Flight Execution and Route Adaptation Considering Multiple Weather Hazards

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6 to 10 November 2017, Météo-France, Toulouse
Motivation

- Weather affects safety and efficiency of aviation
  - Significant share of total delays
  - Increases costs and workload
  - Its integration is key to efficient ATM and TBO

Route planning under consideration of:

- Wind/Temperature: strategically
- Convection: strategically / tactically / reactionary
- Turbulence: reactionary
- Icing: reactionary

<table>
<thead>
<tr>
<th></th>
<th>4-7 %</th>
<th>30-50 %</th>
<th>30-40 %</th>
<th>18.3 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme wx</td>
<td></td>
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<td>Bureau of Transportation (2003-2016)</td>
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<td>FAA (2008-2011)</td>
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<tr>
<td>All</td>
<td>69 %</td>
<td>30-40 %</td>
<td>18.3 %</td>
<td>ATFM</td>
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<td>Eurocontrol (2016)</td>
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</table>

Evaluation of routing effects like hazard encounters and detours
Current Operations: Convection Avoidance

- Convection detectable with on board radar
- Limited awareness
- Geometrical consideration of convective hazard area
- Turbulence mostly not visually recognizable

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Convection avoided, severe turbulence is not!

What effects occur when considering multiple hazards?
Adverse weather avoidance tool DIVMET

DIVMET (divert meteorology)

- **2D consideration of multiple** hazards on flight level (FL) + time (timely synchronization of hazards)

- Lateral avoidance based on geometrics

- Vertical flight profile (climb + FL + descent)

- Airspeed profile + winds (varying ground speed)
Met data sources

CIP/FIP
Icing sev cat 5 → severe
60 min resolution

CoSPA
severe: echo tops > 30 kft
moderate: echo tops > 25 kft
15 min resolution

GTGN/GTG
severe: edr >= 0.35 m\(^{2/3}\) s\(^{-1}\)
moderate: edr >= 0.22 m\(^{2/3}\) s\(^{-1}\)
15 min resolution

Wind data:
NOAA’s Rapid Refresh (RAP)
• 13 km grid
• Interpolated to 60 flight levels (by GTG)

Ground speed*
\[ v_g = \sqrt{v_a^2 - w_x^2} + w_t \]

with
- \(v_a\): Airspeed
- \(w_x\): Crosswind
- \(w_t\): Tailwind

* J. Cheung et al. 2014

Sharman, et al., 2014: Journal of Applied Meteorology and Climatology
Weather situations & Routes

18 Nov 2015

- 7 city pairs with great-circle connections (both directions)
- Departures at the top of every hour between 0000 UTC and 2000 UTC (1800 UTC at MIA and SFO)
- 290 planned trajectories

14 July 2016

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Weather avoidance scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Considered hazard(s)</th>
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<tr>
<td>Ignorance</td>
<td>none</td>
</tr>
<tr>
<td>sC</td>
<td>sev Conv</td>
</tr>
<tr>
<td>msC</td>
<td>mod/sev Conv</td>
</tr>
<tr>
<td>sCsT</td>
<td>sev Conv + sev Turb</td>
</tr>
<tr>
<td>sCmsT</td>
<td>sev Conv + mod/sev Turb</td>
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- 290 planned connections
- 2 cruise levels (FL300, FL400)
- 7 scenarios

Σ: 4060 flight simulations per weather case
Hazard exposure of planned flights

Affected planned flights

- 20151118: 86% exposure
- 20160714: 69% exposure

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Encounter duration distributions (planned flights)
Avoidance mode:

**Deviated and cancelled flights**

Deviation:  
detour > 0

Departure delay:  
15 minute increments, if mod/sev Conv in 10/20 nmi

Cancellation:  
departure delay ≥ 60 minutes

![Graph showing deviated, delayed, and cancelled flights](image)
Relative Detours

Detour = actual flight distance – great circle distance
Relative Detour = detour / great circle distance

Distributions of relative detours - Weather 20151118

Distributions of relative detours - Weather 20160714
Conclusions

• Integration of weather information in routing tools is important
• Exclusive avoidance of (severe) convection is not sufficient → multi-hazard consideration
• Shared situational awareness → data is available

Future Work

• Optimal routing strategies differ for hazard kinds
  o Convection: lateral avoidance
  o Turbulence/Icing: vertical maneuvers
• Integration of nowcast/forecast (plus uncertainty) information is essential
Thank you

Further questions?
Please contact me!
Manuela Sauer
manuelas@ucar.edu

Thank you
Winds along the routes

Wind data:

NOAA’s Rapid Refresh (RAP)
- 13 km grid
- Interpolated to 60 flight levels (by GTG)

Ground speed:

\[ v_g = \sqrt{v_a^2 - w_x^2} + w_t \]

with
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* J. Cheung et al. 2014

For departures at 1200 UTC
Hazard Encounter Reduction

Affected flights - severe hazards

Scenario

Number of flights

0 50 100 150 200 250 300

Ignorance sC msC sCsT sCmsT msCsT msCmsT

Legend:
- 20151118 - FL 300
- 20151118 - FL 400
- 20160714 - FL 300
- 20160714 - FL 400

Absolute Detours

Detour = actual flight distance – great circle distance

Detour Distributions - Weather 20151118

Detour Distributions - Weather 20160714
Encounter duration distributions (scenario sC)
Encounter duration distributions (scenario msC)
Encounter duration distributions (scenario sCsT)

![Graphs showing encounter duration distributions for Weather 20151118 and Weather 20160714 scenarios. The graphs display various percentiles and median values for different hazard types (sev Conv, mod Conv, sev Turb, mod Turb).]
Encounter duration distributions (scenario msCmsT)

Encounter distributions - Weather 20151118 - Scenario msCmsT

Encounter distributions - Weather 20160714 - Scenario msCmsT
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