Airport and Airspace Operations in the US (Air Traffic Control)

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**Discussion fo Flight Rules**

Flight Rules

- **IFR** - instrument flight rules (ATC controlled flights)
- **VFR** - visual flight rules (> 3 nm visibility and 1000 ft from clouds)

Weather conditions

- **VMC** - visual meteorological conditions
- **IMC** - instrument meteorological conditions

An airliner could fly in VMC conditions but always under IFR flight plan rules
Airways are Like Highways in the Sky
The Role of Air Traffic Control

Air traffic controllers maintain aircraft separations and help pilots navigate to their destination providing verbal and datalink instructions.
Classification of ATC Services

There are 3 control components of ATC and one support component. These components interact all time among themselves via telephone or microwave data links.

Control Components:

- Air Route Traffic Control Centers (ARTCC)
- Terminal Approach Control Facility (TCA - TRACON)
- Airport Traffic Control Tower (ATCT)

Support Component (Information)

- Flight Service Stations (FSS)
Air Traffic Control Tower

- Control aircraft traffic (both arrivals and departures) at the airport (includes ramps near gates, taxiways, runways, and airspace up to 5 nm from airport)

- Three controller posts
  - Local controller (runways and landing areas)
  - Ground control (taxiways and aprons)
  - Clearance delivery (provides information on flight plans)

- Some ATCT divide workload into East-West operations

- Use of short and precise language
  - AA52 taxi to RWY 36 via alpha-3
  - UA53 clear for takeoff, wind 040 at 12
  - Aeromexico clear to land RWY 36
# ATC Wake Vortex Separations

**IFR In-trail Separations Near Runways in nautical miles for Medium and Small Size Hub Airports**

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<tr>
<th>LEAD ACFT.</th>
<th>Trailing Aircraft</th>
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**IFR In-trail Separations Near Runways in nautical miles for Large Size Hub Airports**

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TRACON Facilities

- Control terminal traffic (both arrivals and departures)
- Typically 50-80 nm from the aircraft
- Some TRACONS control more than one airport (SW California)
- TRACONs are divided into sectors to ease workload for controllers
- TRACONs “meter” traffic approaching an airport facility
- Heavy use of verbal advisories (“vectors”)
  - AA52 turn right heading 120
  - UA53 descent and maintain 170 (17,000 ft)
  - Aeromexico reduce to 230 (IAS airspeed)
- Minimum separation inside TRACON is either 5 nm (>40 nm from radar antenna) or 3 nm (if < 40 nm from radar antenna)
Sample Flight Paths to and from Miami Airport

Lon: -84 -83 -82 -81 -80 -79 -78 -77

Miami Intl. Airport
TRACON Radar Coverage
Atlantic Ocean
Gulf of México
Aircraft Tracks
Tampa Bay
Detailed View of Flight Tracks (ETMS Data)

Arrivals

Departures

Miami Intl. Airport

Longitude (deg.)
US Air Route Traffic Control Centers (ARTCC)

- Twenty continental ARTCC facilities
- 30-50 sectors (horizontal and vertical) in each ARTCC
- Control over 250-300 nm from radar sites (use of multiple radars to track targets at long distances)
- Longitudinal separation is typically enforced as in-trail
Enroute Control Sectors in the US

- A well organized and hierarchical system
- Communications are via Voice channels
Airspace Sectorization to Control Flights

The NAS airspace is divided into Centers to control flights.

- Atlanta Enroute Center
- Washington Enroute Center
- Miami Enroute Center
- Jacksonville Enroute Center

Longitude (deg.)

Latitude (deg.)
Enroute Separations (vertical)

- Currently in the US a two layer vertical separation system is used
- Below FL 290 separations are every 1,000 ft
- Above FL 290 aircraft are spaced 2,000 ft vertically as shown
ATC Surveillance Mechanisms

Radar (1998)

GPS (2005)

GPS = Global Positioning System
A Hypothetical Flight

- Suppose we fly a Cessna Citation II from Virginia Tech Airport to Miami International.
- The flight takes us across four ARTCC Centers in the U.S. (Washington, Atlanta, Jacksonville, and Miami).
- The aircraft is under continuous control of ATC services even if the day is clear (CAVU conditions).

Cessna Citation II
The Flight Plan (Current NAS)

- The current plan uses high-altitude Jet Routes (Jet airways)
- A codified instrument approach procedure (Heath II) is used during the transition into the Miami TRACON
Activities of the Flight

- Pilots arrive to VPI Airport (BCB) an hour before the flight (to review weather and submit a flight plan)
- Few minutes before departure they contact Roanoke ATC for flight plan approval
- BCB has no control tower (but a UNICOM frequency is used to establish intent - blind verbal statements)
- Out of BCB pilots contact Roanoke TRACON for climb instructions (to intercept J-48 a Jet Route)
- At FL 100 (10,000 ft) the pilots contact Washington Center - ZDC (briefly)
- A few minutes later ZDC hands-off the flight to ZTL (Atlanta ARTCC)
Flight Activities

- ZTL controllers (4 sectors total for this trip) direct this flight to switch to J-53 to Spartanburg VOR (a NAVAID facility)

- The aircraft reaches its enroute cruising altitude of FL 350 (heading is around 187 degrees - South)

- The flight then moves over to J-81 West of Augusta, GA

- 100 nm North of Jacksonville ZTL controllers hand-off the flight to ZJX controllers (Jacksonville Center)

- The flight takes J-45 and passes a few miles West of Daytona Beach (flies over Daytona Beach VOR called DAB)

- The flight is handed-off to ZMA (Miami ARTCC Center)

- ZMA controllers start descending the flight 100 nm from MIA VOR near Vero Beach VOR
Enroute Part of the Trip
Final Part of the Trip (Activities)

- The flight is handed over to MIA TRACON 60 nm from the airport East of the West Palm Beach VOR
- The flight progresses inside the MIA terminal area flying a codified Standard Terminal Arrival Route (STAR)
- The flight is continuously given vectors inside the 50 nm radius from MIA
- The TRACON controller sequences our flight behind a “heavy” (Boeing 757 of American Airlines) and establishes 6 nm of separation
- 5 nm from MIA airport the flight is handed-off to MIA tower
- The flight lands on RWY 27 R per local controller instructions
- The flight taxis to the ramp following instructions of a ground controller
Final Approach and Terminal Area

Vero Beach

Miami
Aircraft Instrumentation and Navigation

Modern transport aircraft have plenty of instrumentation to navigate across the U.S. and over the oceans
Future Navigation (Free Flight)

In Free Flight a pilot navigates directly from an origin to a destination using Satellite Navigation (SATNAV) systems.
Sample Individual Free Flight Track

Flight plans will be more flexible and allow pilots to save time and fuel.
North Atlantic and Pacific Operations
Why Collision Risk Analysis?

- There are about 15-30 aircraft collisions in the U.S. every year.
- Most of these occur on the ground and involve General Aviation (GA) type aircraft.
- According to the Office of Technology Assessment statistics, the number of collisions has increased quadratically with flight operations.
- Collisions are rare events but “near misses” incidents are more numerous.
- Enroute collisions do not happen very often (once every 10-20 years).
- Modeling rare events is challenging.
The Role of Air Traffic Control

Air traffic controllers maintain aircraft separations and help pilots navigate to their destination providing verbal instructions.
Modeling Collision Risk in NAS Operations

- We use **computer simulation models** to replicate the real system (i.e., airports, aircraft, airways, sectors, etc.)
  - Simulation models are mathematical abstractions on how the system works
  - Simulation models have a lot of logic and math behind them
- Computer simulations integrate **mathematics** and computer science expertise
- Collisions are rare so we need to create models to predict their predecessors (incidents)
- Collisions could be a detrimental to the growth of air transportation
First Application of CRM Models

• 1963 - Reich and Marks start development of the first Collision Risk Assessment model

• 1968 - Reich-Marks model accepted for oceanic operations
  - Established longitudinal, lateral and vertical separation minimums to fly over the North Atlantic
  - 120 nautical mile lateral separation (90 nm separation considered unsafe using the model)
  - The longitudinal separation was 20 minutes initially
  - 15 minutes in-trail adopted in 1978
Reich-Marks Model

- Reich- Marks model (target level of safety at $2.5 \times 10^{-9}$ collisions per flight hour)

2000 ft

120 nm

$S_x = 20$ minutes
Composite Rule Changes

- 1971 - First reduction in lateral separation (120/60 composite rule separation)
MNPS Changes in NATS

- Navigation equipment was more accurate

![Diagram showing 2000 ft, 60 nm, 120 nm, and Sx = 10 minutes]
MNPS Changes

- Avionics/aircraft equipment needs to be certified under stricter rules to operate in NATS (North Atlantic Track System)

Vertical Error PDF
\[ \mu = 0 \text{ ft} \]
\[ \sigma = 82 \text{ ft} \]

Lateral NAV Error PDF
\[ \mu = 0 \text{ ft} \]
\[ \sigma = 3000 \text{ ft} \]
RVSM Rule Changes

In 1990 a new study concluded that 1000 ft vertical separation was acceptable over the North Atlantic.

1000 ft

Sx = 10 minutes

60 nm
New Separations over NATS (North Atlantic Organized Track System)

- 1000 foot vertical separation between flight levels 290 and 390 (implemented in March 1997)
- 60 nm lateral separation between adjacent flight tracks
- 10 minute longitudinal separation between successive aircraft (about 150 km if flying at Mach 0.80)
- Requires strict enforcement of Minimu Equipment Lists (MLE) and RVSM (Reduced Vertical Separation Measures) certification (aircraft specific)
- Wake turbulence and issue sometimes (pilots are given the freedom to deviate 2 miles off the track to avoid wake turbulence)
Separations Over NAS

Much smaller than over NATS (5 nm for distance > 40 nm from radar)

- Positive control (radar control for all IFR flights)
- 2000 ft above 29,000 ft. (flight level 290)
- 1000 ft below FL 290

*Free Flight* will introduce a new dimension in complexity

- NASA / FAA want to reduce incidents and collisions by a factor of 5-10 in a decade
- Need to assess the collision risk over NAS if reduced separation criteria is used
VPI Involvement

- We are developing a model to assess the risk of collision under Free Flight NAS operational concepts
- Joint FAA/Eurocontrol effort
- Approach
  - Develop scenarios
  - Develop a blind conflict model
  - Work out the end-game dynamics (ATC/Pilot)
  - Introduce reliability factors to the model
Scenario Development (Free Flight)
Sample Results (CPA distances)

Shown above are Closest Point of Approach (CPA) distances between pairs of aircraft traversing Atlanta Enroute Center over an 8 hour period (NOTE: these are blind conflicts).
Sample Results (Conflict Times)

Conflict times contribute to workload and serve as precursors to establish ATC controller resolution advisories.
The conflict geometry is another important factor to determine workload and possible ATC/Aircraft end-game interactions.
Future Steps

• We are developing a plan for the end-game model to be associated with ASOM and CAM models developed at VPI

• Reliability modeling of ATC controllers, pilots and aircraft is not an easy task. Several options are possible:
  - Dynamic fault tree analysis
  - Event tree analysis
  - Petri nets
  - Neural nets
  - Artificial intelligence models

• Regardless the technique employed all these models require significant human-in-the-loop simulation studies to assess ATC and Pilot reactions to airspace conflict scenarios
Implications for Air Transport Systems Analysts

- ATC services housed at the airport
  - Airport surveillance radars
  - VOR - very high frequency omnidirectional range and TACAN systems
  - ILS - instrument landing systems

- ATC aircraft separations **dictate capacity** of the airport and in the airspace

- Runway separation criteria are dictated by ATC technology
Runway Separations at Airports Depend on Technology

The same technology used to establish the position of aircraft in the airspace is used to perform surveillance activities near airports

- Radar technology has inherent weaknesses for surveillance
- The farthest from the antenna, the larger the uncertainty to determine accurate positions
- Primary radar (skin paint)
- Secondary radar (transponder inside aircraft - Modes C and S)
Independent ILS or Precision Approaches

- IFR operational conditions
- 4,300 ft between runway centerlines
- Standard radar systems (scan rate of 4.8 seconds or more)
Independent Parallel Approaches using the Precision Runway Monitor (PRM)

- The purpose of this standard is to use the Precision Runway Monitor (PRM) to allow independent ILS approaches to parallel runways separated by 3,400 feet (FAA, 1993)
- This standard currently applies with PRM (fast-scan technology)
- Radar scan rate of 1 second or less
Independent Triple and Quadruple Approaches To Parallel Runways

- The idea behind this concept is to allow triple and quadruple parallel approaches to runways separated by 5,000 feet using current radar systems (scan update rate of 4.8 seconds) at airports having field elevations of less than 1,000 feet.
- Increase to 5,300 ft spacing between runways for elevations above 5,000 ft.
Independent Simultaneous Approaches to Converging Runways

Procedures governing independent converging approaches require that the distance between the missed approach points be 3 n.m. apart and that the Terminal Instrument Procedures (TERPS) surfaces not overlap. Because of these restrictions, minimums are high, thereby limiting the number of airports.

NTZ - No Transgression Zone

Assumes the Missed Approach Envelopes are Non-overlapping