Introduction to Air Traffic Management

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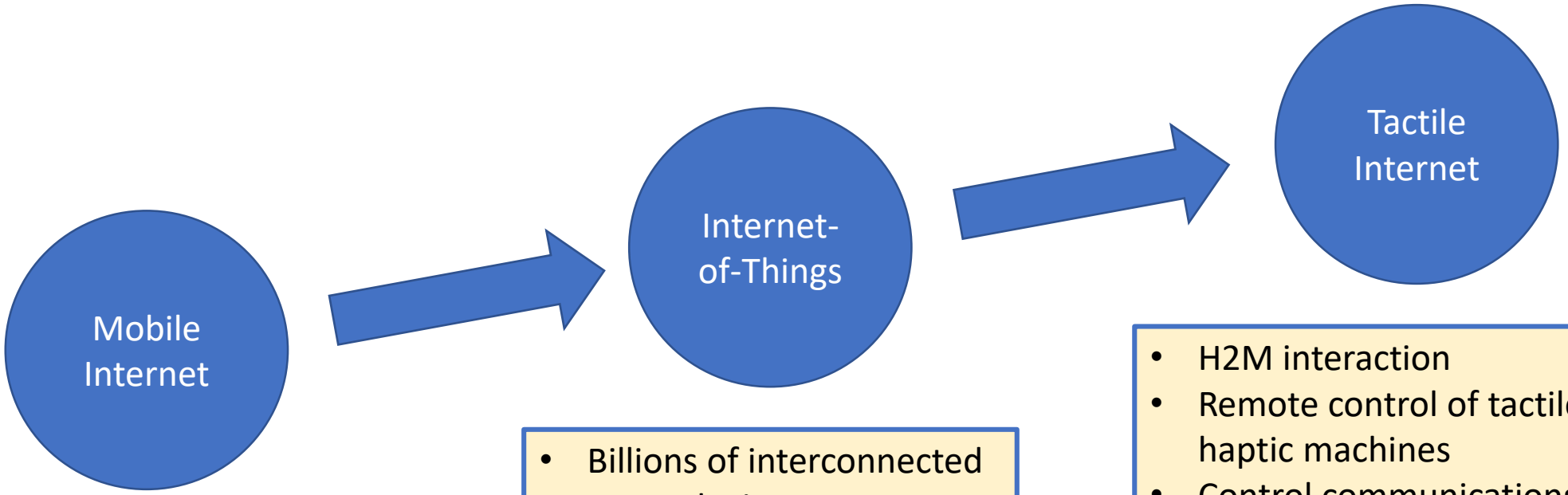
Outline

- Roadmap to Internet-of-Things and Beyond
- Transportation Systems
- Multidisciplinary Research
- History of Flight
- Description of the National Airspace System
- Airspace Geometry
- Federal Regulations
- Air traffic controller roles and responsibilities
- Wind and Weather
- Separation Assurance
- Traffic Flow Management

Roadmap To IOT and Beyond



- Optimized for static and streaming content
- Round-trip latency adequate for telephony, web browsing and limited resolution videos

- Billions of interconnected smart devices
- M2M Communications
- Low latency, latency-tolerant
- Security and reliability

- H2M interaction
- Remote control of tactile and haptic machines
- Control communications
- Security and high availability
- Ultra-fast reaction times and carrier-grade reliability

Maier, M., et. al., “The Tactile Internet: Vision, Recent Progress, and Open Challenges,” IEEE Communications Magazine, May 2016

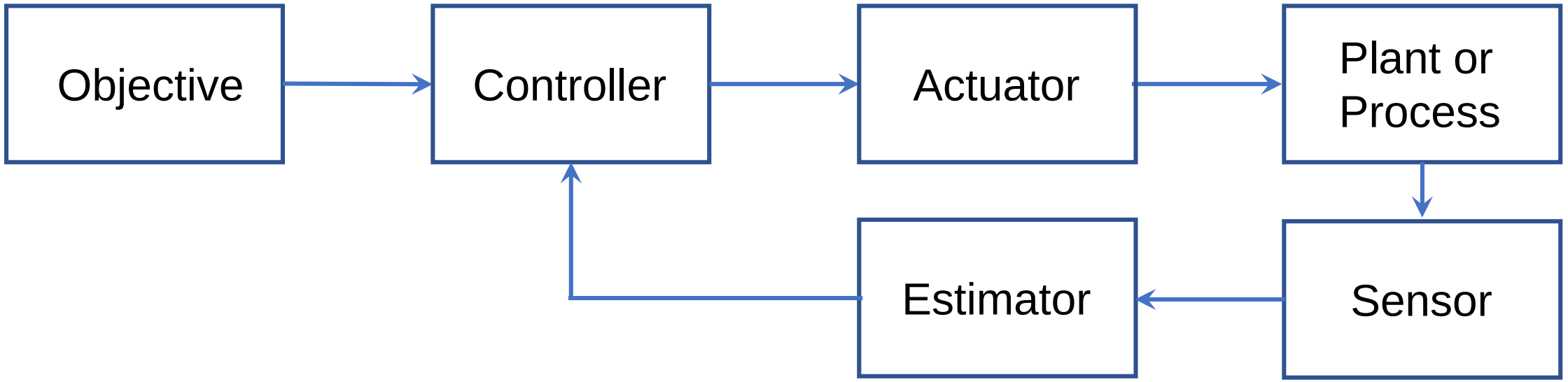
Transportation Systems

Air Traffic	Highway Traffic	Data Traffic
Departure Airport	Origin	Source-node
Arrival Airport	Destination	Destination-node
450 knots (518 mph)	70 mph	6.71×10^8 mph
Pilot & ATM	Driver	Router
Airspace region	Road segment	Link
Airspace layout	Road network topology	Network topology
Aircraft	Road vehicle	Data Packet
Flight-plan	Route	Route
Capacity	Capacity	Bandwidth
Transit-time	Trip-time	Processing-time
Metering & Rerouting	Metering & Rerouting	Metering & Rerouting
Delay	Delay	Delay & packet loss

Purpose of Data Science in Air Traffic

Air Traffic Management

- Air Traffic Control (ATC)
- Traffic Flow Management (TFM)



Why is ATM Challenging?

- Data complexity — flight-data, radar-data, geometric data, wind, weather, models
- Interaction complexity — human-to-human, human-to-machine, machine-to-machine
- Communication complexity — wireless radio-based and wired voice and digital communication with aircraft and geographically distributed sensors and decision-support systems
- Governing regulations and directives
- Complex infrastructure — radar systems, surveillance systems, radio beacons, landing systems, lighting systems, computer systems
- Uncertainties — weather (wind, severe weather, fog), equipment and airline
- Operational complexity — safety, efficiency, fairness, quality assurance, multiple stakeholders, certification, advocacy

Multidisciplinary Research

- Dynamics, Estimation, Guidance, Navigation, and Control
- Operations Research, Queuing Theory and Optimization Methods
- Communications Networks (Control Plane and Data Plane models)
- Highway Transportation
- Computer Science (Networks, Graph Theory, Database)
- Computer Vision, Machine Intelligence and Robotics
- Hybrid Systems
- Fluid Mechanics
- Economics
- Management

First Air Traffic Controller

- Pilot, engine and aircraft mechanic
- ATC Commands:
  - Red Flag: Hold position
  - Checkered Flag: Go
- Degree in Aeronautical Engineering from Washington University in St. Louis
- Retired as Assistant Administrator FAA in 1973

Archie William League at Louis Lambert Municipal Airport in 1929.

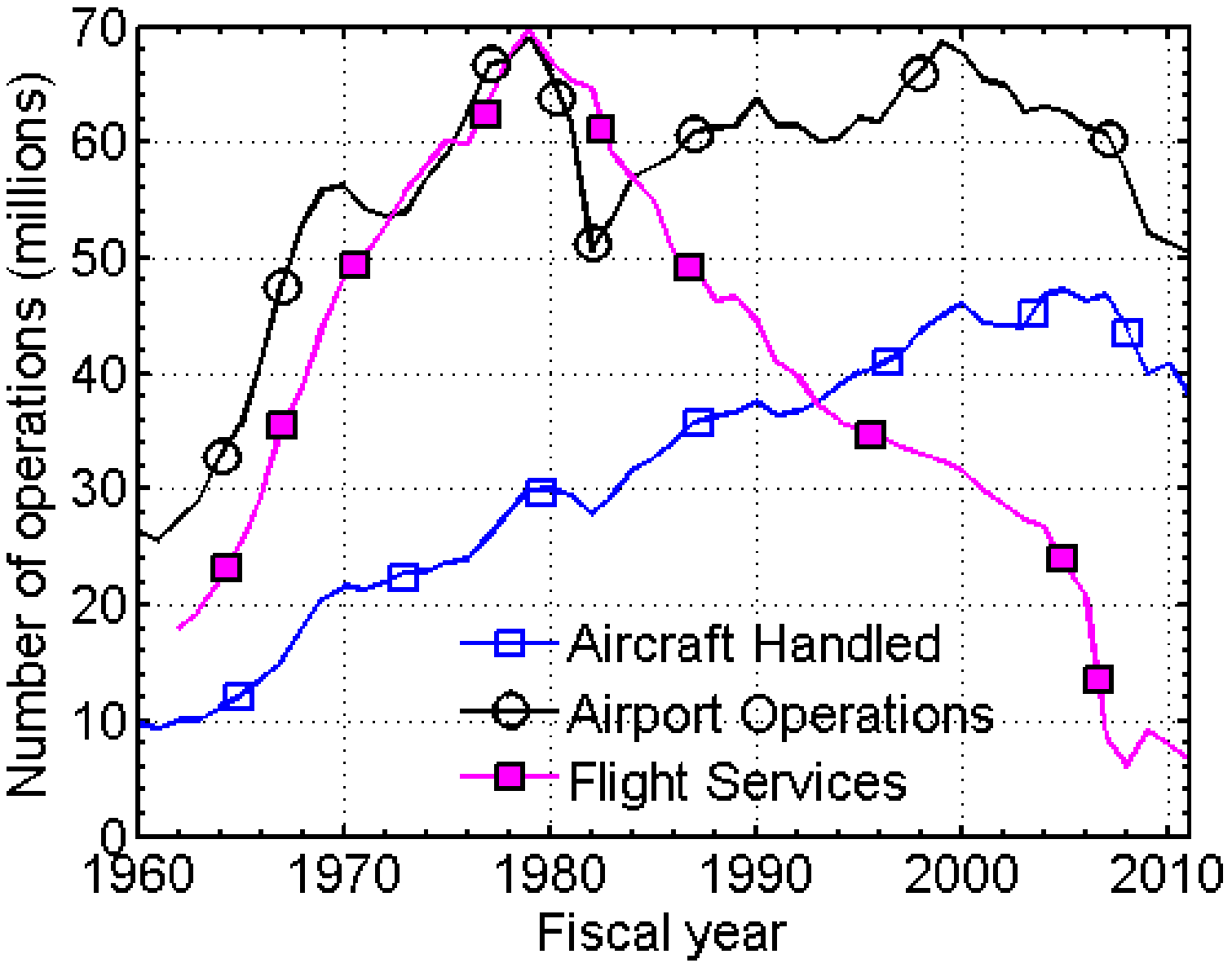
History of Flight

- 1903- Wright Flyer. First flight 12 seconds; distance 37 meters (120 feet).
- Airmail Act of 1925 – Allowed Postmaster General to contract private individuals & corporations for transporting mail. Boeing, Douglas, Pratt & Whitney got into the business.
- 1926-1934 – Charles Lindberg's flight across the Atlantic (May 21, 1927; Ryan NYP). Development of two-way radio and radio equipped control tower. Colonial (American), Western Express (TWA), Northwest and United formed.
- 1934-1955 – Bureau of Air Commerce. Interline agreements to coordinate traffic into Newark, Chicago and Cleveland. Civil Aeronautics Administration in 1940. Visual Flight Rules and Instrument Flight Rules. English common Air Traffic Control language. International Civil Aviation Organization (ICAO) formed in 1947. Instrument Landing System developed.
- 1955-1965 – VORTAC & ARSR developed. ATC computer at Indianapolis Center. ATCRBS developed. Commercial jet aircraft. Separation standards and *sectors* developed. Federal Aviation Agency created in 1958.

History of Flight (1965 onwards)

- Department of Transportation (DOT) created in 1967. Federal Aviation Agency brought under DOT as Federal Aviation Administration.
- National Transportation Safety Board (NTSB) created to investigate transportation accidents.
- Radar Data Processing (RDP) developed. FDP & RDP parts of ARTCC Host.
- Automated Radar Terminal System — ARTS-IIIA, ARTS-II and Enroute ARTS (EARTS) developed.
- Airline Deregulation Act of 1978 — Hub-and-Spoke operations.
- Professional Air Traffic Controllers Organization (PATCO) strike of 1981.
- Formation of National Air Traffic Controllers Association (NATCA) in 1987.

Air Traffic Activity

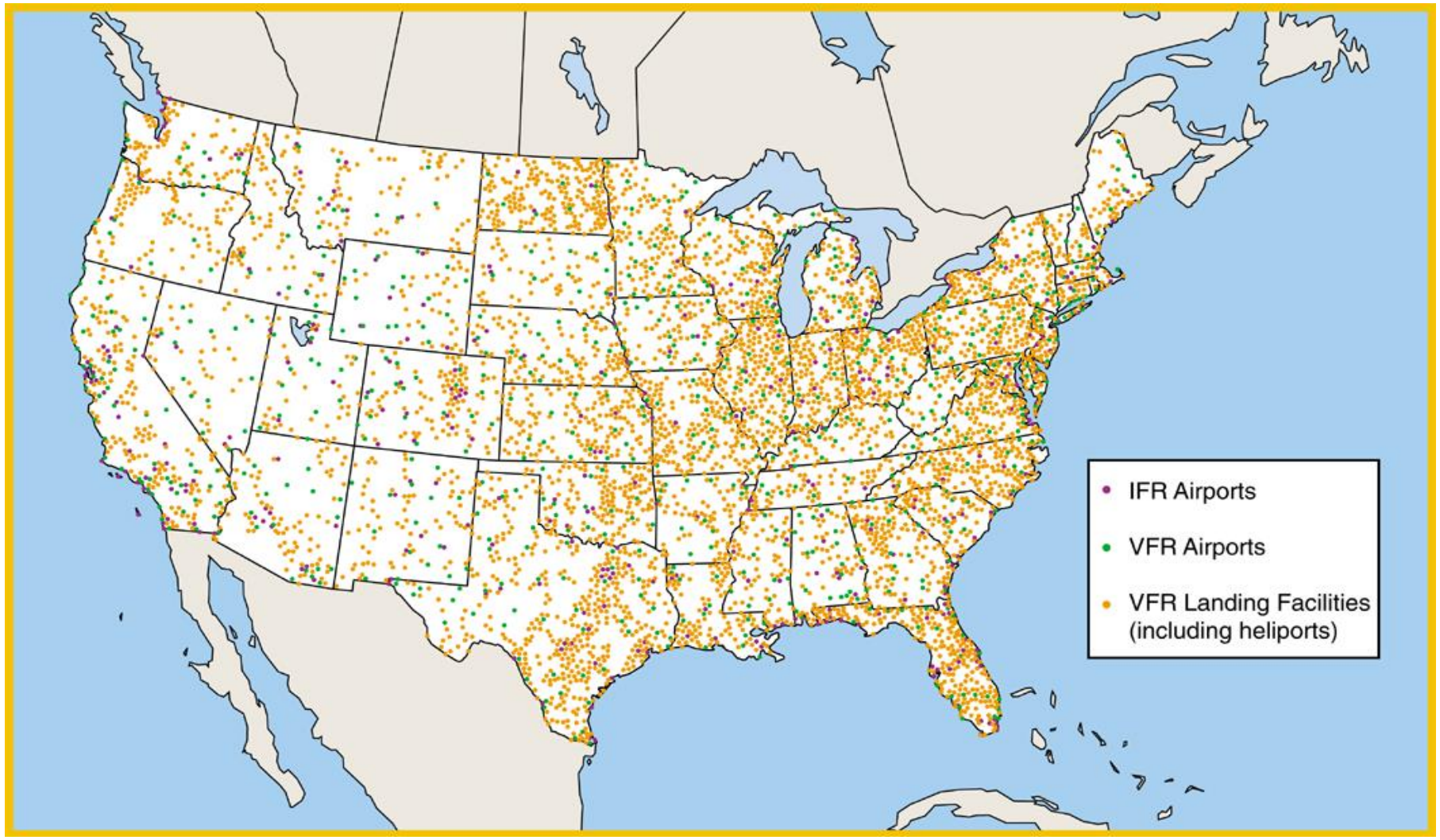


National Airspace System (NAS)

A network of airspace, air navigation facilities, equipment, services, airports and landing areas, aeronautical charts, information services, rules, regulations, procedures, technical information, personnel and material. Included in the NAS are system components shared jointly with the military.

- Over 609,000 active pilots in the United States.
- Operating more than 280,000 aircraft, anything from large commercial aircraft to small private airplanes, helicopters, gliders, balloons and experimental aircraft.

5233 Public Use Airports*



*“Public Use Airports,” FAA, FAA Administrator’s Fact Book, April 2007, Public domain.

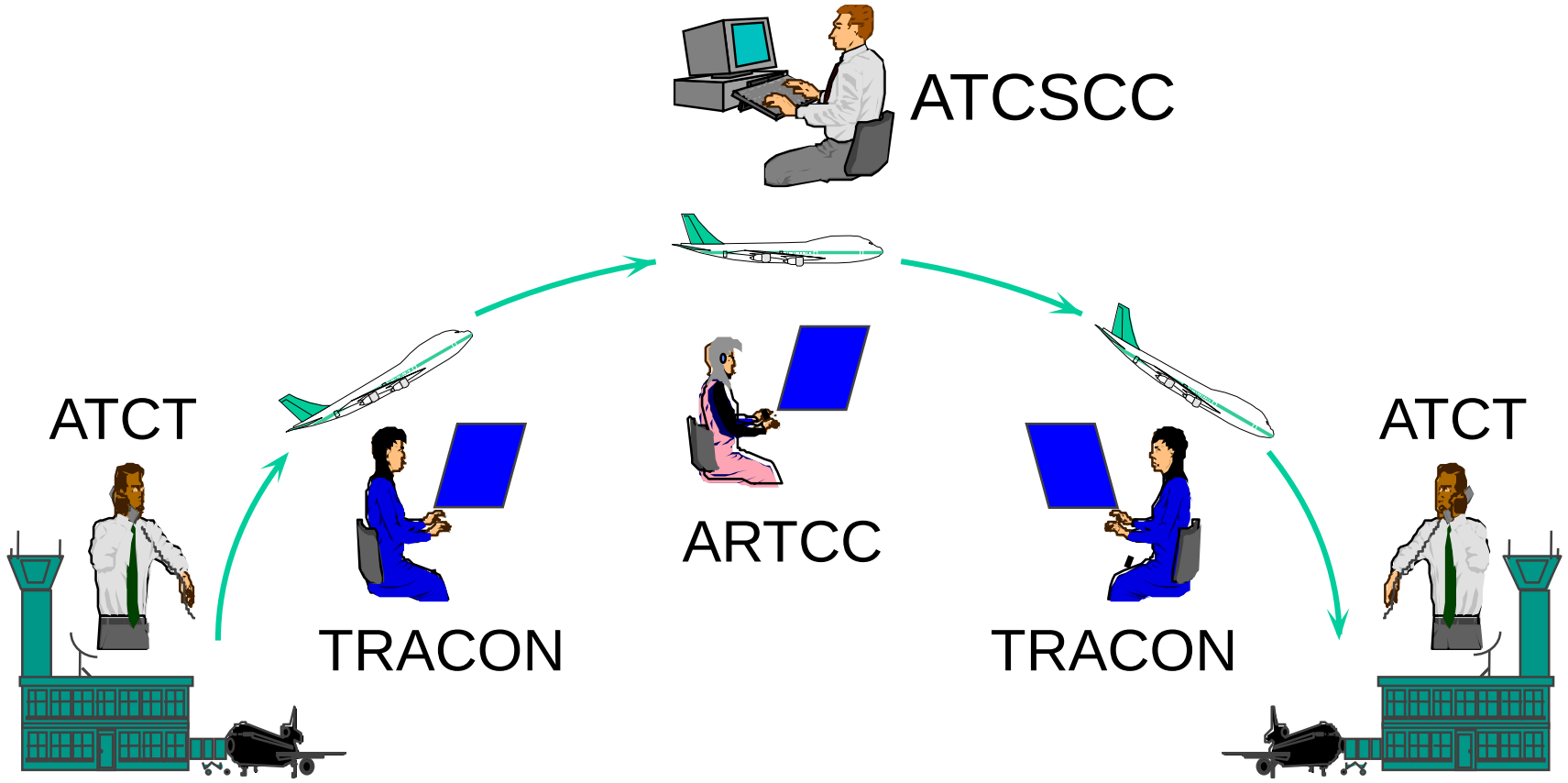
Airports in the NAS

19,983 Airports in the US (including military and private fields)

- Public Use 5,233
- Private Use: 14,757
- Certificated airports*: 604 Civil

*Certificated airports serve Air Carrier Operations with aircraft seating more than 9 passengers seats. (Federal Aviation Regulation (FAR) Part 139).

Air Traffic Control System



ARTCC — Air Route Traffic Control Center
ATCSCC — Air Traffic Control System Command Center
ATCT — Air Traffic Control Tower
TRACON — Terminal Radar Approach Control

Air Traffic Control Facilities

Flight Service facilities:

76 Flight Service Stations (FSSs)

– Under contract with Leidos (after merger with part of Lockheed Martin)

Terminal facilities:

- 517 Air Traffic Control Towers
- 185 Terminal Radar Approach Controls

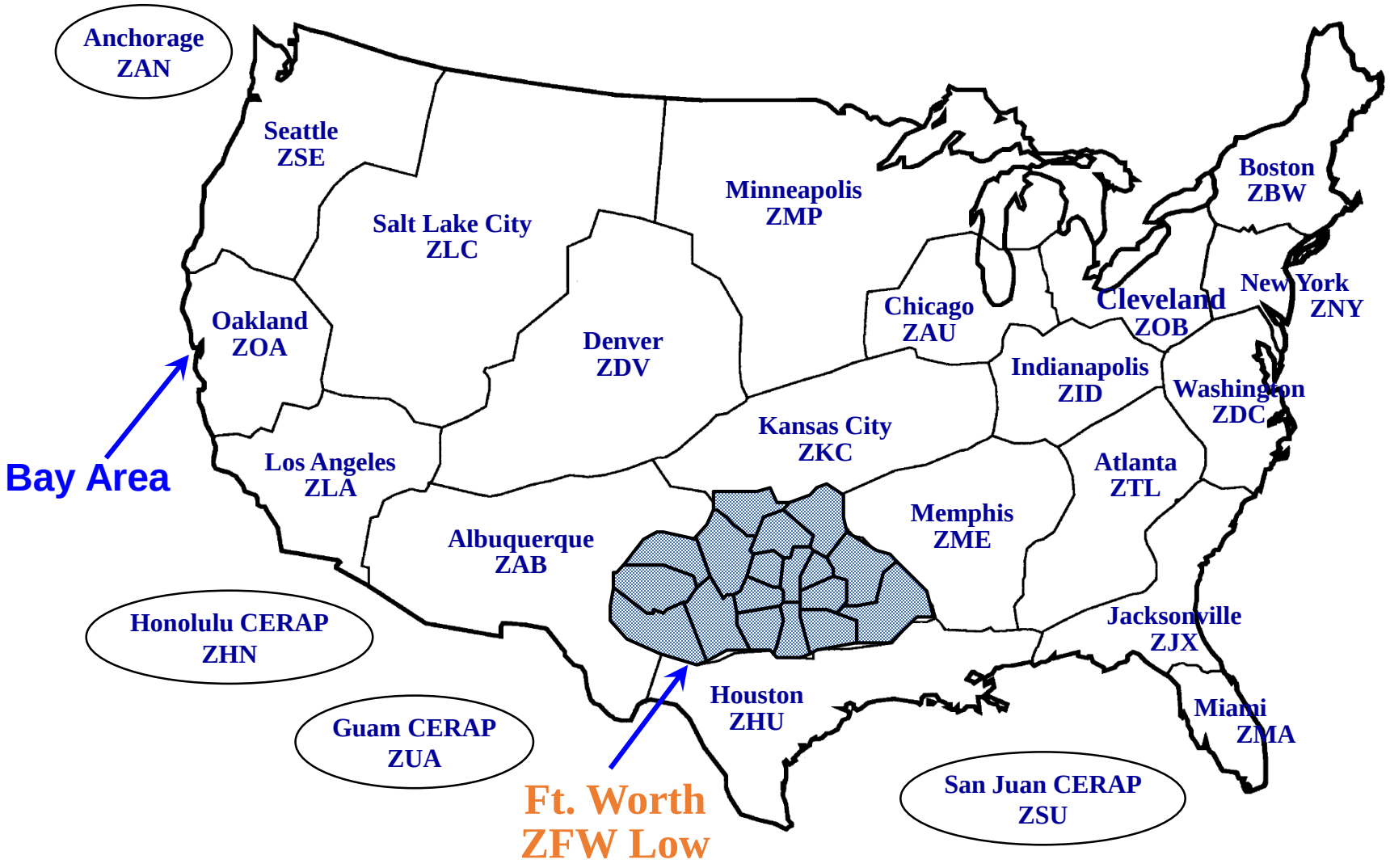
Enroute facilities:

- 21 Air Route Traffic Control Centers
- 3 Combined Center & Radar Approach Control

Air Traffic Control System Command Center:

National air traffic management facility at Warrenton, VA

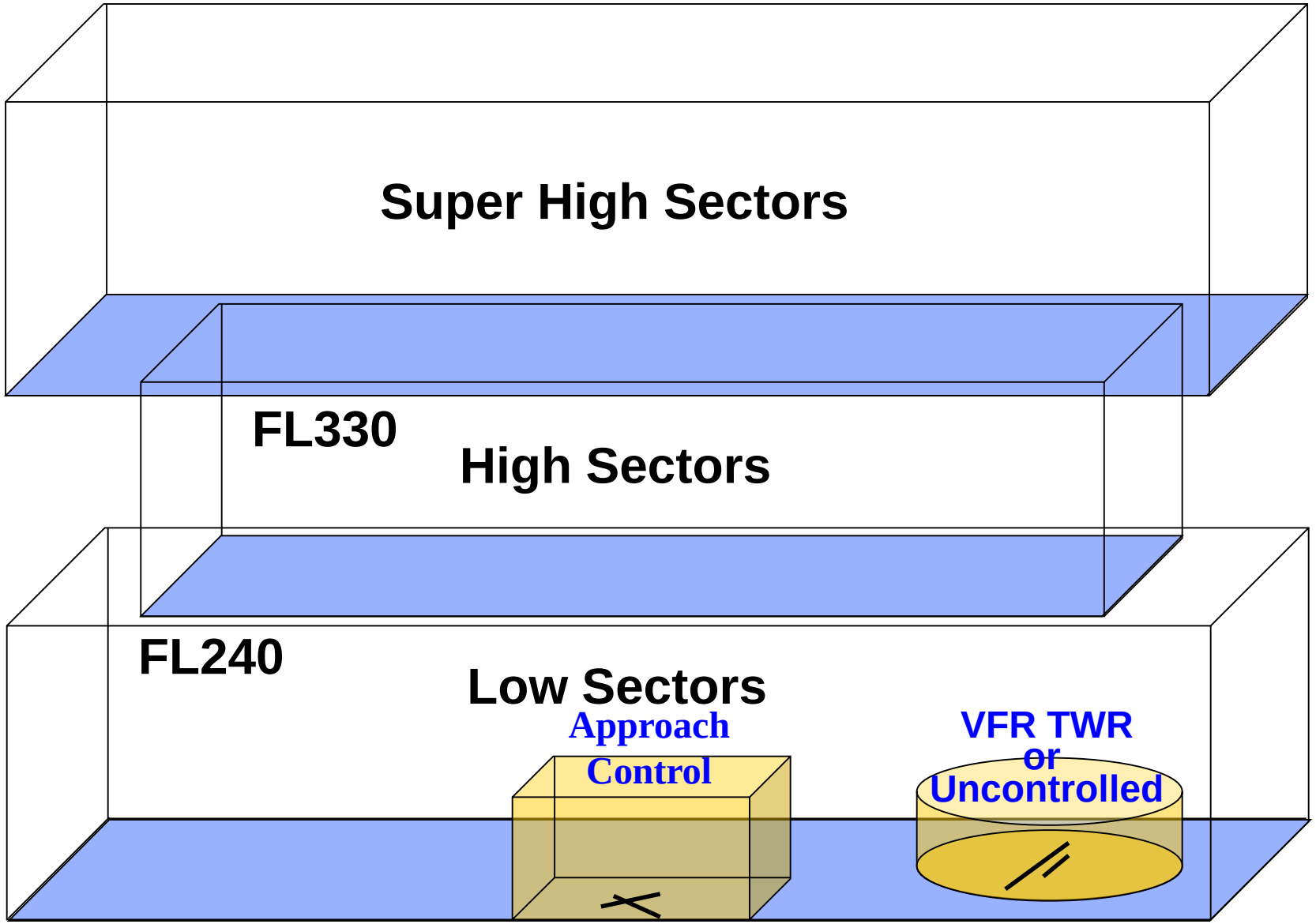
Air Route Traffic Control Centers



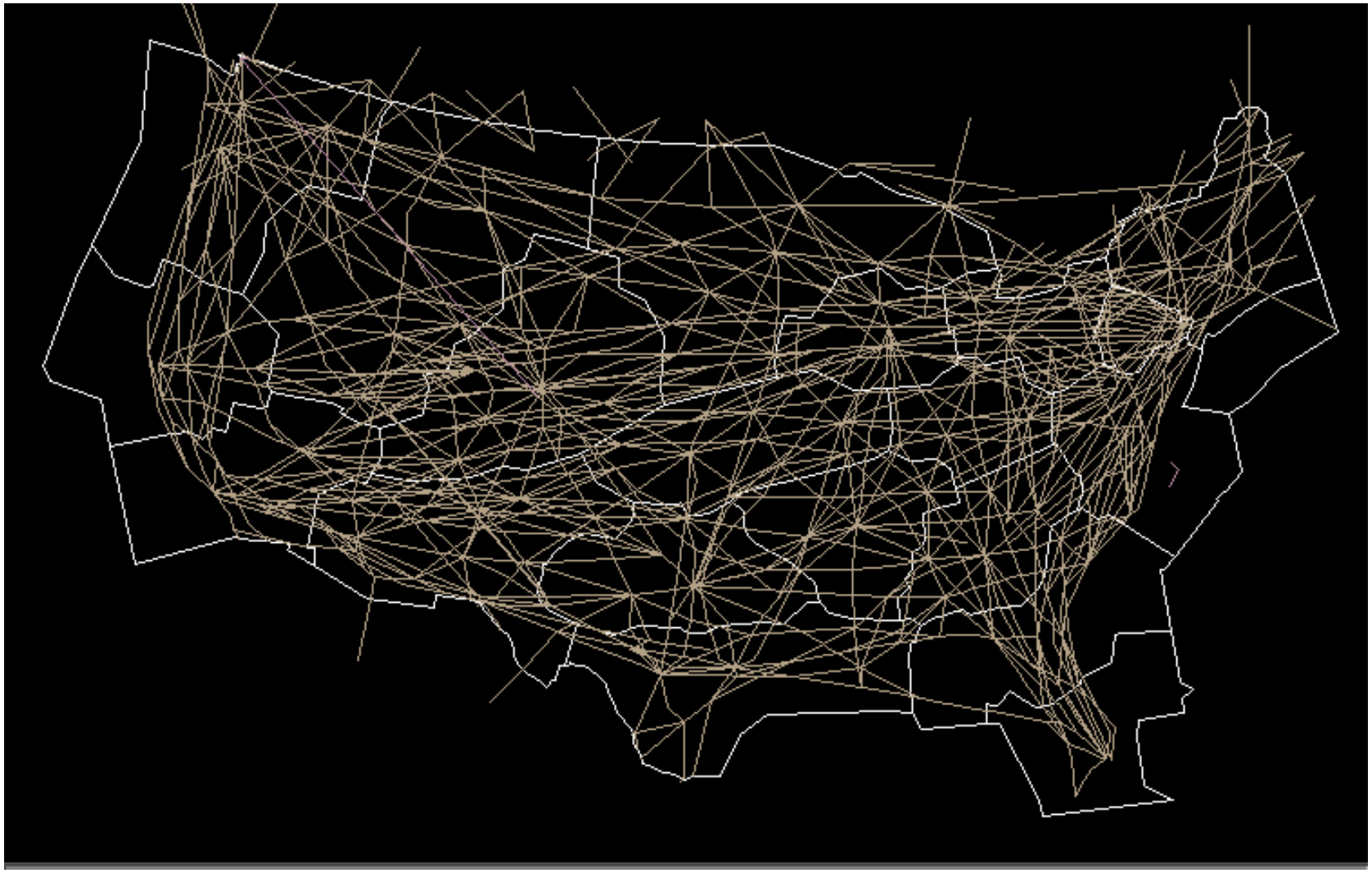
- 21 ARTCCs
- 3 CERAPs

CERAP — Combined Center & Radar Approach Control

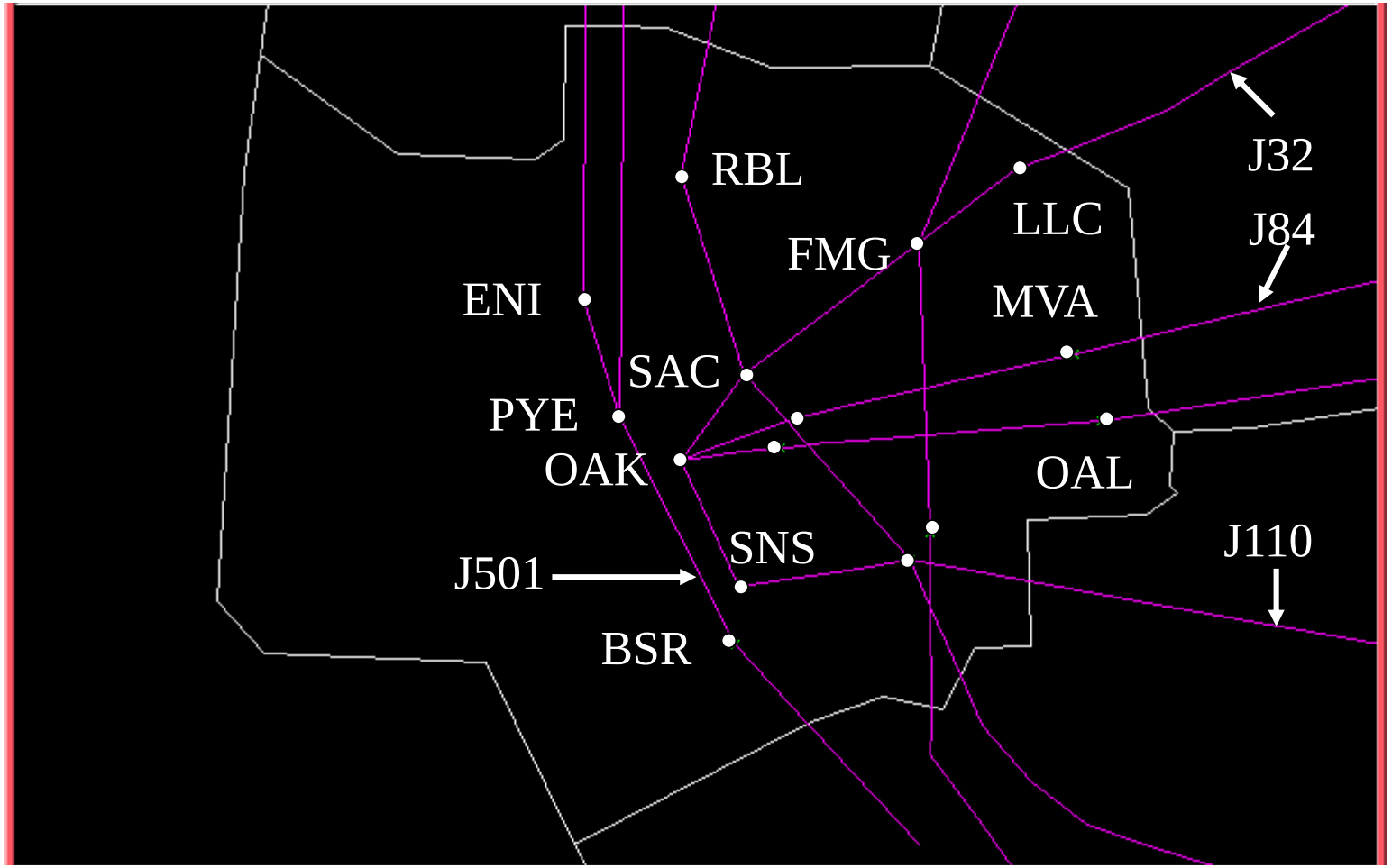
Sectors


Super High Sectors
FL330
High Sectors
FL240
Low Sectors
Approach
Control
VFR TWR
or
Uncontrolled

High-Altitude Jet Routes



Navaids & Airways (Oakland ARTCC)



Governing Regulations and Directives

- Code of Federal Regulations (CFR): General and permanent rules published in the Federal Register by the executive departments and agencies of the Federal Government. It is divided into 50 titles that represent broad areas subject to Federal regulation.

- Title 14: Covers Aeronautics and Space and includes numerous parts also known as Federal Aviation Regulations or FARs – some examples:
  - Part 1: Definition
  - Part 71: Designation of classes of airspace
  - Part 73: Special Use Airspace
  - Part 91: General Operating and Flight Rules
  - Part 121: Operating requirements for domestic, flag, and supplemental operations
  - Part 135: Operating requirements for commuter and on-demand operations

General Operating and Flight Rules (14 CFR Part 91)

PART 91—GENERAL OPERATING AND FLIGHT RULES

SPECIAL FEDERAL AVIATION REGULATION NO. 50–2
SPECIAL FEDERAL AVIATION REGULATION NO. 60
SPECIAL FEDERAL AVIATION REGULATION NO. 71
SPECIAL FEDERAL AVIATION REGULATION NO. 77
SPECIAL FEDERAL AVIATION REGULATION NO. 79
SPECIAL FEDERAL AVIATION REGULATION NO. 87
SPECIAL FEDERAL AVIATION REGULATION NO. 97
SPECIAL FEDERAL AVIATION REGULATION NO. 104

Subpart A—General

Sec.
91.1 Applicability.
91.3 Responsibility and authority of the pilot in command.
91.5 Pilot in command of aircraft requiring more than one required pilot.
91.7 Civil aircraft airworthiness.
91.9 Civil aircraft flight manual, marking, and placard requirements.
91.11 Prohibition on interference with crewmembers.
91.13 Careless or reckless operation.
91.15 Dropping objects.
91.17 Alcohol or drugs.
91.19 Carriage of narcotic drugs, marihuana, and depressant or stimulant drugs or substances.
91.21 Portable electronic devices.
91.23 Truth-in-leasing clause requirement in leases and conditional sales contracts.
91.25 Aviation Safety Reporting Program: Prohibition against use of reports for enforcement purposes.
91.27–91.99 [Reserved]

Subpart B—Flight Rules

GENERAL

91.101 Applicability.
91.103 Preflight action.
91.115 Right-of-way rules: Water operations.
91.117 Aircraft speed.
91.119 Minimum safe altitudes: General.
91.121 Altimeter settings.
91.123 Compliance with ATC clearances and instructions.
91.125 ATC light signals.
91.126 Operating on or in the vicinity of an airport in Class G airspace.
91.127 Operating on or in the vicinity of an airport in Class E airspace.
91.129 Operations in Class D airspace.
91.130 Operations in Class C airspace.
91.131 Operations in Class B airspace.
91.133 Restricted and prohibited areas.
91.135 Operations in Class A airspace.
91.137 Temporary flight restrictionsin the vicinity of disaster/hazard areas.
91.138 Temporary flight restrictions in national disaster areas in the State of Hawaii.
91.139 Emergency air traffic rules.
91.141 Flight restrictions in the proximity of the Presidential and other parties.
91.143 Flight limitation in the proximity of space flight operations.
91.144 Temporary restriction on flight operations during abnormally high barometric pressure conditions.
91.145 Management of aircraft operations in the vicinity of aerial demonstrations and major sporting events.
91.146–91.149 [Reserved]

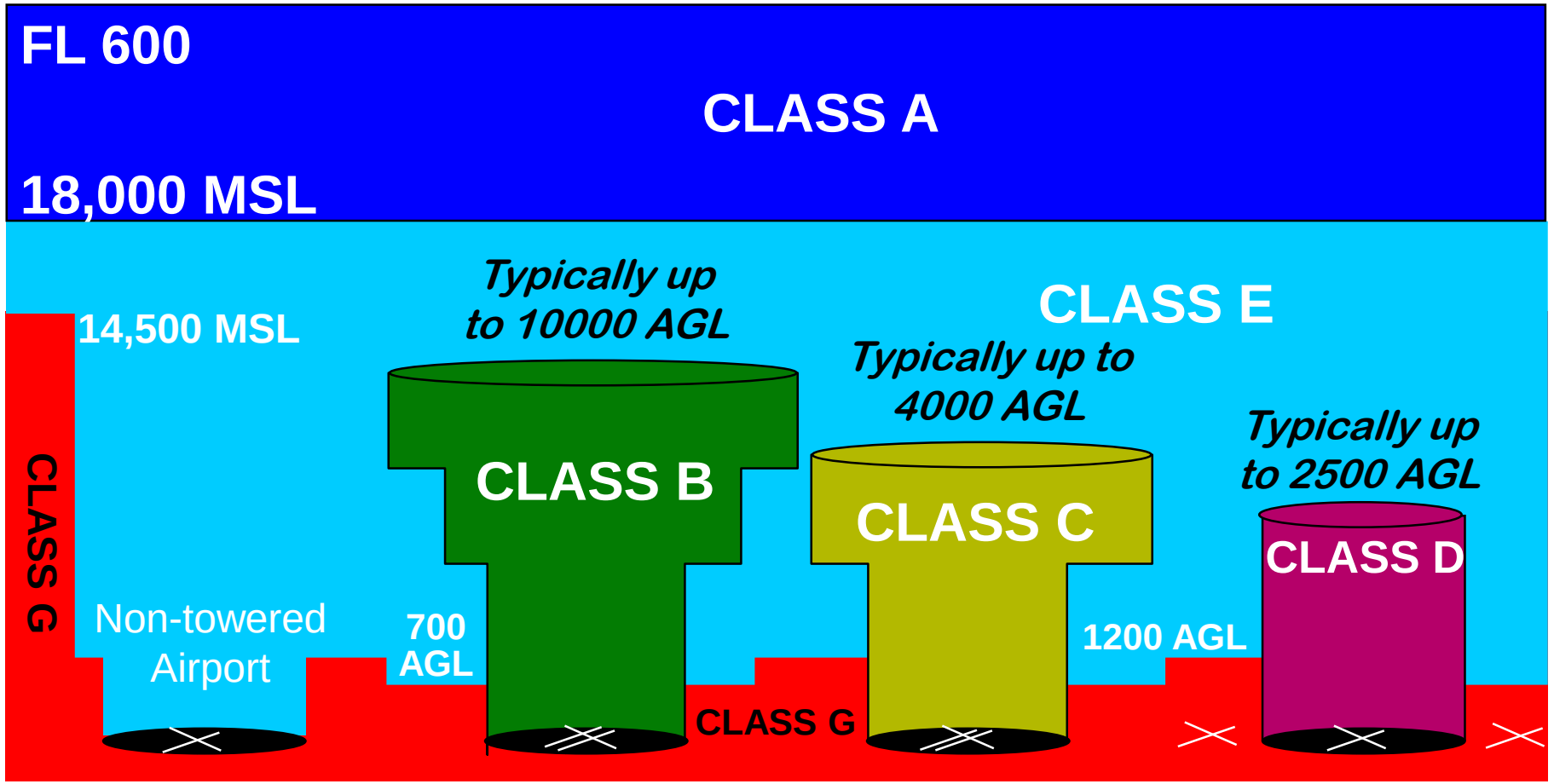
VISUAL FLIGHT RULES

91.151 Fuel requirements for flight in VFR conditions.
91.153 VFR flight plan: Information required.
91.155 Basic VFR weather minimums.
91.157 Special VFR weather minimums.
91.159 VFR cruising altitude or flight level.
91.161–91.165 [Reserved]

INSTRUMENT FLIGHT RULES

91.167 Fuel requirements for flight in IFR conditions.
91.169 IFR flight plan: Information required.
91.171 VOR equipment check for IFR operations.
91.173 ATC clearance and flight plan required.
91.175 Takeoff and landing under IFR.

Airspace Classification (14 CFR part 71)



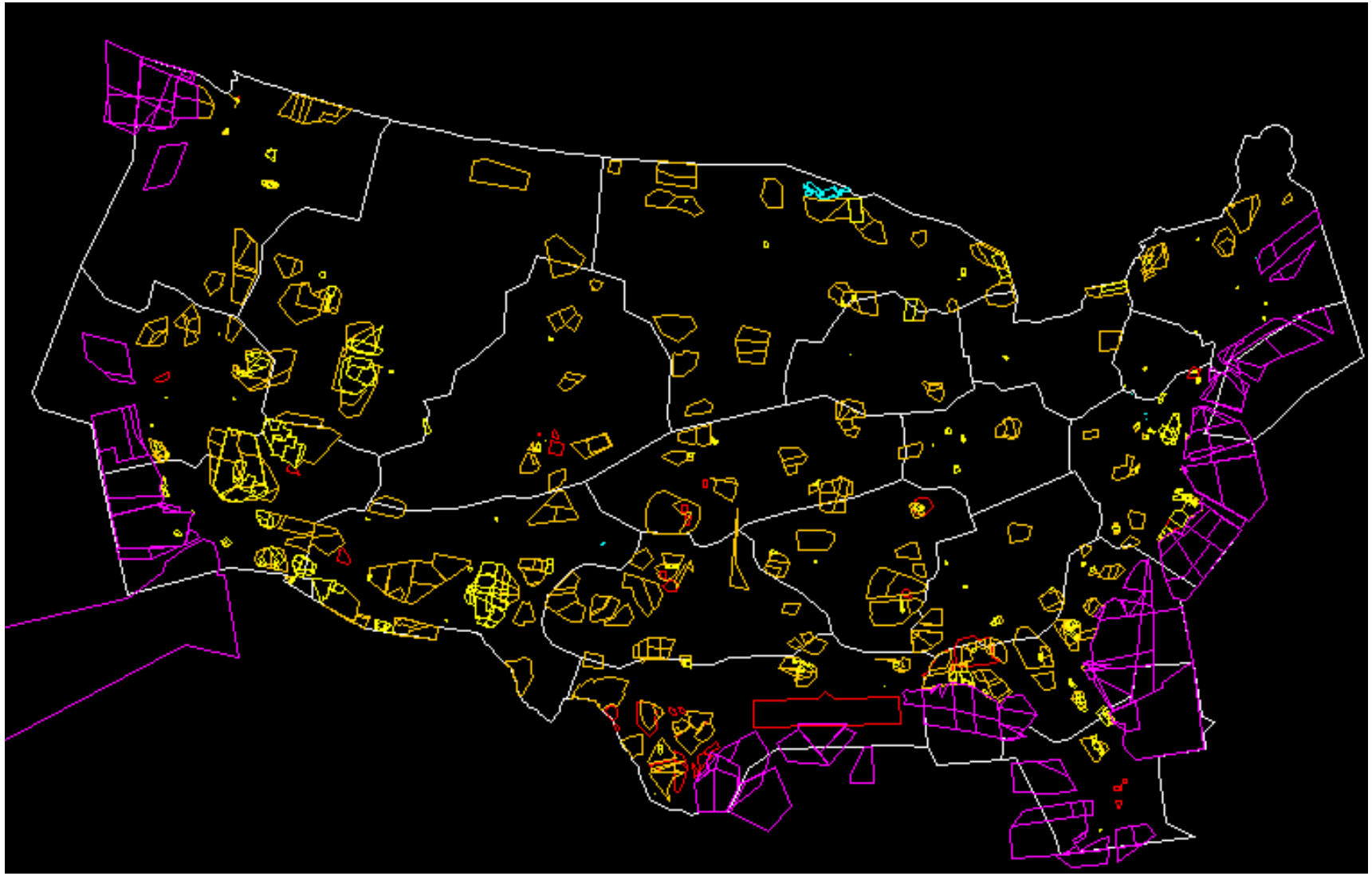
FL=Flight level
MSL=Mean Sea Level
AGL=Above Ground Level

CLASS G (Uncontrolled Airspace) is virtually all located in the western US

Airspace Classification (14 CFR part 71)

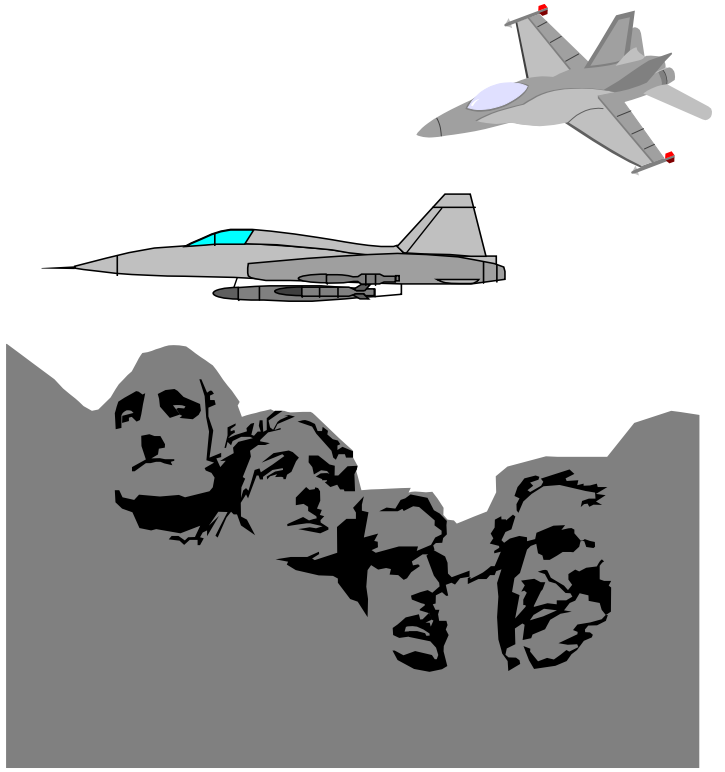
Airspace Features	Class A	Class B	Class C	Class D	Class E	Class G
Former Airspace Equivalent	Positive Control Area	Terminal Control Area	Airport Radar Service Area	Airport Traffic Area and Control Zone	General Controlled Airspace	Uncontrolled Airspace
Operations	IFR	IFR & VFR	IFR & VFR	IFR & VFR	IFR & VFR	IFR & VFR
Entry Req.	ATC Clearance	ATC Clearance	ATC Clearance IFR	ATC Clearance IFR	ATC Clearance IFR	None
Radio	Yes	Yes	Yes	Yes	Yes IFR	No
Visibility	N/A	3 miles	3 miles	3 miles	3 miles	1 mile
Separation	All	All	IFR & runway	IFR & runway	IFR	None
Traffic Advisories	N/A	N/A	Yes	Workload permitting	Workload permitting	Workload permitting

Special Use Airspace (14 CFR Part 73)



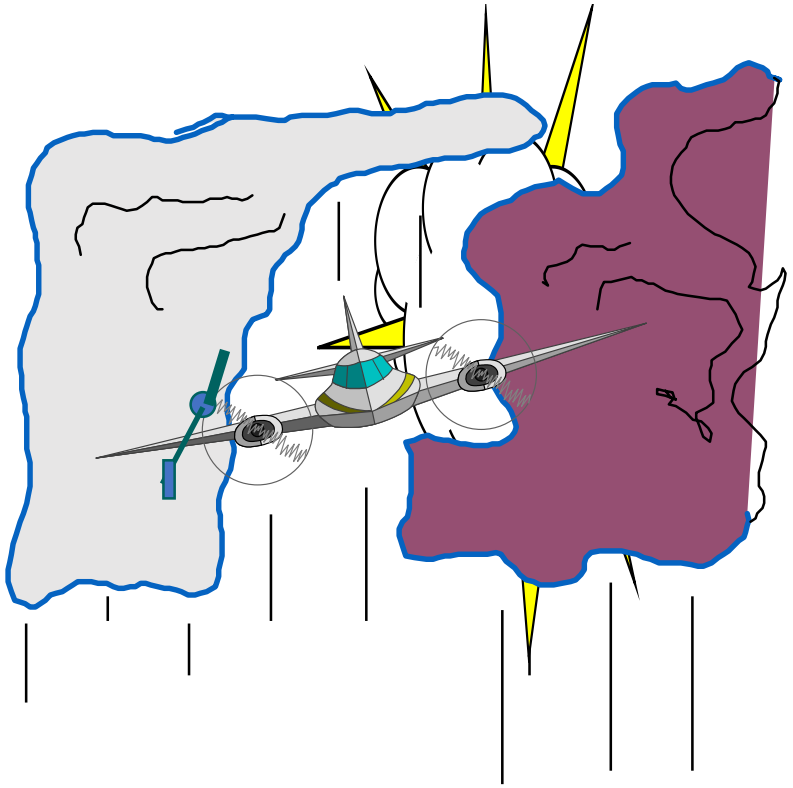
Visual Flight Rules (VFR) (14 CFR Part 91)

- Flight plan is optional
- Radio contact with ATC is voluntary, except in Class B, C and D airspace
- Pilot must see and avoid traffic
- Can fly only in good visibility, remaining clear of clouds
- VFR cloud clearance and visibility minimums vary with type of airspace



Instrument Flight Rules (IFR) (14 CFR Part 91)

- Flight plan is required
- Contact with ATC mandatory
- Separated from other traffic by ATC
- Can fly in Instrument Meteorological Conditions (IMC) – low or no visibility
- IFR Clearance required for operations in Class A Airspace



Flight Plan (14 CFR Part 91)

Pilots file a flight plan describing a precise route:

Instrument Flight Rules (IFR) Flight Plan information:

- Flight description: Callsign, aircraft type, cruise speed, cruise altitude
- Origin and destination
- Airport Departure Procedure
- Route: Airways, waypoints, fixes, navaids, intersections, fix-radial-distance
- Airport Arrival Procedure

Flight Plan (14 CFR Part 91)

Form Approved OMB NO. 2120-0026

U.S. DEPARTMENT OF TRANSPORTATION FEDERAL AVIATION ADMINISTRATION **FLIGHT PLAN**	(FAA USE ONLY) ☐ PILOT ☐ VNR ☐ STOPOVER	TIME STARTED	SPECIALIST INITIALS

1. TYPE	2. AIRCRAFT IDENTIFICATION	3. AIRCRAFT TYPE/ SPECIAL EQUIPMENT	4. TRUE AIRSPEED	5. DEPARTURE POINT	6. DEPARTURE TIME		7. CRUISING ALTITUDE
X VFR / IFR / DVFR	**AAL278**	**B-767/R**	**468** KTS	**DFW**	PROPOSED (Z) **1909**	ACTUAL (Z)	**330**

8. ROUTE OF FLIGHT

DFW.DALL8..TXK..LIT.J6.HVQ.CSN2.IAD

9. DESTINATION (Name of airport and city)	10. EST. TIME ENROUTE		11. REMARKS
	HOURS	MINUTES	
IAD	**3**	**15**	

12. FUEL ON BOARD		13. ALTERNATE AIRPORT(S)	14. PILOT'S NAME, ADDRESS & TELEPHONE NUMBER & AIRCRAFT HOME BASE	15. NUMBER ABOARD
HOURS	MINUTES			
4	**30**	**JFK**	17. DESTINATION CONTACT/TELEPHONE (OPTIONAL)	

16. COLOR OF AIRCRAFT	CIVIL AIRCRAFT PILOTS. FAR Part 91 requires you file an IFR flight plan to operate under instrument flight rules in controlled airspace. Failure to file could result in a civil penalty not to exceed $1,000 for each violation (Section 901 of the Federal Aviation Act of 1958, as amended). Filing of a VFR flight plan is recommended as a good operating practice. See also Part 99 for requirements concerning DVFR flight plans.

FAA Form 7233-1 (8-82)

CLOSE VFR FLIGHT PLAN WITH _____ FSS ON ARRIVAL

Weather Briefing

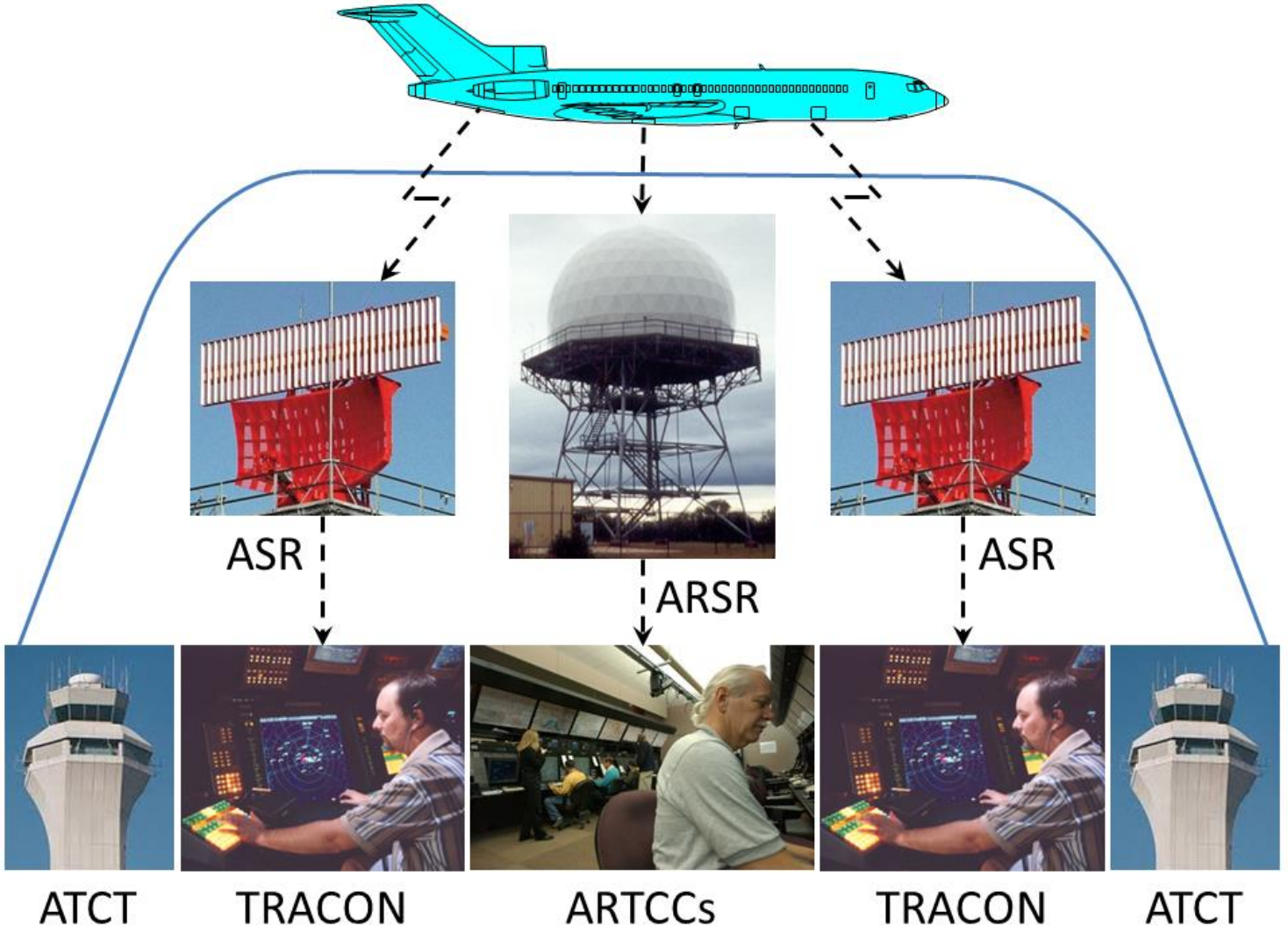
- Flight Service Stations (FAA contracted to Lockheed Martin)
  - Aviation weather reports, forecasts and advisories
  - Notice-to-Airmen (NOTAM)
  - Flight plan filing
  - Inflight service via radio communications

- National Weather Service Office: https://www.weather.gov/
- www.1800wxbrief.com
- www.aviationweather.gov
- iPad and Android Electronic Flight Bags

ATC Equipment

- Airport Surface Detection Equipment (ASDE-X)
- Airport Surveillance Radar (ASR)
- Air Traffic Control Radar Beacon System (ATCRBS)
- Automated Radar Terminal System (ARTS)
- ARTCC En-Route Automation Modernization (ERAM)
- Direct Access Radar Channel (DARC)
- Very High-Frequency Omni Range (VOR)
- Tactical Air Navigation System (TACAN)
- Aircraft Communications, Addressing, and Reporting System (ACARS) & Voice Communications (party line)

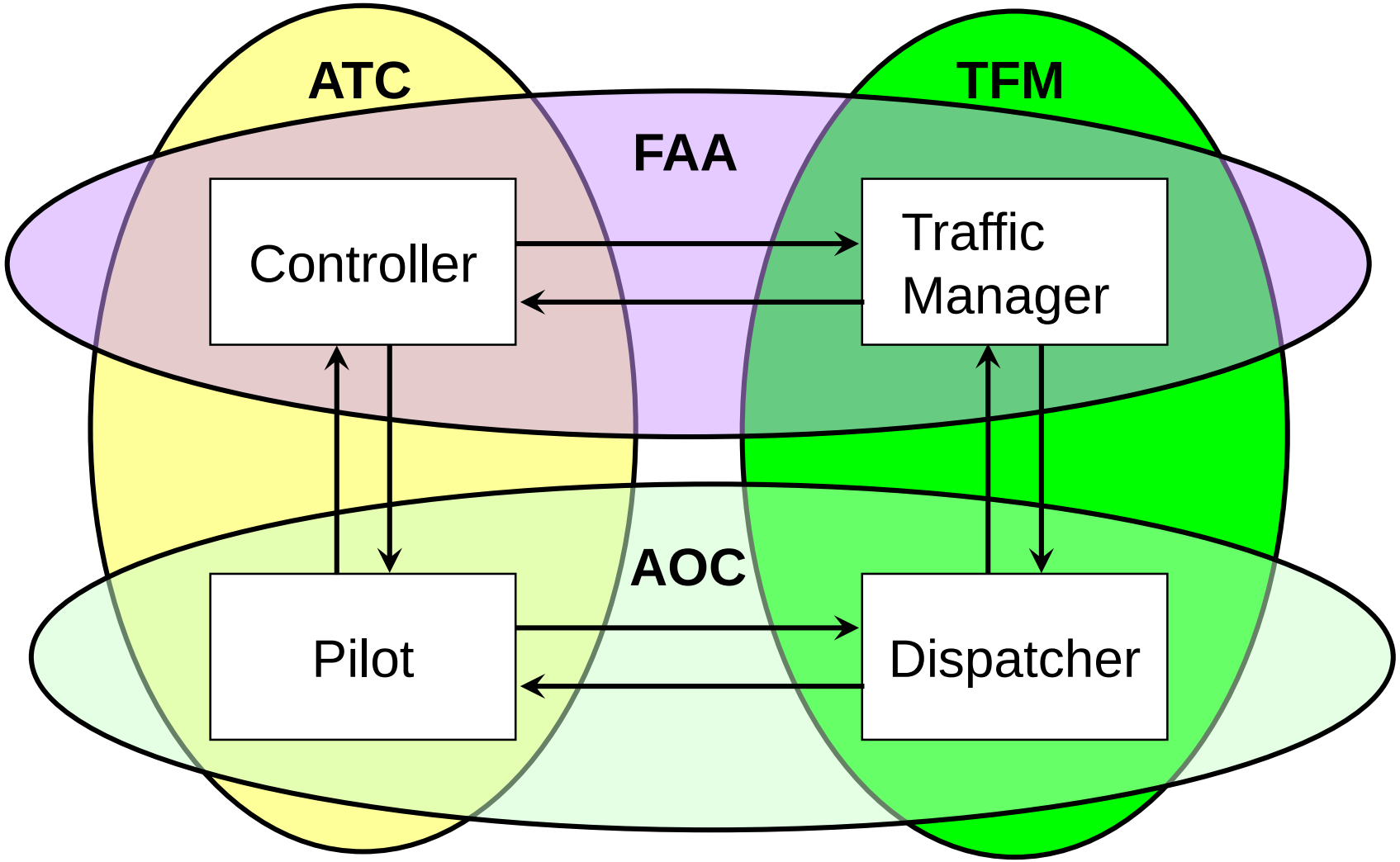
Surveillance Equipment



State Estimate

- Latitude
- Longitude
- Altitude
- Groundspeed
- Heading
- Rate-of-Climb-Descent (ROCD)

Air Traffic Management Functions (Separation Assurance + Flow Management)



Airline Operations Control

- Schedule development (Airline's main product) — Dispatcher flies a schedule.

- Flight planning
  - Most efficient route of flight
  - Alternative airports
  - Fuel, weight and balance
  - Maintenance requirements
  - Minimum equipment list

- Resource scheduling
  - Aircraft
  - Crew
  - Passengers

- Flight Following
  - Advice aircrew on options
  - Separate aircraft from weather

ATC Controllers

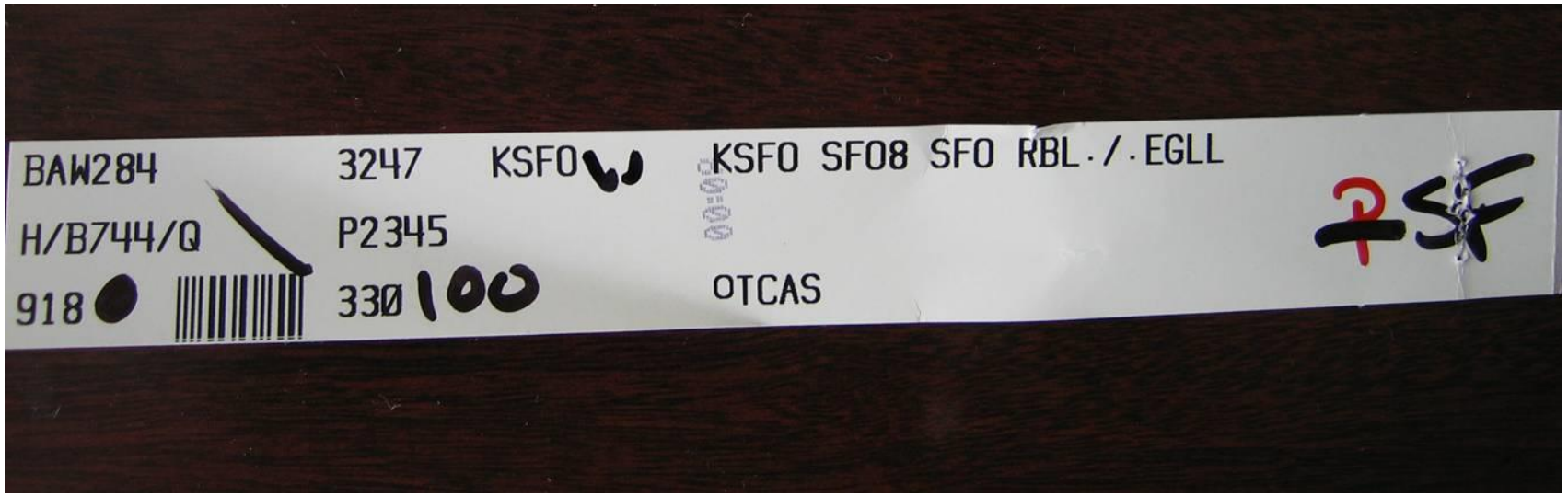
Tower Controllers

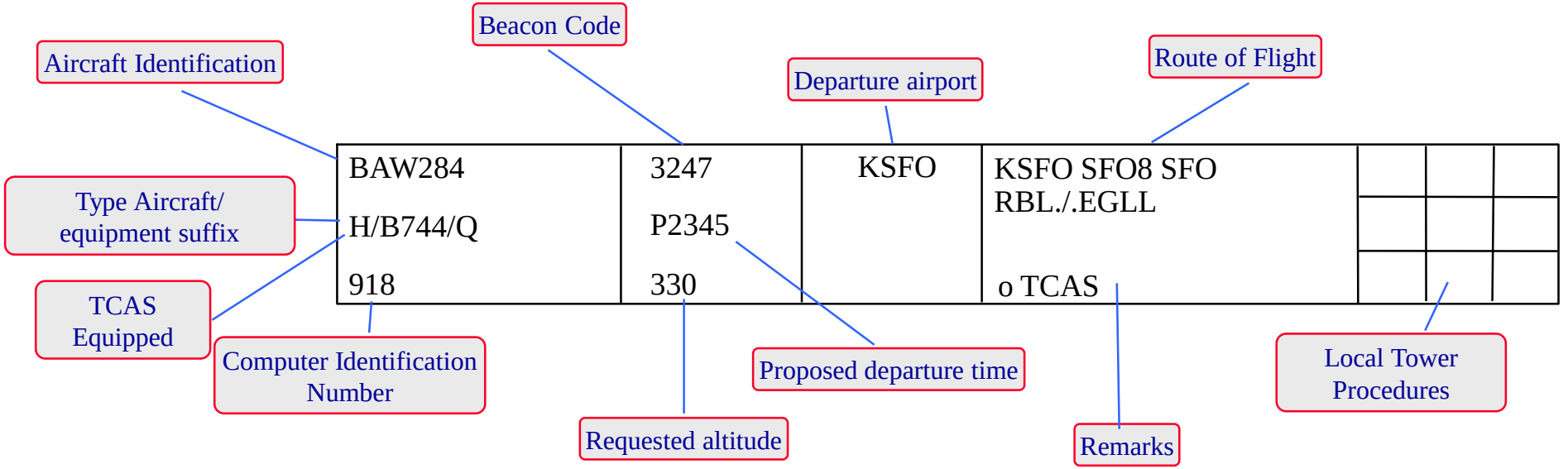
- Clearance Delivery – Checks the printed flight progress strip agrees with the letters-of-agreement with TRACON.
- Ground Controller – Instructs pilot to taxi to active runway.
- Local Controller – Sequences the flight into local flow. Makes sure aircraft separated from inbound and outbound traffic.

TRACON Controller

- Departure Controller – Hands the aircraft off to the ARTCC.
- Approach Controller – Receives handoff from ARTCC and hands it to the Local Controller.

Flight Progress Strip





ATC Controllers

ARTCC Controllers

- Radar Controller (R-Side) — Tracks the aircraft on the Plan View Display and provides separation services to the aircraft.
- Assistant Controller (D-Side) — Updates the flight progress strip and provides separation services in non-radar environment.
- Coordinator (Tracker) — Provides communication services when busy.

Traffic Management Unit

Traffic Management Coordinator (TMC) — Ensures sector controller's workload stays within acceptable limits. Coordinates traffic flow management initiatives. Uses Traffic Flow Management System (TFMS) for demand predictions for TFM.

ATM Services: Safety & Efficiency

Air Route Traffic Control Center (ARTCC)

Separation Assurance & Local Traffic Flow Management:

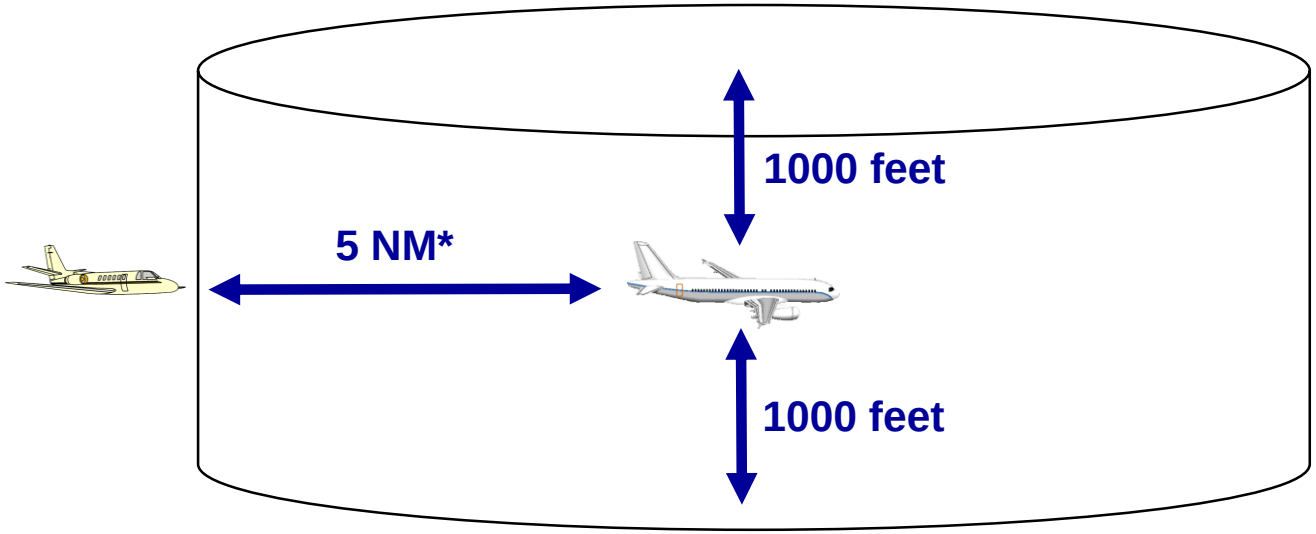
- Ensure IFR aircraft are separated
- Maintain throughput

Air Traffic Control System Command Center (ATCSCC)

System-Wide Traffic Flow Management:

- Maintain safety and efficiency by preventing congestion
- Coordinate the actions of ARTCCs

Enroute Radar Separation

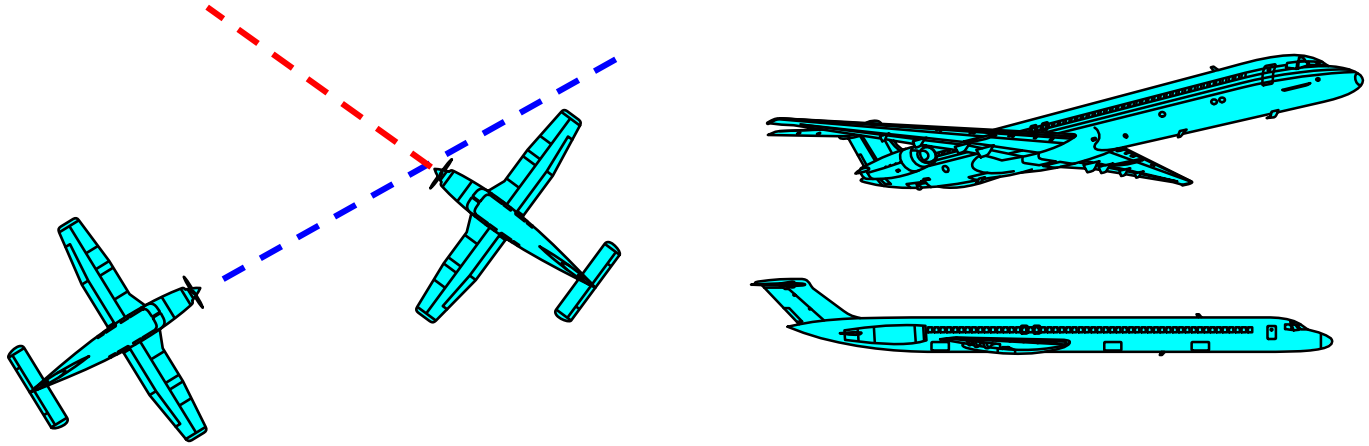


* Three nautical-miles when within 40 nautical-miles from antenna or when using single (non-mosaic) radar data source.

Ref: FAAO 7110.65, 5-5-4 Radar Minima

Conflict Resolution Methods

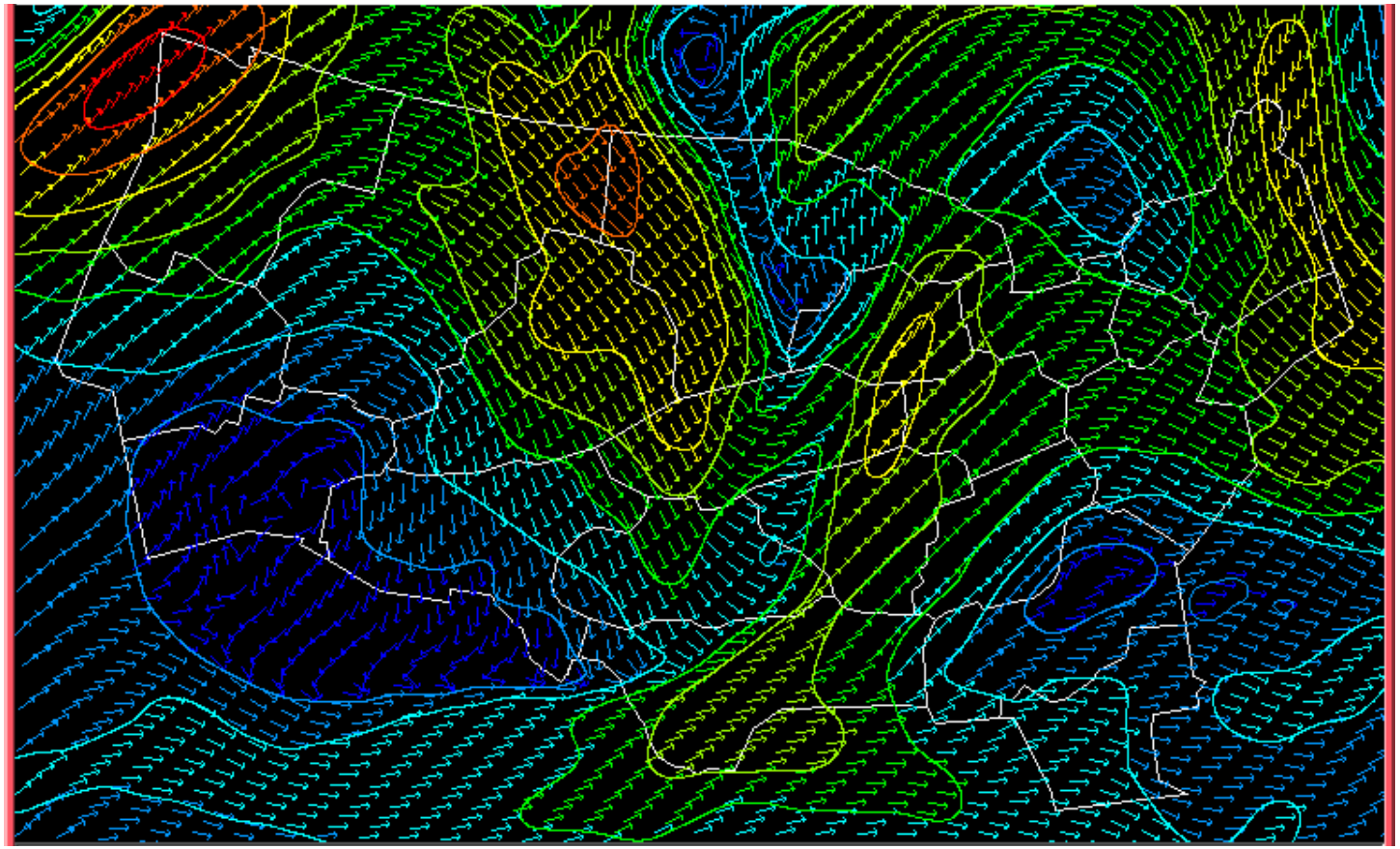
- Altitude control- Climb & Descent
- Vector – Heading change
- Speed – Speedup or slowdown



Traffic Flow Management

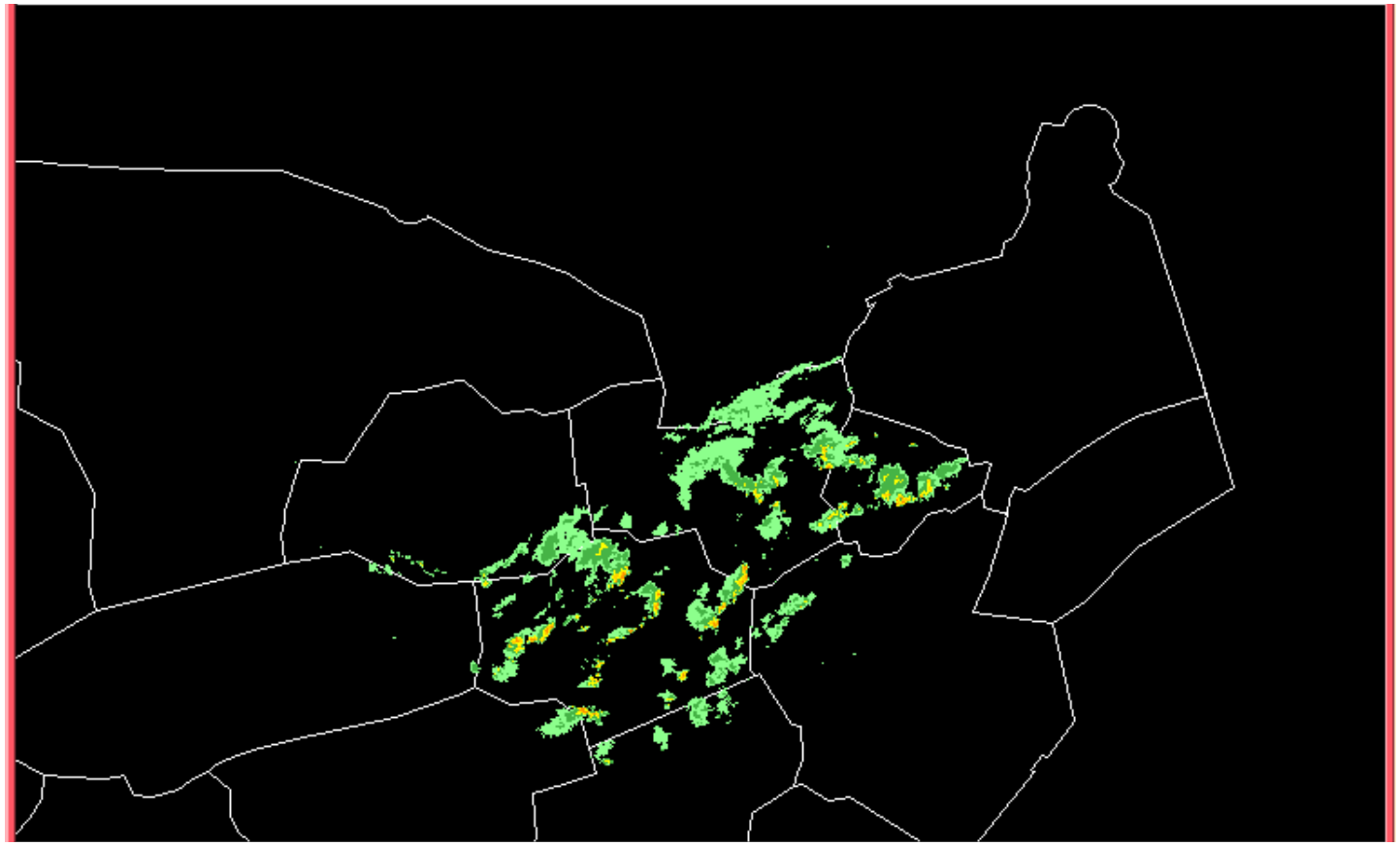
- Input:
  - Traffic demand
- Flow constraints:
  - Airport capacity
  - Airspace capacity
- Objective:
  - Maximize throughput
  - Minimize delays
  - Distribute delays equitably
  - Consider user preference
- Control:
  - Traffic flow management initiatives – ground delay, miles-in-trail, minutes-in-trail, reroute, holding

RUC Wind Velocity Vectors

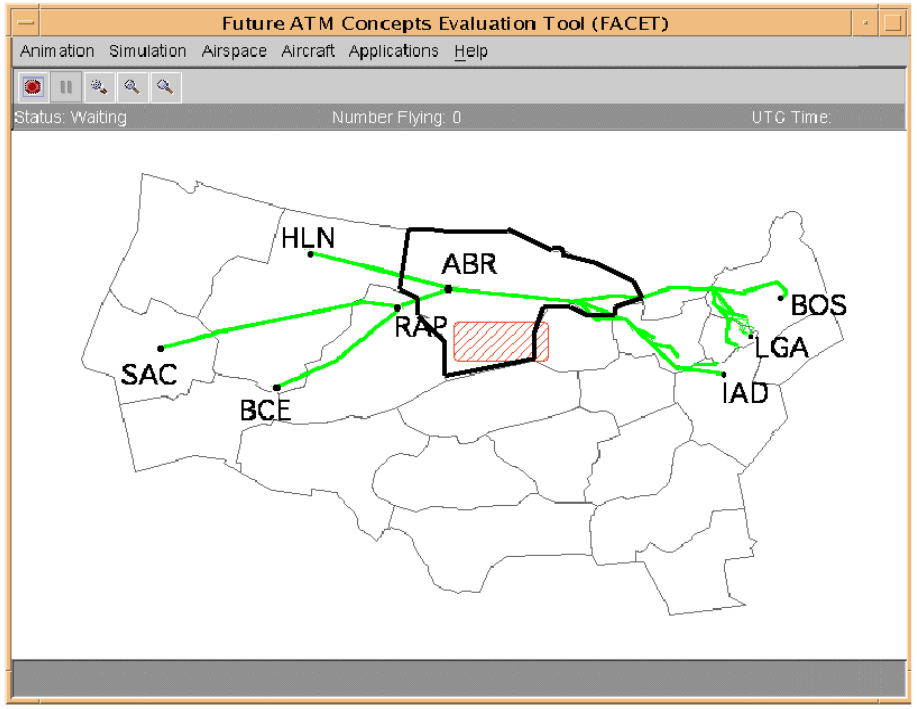


0 – 15 knots 60-75 knots 100 – 120 knots

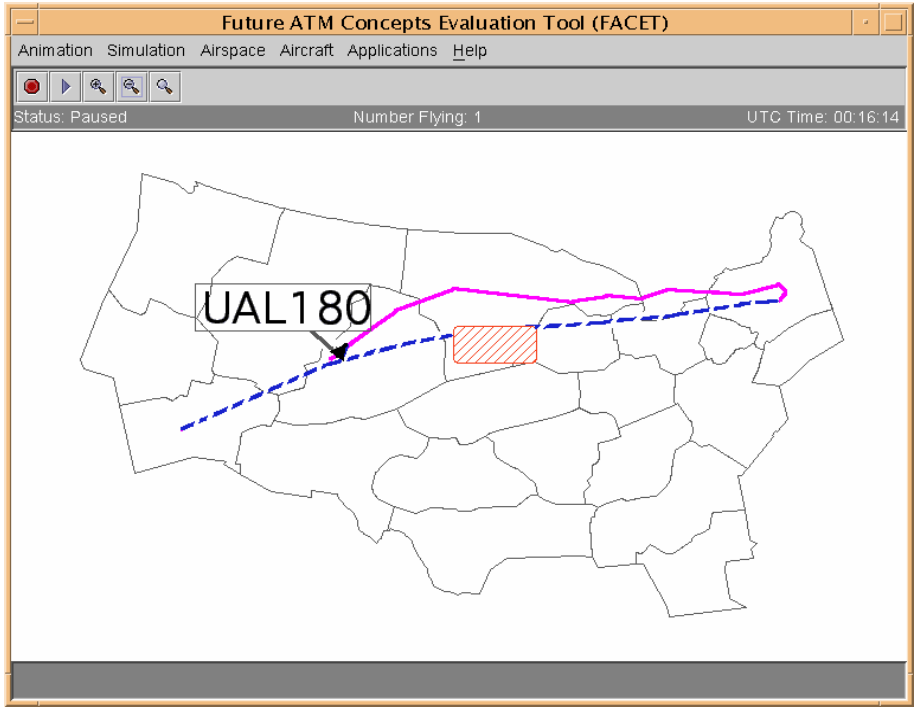
Collaborative Convective Forecast Product (CCFP)



TFM Rerouting Using Playbook Routes

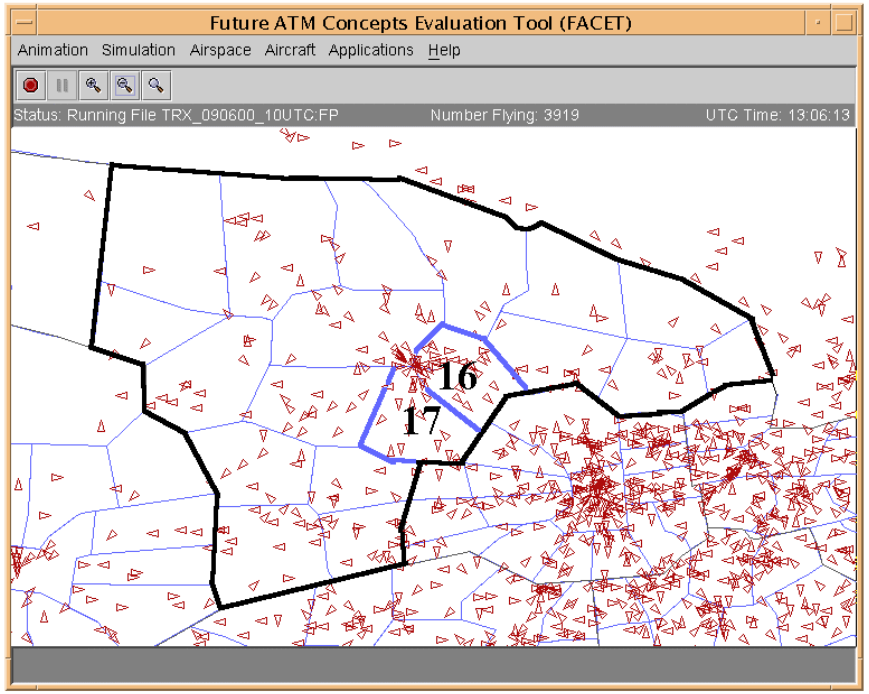


West Watertown Playbook Route through Minneapolis ARTCC.

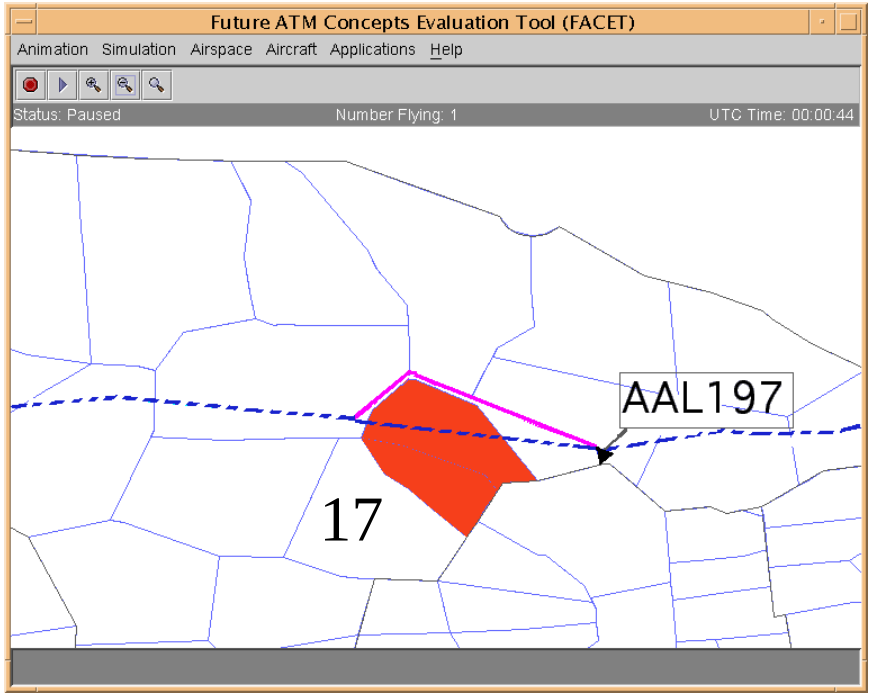


Rerouting UAL180 enroute from LAX to BOS.

TFM via MIT & Local Rerouting

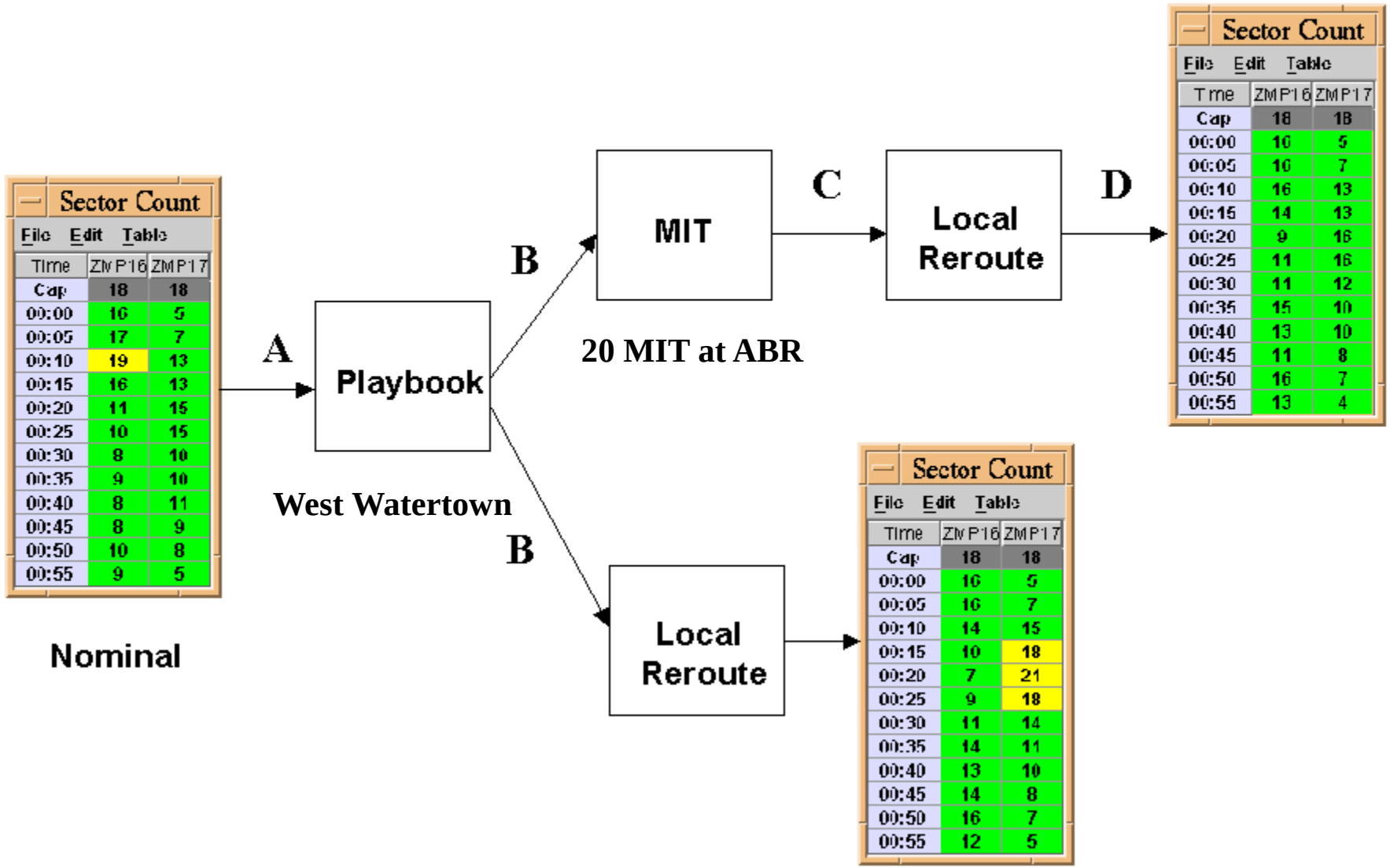


Sector 16 capacity (18 aircraft) exceeded by Playbook Route.



Local rerouting around Sector 16 in Minneapolis ARTCC.

Sector Congestion After Playbook Route, MIT & Local Rerouting



Summary

- Described the National Airspace System
  - Air Traffic Control facilities
  - Air Traffic Control equipment
  - Air traffic controller roles and responsibilities
  - Regulations and directives
  - Separation assurance
  - Traffic flow management
- ATM data for data-science
  - Airspace Geometry data
  - Flight-plan data
  - Surveillance data
  - Wind & weather data