas Augmentation System (0.1m)
   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

navigating on route diff. than navigating for landing

need a correction system

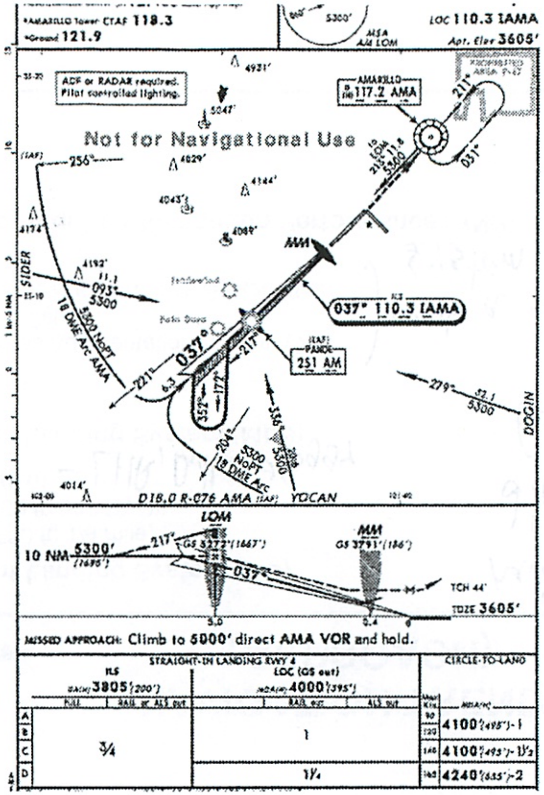
MIT ICAT

NAVIGATION TRENDS



glide slope

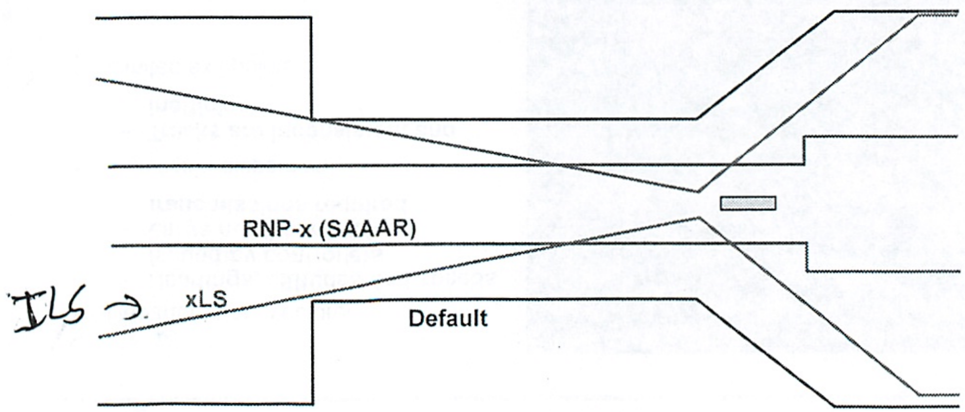
S



GPS/RNP Approach Navigation

- **Requirements**
  - Accuracy (RNP)
  - Availability
  - Integrity
- **Differential GPS**
  - Sattalite Based Autmentation System (SBAS)
    - Wide Area Augmentation System (WAAS)
  - Ground Based Augmentation System (GPAS)
    - Local Area Augmentation System (LAAS)
- **Required Navigation Performance (RNP)**
  - Lateral Containment
  - RNP 0.3, RNP 0.15, RNP 0.1
  - Vertical Performance Limits (VPL) Dominate

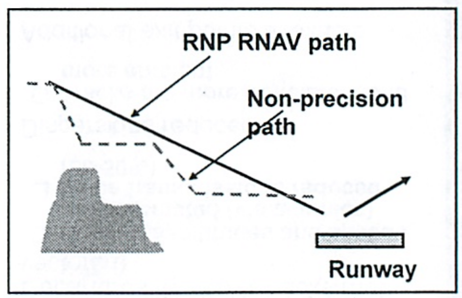
Performance-Based NAS Approaches

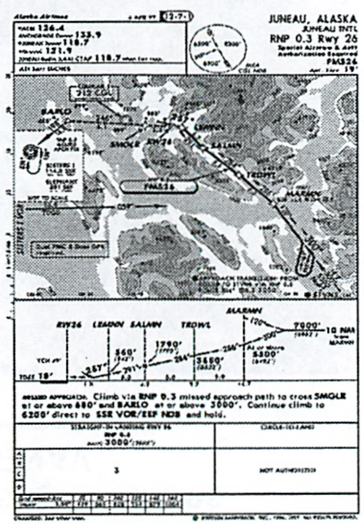


(Notional figure)

Originally from Alaska Airways for Juno

Required Navigation Performance (RNP)





•Allows tighter route spacing and vertical guidance

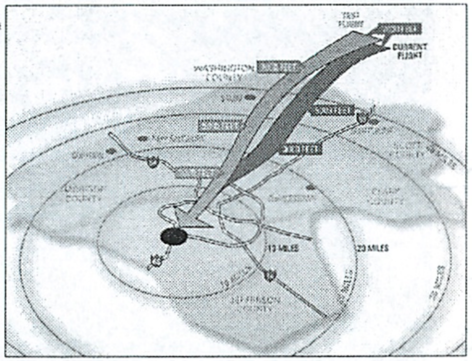
•Shift to Satellite Nav Systems
•GBAS
•SBAS

·Source: Brian Kelly, Boeing

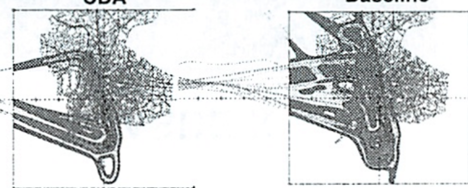
MIT involved in trials

Continuous descent approach

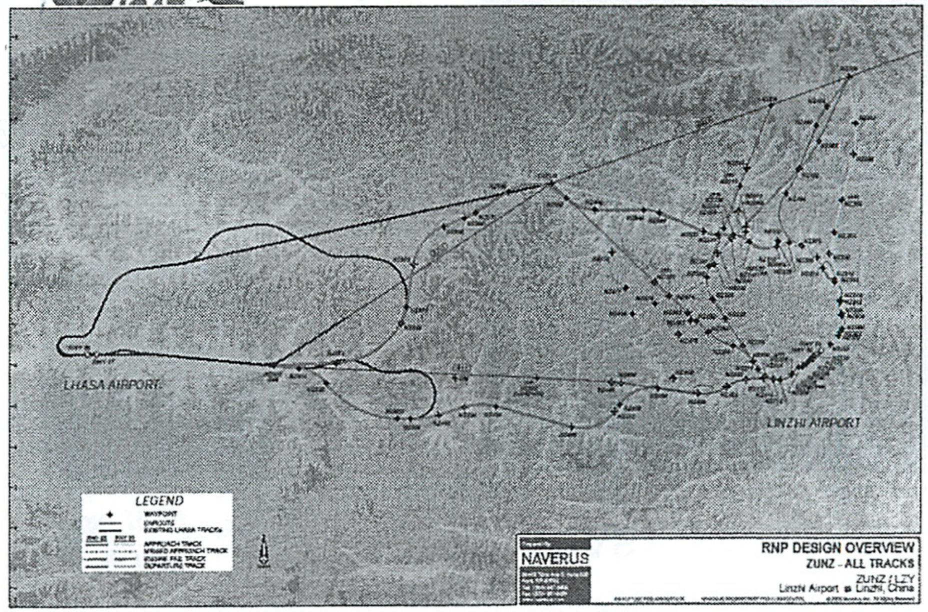
- MIT, FAA, NASA, UPS, Louisville Airport
- 125 UPS aircraft
- 3-6 dB noise reduction
- 35% NOx reduction
- 13-20% CO reduction
- 11-25% UHC reduction
- >120 lbs fuel reduction
- 2-3 min. flight time reduction
- Rapid transition to application (mid '05?)



CDA | Baseline

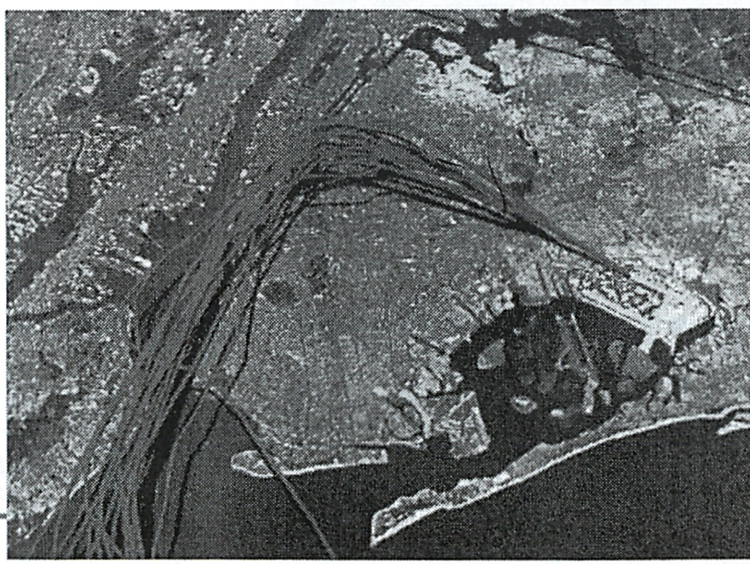


Lhasa, Linzhi RNP Approaches



tibet

Proposed NY RNP Procedures

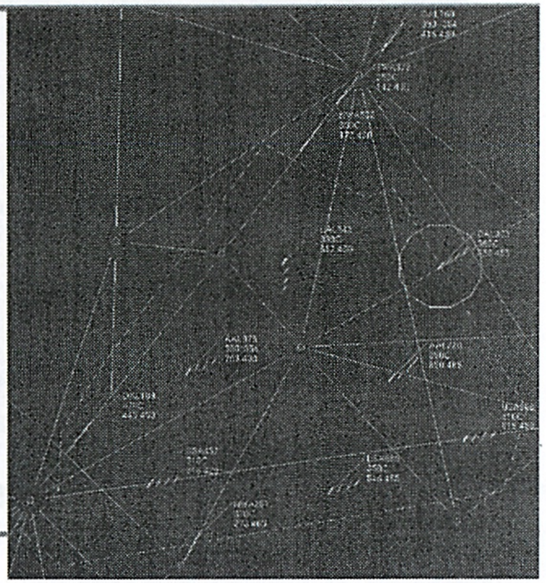


SURVEILLANCE TRENDS

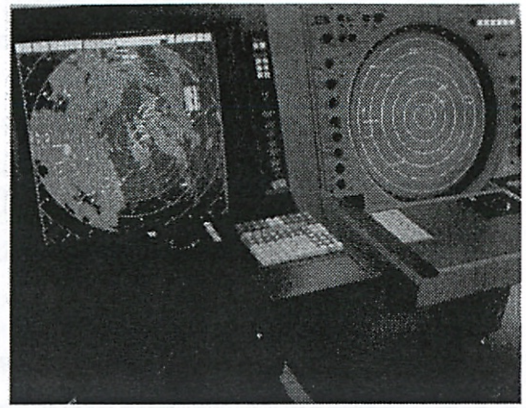
- **Primary radar**
  - Enroute (12 sec scan)
  - Terminal area (4.2 sec scan)
- **Secondary radar**
  - Transponders
    - Mode C (altitude)
    - Mode S (2-way data exchange)
- **Onboard surveillance**
  - TCAS
- **Automatic Dependent Surveillance (ADS)**
  - Oceanic ADS-C (Contract)
  - Domestic ADS-B (Broadcast)

Radar Display Example

CO 123
350C
B757 310



STARS (Standard Terminal Automation Replacement System)

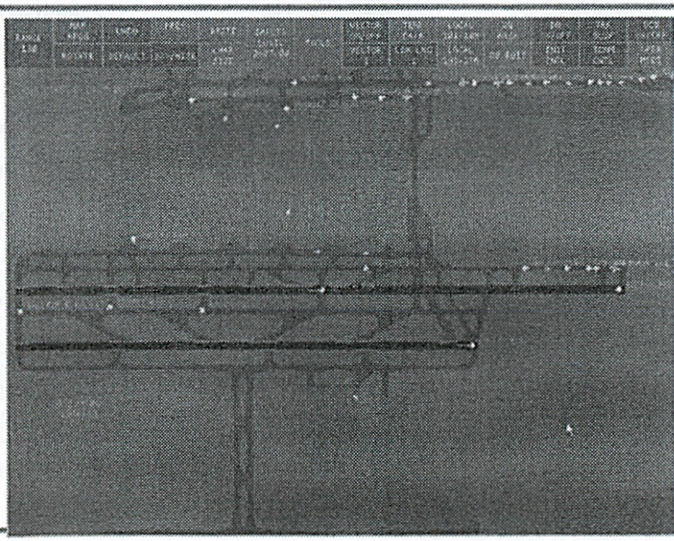


Cold

↑
new

STARS & ASR-9 Consoles

ASDE-X

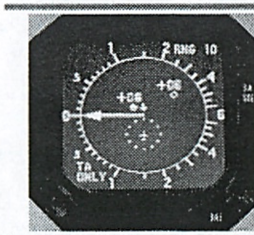


Survalence on surface

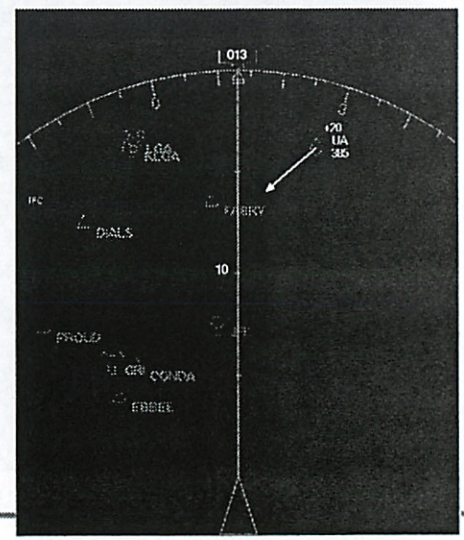
– uses various data sources

http://www.tsc.com/SETS/_3SurfaceS.htm

TCAS



data from transponders

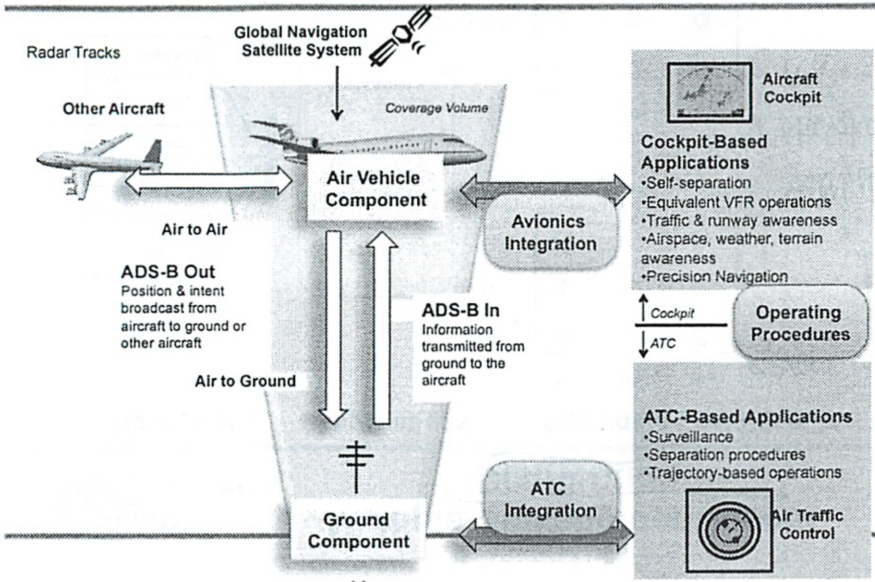


backup if airtrafic control fails

– only works in vertical direction

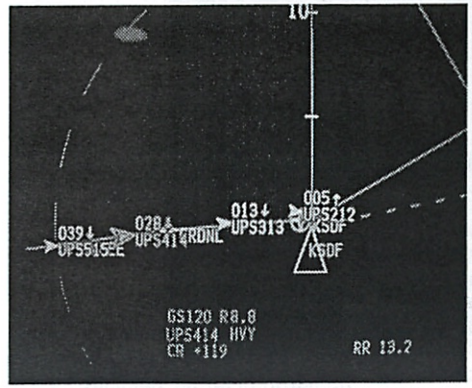
moving towards

ADS-B (1 sec update)



Cheaper than Radar

ADS-B: Cargo Airline Association Safe Flight 21

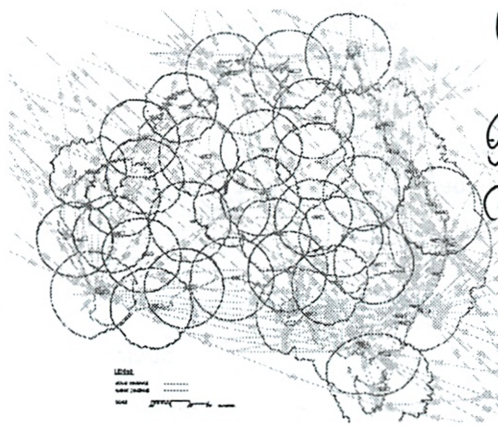


Bob Hilb
UPS/Cargo Airline Association

ADS-B Australia Implementation

ADS-B Track

Radar Track

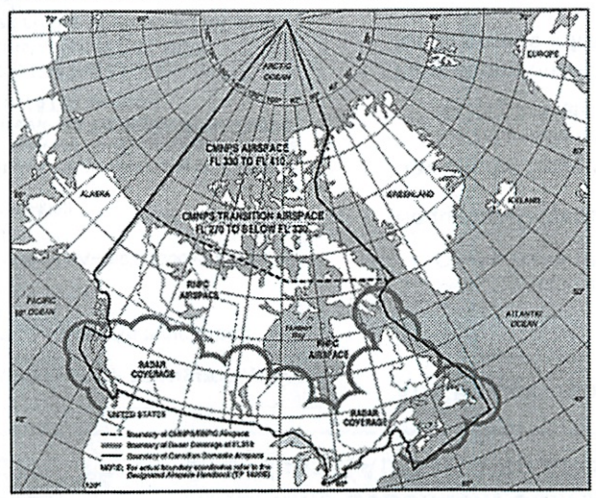


did it 1st

get more coverage - cheaper - just a radio - not a radar

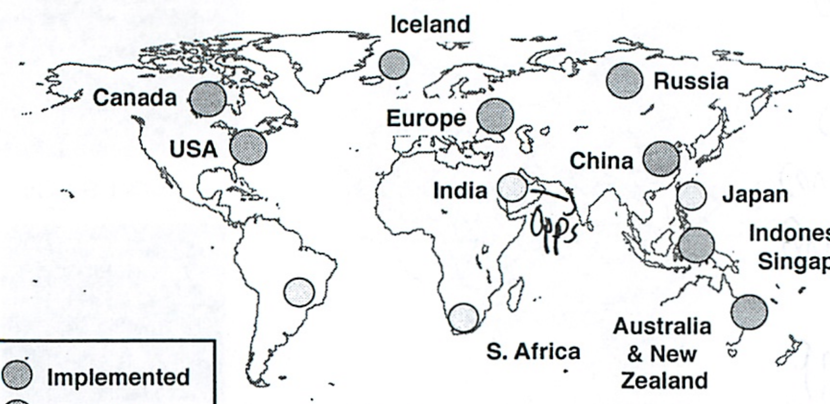
Source: Greg Dunstone
ADS-B Program Manager

ADS-B Hudson Bay Canada



Source: Canadian http://www.tc.gc.ca/CivilAviation/publications/tp14371

ADS-B Implementation Plans



- Implemented
- Committed
- Expected
- Evaluated

Out of date

Automatic Dependent Surveillance Broadcast (ADS-B) Mandate NPRM

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Part 91

[Docket No. FAA–2007–29305; Notice No. 07–15]

RIN 2120–AI92

Automatic Dependent Surveillance—Broadcast (ADS–B) Out Performance Requirements To Support Air Traffic Control (ATC) Service

AGENCY: Federal Aviation Administration (FAA), DOT.

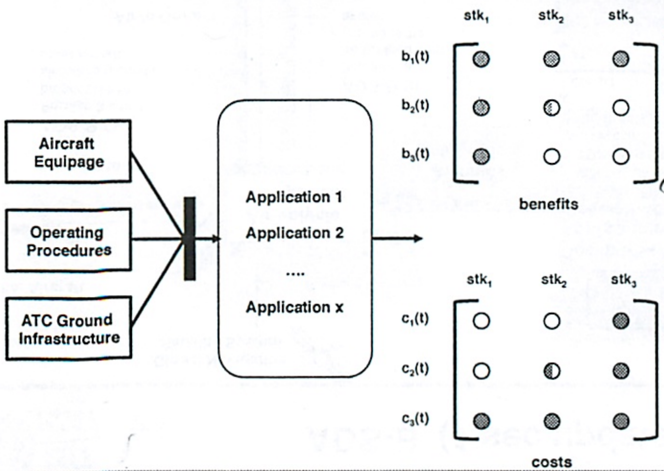
ACTION: Notice of proposed rulemaking (NPRM).

SUMMARY: This notice proposes performance requirements for certain avionics equipment on aircraft operating

- ADS-B " Out" mandate by 2020
- Impacts
  - Class A, B, C
  - Mode C veil (30 nm radius)
  - Class E above 10,000
- Requires DO-260A Change 2
- Nav Source Requirements
  - NAC of 9 ~30 meters
  - NIC of 7 (0.3 nm)
- Final commitment date of 2013 for all ground infrastructure

Multiple-Stakeholder Benefit Distribution

Capabilities | **Applications** | **Aggregate Cost/Benefits**



green

need benefits > cost

stakeholder 1

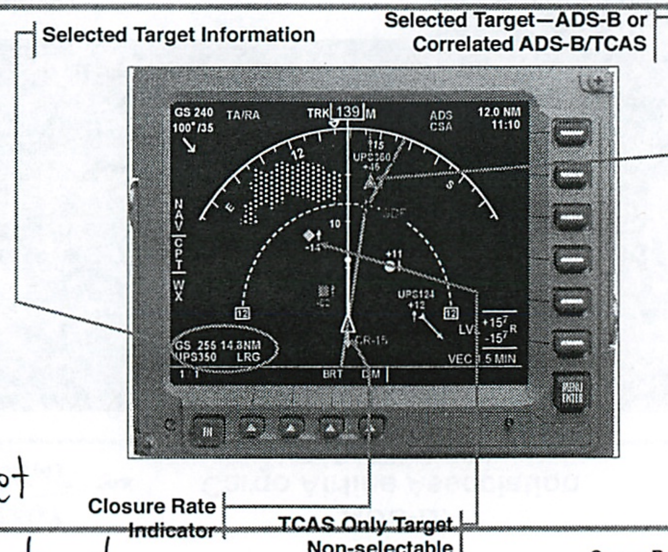
stakeholder 3

red

need to get everybody to do

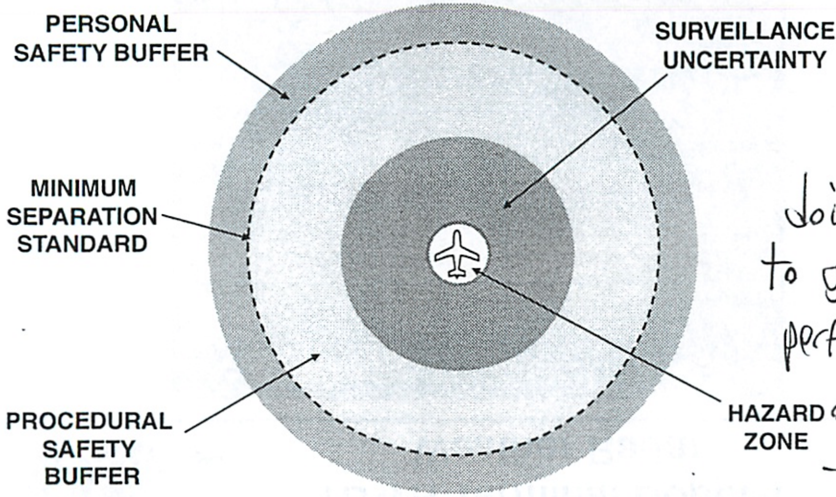
Adapted from: Dr. Karen Marais & Prof. Annalisa Weigel (MIT) " Encouraging and Ensuring Successful Technology Transition in Civil Aviation"

Cockpit Display of Traffic Information (CDTI)



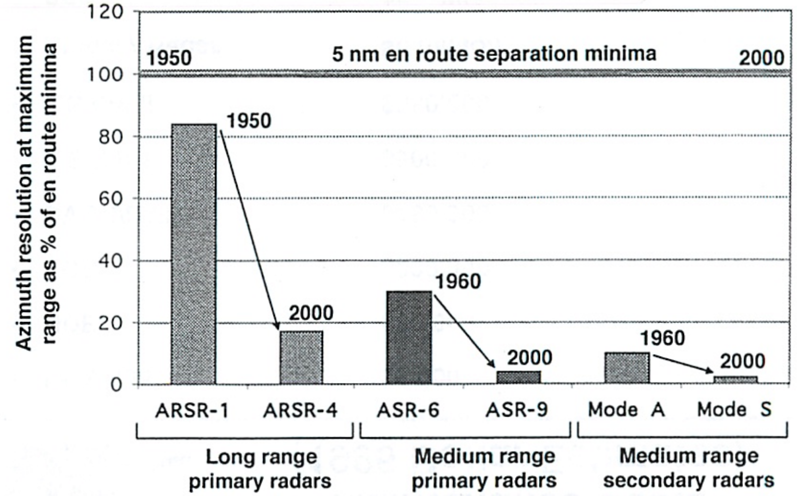
Sorce: Bob Hilb UPS

Separation Standards



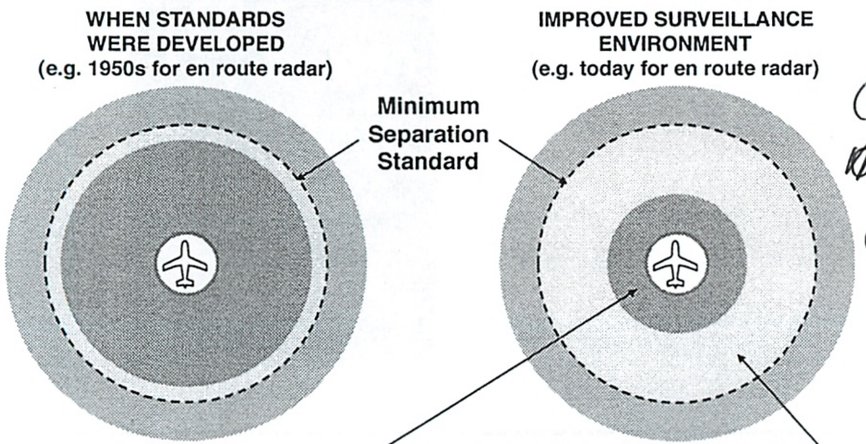
doing this to get better performance out of station - now 5 miles

EN ROUTE MINIMA HAVE NOT CHANGED DESPITE 5 x IMPROVEMENT IN RADAR PERFORMANCE



back in the 1950s - they just made the 5 mile rule up; raders have gotten better, but seperation standard has not changed

Need to adjust standards when capability comes online (eg ADS-B)



- Surveillance has improved, but separation minima have not changed: procedural safety buffer has implicitly increased

can put ~~them~~ planes closer together

WEATHER TRENDS

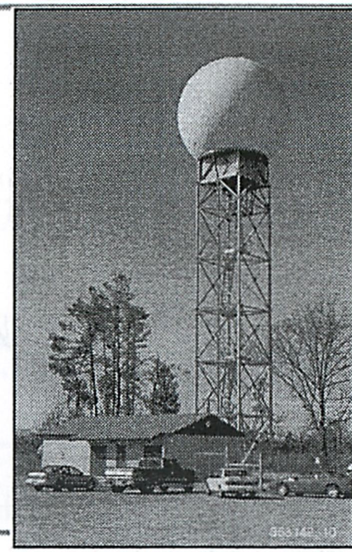
- **Surface observations**
  - Human
  - Assisted
  - Automated (ASOS, AWS)
- **WX radar**
- **Satellite observations**
  - VIS
  - IR
  - Soundings
- **Pilot observations**
  - PIREPs (voice)
  - ACARs downlink
    - Winds, temperature
- **Forecasts**
  - Model based (ETA → 20km grid)
  - Terminal
-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

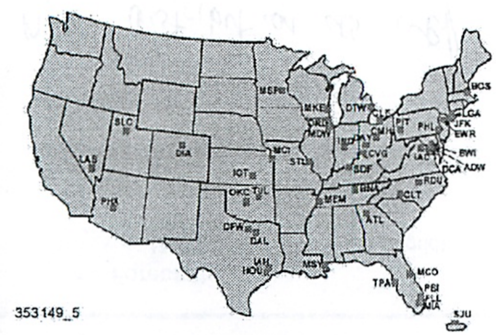
need distribution as well

weather has leading use of any communication standard

ASOS (Automated Surface Observation System)

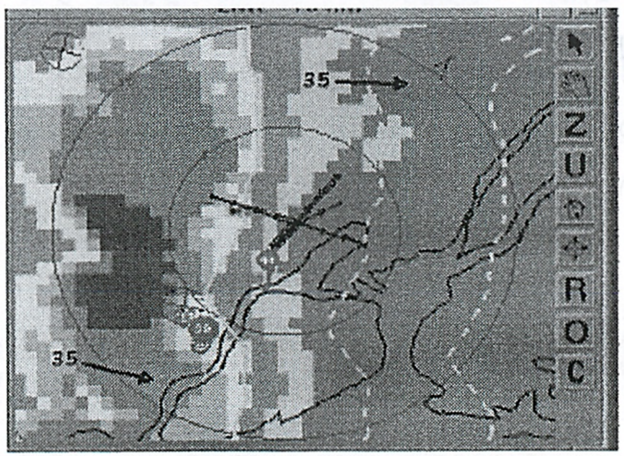
TDWR Terminal Doppler Weather Radar





http://www.ll.mit.edu/AviationWeather/TDRW-flyer.html

TDWR Terminal Doppler Weather Radar



http://www.ll.mit.edu/AviationWeather/TDRW-flyer.html

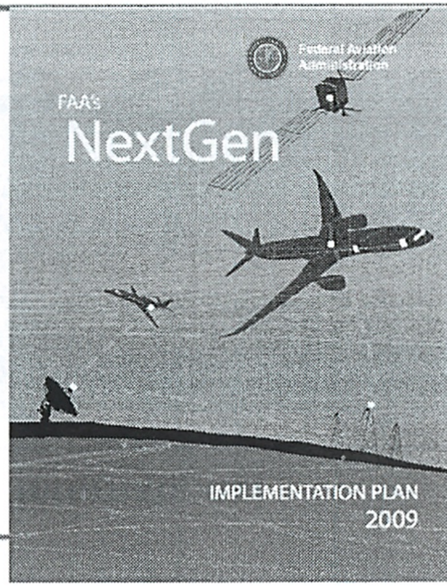
Maintenance Costs (1995 Dollar Estimates)

• 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

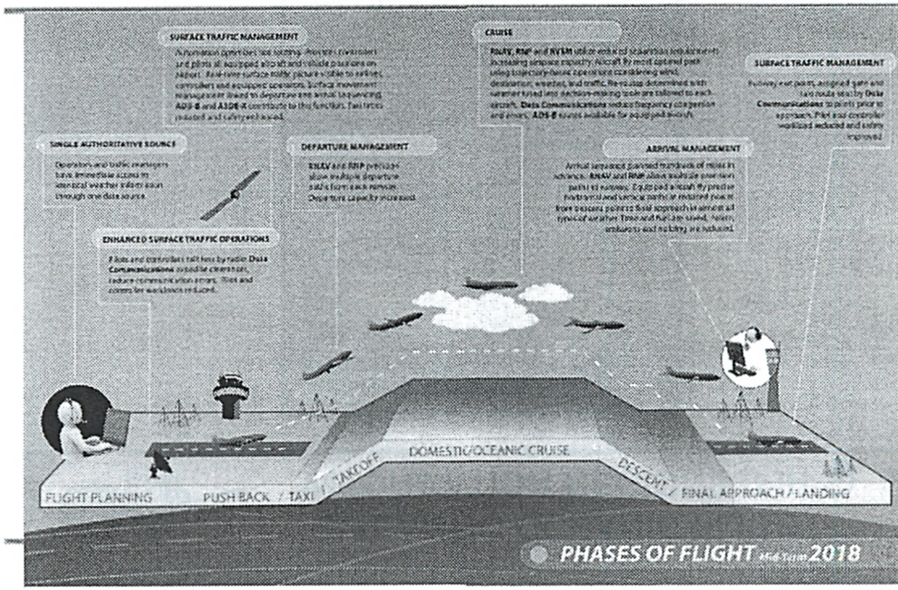
Source: ICAO FANS Investment Plan for India

NextGen Implementation Plan

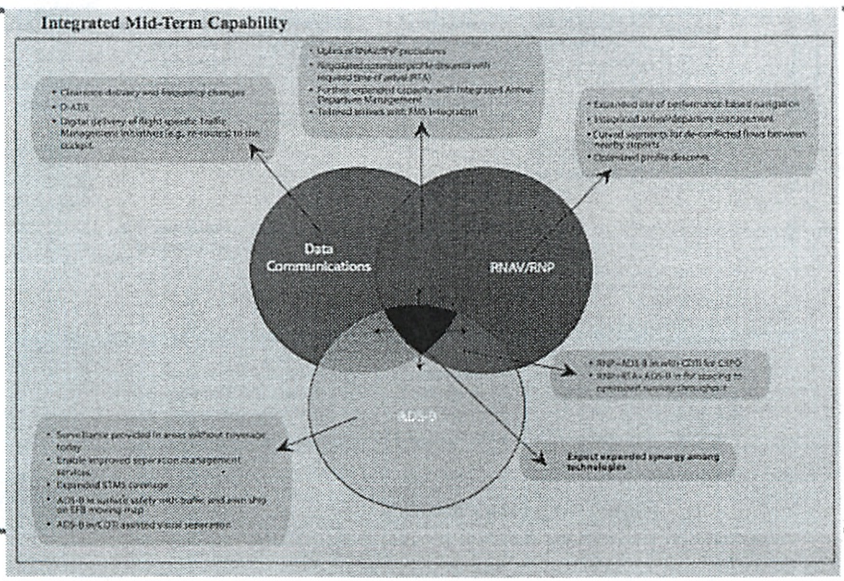
- Focus on first phase of NextGen Transition to 2018



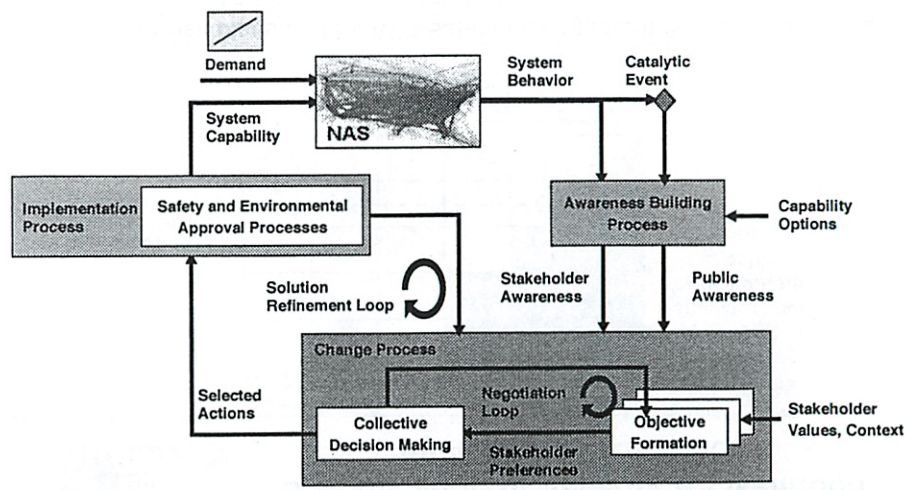
NextGen Implementation Plan



NextGen Implementation Plan



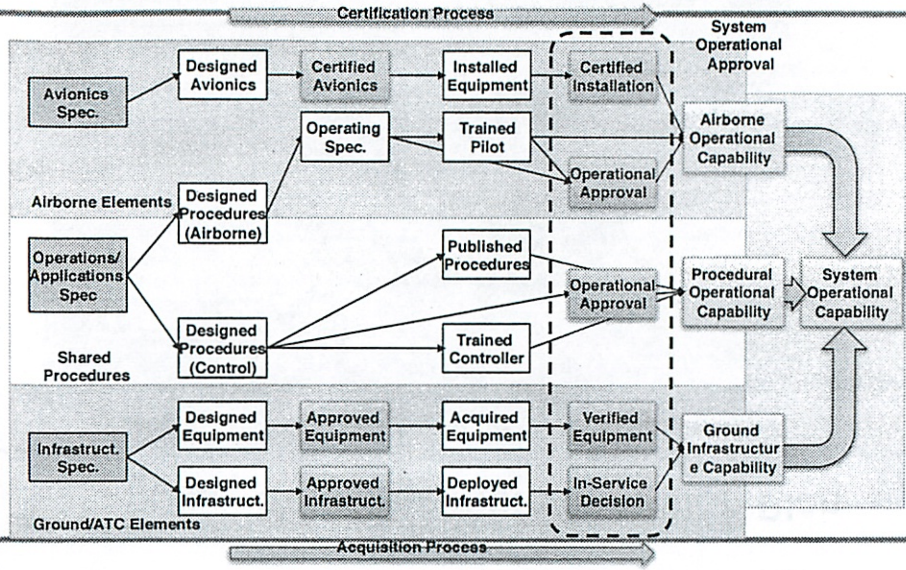
Key Challenge
Certification and Operational Approval of New Concepts and Technologies



MIT ICAT

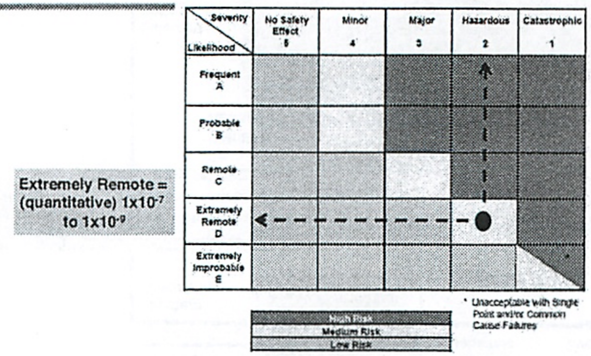
Simplified Set of States Required to Achieve Operational Capability

General Air/Ground Integrated System



MIT ICAT

Classification of Severity & Likelihood by ATO SMS Guidance



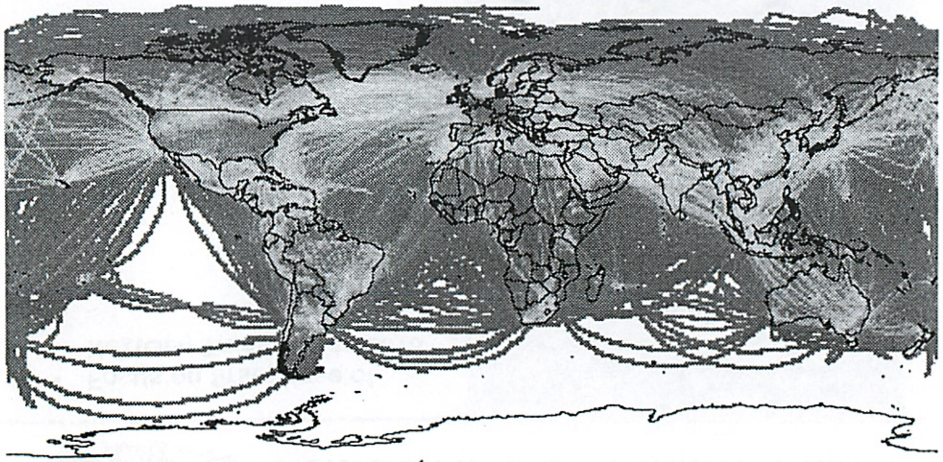
Hazardous = "Serious or fatal injury to small number of occupants or cabin crew"

- **Target risk classified by ATO Safety Management System standards**
  - Hazardous assumption & 10^{-7} assumption
- **Risk also compared to ground fatality risk from commercial aviation**
  - Frequency approximately $1x10^{-7}$ fatalities/hr due to Part 91 ops

how to make changes while keeping system safe

MIT ICAT

International

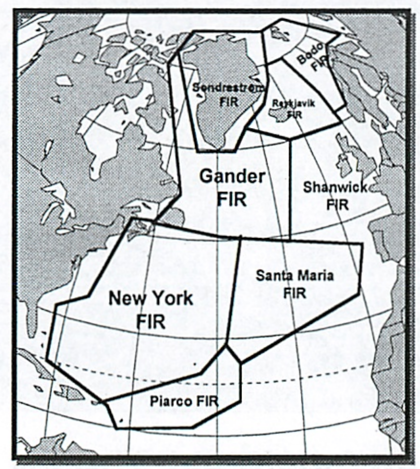


Traffic Source: Sage Analysis courtesy Prof Ian Waitz

** Presentation for Educational Use Only*

MIT ICAT

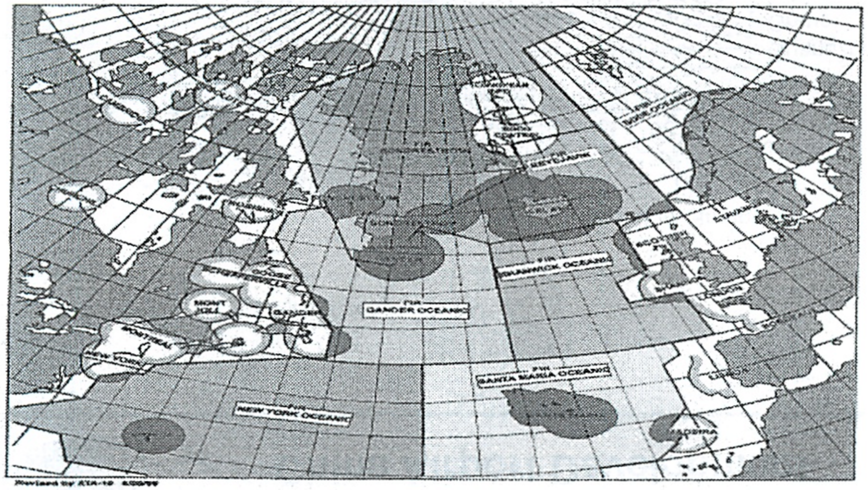
ATLANTIC OCEANIC FLIGHT INFORMATION REGIONS (FIR'S)



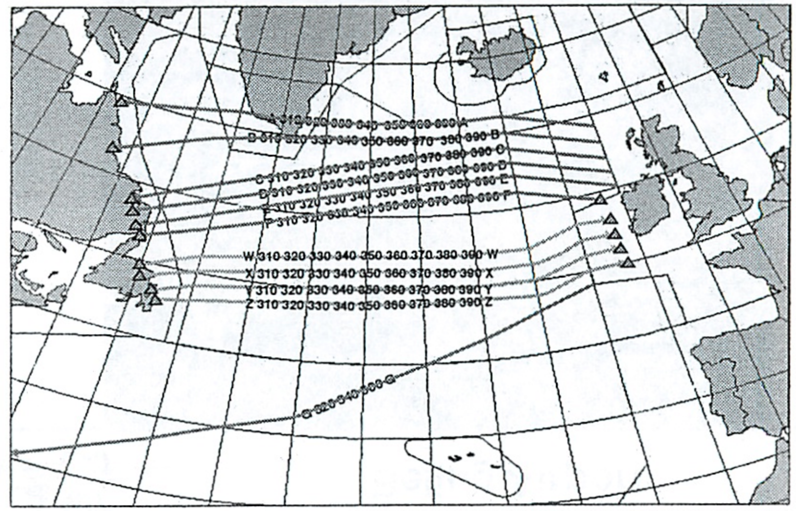
Adapted from "Implementation Plan for Oceanic Airspace Enhancements and Separation Reductions", FAA, 1998

MUCH OF ATLANTIC AIRSPACE OUT OF RANGE OF VHF & RADAR

Use HF

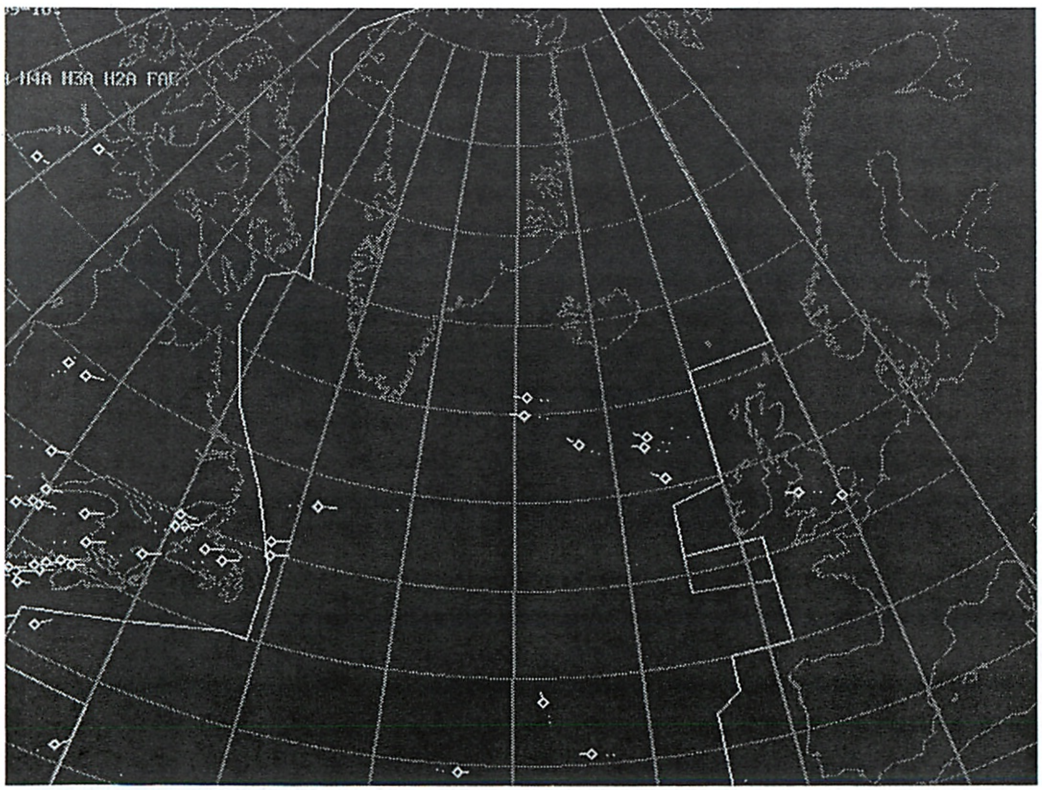


NORTH ATLANTIC TRACKS



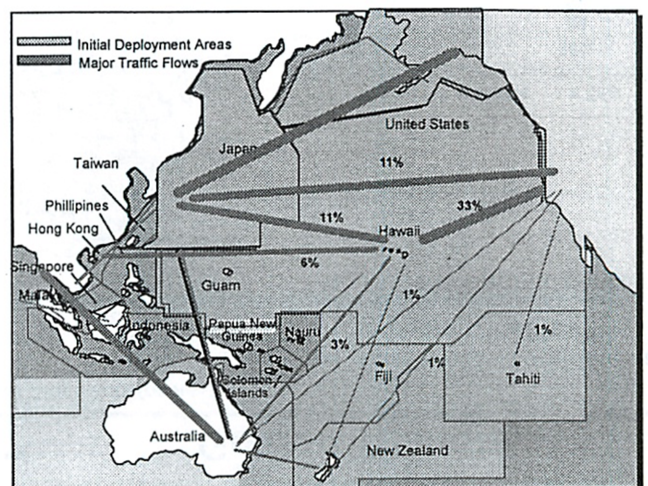
Set each day based on wind

mostly speed control – only check in ~45 min



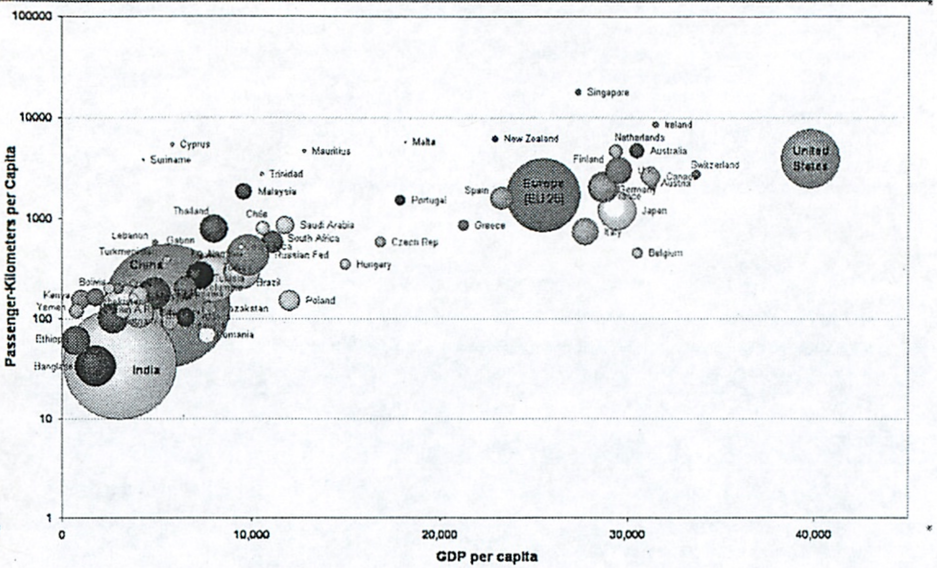
PACIFIC OCEANIC FLIGHT INFORMATION REGIONS (FIR'S)

FANS Data Link Deployment Areas in Grey



Air Transportation Markets

2004 Data

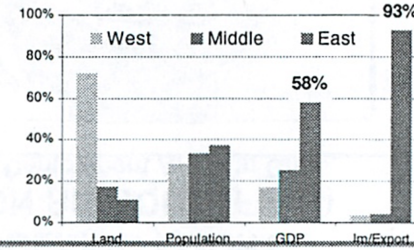


China Golden Triangle

Distribution of Cities and Towns

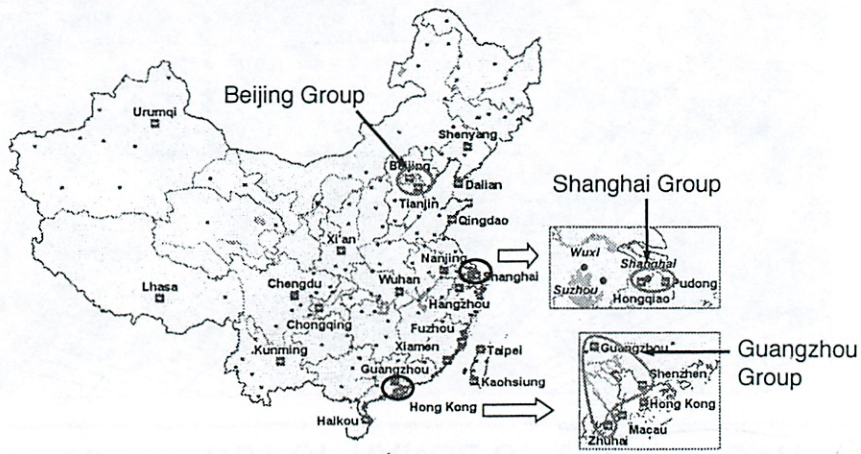
Land	9.6 mn km²
Population	1,284 mn
GDP in 2002	10,240 bn RMB
Intl Trade in 2002	621 bn USD

- East region dominates all economic metrics
- Three economic centers
  - Beijing
  - Shanghai
  - Guangzhou



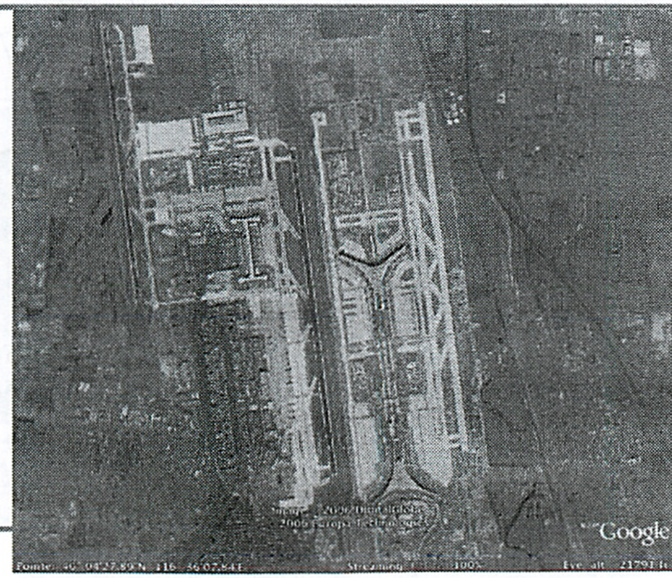
Source: National Bureau of Survey & Mapping of China, NBS

China Airport Development

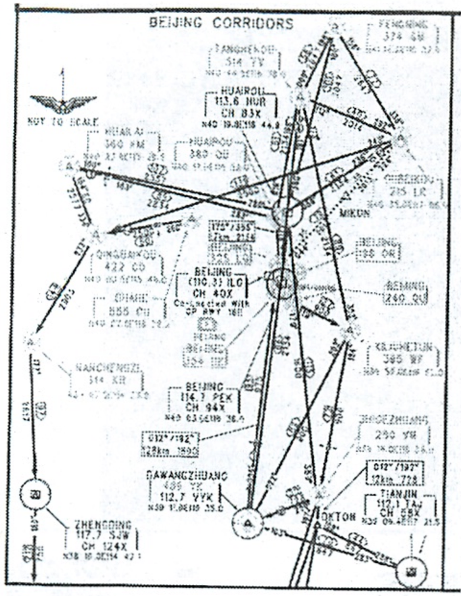


- ~150 commercial airports operational in 2002
- 237 airports expected by 2010 (CAAC), most are regional airports

Bejing Airport



Bejing Corridors



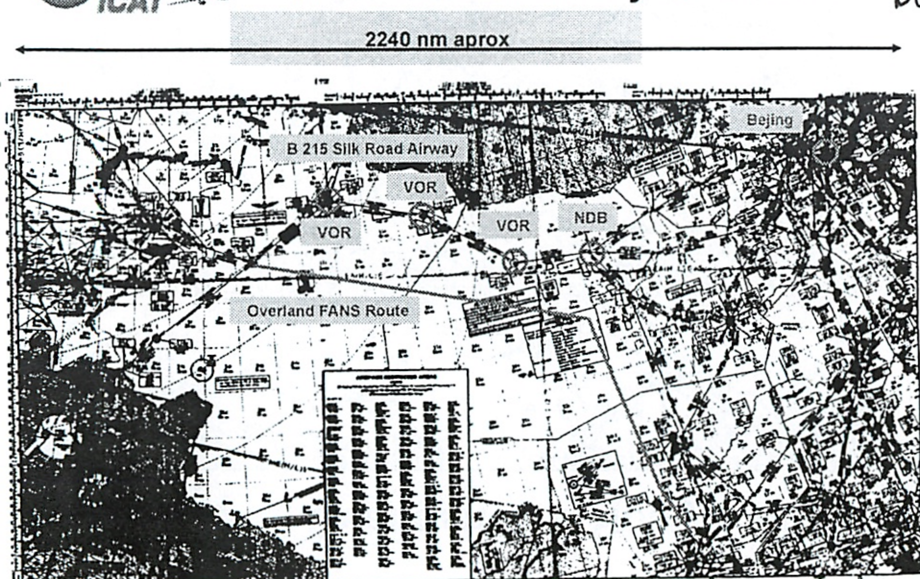
- 3 Arrival Corridors
- 3 Departure Corridors
- 2 Overflight Corridors

military airspace around city
- have to go through convective airspace

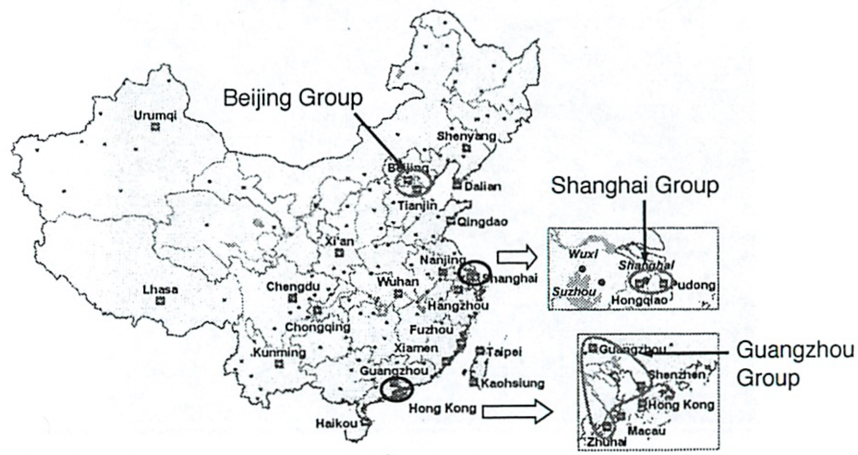
military runs airtraffic as a for-profit biz

↓ central china - used to only have 1 beacon

West China Airway Structure



China Airport Development



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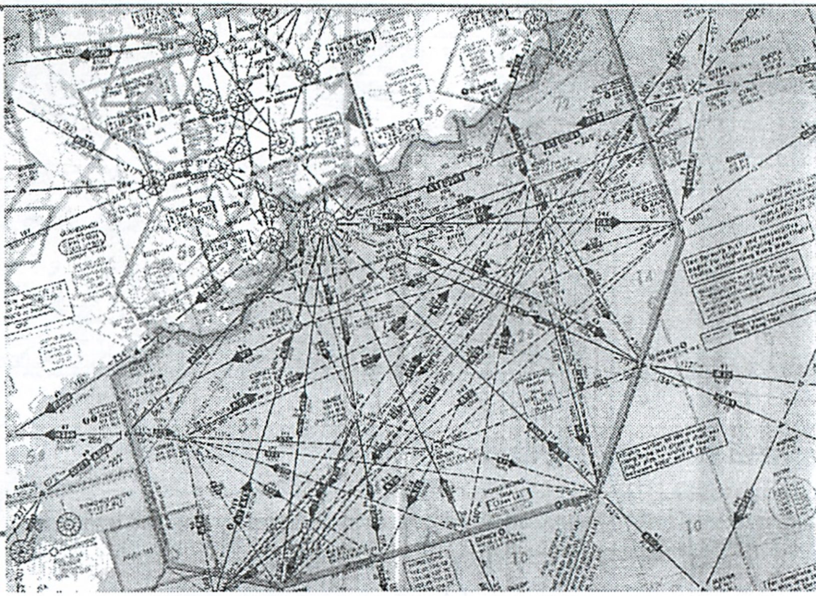
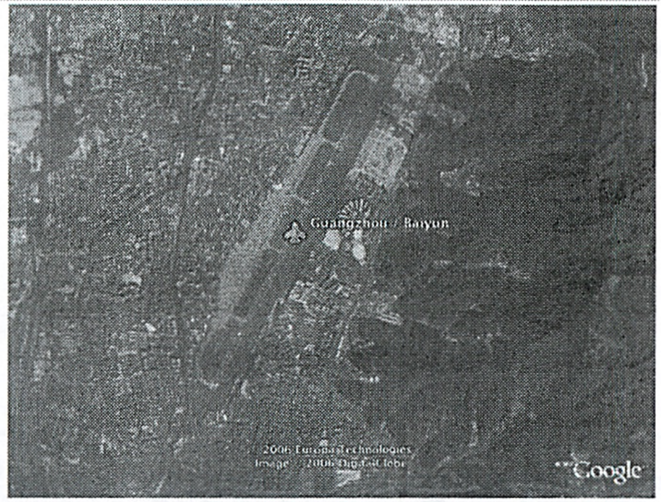
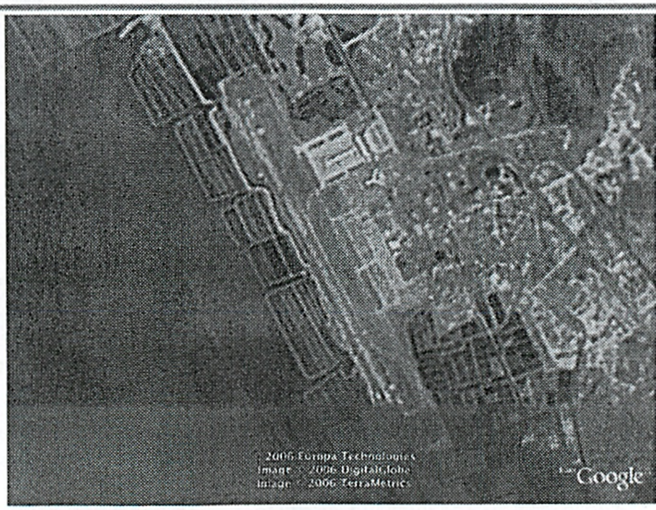
Guangshou & Hong Kong



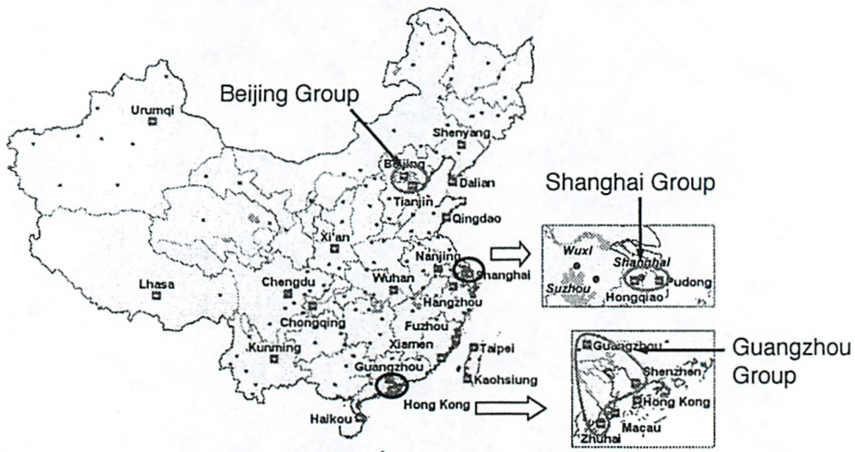
Guangshou-Baiyan Airport



Shenzen Airport

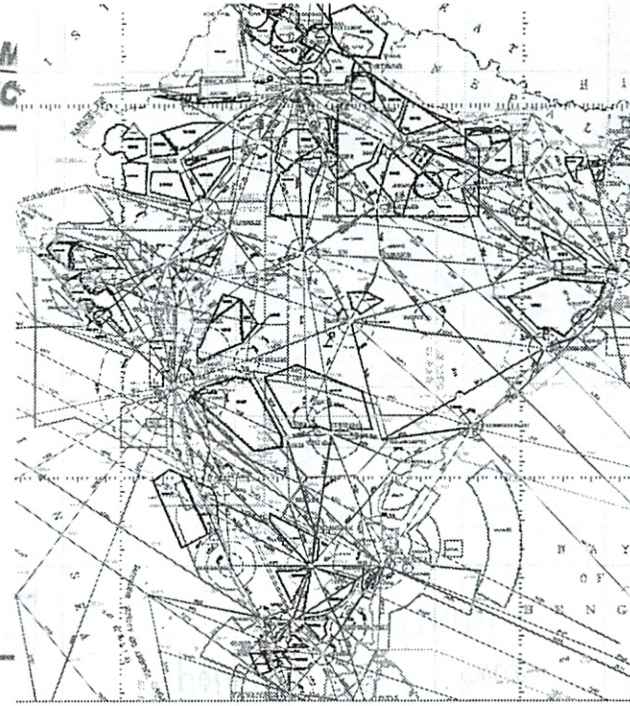


China Airport Development



- ~150 commercial airports operational in 2002
- 237 airports expected by 2010 (CAAC), most are regional airports

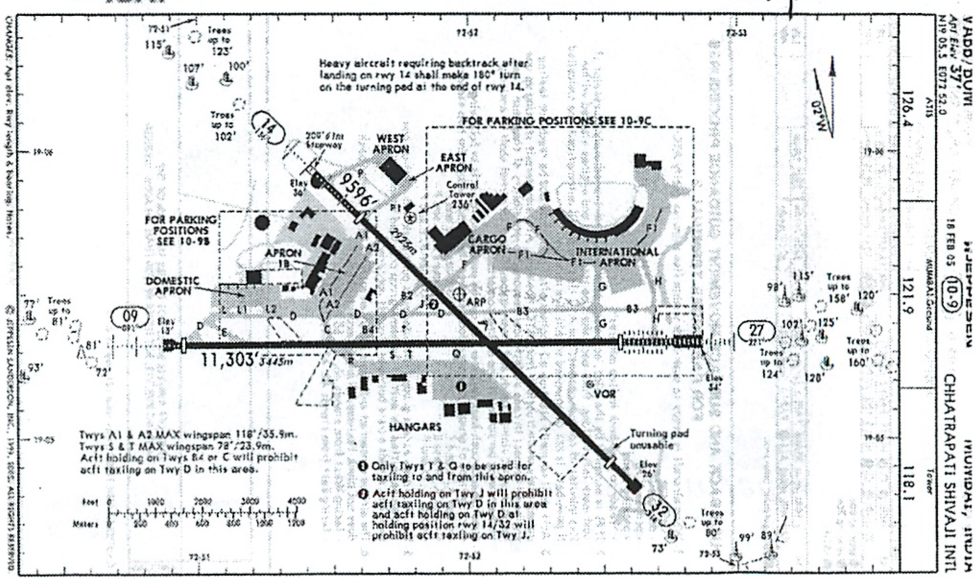
Shanghi



Mumbai

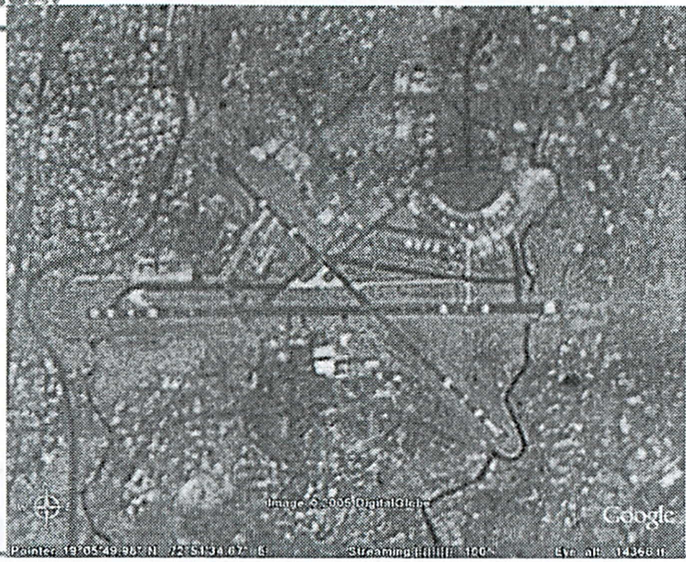
Mumbai

not a high performing airport



hard to expand

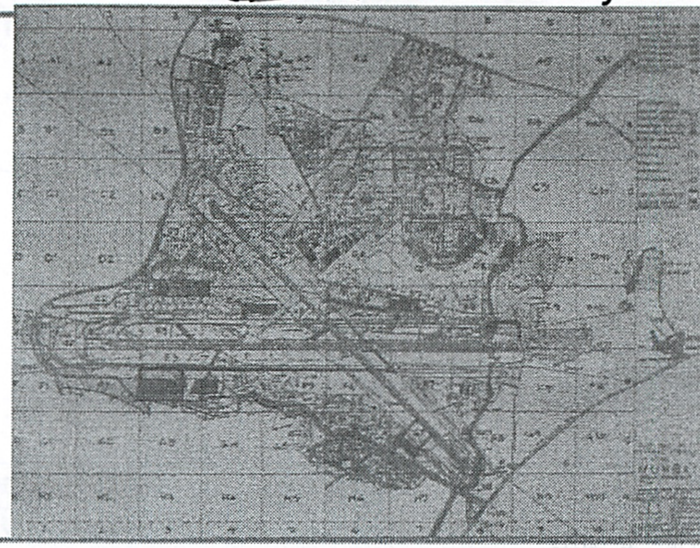
Mumbai



very limited on space

High Local Population Density Limits Expansion

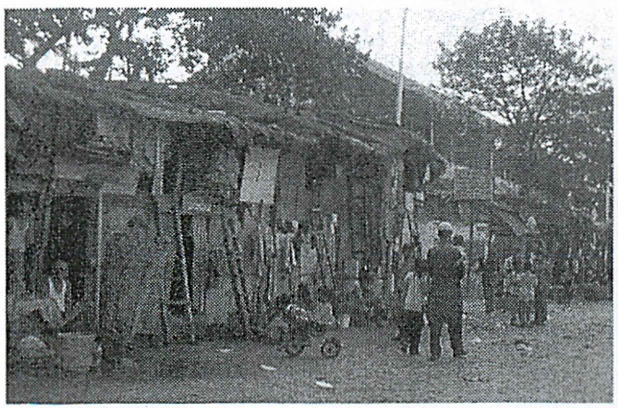
Mumbai
Encroachment areas in yellow



High Local Population Density and Topography Limits Expansion

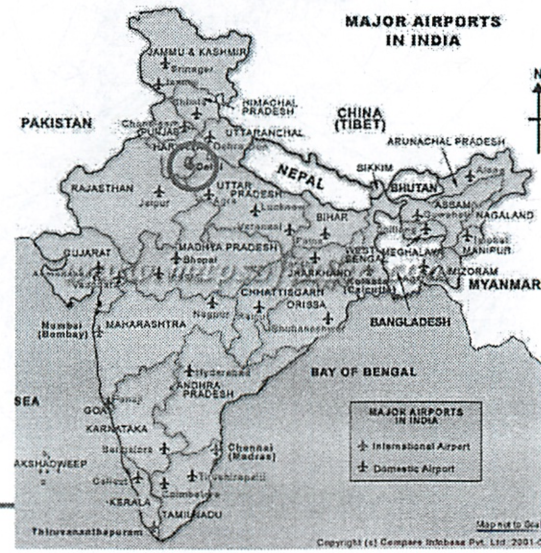
people live on airport property
– politically can't move

Mumbai Encroachment Issue

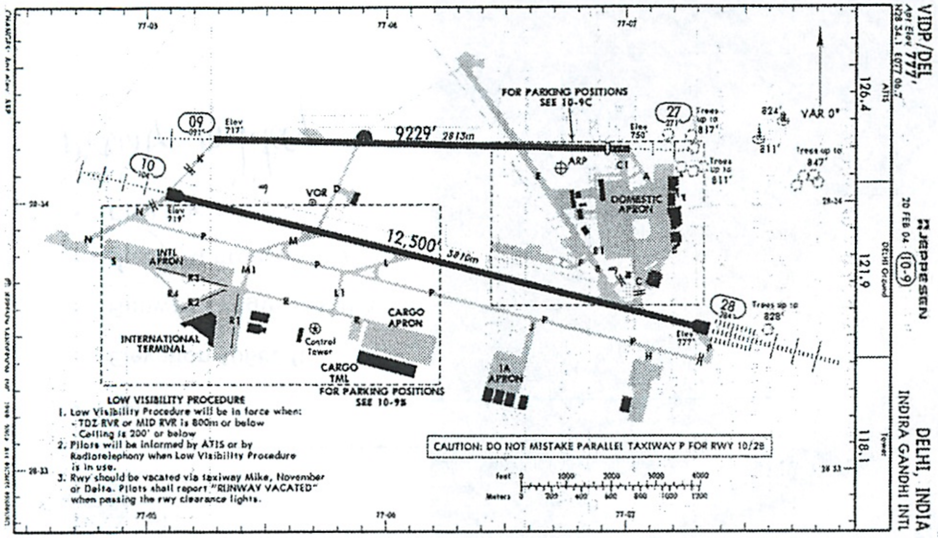


High Local Population Density and Topography Limits Expansion

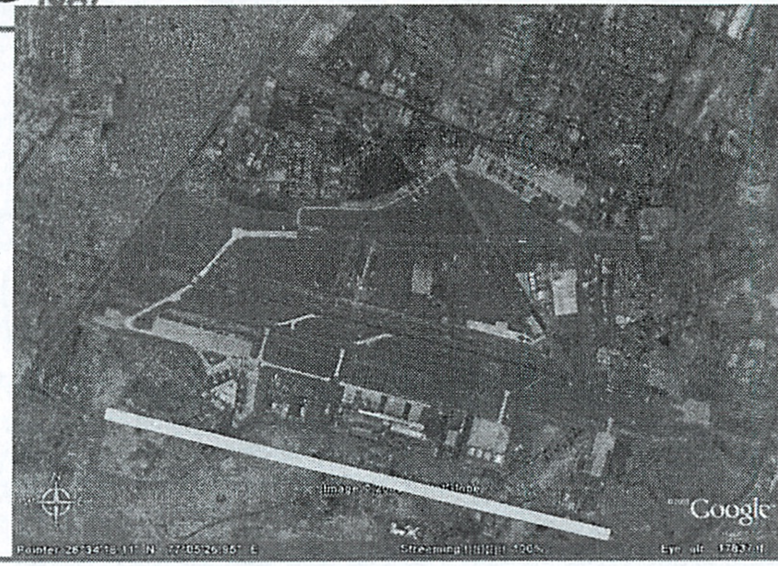
Delhi



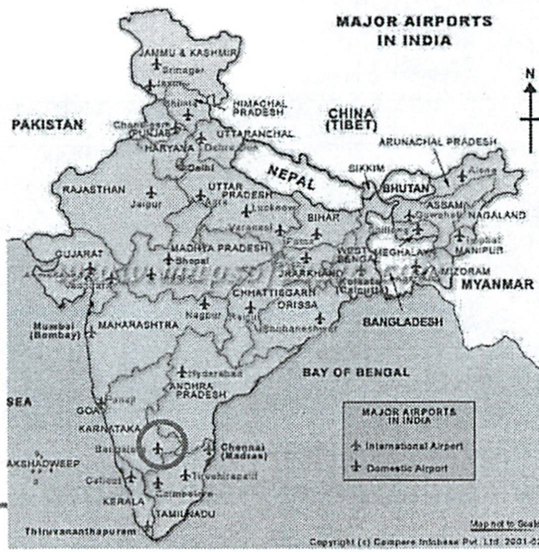
Delhi

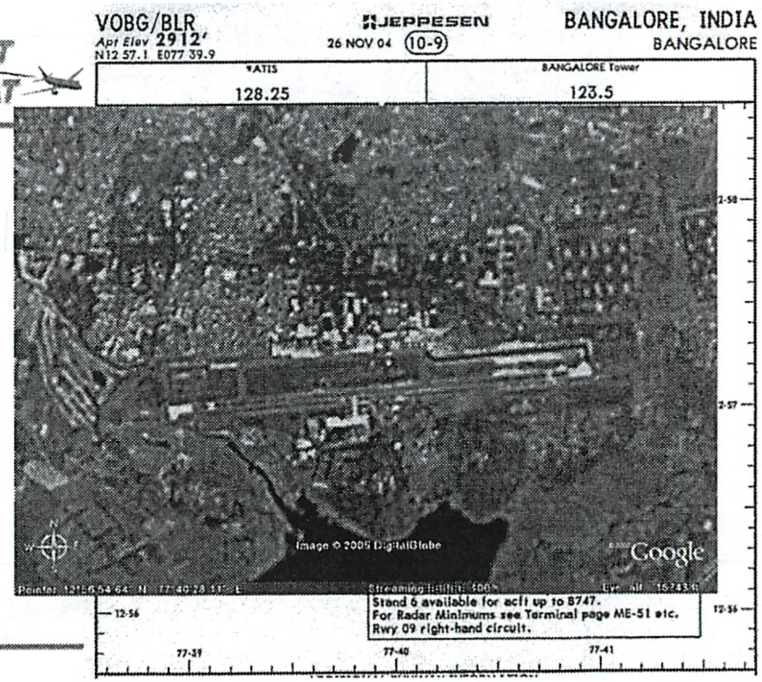


Delhi

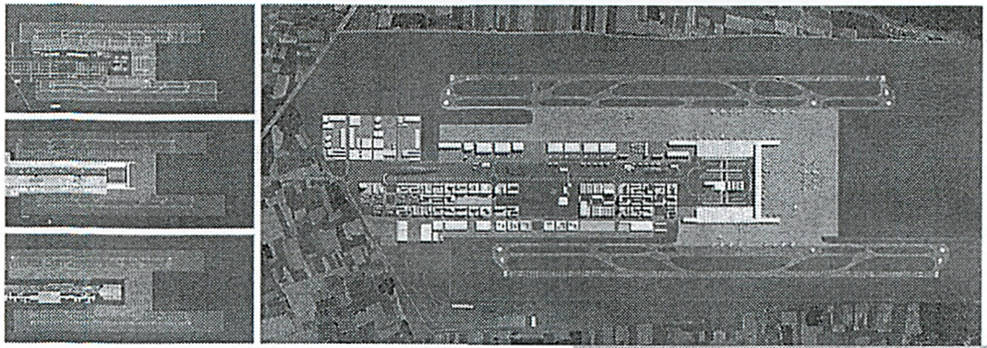


Bangalore





Bangalore "Greenfield" Airport
PPP International Investment



Source: Bangalore Airport Watch http://www.karnataka.com/watch/bi-airport/

Airport Design: Kaufmann, van der Meer Planer AG

Leh

most difficult airport in country

- Leh (IXL)
- Elevation 10682 ft
- Runway Length 10100 ft
- Visual Approach Only
- Civil Enclave

mainly military