Use of Next Generation Satellite Systems for Aeronautical Communications

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NEXTOR Research Symposium
November 14, 2000

Research Motivation

- NASA Glenn (former NASA Lewis) is developing advanced broadband network techniques
  - Use of standard protocols (TCP/IP or ATN)
  - Higher bandwidth
  - Perhaps up to 6 Gbs transfer rates on the network
- Possible impact in aviation communications
- Improves efficiency in aviation operations
- Possible capacity benefits

Application of LEO COMM Systems

- Air Traffic Management
  - Strategic (traffic flow management)
  - Tactical (air traffic control)
- Aircraft Status Information
- Aircraft as Sensor
- Airport and Terminal Area Status
- AOC Related Information
- General NAS Status

Strategic Air Traffic Management

Principal goal: overall airspace efficiency

- Characteristics:
- Strong AOC role
- Interaction with FAA Systems Command Center (ATCSCC)

System Constraints:

- Sector capacities
- Weather patterns (fronts)
- Airport constraints (AAR)

Tactical Air Traffic Management

Principal goal: collision avoidance

- Characteristics:
- Limited role for AOC
- Interactions with ARTCC sector controllers

Constraints:

- Weather (close in + high accuracy)
- Positions of other aircraft
- SUA restrictions

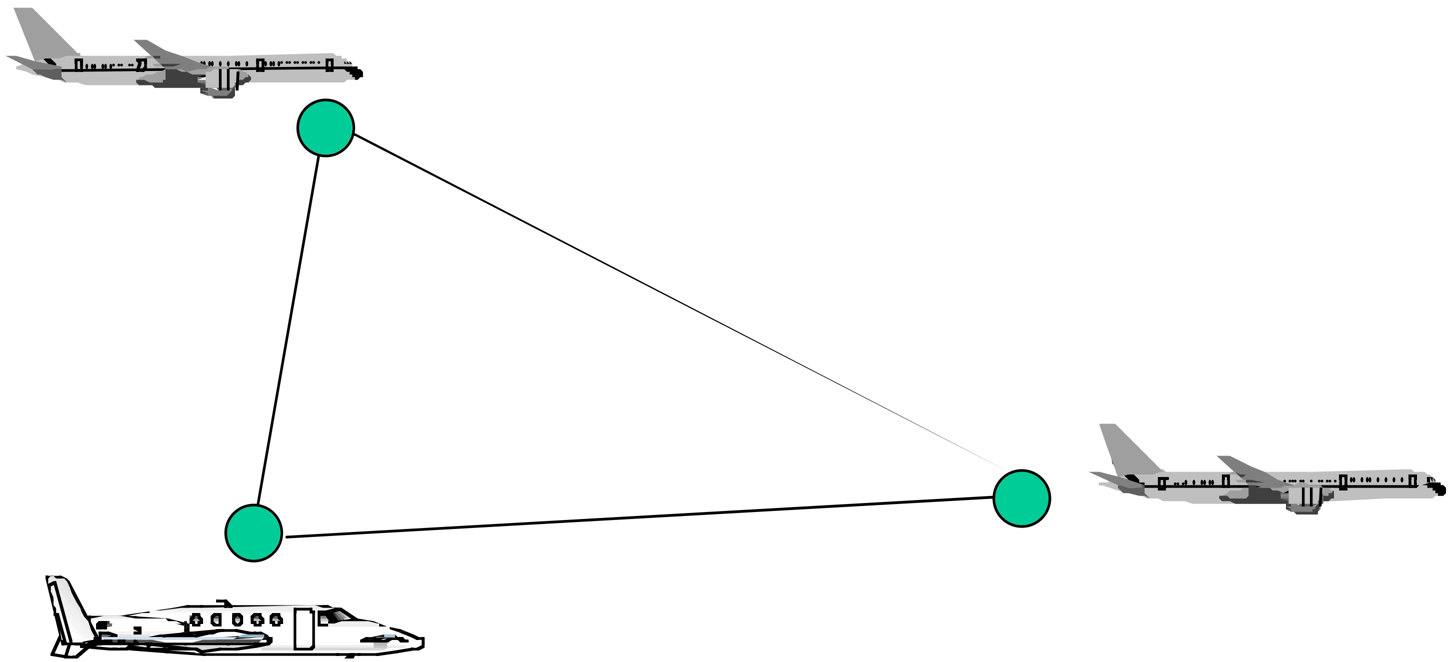
Tactical Air Traffic Management (Cont.)

Aircraft "network":

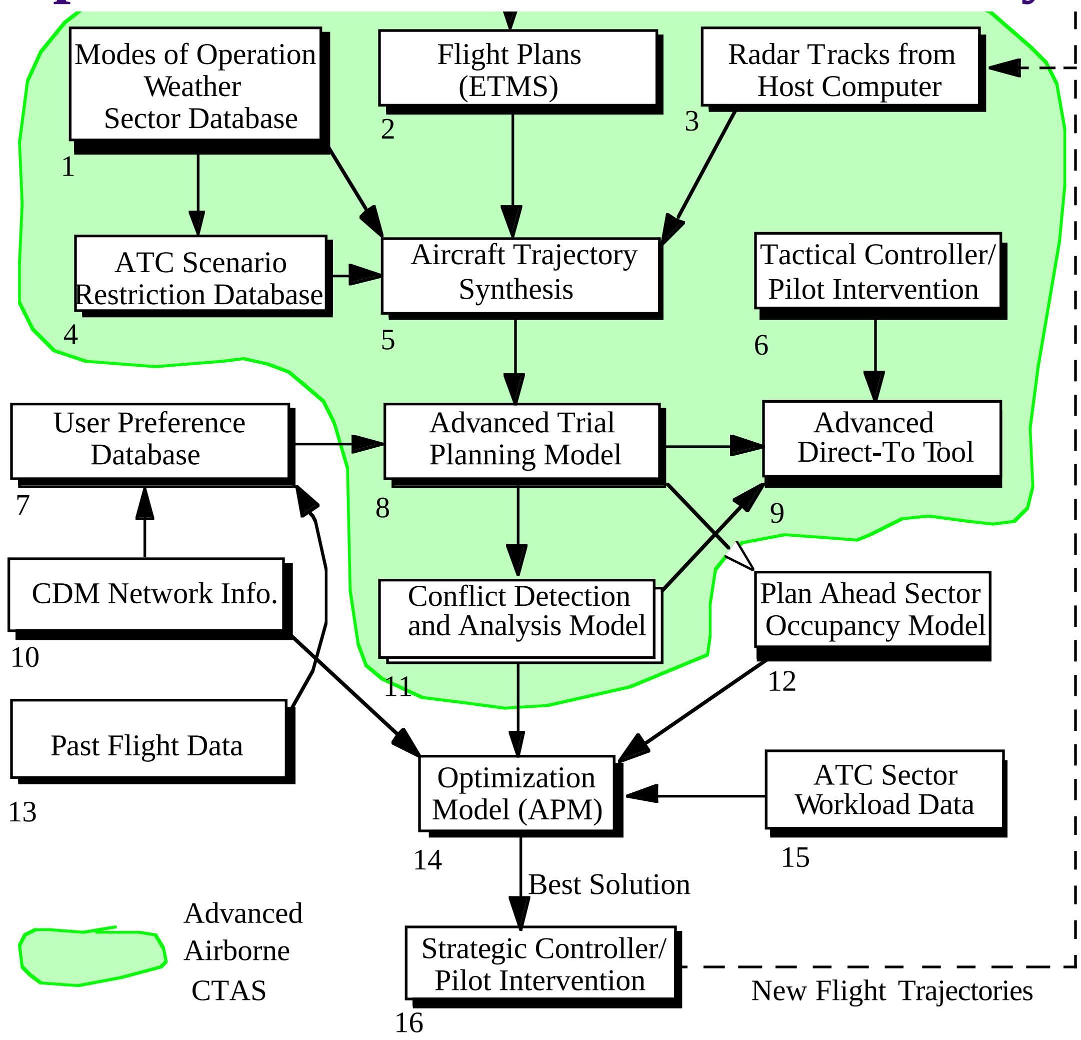
- inter-aircraft communication
- integration with ADSB + WAAS
- inter-aircraft distributed decision making algorithms

Example of Airborne Network

- Aircraft form a distributed computing network
- Distributed control algorithms devise aircraft maneuvers (advanced airborne CTAS functionality)



Example of Advanced CTAS Functionality



Emphasis on Weather Information to the Cockpit

- Documents possible aviation weather product communication requirements in NAS (circa 2020)
- Establishes a first order approximation method to size aviation weather data requirements in NAS (circa 2020)
- Illustrates the use of ground and airborne sensors to determine a more complete weather information in NAS
  - Airborne weather radar
  - Ground doppler radar
  - Airborne sensor information

Cockpit Technology with Advanced Displays (Includes Weather)

Agate video animation still – instrument panel
NASA Langley Research Center 12/3/1997 Image # EL-1997-00277

Approach

- The aviation weather data communications needs will be initially derived for a single aircraft.
- Extensions based on previous analysis of the airport, terminal areas and enroute airspace will then be made.
- Both ground and airborne weather gathering sources are considered in this problem.
  - The primary source for ground-based weather component is advanced Doppler radar (NEXRAD)
  - The primary source for airborne-based weather information is the airborne weather radar of each aircraft in the area of analysis

Domains of Analysis

Three decision making domains of analysis are considered in this problem:

- **Tactical** decision-making (20 minutes ahead)
- **Near strategic** decision-making (20-60 minutes ahead)
- **Far strategic** decision-making (>60 minutes ahead)

These domain specifications are **based on time rather than distance** since aircraft speeds vary significantly along a typical flight path and across Air Traffic Control (ATC) domains.

Time variations allow pilots to make better weather avoidance decisions throughout a typical flight without complicated weather cell resolution rules.

A Typical Flight

In order to consider how decision making information domain specifications play a role in aviation communications the following transcontinental flight is illustrated in the following paragraphs.

The parameters of this flight have been derived from the Enhanced Traffic Management System (ETMS).

% The following example illustrates the ETMS data base

AAL1________00_0 YYY B767 YYY YYY 1

AAL1________00_0 JFK LAX 40.640 73.779 866 33.943 118.408 1152 14:26 286 0 C 50

IZYYYYYY 40.633 73.783 0 866.000 123 123

YYYYYYYY 40.417 74.143 112 871.885 330 304

YYYYYYYY 40.200 74.500 208 875.749 386 345

YYYYYYYY 40.285 74.988 282 879.526 441 386

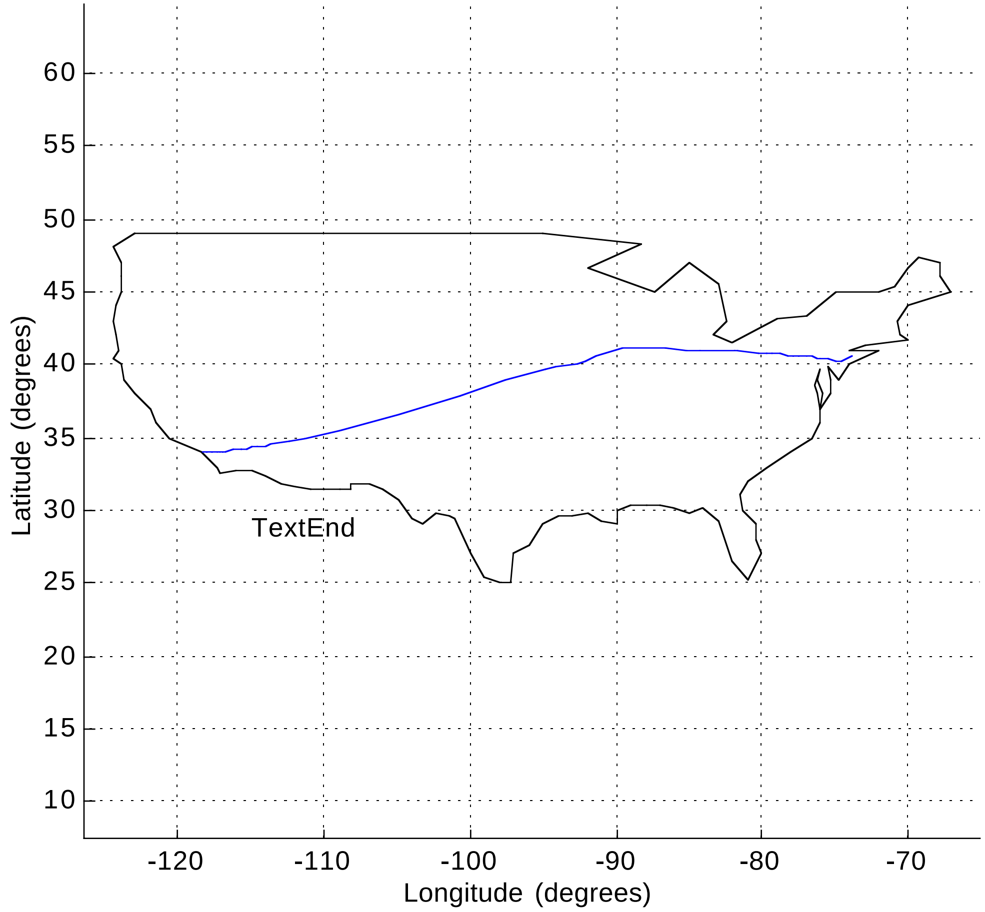
.....

LZYYYYYY 33.950 118.400 0 1168.621 219 225

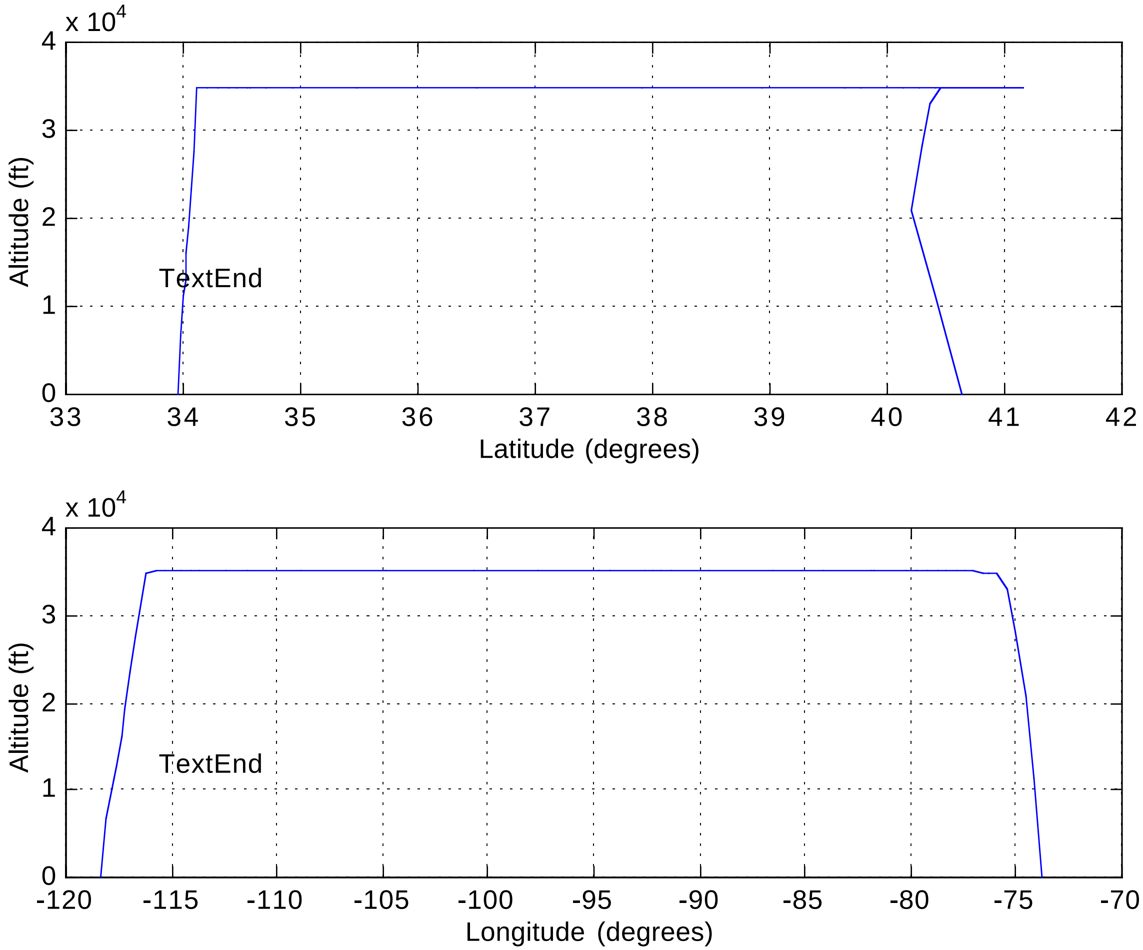
Flight Information

- Boeing 767-200
- Origin = JFK (New York)
- Destination - LAX (Los Angeles)
- Flight departure time = 866 UTC (minutes)
- 50 waypoints along the route are filed by the pilot in this case indicating a full trajectory from JFK to LAX
- The entire trip crosses 5-6 ARTCC centers in NAS and involves 2 terminal area crossings (at origin and destination airports)

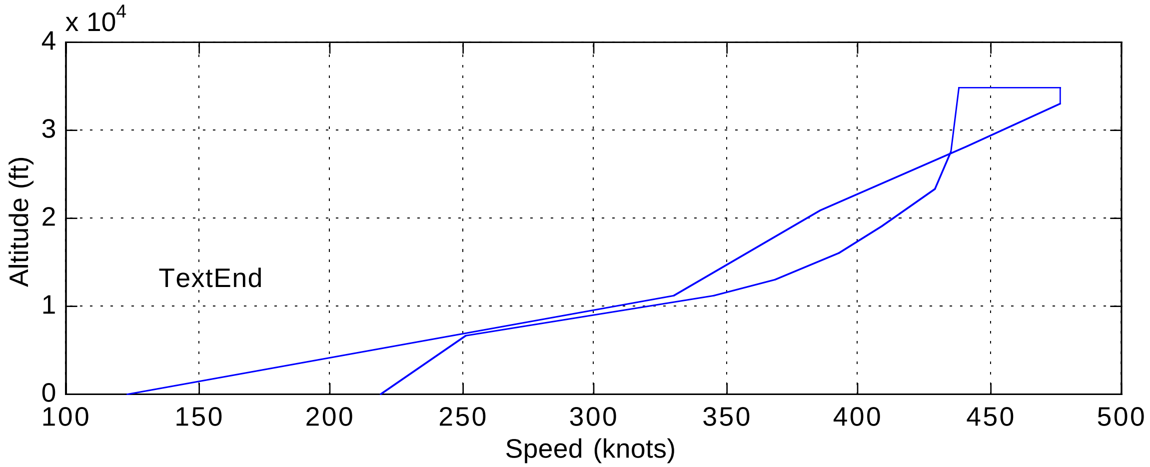
Pictorial Representation of the Flight

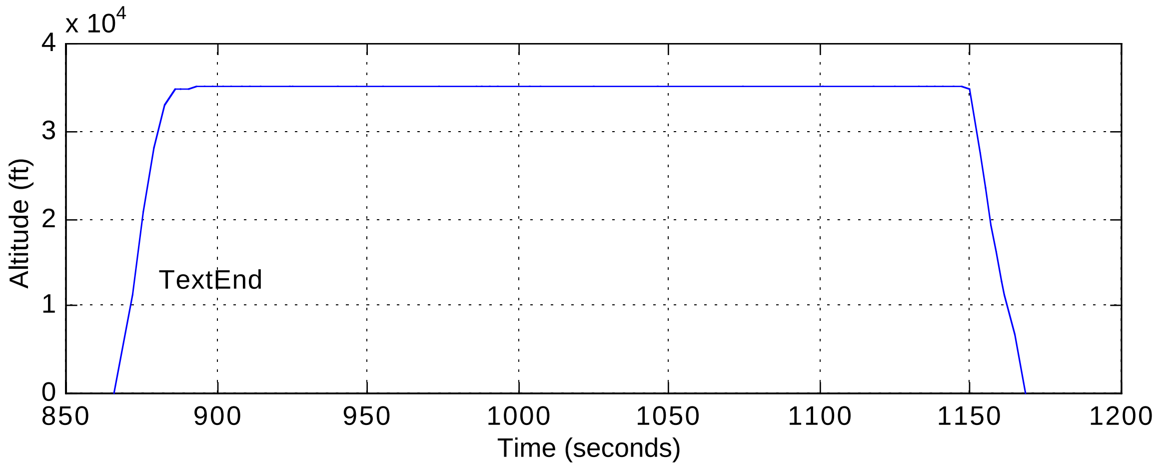


Composite Plot of the Trajectory



Aircraft Trajectory (2)





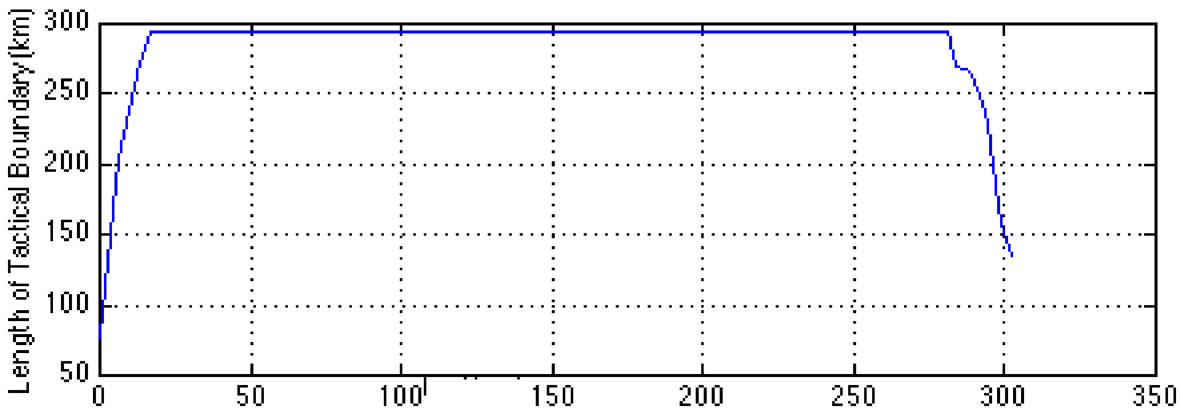
Distance Implication of Decision-Making Domains

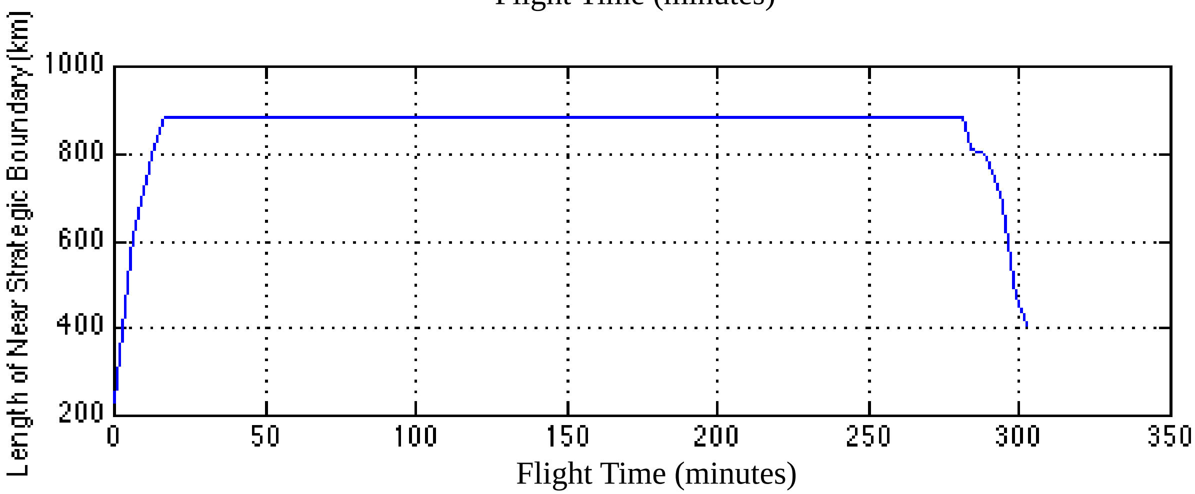
The figure on page 11 illustrates the size (look ahead function) of two decision making domains: tactical and near strategic

The following points can be made about this figure:

- The variations in tactical and near strategic domain are substantial as they are functions of time and speed (rather than static distances)
- A fast transport aircraft (like the Boeing 767 represented in this analysis) requires substantial amount of information ahead of time (note the near strategic domain boundary is near 900 km in cruise - equivalent to one hour flight time at the present speed)

Variations of Decision-Making Boundaries in Flight





Air Traffic Control Domains

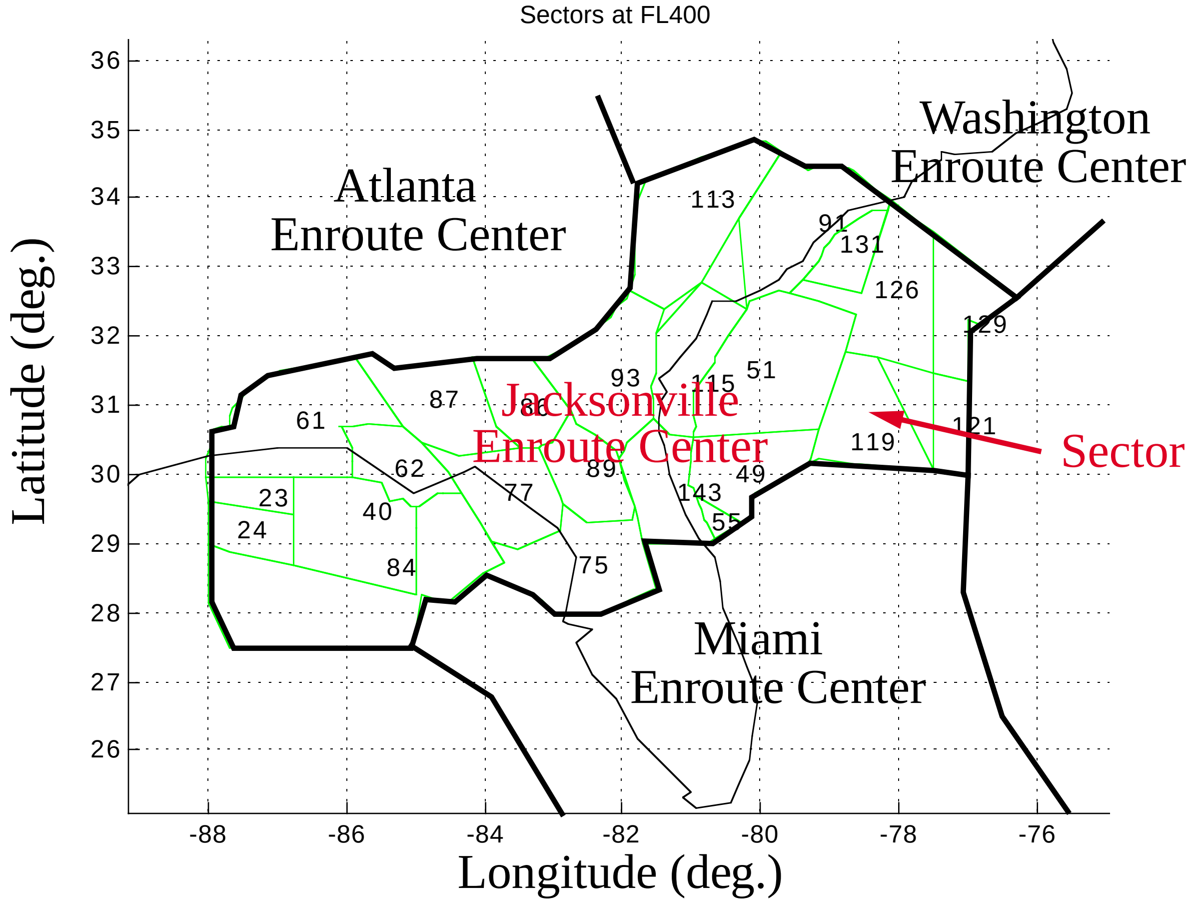
Control activities in Air Traffic Control (ATC) are usually segregated into the following domains:

- Airport Air Traffic Control Tower (ATCT)
- Terminal Radar Approach and Departure Control Areas (TRACON)
- Enroute Air Traffic Control Centers (ARTCC)
- Air Traffic Control Systems Command Center (central flow control) - ATCSCC

An **information component** of ATC also includes a multitude of Flight Service Stations to provide weather and flight plan approvals:

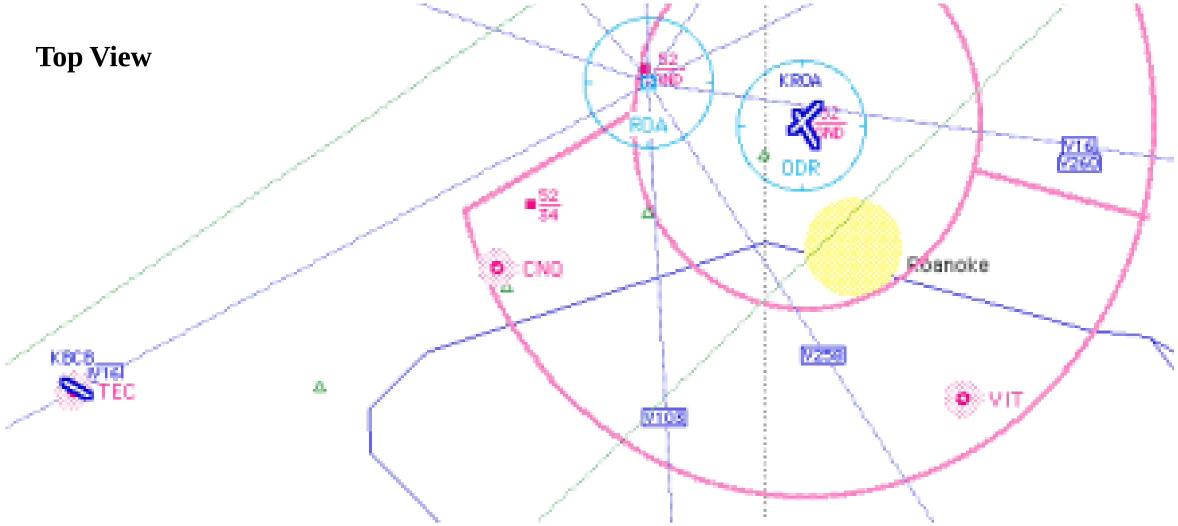
- Flight Service Stations (FSS)

Schematic of ATC ARTCC Representation

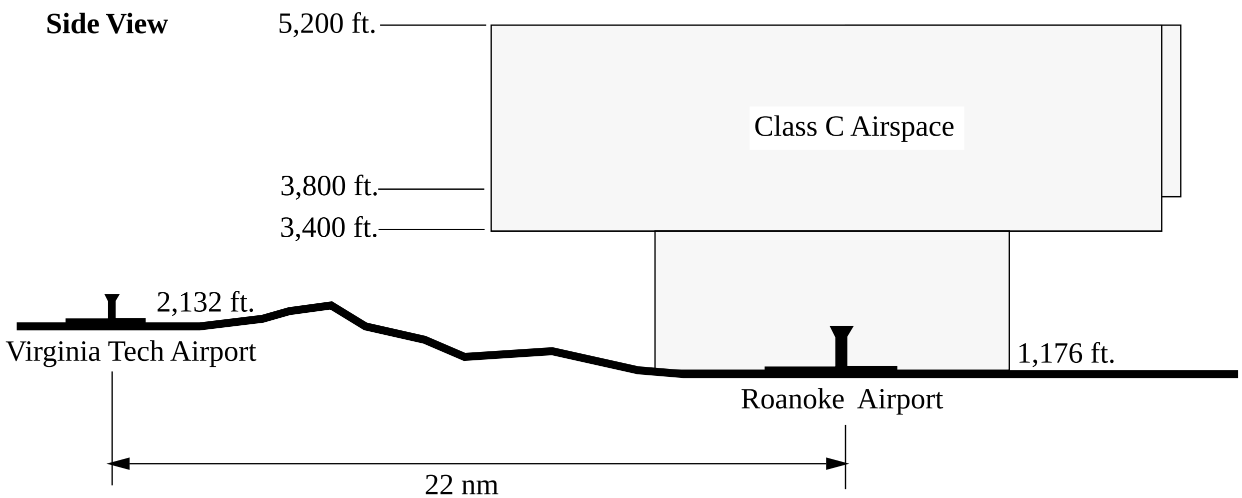


Representation of ATCT and TRACON

Top View



Side View



Importance of ATC Domain Areas in Communications

Each ATC domain area has specific aviation data requirements

- The exchanges of information (including weather) vary across NAS according to the ATC domain area in question
- The resolution of aviation weather services improves as each flight transitions from ARTCC to the airport area due to the physical resolution of the weather sensors (i.e., Doppler radar, Low Level Wind Shear, etc.) installed near or at the airports.
- It is expected that as new advances in weather technology take place the resolution of the minimum cell of weather information will improve. However, it is likely that the density of services would probably remain unevenly distributed across NAS ATC services.

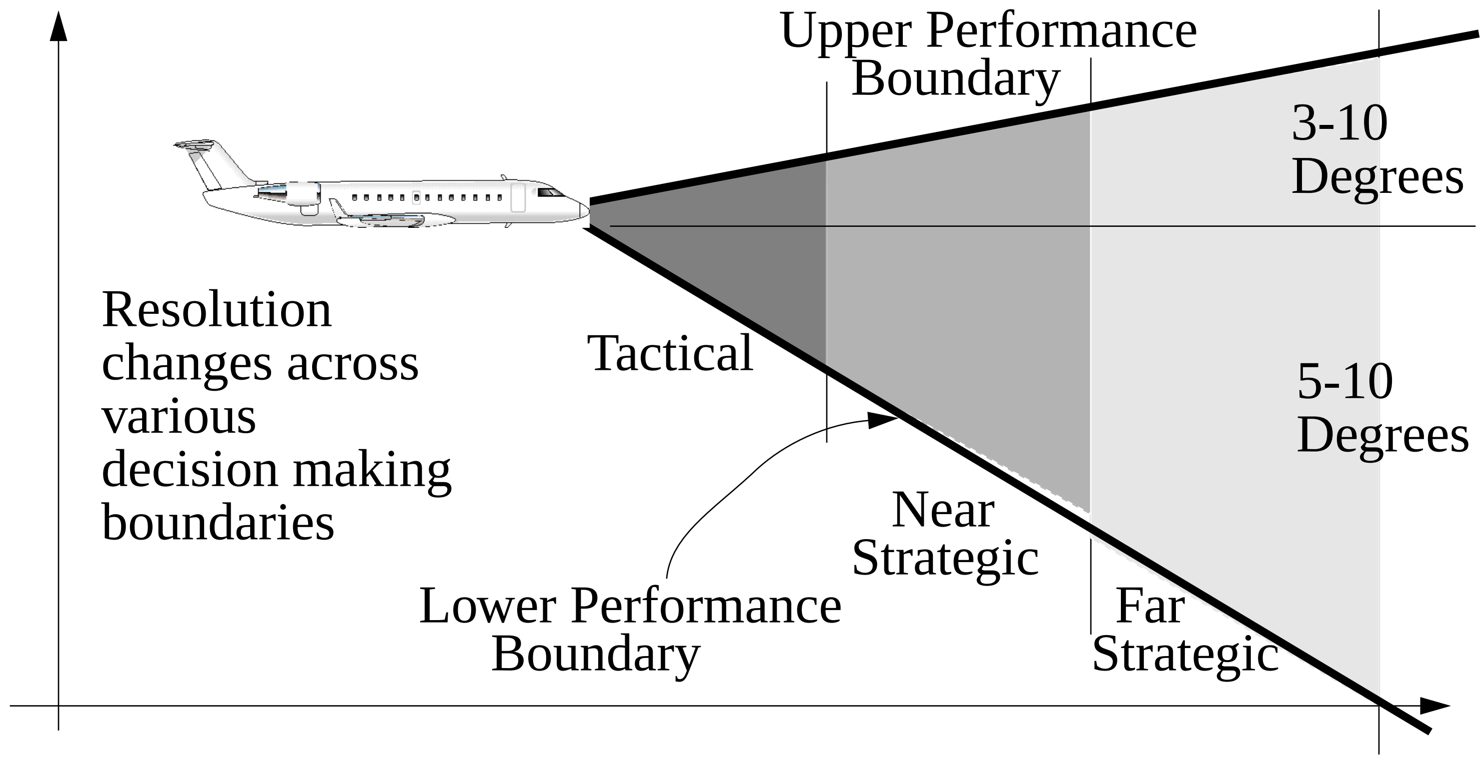
Communication Requirements Analysis

The following steps are necessary to derive realistic communication requirements associated with aviation applications:

- Derive a concept of operations
  - How do aircraft, ATC services, and weather information interact
  - What type of weather information is derived from sensors (both airborne and ground-based)?
  - How often is the information requested by airborne users? How often is the information available to ground sensors?
- Determine the size of weather exchanges
- Determine possible communication modes of operations (segregated channel vs. broadcast mode, etc.)
- Perform the communication channel analysis

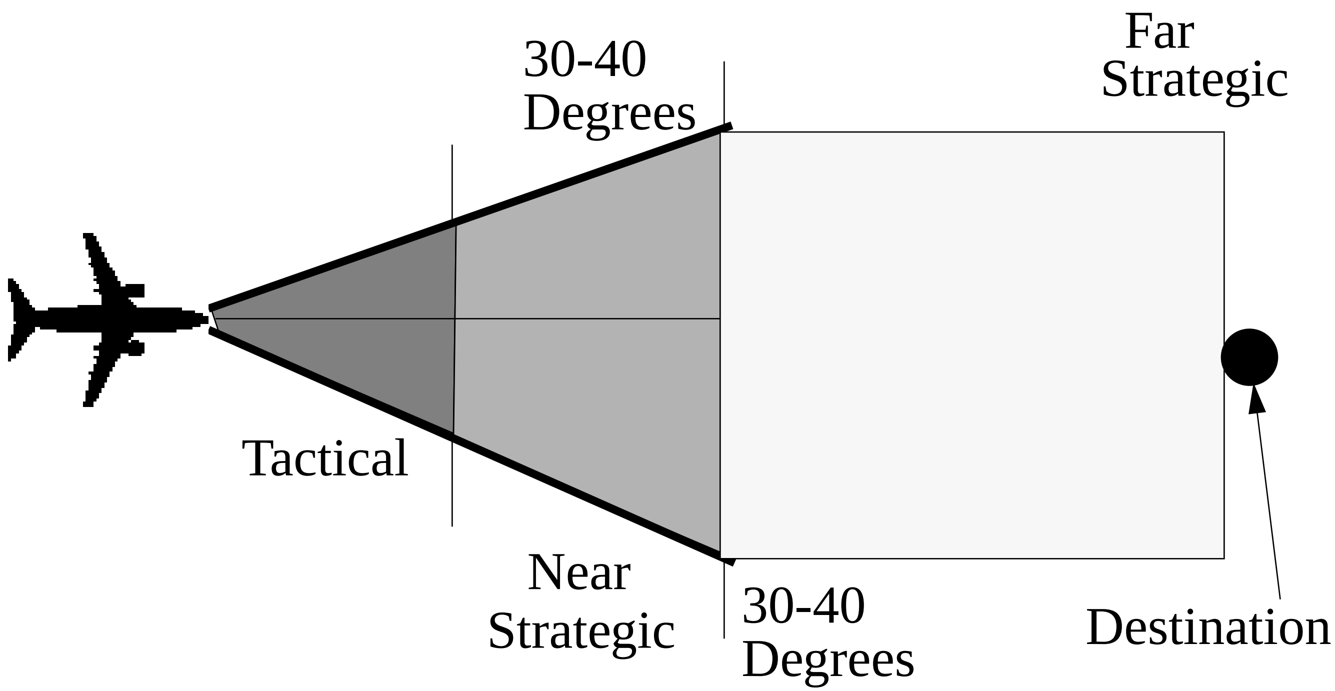
Airborne Weather Advisory System

It is desirable to have real-time weather information available in the cockpit at all levels in the decision-making process (i.e., tactical, near strategic and far strategic).



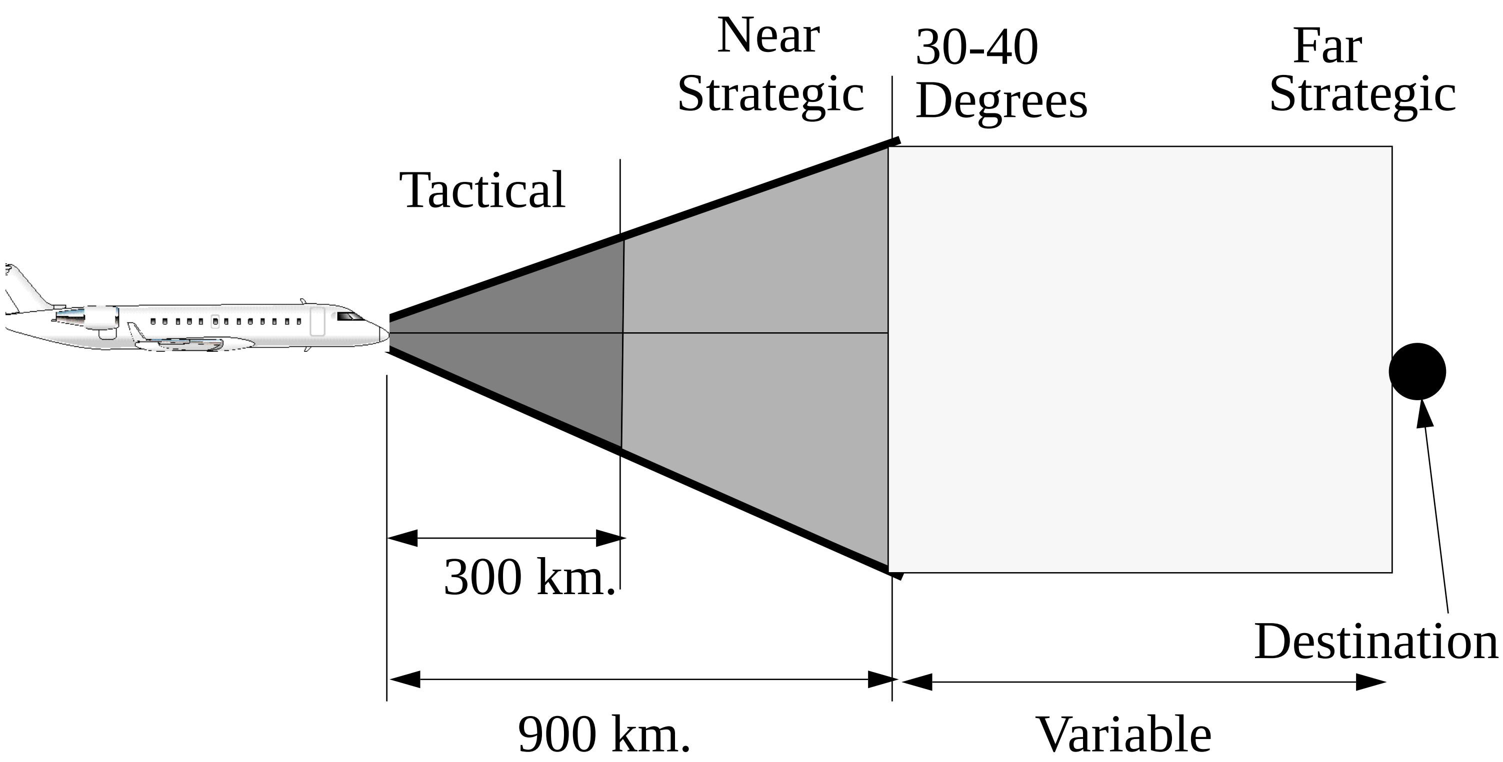
Airborne Weather Advisory System

Top view of the weather information displayed in the cockpit.



Decision-Making Region Sizes

The following illsutrates typical sizes of the regions of interest.



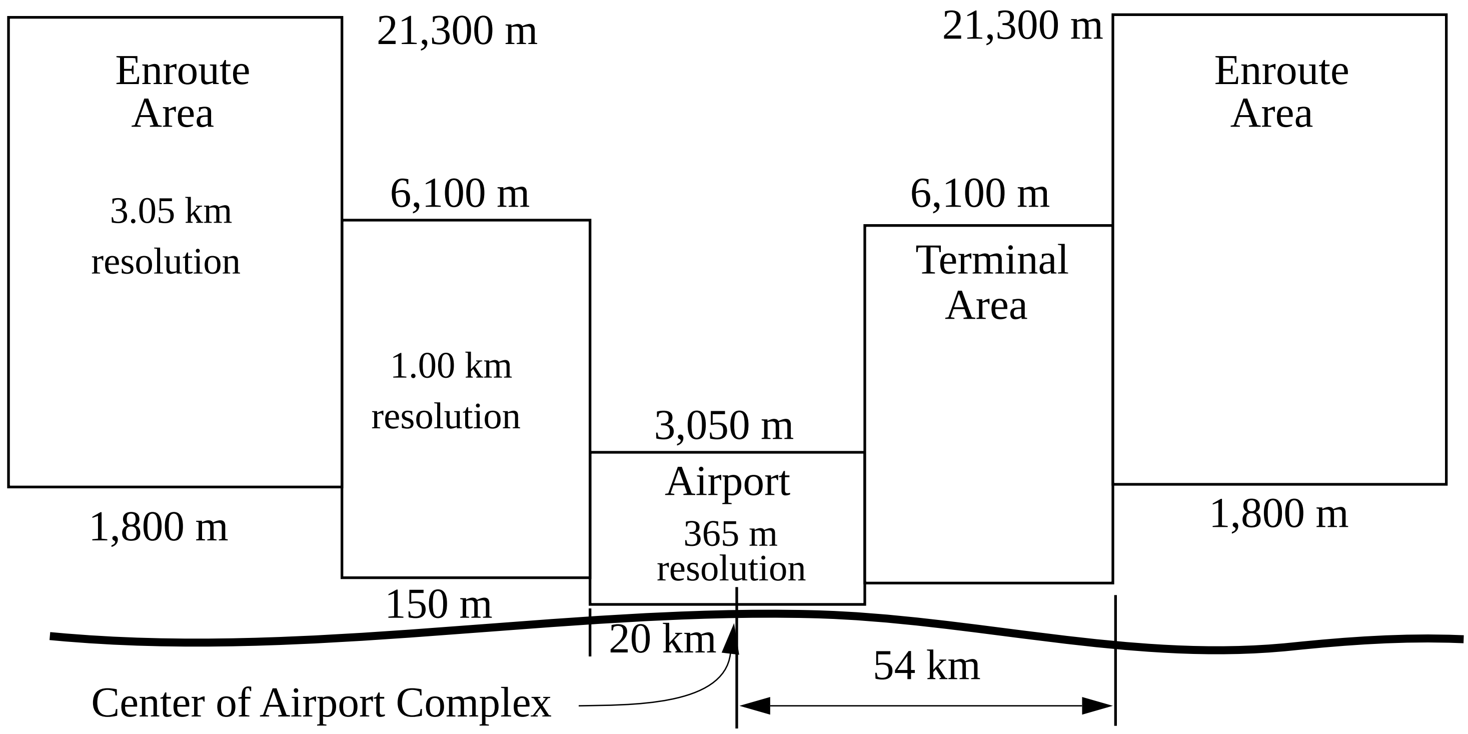
Resolution of Weather Information

The resolution of the weather information provided to the cockpit changes as a function of time and space over NAS for several reasons:

- Ground-based Doppler radar information has **uneven volume resolutions** as we move away from the radar antenna
- Airborne sensor information (i.e., weather radar and other sensors) are **limited in scope** to two hundred kilometers at best (this only applicable to wether radars)
- The **distribution of both ground and airborne sensors** is not even across NAS
- Fortunately, the **most advanced weather sensors** are usually located near large airports thus contributing to better weather volume resolutions in the critical phases of flight (landing and takeoff - see FAA sensor criteria next)

Spatial Resolution of Ground Based Weather Sensors (FAA Criteria) - per Mahapatra

The spatial resolution of weather sensors can be modeled as three distinct components according to the FAA



Ground Sensor Information

Advanced ground Doppler radar is the primary source of weather information (from the ground to the air)

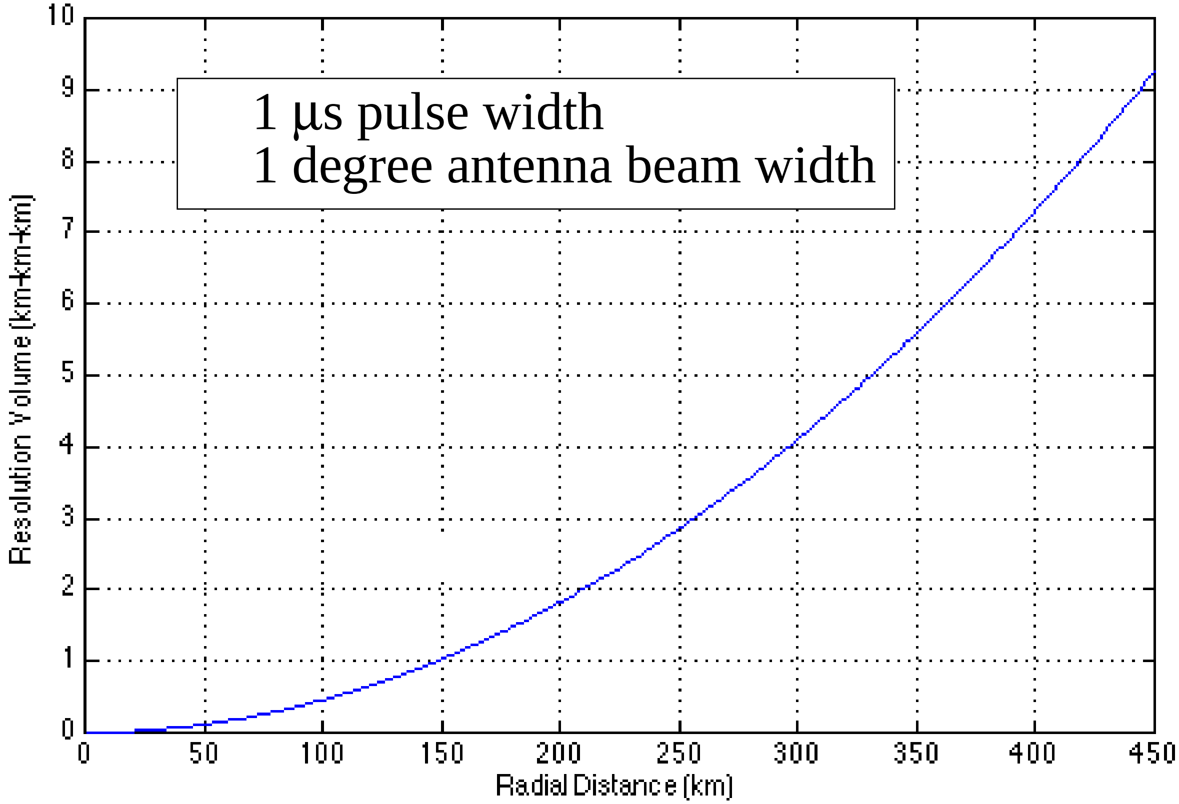
- Uneven resolution volumes
- Good velocity trace capability (both radial and azimuthal)
- Good convective detection capability
- Good range characteristics (up to 450 km)

Airborne weather radar could be used to improve the resolution of weather data to other aircraft

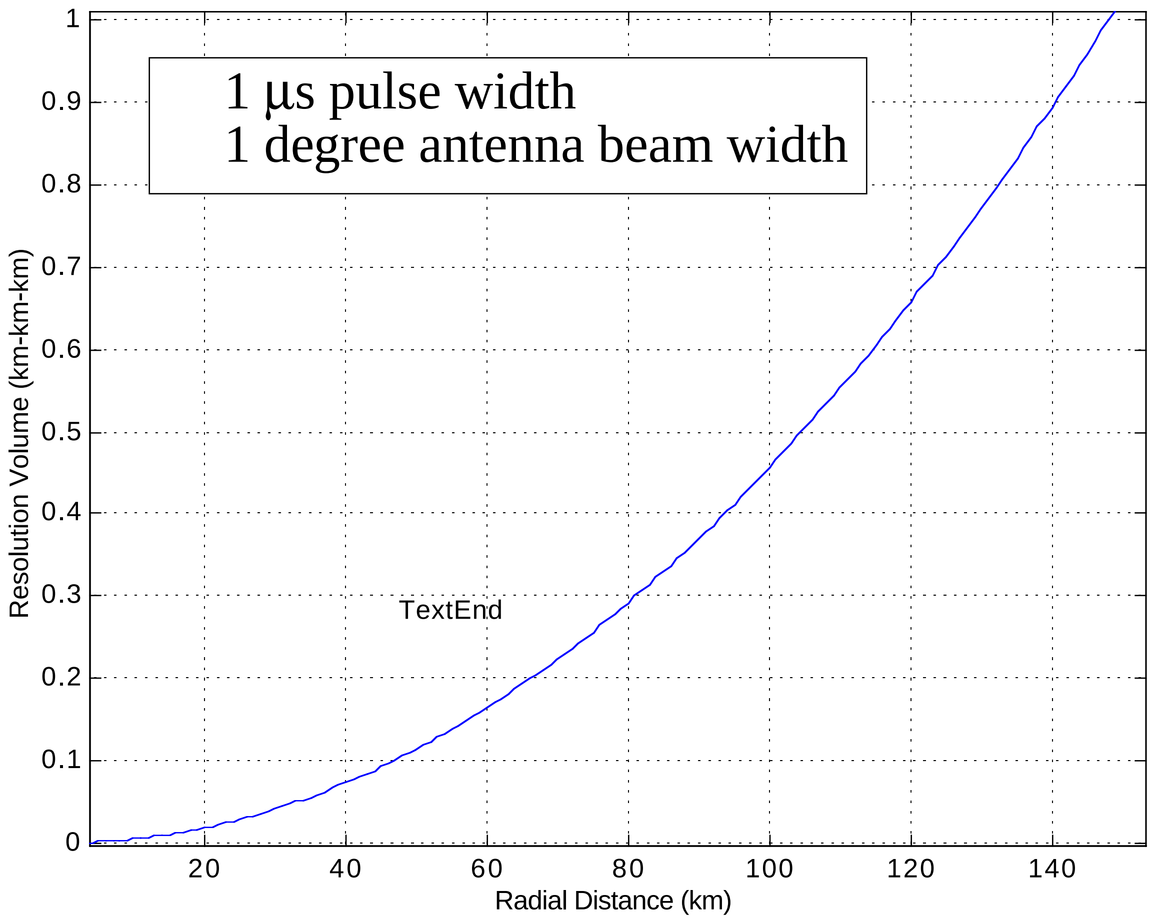
- Limited range (up to 150 km)
- Could provide advisories to other pilots if data is properly relayed through high-bandwidth channel

Doppler Radar Volume Resolution with Distance

The following graphic illustrates the variations in radar volume resolution as we move from the radar antenna (single radar)

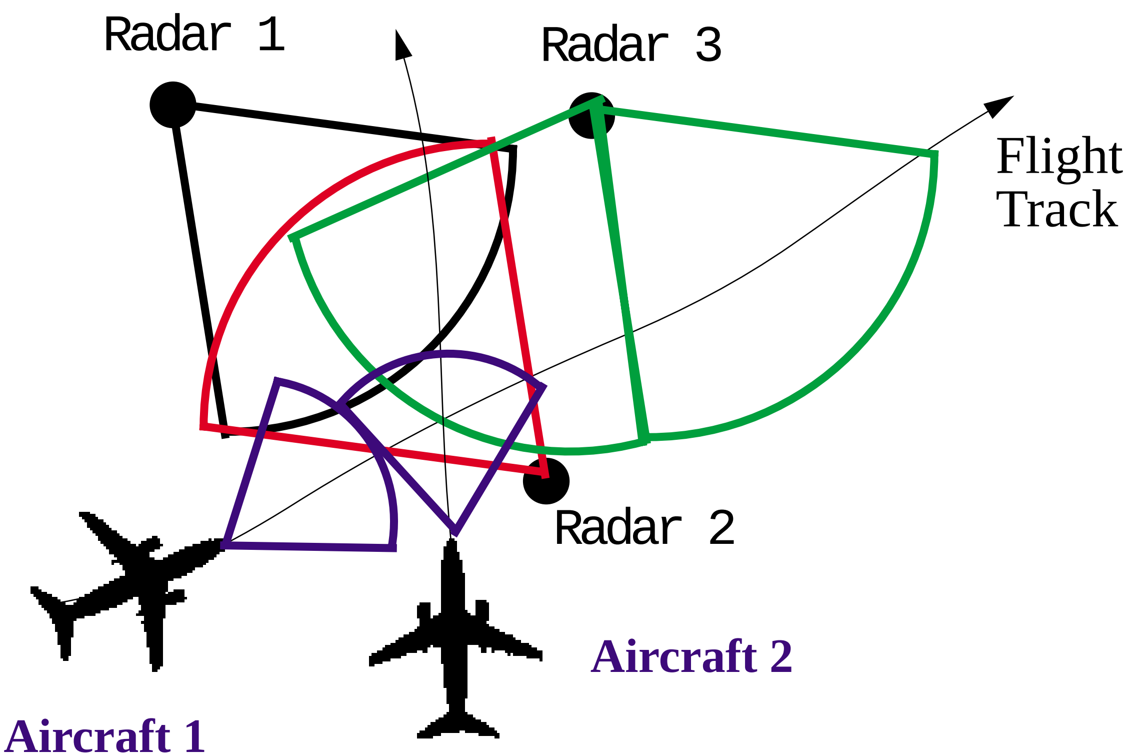


Doppler Radar Volume Resolution in Terminal and Airport Areas



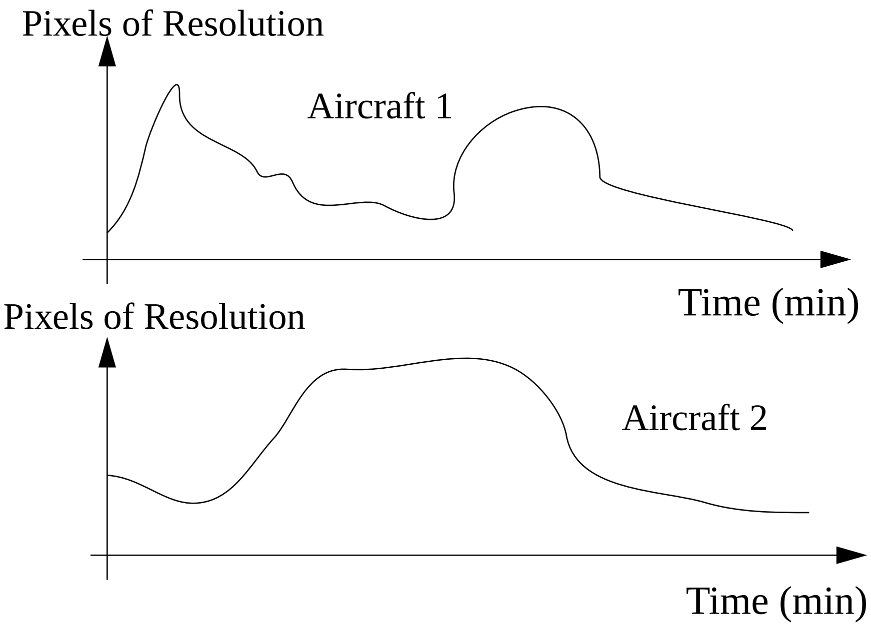
Mosaic Composition of Multiple Radar Sites

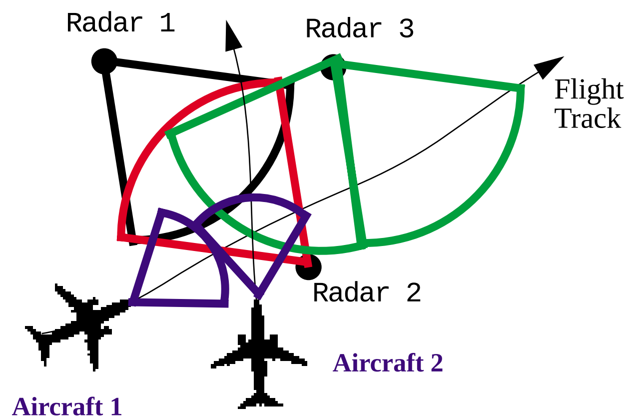
When an airborne platform flies over NAS the weather information received and displayed in the cockpit will be the fuzed signal of multiple ground and airborne radar sites as shown below.



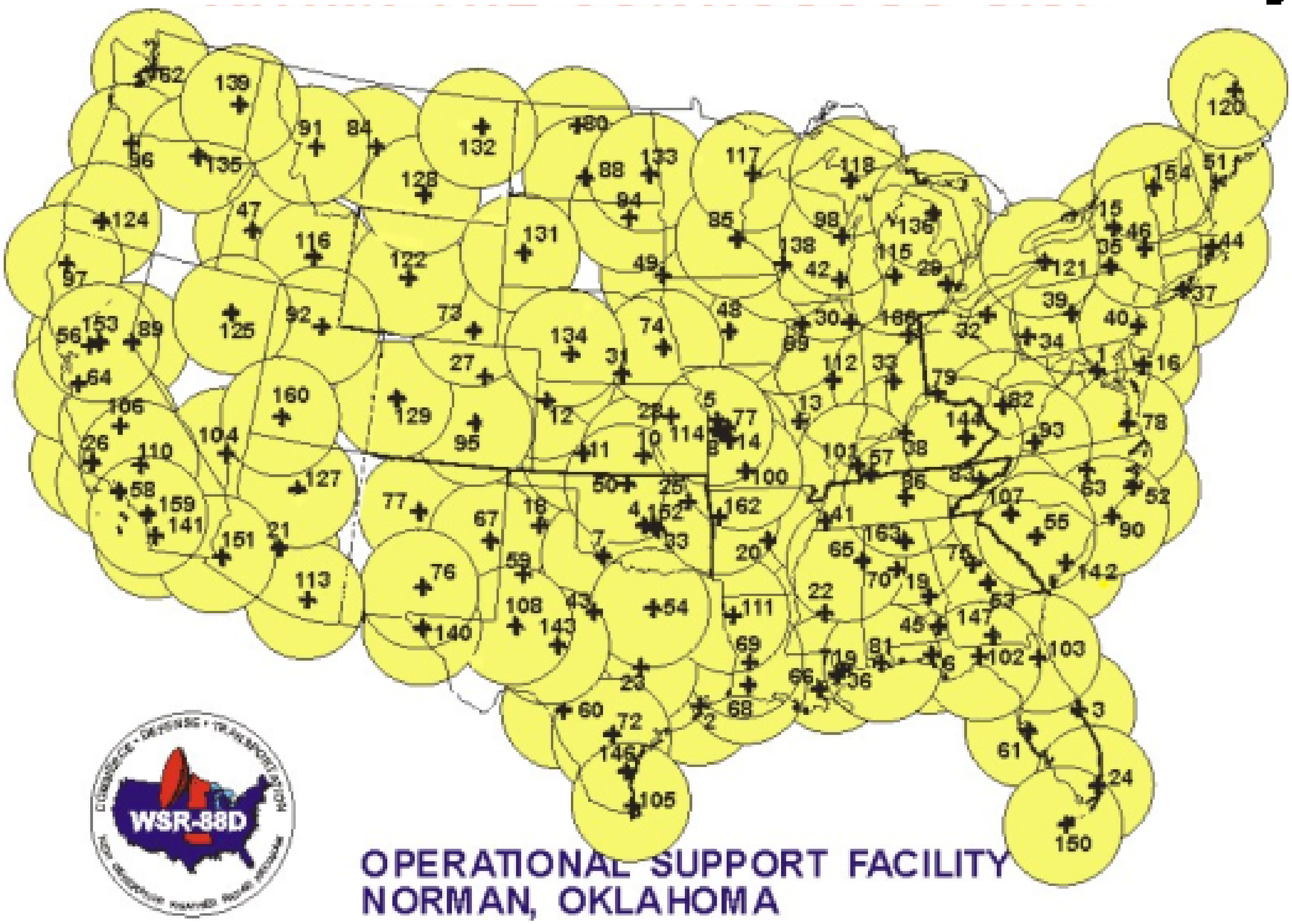
More on Composition of Weather Sensor Information

The traversal of various ground and airborne weather sensor sites yields and uneven time history of the number of pixels of resolution available at each one of the three decision-making domains as shown below.





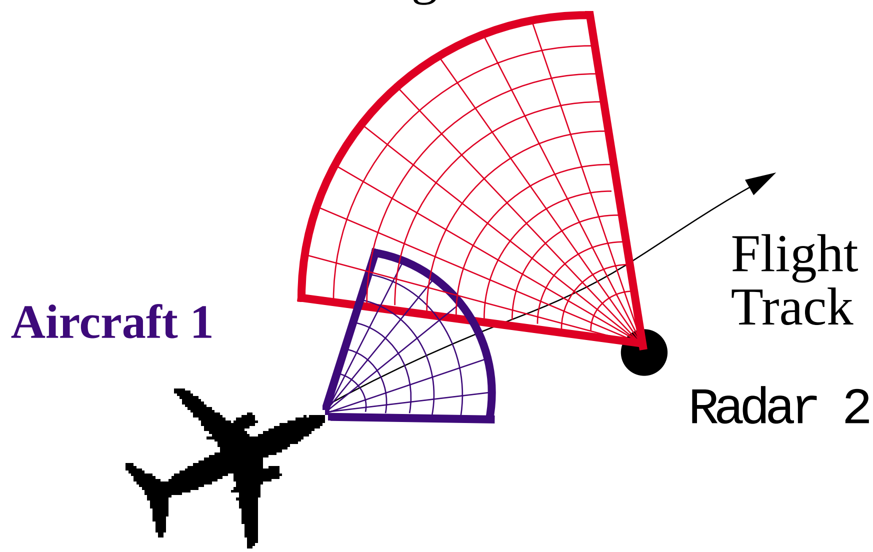
Spatial Location of NEXRAD Sites



First-Order Weather Information Values

In order to derive first-order weather cell resolution information we use a simplified conical grid for each one of the three decision-making domain areas previously described.

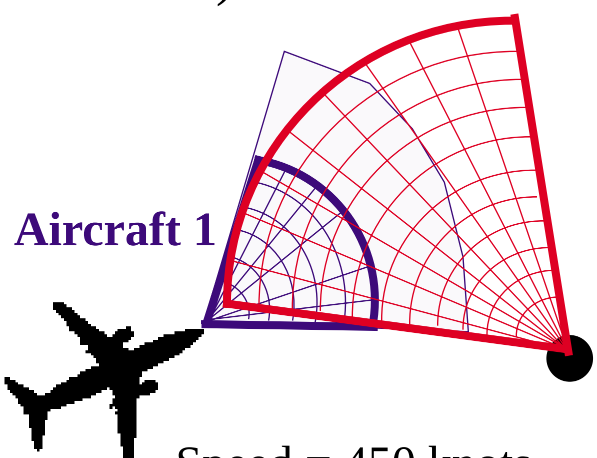
The number of pixels represented in each domains proportional to the volume resolution of the ground and airborne sensors used.



Tactical Weather Cell Resolution Levels (Radar Equipped Aircraft)

Suppose the aircraft in question has an active weather radar.

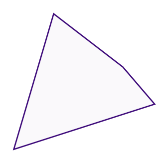
The **tactical domain weather information** is assumed to be the resolution cells of the on-board equipment plus ground sensor information needed to complete the tactical boundary (see diagram below).



Speed = 450 knots

Assumed resolution = 2 bytes per pixel
Radar range = 200 km (maximum)
Training angles = +- 30 azimuth, +- 10 elevation
Pulse width = 1 μs

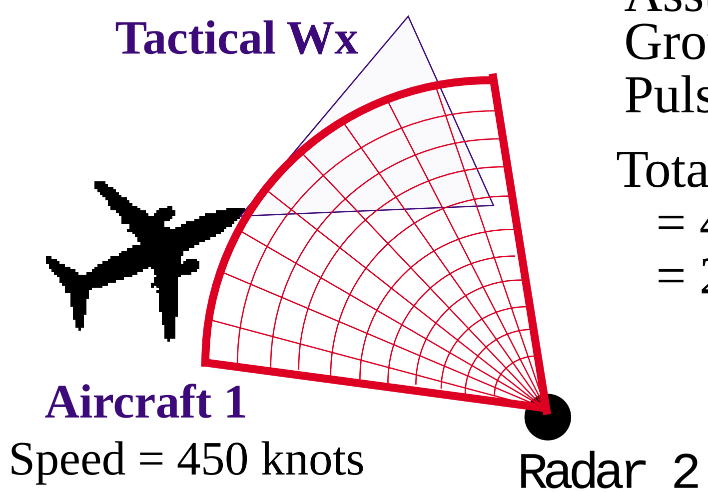
Total weather cell info / cycle = 4.8 E 6 bytes



Tactical Boundary

Tactical Weather Cell Resolution Levels (Non-Radar Equipped Aircraft)

Suppose the aircraft in question has no on-board weather radar. The tactical domain weather information is assumed to be the resolution cells of the ground sensor as shown below. Worst case scenario applies when aircraft is flying near the ground sensor.

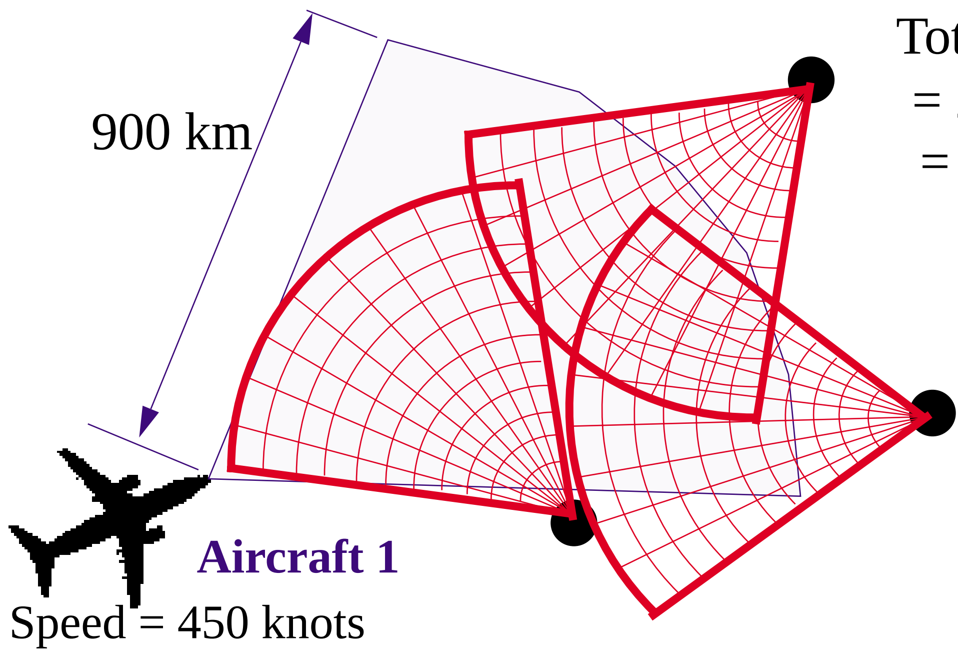


Assumed resolution = 2 bytes per pixel
Ground radar range = 450 km (maximum)
Pulse width = 1 μs

Total weather cell info / cycle
= 4.8 E 6 bytes (worst case)
= 2.8 E 6 bytes (typical)

Near Strategic Weather Cell Resolution Levels (All Aircraft)

The near strategic domain weather information is assumed to be the resolution cells of the ground sensors available in the flight track (no collaborative weather information is assumed for airborne sensors yet).

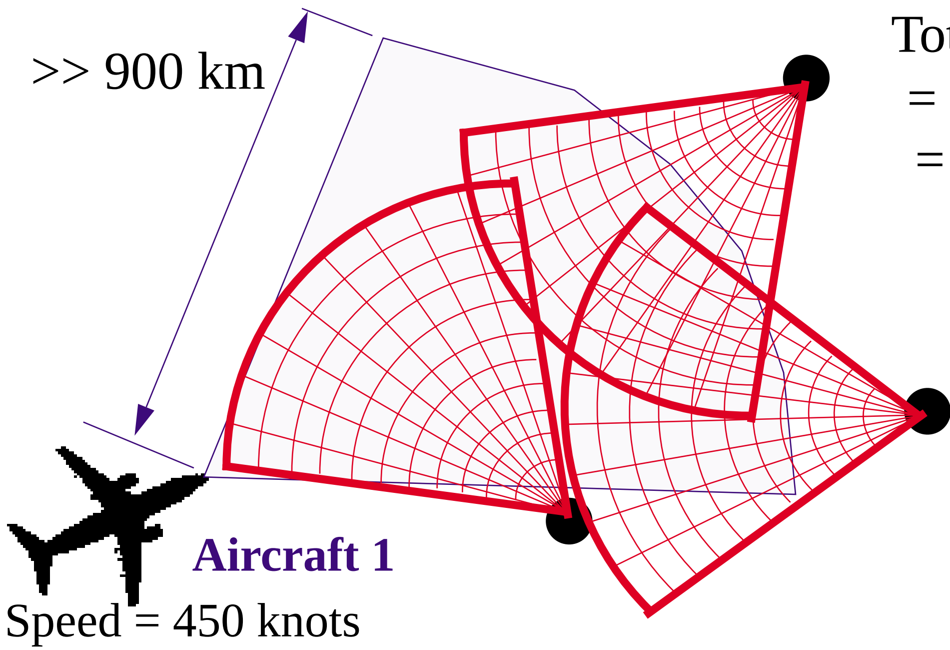


Total weather cell info / cycle
= 28 E 6 bytes (worst case)
= 22 E 6 bytes (typical)

Note: assumes all radial cell info is available (150 m resolution)

Far Strategic Weather Cell Resolution Levels (All Aircraft)

The near strategic domain weather information is assumed to be the resolution cells of the ground sensors available in the flight track with simplification of the radar picture (5 pixels into 1).



Total weather cell info / cycle
= 5.0 E 6 bytes (worst case)
= 4.0 E 6 bytes (typical)

Note: assumes all radial cell info is fuzed at a factor of 5 pixels for 1 (1-2 km radial resolution)

Possible Data Communication Savings

Techniques to reduce bandwidth requirements should be addressed in this analysis:

- Data compression techniques
- Data validation/filtering algorithms that refresh weather cell elements that change from successive observations

Anecdotal information from the AWIN program shows that tactical weather information savings are substantial using these two techniques. In one case the data filtering algorithms changed 41 kbytes of a complete weather display (several Mbytes of information at 8 bit resolution)

Weather Information Refresh Rates

Assumptions:

1) **Tactical domain** matters the most (fastest cycle time)

- Suggest an equivalent to **1 minute update** for all cells in the weather map

2) **Near Term Strategic** is second place in importance

- Can wait up to **3 minutes** in updates of the near term weather picture
- We need to examine the impact of 60 degree coverage angle in the near strategic picture. This might not be necessary for all flights as diversions from intended path seldom result in such large lateral excursions.

3) **Far term strategic** can be updated every **10 minutes**

Data Analysis per Unit Area (Individual Aircraft)

The following table shows the typical data requirements associated with an advanced airborne weather information system covering the three areas in question. Requirements are for individual aircraft.

Domain	**Total Weather Data Size (bytes)**	**Region Size[a] (km^2)**	**Data (bytes per sq. km)**	**Sampling Rate (seconds)**
Tactical	4.8 E 6	4.71 E 4	101.85	60
Near Strategic	22 E 6	4.24 E 5	51.86	180
Far Strategic	4.0 E 6	2.700 E 6	1.48	600

a. For a typical transport-type aircraft traveling at 900 km/kr. (460 knots).

Data Savings Analysis

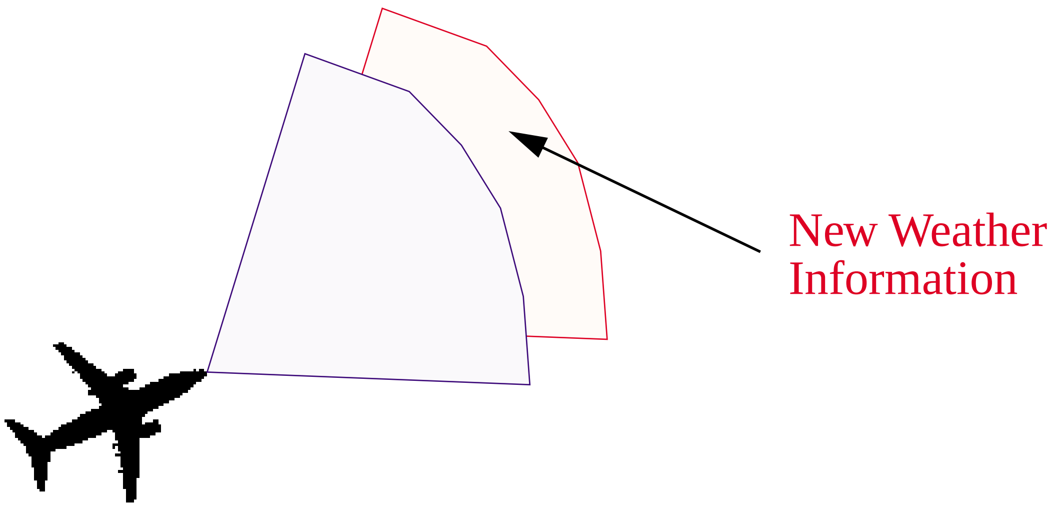
The data transmitted in broadcast mode will have to be refreshed according to the tables previously shown.

Because of the nature of weather information the savings for each data set (i.e., % of the data that needs to be transmitted at each refresh point) will vary according to the region of interest.The values below are suggested numbers in the first order analysis:

- **Tactical** - Up to 30% of the information will have to be refreshed divided into two components:
  - 5% of the data changes in the region of interest of every aircraft because the aircraft moves 15 km. forward in one minute traveling at 900 km/hr. (see figure in the next page)
  - Up to 20% of the old data could change if significant weather phenomena changes occur in the terminal area.

Data Savings Analysis (Near Strategic)

- **Near Strategic**- Up to 25% of the information will have to be refreshed divided into two components:
  - 10% of the data changes in the region of interest of every aircraft because the aircraft moves 45 km. forward in one minute traveling at 900 km/hr.
  - Up to 15% of the old data could change if significant weather phenomena changes occur in the enroute scenario.



Other Weather Information

So far the discussion has been centered around the use of airborne and ground-based weather sensors to detect two types of weather services:

- Convective weather (from doppler and airborne radar sources)
- Wind information (collected from tracers detected by doppler radar)

There are other on-board sensors that can be exploited to derive more accurate **point measurements** of weather -related services useful to pilots

- wind data at along the flight track (derived from FMS, INS or GPS sensors)
- Turbulence levels derived from aircraft accelerators, etc.

Table of Other Weather Services

The following table illustrates other weather services that can be derived from on-board sensors **other than airborne weather**

Service Type	Sources of Data	Sampling Rate	Data Size
Winds Aloft along the flight track	FMS or GPS derived wind data	Continuous variables reported (direction, magnitude, location, time) every 10 seconds for all aircraft types	512 bits[a] per aircraft per measurement
Icing	Vehicle icing sensors and on-board temperature gradient measurements	every 10 seconds (all types of aircraft) reported as	64 bits per aircraft per measurement
Turbulence	Vehicle accelerometers, mechanically measured	every 10 seconds (all types of aircraft) reported as	64 bits per aircraft per measurement
Convective	Moisture content instruments, Pressure, etc.	every 10 seconds (all types of aircraft) reported as	128 bits per aircraft per measurement

a.Assumes no compression

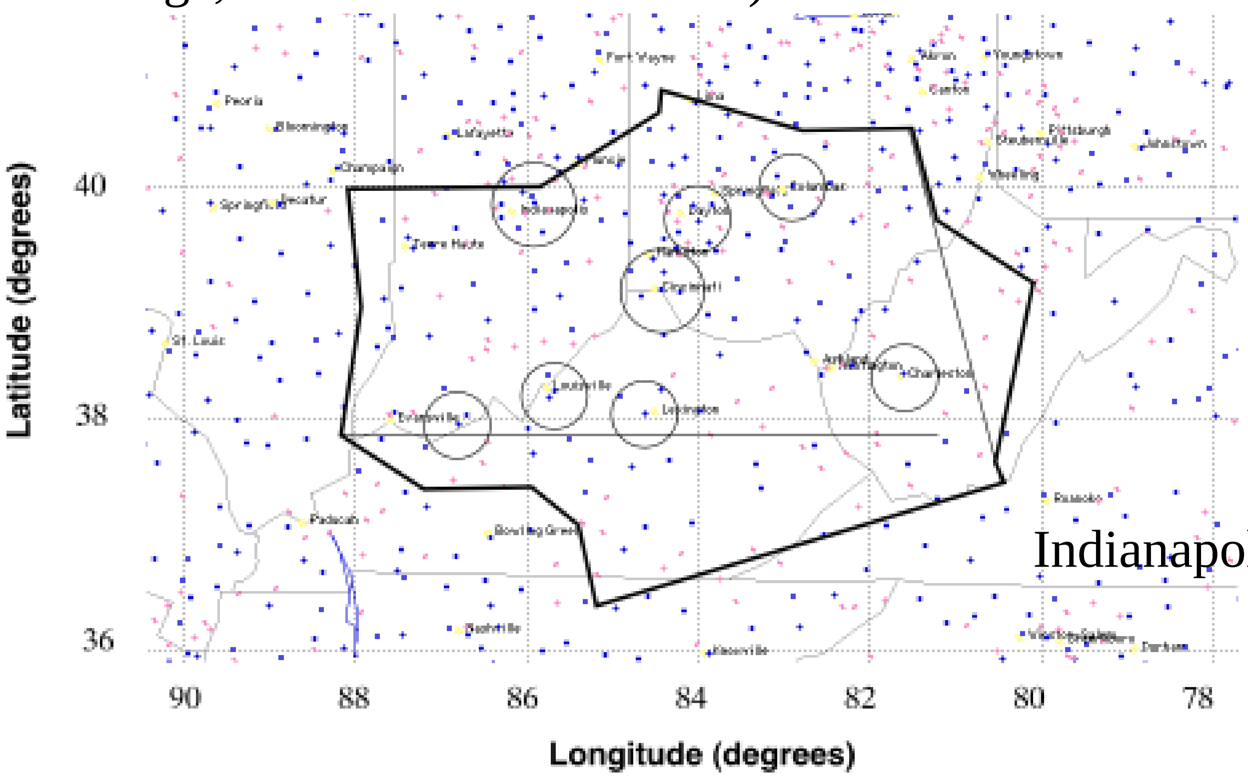
Traffic Flows in Typical Regions of NAS

The following analysis details some of the expected traffic scenarios inside the volume of airspace bounded by a typical ARTCC Center and extending to ground level.

This volume of airspace is just used to derive a number of **simultaneous airborne platforms** requesting communication services.

Traffic Inside a Typical ARTCC

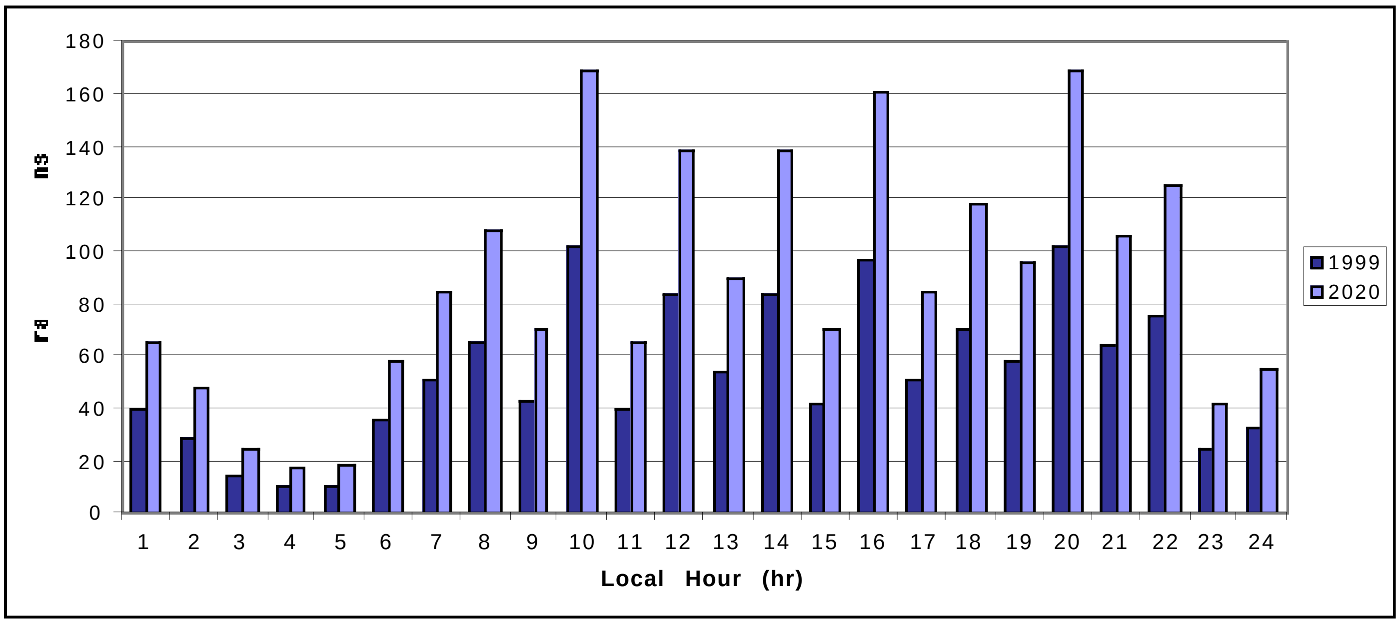
The average ARTCC region is NAS is composed by 40-50 sectors ensompassing 5-8 terminal areas and perhaps up to 120 airports (6-8 large, medium and small hubs).



Indianapolis ARTCC

Airport Area Flows (Large Hub)

The following diagram illustrates the airport area aircraft flows for a typical large hub airport



Typical Aircraft Loads Inside Region

Expected aircraft activity in the 2020 scenario.

FAA Service Area	Aircraft Type	Total Aircraft inside Region of Interest (Aircraft per hour)	Instantaneous Aircraft inside Region of Interest
Airport	General Aviation	231	35
	Corporate	32	5
	Commuter	140	28
	Transport-Type	245	61
	Total	**647**	**128**
Terminal Area	General Aviation	128	128
	Corporate	16	16
	Commuter	66	66
	Transport-Type	101	101
	Total	**311**	**311**
Enroute	General Aviation	516	438
	Corporate	71	32
	Commuter	312	156
	Transport-Type	547	219
	Total	**1446**	**845**

Future Tasks

- Develop the application with collaborative airborne weather information
- Develop a computer model to systematically study the cell coverage for any flight in NAS
- Develop some trade-off studies on possible tradeoff studies in the resolution in the far and near strategic scenarios to see the impact on bandwidth
- Develop applications with flight critical plus weather information