Metrics for Evaluating the Impact of Weather on Jet Routes

J. Krozel, M. Ganji, S. Yang, J.S.B., Mitchell, and V. Polishchuk

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Agenda

• Background
• Metrics
• Analysis
• Conclusions
Early Work on Weather Deviations and Penetrations

Number of Deviations and Penetrations

Within the TRACON

Outside TRACON

Results of MIT-Lincoln Laboratory
Convective Weather Avoidance Model (CWAM)

Results of MIT-Lincoln Laboratory
CWAM Weather Avoidance Fields (WAFs)

Weather Forecast Data → extract predictors → CWAM

Observe 1000s of flights and classify as deviate or non-deviate

Deviation Probability

En Route models differ from Terminal models

Results of MIT-Lincoln Laboratory

METRON AVIATION
THE SCIENCE OF HARMONIZING AIR TRAFFIC
Mincut Metric

(a) Weather hazard defined by WAF threshold

(b) Mincut bottleneck and maximum number of lanes of traffic that may pass through the airspace

- **Minimum Cut (Mincut) and Maximum Flow (MaxFlow)** are geometrically related via Duality: MaxFlow-Mincut Theorem
- Mincut can quantify the maximum flow through an airspace given a weather hazard map
- We are interested in how it characterizes the “wiggle room,” “operational flexibility,” or “permeability” of the airspace around a jet route or an aircraft trajectory.
Route Blockage / Route Availability

Weather Forecast Data $\rightarrow$ Route Availability

Results of MIT-Lincoln Laboratory
Metric 1: Based on Route Blockage Geometry

w = width

Is this route blocked by hazardous weather?

Current Work
Voronoi Diagram Geometry

Voronoi Diagram of set of Weather Constraints
Homotopy Class

Path within Voronoi Diagram that has the same routing among constraints as the flow/route
Metric 2: Constrained Airspace Metric

Purple region defines the volume of unconstrained airspace in vicinity of routing structure

Locus of maximal disks (purple) centered along Voronoi path

Future Work
Metric 3: Constrained Airspace Metric within a Sector

Future Work
Metric 4: Considering Sector and Merge Tree (e.g., STAR)

Future Work
Weather Deviations and Penetrations – Transition Airspace

TRACON

ORD

Deviation

CWAM WAF Hazard

Filed Route

Penetration

JFK

Penetration

Deviation
Weather Deviations

- Moving window along the filed route measures route blockage
- Width = \( w \in \{10, 20, 30, 40\} \) nmi
- Length = \( L \) corresponds to 4 data points of flight track data (approx 4 min)
Data Analyzed

ETMS data:
- flight filed route geometry,
- flight actual position (time, latitude, longitude and altitude)
- 1 minute update rate

Time Periods:
1- July 13 2010  arrivals between 10:45 AM and 12:00 PM
2- July 13 2010  arrivals between 16:05 PM and 17:20 PM
3- July 22 2010  arrivals between 10:45 AM and 12:00 PM
4- July 13 2010  arrivals between 15:45 PM and 17:00 PM

Number of flights= 3535

Weather Data:
- CWIS $\rightarrow$ Deterministic WAF
- Altitudes for WAF polygons $= [5000:1000:35000]$ ft
- Only nowcasts with 10 min update rate
Clear Weather Baseline for Deviations

- Flights with no weather activity in their vicinity
- Up to 10 nm of actual route centerline and up to 10 nm of filed route centerline
- Includes direct to routing, path stretching, conflict avoidance, and other causes

Number of flights=3060
Penetrations

- Flight penetrating the weather with complete route blockage
- Blockage up to 10 nmi of actual route centerline and 10 nmi of filed route centerline

Number of flights=219
Relationship between Actual Route Permeability and Range

One **Penetration** incident if at any given point of flight data:

1- **Deviation < 4 nmi** and
2- Mincut value within 10 nmi of the flight actual route centerline is less than 10 nmi (or 8,6,4,2 nmi)

One **Deviation** incident if at any given point of flight track data:

1- **Deviation > 4 nmi** and
2- Mincut value within 10 nmi of the flight actual route is more than 10 nmi and
3- Minimum Mincut value within 10 nmi of the flight filed route centerline from that point to arrival fix is less than 10 nmi.
Mincut Permeability: Filed Route vs Flown Trajectory

40 < Range < 80 nmi

80 < Range < 120 nmi

120 < Range < 200 nmi

Range from Destination Airport
Conclusions

• Studied the permeability of the airspace on the filed route versus the trajectory flown around weather constraints for transition airspace arrival traffic into major airports.

• Four metrics were defined; one (a mincut permeability metric) was used to analyze pilot weather avoidance decision making.

• Pilots are more likely to penetrate weather or penetrate through smaller gap sizes between weather cells closer to the metering fixes than further away.

• Deviations away from the filed route are larger the further the aircraft is from the metering fix.

• Future work - explore alternative metrics, determine the metric size triggering “route blockage,” and if a local adjustment of the route can provide acceptable