Friends and Partners in Aviation Weather

A Day In the life of the Aviation System Under NextGen

July 2008

Bill Leber
The Next Generation Air Transportation System (NextGen) Plan Defines A System That Can Meet Demands For The 21st Century

- Trajectory-Based Operations
- Performance-Based Operations and Services
- Precision Navigation
- Weather Integration
- Network-Centric Information Sharing
- Surveillance Services
- Equivalent Visual Operations
- Super Density Operations
- Layered, Adaptive Security
Responding to the Challenges

An Outlook for the Next Decade

• Automated, high-precision operations with deconflicted RNP/RNAV routes
• Additional routes designed to increase flexibility, efficiency, and capacity
• Responsibility for problem prediction moves from controller to automation
• Controllers resolve problems with automated resolution assistance
• Problems are predicted and resolved strategically
• Routine ATC tasks are automated
• Time-based metering used to manage traffic to constrained resources
• Airspace designed to optimize service and productivity improvements
• Automation assists with sequencing, merging, and spacing
• En route flow management directives smooth transition
• Automated, high-precision operations with deconflicted RNP/RNAV routes
• Additional routes designed to increase flexibility, efficiency, and capacity
Decision-Making Time Horizons
Strategic vs Tactical

Strategic ATCSCC
-360 -240 -120
Cefp

Tactical ATCSCC
-60 -45
ITWS

Strategic ARTCC
Tower
-ARTCC TMU
Out

Tactical ARTCC
Tower
On

Strategic ARTCC
ARTCC
TACON
On

Strategic ARTCC
ARTCC
TACON
Out

Tactical ARTCC

Impact delays
Airborne holding, flight diversions
Flight deviations
MIT management
Shutting the door on adjacent sector
Route status

+Time En-Route
NEXRAD

METAR
PIREP s
Airborne RADAR

SIGMET

Outlook.. Convective SIGMET

TAF
Airspace is the Foundation to the Future

**Near-term 2015-2020 NextGen Foundation Projects**

- Effectively **APPLY** the solutions that we have available today
- **EXPEDITE** the most promising and cost-effective solutions of the future

**FILL THE OPERATIONAL GAP**

- Move from individual RNAV/RNP routes to large scale, networked implementation
- Airspace design balancing operational, resource, security needs
- Agile and adaptive airspace structure
- Align airspace to function instead of geography
Airspace Configuration Concept

Provide flexibility where possible and structure where needed

Automated Separation Assurance Operations Airspace (Non-exclusionary/Exclusionary)

High Altitude Airspace (Generic Airspace)

Structured/Classic Low Altitude Airspace

Super Density and Metroplex Areas

Exact boundaries will depend on the equipped aircraft and traffic density
Adaptable Airspace

- En route congestion problem
- Structure and boundaries change based on traffic demand
  - Near term: airspace playbook concept
  - Far term: completely adaptable airspace

Research Issues

- When, how much, and where to change airspace?
- How much advance notice to provide to the operator?
Restructured Airspace

• New airspace categories for advanced concepts
  – Automated separation operations (ground or airborne) airspace
  – Corridors-in-the-sky
  – Dynamic sectors
  – Larger airspace sectors
Corridors-in-the-Sky

- Design of tube networks that capture large amount of traffic and reduce extra flight distance needed
- Small number of corridors and high volume of traffic corridors
Scenario 1
Preplanning
Collision Avoidance
- Ensure safe separation

Separation Management
- Manage trajectories within flows
- Negotiate trajectories
- Assign sequencing & spacing

Trajectory Management
- Apply Flow Contingency Management procedures and policy to ensure safe levels of traffic at resulting capacity levels
- Forecast demand/capacity imbalances
- Identify high complexity airspace
- Identify Constrained airspace

Flow Contingency Management
- Design airspace
- Assign staffing
- Field infrastructure

Capacity Management

If the C-ATM process does not identify an appropriate capacity management strategy

Demand/Capacity Imbalance Forecast

Through C-ATM, Assess Range of Options To Create Capacity

Select a Capacity Management Strategy

Short Term
- Apply known procedures, adjust airspace boundaries, or allocate personnel for forecast demand period

Long Term
- Develop new airspace designs, new tools, etc. to better accommodate demand

Long Term
- Initiate activities to address changes in US or international regulations and guidelines
Virtual 4D Weather Cube

Aviation weather information in 3 dimensions (latitude/longitude/height)

Observation

Hazard

0 - 15 mins

15-60 mins

1 - 24 hrs

4th dimension time
Flying LGA to ORD in Weather

Common Weather Situation
“No routes available”
Adaptive ATM

LGA – ORD route envelope

Incrementally define Route and Decision Points
Adaptive ATM

20060727-225400 UTC

Fraction of Normal Sector Capacity

Departure Solution - RAPT

LGA

ORD
Adaptive ATM

As the flight progresses, Uncertainty is reduced
Adaptive ATM

20060727-225400 UTC

Arrival Solution
Time-Based Metering
Probabilistic Future Sector Demand and Capacity Graph

Sector 02

- **15:00**
  - Demand: Red
  - Capacity: Green
- **16:00**
  - Demand: Red
  - Capacity: Green
- **17:00**
  - Demand: Red
  - Capacity: Green
- **18:00**
  - Demand: Red
  - Capacity: Green

**Impact of Weather Forecast Uncertainty**

- **Red**: Probability of congestion > 75%
- **Yellow**: Probability of congestion > 50%
- **Green**: Probability of congestion < 50%
Managing Congestion to an Acceptable Level of Risk (Probability)

Sector 02

<table>
<thead>
<tr>
<th>Time</th>
<th>Demand</th>
<th>Capacity</th>
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<td>15:00</td>
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Probability of congestion > 75%
Probability of congestion > 50%
Probability of congestion < 50%

Impact of Weather Forecast Uncertainty
Congestion Resolution Decision Tree

Initial Congestion Forecast for time T
Decision Point 1: T – 90 min
Traffic, WX situation evolves, forecasts change...
Decision Point 2: T – 60 min

Of the possible decision paths, which one reaches the congestion management goal with the least operational impact?
Time-Optimal Decision Making Simulation

Start:
Set of predicted trajectories and corresponding congestion probabilities

Decision Point 1
- 1.0
  - \( J_{11} \)  
  - \( J_{12} \)  
  - \( J_{13} \)

Decision Point 2
- 1.0
  - \( J_{21} \)  
  - \( J_{22} \)  
  - Lines represent Monte-Carlo ensembles of possible outcomes

Decision Point 3
- 0.5
  - \( J_{31} \)

Predicted Congestion
- 0.5

Path 0.6-1.0-0.5 mean cost:
\[
E(J) = J_{12} + E(J_{21} | J_{12}) + E(J_{31} | J_{21} | J_{12})
\]

\( J_{ij} \) = resolution cost distribution at decision point \( i \) of option \( j \)
Scenario 2
Enroute
En Route Congestion

Uncertain weather forecasts indicate current and future loss of airspace capacity...

Uncertain traffic forecasts provide airspace demand...

If demand exceeds capacity, delays will occur and safety may be compromised.

Given the uncertainty:
When should air traffic be restricted?
Which flights should be affected?
How do NAS operators participate?
Location of the Weather Matters
--- Flow Impact

Case A

Case B

Probability

Probability

Capacity

Capacity
Lincoln Lab Pilot Behavior Analysis and the WAF Altitude Field

VIL coverage in 60X60 region

90th pct. Echo top in 16X16 region

WAF Altitude

90th pct. 16km echo top

DeltaZ

% VIL pixels in 60km region

DeltaZ

20 40 60

-10 0 10

DeltaZ
Developing Concept for Automated Tactical ATC Weather Avoidance

30 minutes and higher lead time before a flight intersects weather problems: TFM automation uses weather forecasts to predict congestion, and produces initiatives to reduce volume around weather. ATC implements initiatives and resolves any near-term conflicts with other aircraft and weather.

20 – 25 minutes lead time: ATC automation responds to proactive requests via data link for reroutes around weather.

Up to 20 minutes lead time: ATC automation uses weather forecasts to predict aircraft to convective weather intersections and generates resolutions that avoid other aircraft and weather. Clearances are automatically distributed to data link equipped flights. Pilots have the option to request changes to the route, including requesting a route back through the weather.
Example of NASA Weather ATM Integration Research

Movie loop shows one way to adjust to enroute storms
Weather Avoidance Algorithms for En Route Aircraft

1 Flow
Weather Avoidance Algorithms for En Route Aircraft

2 Flows
Weather Avoidance Algorithms for En Route Aircraft

3 Flows
Weather Avoidance Algorithms for En Route Aircraft

4 Flows

→ Are 3 Routes through the Sector a Maximum?

Violation of Sector Boundary Constraint!

Too Close!
Algorithm: Mincut (Deterministic)

1. Airspace with Hazardous Weather Constraints
Algorithm: Mincut (Deterministic)

2. Define Critical Graph – connect closest points (B, T, a → g)
Algorithm: Mincut (Deterministic)

2. Define Critical Graph – connect closest points
Assign cost using floor $\lfloor x \rfloor$ function
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3. Search for **Shortest Path Tree** within Critical Graph
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4. Shortest B-T Path in Shortest Path Tree defines the mincut
Algorithm: Mincut (Deterministic)

5. Find **maximum number of air lanes** through the mincut
Maximum Number of Air Lanes at Bottleneck

3 Planned Air Lanes
Maximum Number of Air Lanes at Bottleneck

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- **Current Time:** 14:30Z
- **Forecast from 15:00Z - 16:00Z**

**3 Planned Air Lanes**

Max Capacity
Maximum Number of Air Lanes at Bottleneck

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Variations in the Size of the Gap (RNP Requirement)
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Mixed-RNP Demand

Want 3 Air Lanes

Want 2 Air Lanes

Want 2 Air Lanes

Sorry, PBS-rules… Advisory sent out via SWIM to restrict traffic to RNP-3 and RNP-5 only
Variations in the Size of the Gap (RNP Requirement)

Mixed-RNP Demand

- Want 3 Air Lanes
- Want 2 Air Lanes
- Want 2 Air Lanes

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Unidirectional Flows

Free Flight (Monotonic Rule)
Platooning of 1

Free Flight (Unidirectional Rule)
Platooning of 2

Free Flight (Unidirectional Rule)
Platooning of 3

Free Flight (Unidirectional Rule)
Platooning of N \(\rightarrow\) Flow-Based Route Planning

Free Flight (Unidirectional Rule)

Packed Unidirectional Flow
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Platooning of N → Flow-Based Route Planning

Free Flight (Unidirectional Rule) → Packed Unidirectional Flow
Scenario 3

New York Arrival and Departure
Super Density Operations
Now to NextGen

- Mitigation Today
  - Procedural
  - Manual process
  - Tendency to be reactive

Mid-Term – Improved Integration utilizing mature technology
- Improved techniques to decision-making
- Remains manual in coordination and implementation
- Tendency to be more Pro-active

NextGen – New Integrated Technology
- Technology assisted decision-making
- Automated processes
- Common information exchange

Reactive

Pro-active

Automated Assisted
Evaluation & Exploratory
(expanded time-horizons)

Integrated
decision – support system
Credits

- FAA/JPDO
- Metron
- MITRE
- MIT/Lincoln Labs
- NASA
Integrated Traffic and Weather for Departure Planning
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