6th USA/Europe ATM 2005 R&D Seminar

Assessment of the 3D-separation of Air Traffic Flows

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**Introduction:**
general concept, contexts, underlying problems

**Algorithms and models:**
algorithms, basic model, a more realistic model, detection of trajectory interferences

**Results:**
figures of separated 3D-airways over France and Europe

**Validation:**
objectives, effectiveness of 3D-separation, validation results, nature of remaining conflicts, potential benefits, concept assessment

**Conclusion**
The general concept of 3D-separation

- Network of 3D-airways (tubes), for the main traffic flows
- Geometric separation of the 3D-airways.

Traffic on the 3D-network:
- should be scheduled by DMAN and AMAN, on each 3D-airway.
- would have priority over the rest of the traffic.
- would be removed from the slot allocation process.

- Extension of the « TMA-to-TMA Handover » concept.
- Expected benefits:
  - cumulated delays (see TOSCA WP3): divided by 3 with 18% of the traffic on the new network, or by 7 with 32% traffic?
  - decrease in the number of conflicts?
3D-separation in 2 different contexts

*France*
- 75% international traffic over France
  - variety of entry and exit levels
- Entry and exit points issued from standard routes
  - high concentration of traffic on a few origin-destination links
    (70 links: 40% of the traffic)

*Europe*
- 95% intra-european flights
- airport-to-airport links
- needs many links to handle a significant amount of traffic
- (74 links: less than 7% of the traffic)
- star-shaped network
Underlying problems

Classification
- Define 3D-flows, considering entry, cruise, and exit levels.

Optimization
- Find optimal separated 3D-trajectories for these 3D-flows,
  - satisfying separation constraints,
  - as close as possible from the « default trajectories ».

Scheduling
- Departure sequence --> no conflict within the same flow,
- Arrival sequence --> no conflict over TMA entry points.

This problem is not addressed here
Algorithms

Classification

- one trajectory per *origin-destination* link,
- additionnal trajectories, for flights climbing from, or descending to airports near the border,
- several trajectories per *origin-destination* link -> k-means partitionning method, applied to entry, cruise, and exit levels.

Optimization

- 1 vs n: build each trajectory in turn --> tree search method (A* algorithm),
- global optimization --> stochastic method (evolutionary algorithm).
Basic model

- All airports at altitude 0
- One trajectory per *origin-destination* link
- Same aircraft performances: linear climb/descent slopes,
- Default trajectory= direct route + cruise at the RFL
- Lateral and/or vertical deviations:
A more realistic model

- Standard routes or direct routes
- Several 3D-flows models (UNIC, PROX, MULTI) with one or several 3D-airways per O-D link
- Real aircraft performances
- Uncertainty zones
Detection of trajectory interferences

★ Three detection modes
  ▶ Distance between 3D-line segments
  ▶ Intersection of tubes defined around 3D-line segments
  ▶ Intersection of tubes defined around uncertainty zones

★ No-detection areas in the vicinity of airports (15 NM)

★ Inhibition of the detection
  ▶ for two *initial climbs* from a same airport,
  ▶ for two *final descents* towards a same airport.
France, direct routes, 71 traj.
(1 per O-D, Nb flights per link > 20)
France, standard routes, 72 traj. (1 per O-D)
France, standard routes, side view of the 72 traj.
France, 95 traj., airports near border, side view
France, 139 traj., several traj. per O-D, side view
Europe, 65 trajectories
Europe, 65 trajectories
Validation

★ Objectives:
- make sure that the 3D-separation is effective,
- assess the potential benefits of the 3D-separation concept.

★ Fast-time traffic simulations, using CATS/OPAS on one day of traffic, over France

★ Assess the number and nature of conflicts.

★ Reference traffic vs. Traffic with 3D-network
Effectiveness of traffic separation
Effectiveness of traffic separation
Validation results
(A*, France, direct routes, 71 traj., 1 per O-D)

<table>
<thead>
<tr>
<th>Detection mode</th>
<th>DIST-A320</th>
<th>ITUBES-A320</th>
<th>IZONES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb. fail</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Cost</td>
<td>296.64</td>
<td>260.03</td>
<td>(205.22)</td>
</tr>
<tr>
<td>Nb FL. &gt; FL145</td>
<td>19</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>Nb FL &lt; FL145</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Route elong.</td>
<td>0.67 %</td>
<td>0.60 %</td>
<td>0.14 %</td>
</tr>
<tr>
<td>% traffic</td>
<td>39.60 %</td>
<td>39.60</td>
<td>39.30 %</td>
</tr>
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</table>

Above FL145

<table>
<thead>
<tr>
<th></th>
<th>DIST-A320</th>
<th>ITUBES-A320</th>
<th>IZONES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb conflicts REF</td>
<td>1750</td>
<td>1750</td>
<td>2042</td>
</tr>
<tr>
<td>Nb conflicts OPT</td>
<td>1870</td>
<td>1745</td>
<td>1878</td>
</tr>
<tr>
<td>Same flow</td>
<td>329</td>
<td>308</td>
<td>358</td>
</tr>
<tr>
<td>Profit</td>
<td>11.94 %</td>
<td>17.89 %</td>
<td>25.56 %</td>
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</table>

Above FL195

<table>
<thead>
<tr>
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<th>DIST-A320</th>
<th>ITUBES-A320</th>
<th>IZONES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb conflicts REF</td>
<td>1389</td>
<td>1389</td>
<td>1582</td>
</tr>
<tr>
<td>Nb conflicts OPT</td>
<td>1446</td>
<td>1371</td>
<td>1476</td>
</tr>
<tr>
<td>Same flow</td>
<td>321</td>
<td>300</td>
<td>342</td>
</tr>
<tr>
<td>Profit</td>
<td>19.0 %</td>
<td>22.89 %</td>
<td>28.32 %</td>
</tr>
</tbody>
</table>
Nature of the remaining conflicts

<table>
<thead>
<tr>
<th>FL&gt;195</th>
<th>Total</th>
<th>Same flow</th>
<th>≠ flows</th>
<th>Mixed</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb Conflicts</td>
<td>1446</td>
<td>321</td>
<td>18</td>
<td>543</td>
<td>564</td>
</tr>
<tr>
<td>% conflicts</td>
<td>100 %</td>
<td>22.2 %</td>
<td>1.2 %</td>
<td>37.6 %</td>
<td>39.0 %</td>
</tr>
</tbody>
</table>

Detection mode: DIST-A320
## Validation results
(A*, France, standard routes, 72 traj., 1 per O-D)

<table>
<thead>
<tr>
<th>Detection mode</th>
<th>DIST-A320</th>
<th>ITUBES-A320</th>
<th>IZONES</th>
</tr>
</thead>
<tbody>
<tr>
<td>% traffic</td>
<td>39.04 %</td>
<td>39.04 %</td>
<td>40.02 %</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Above FL195</th>
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</thead>
<tbody>
<tr>
<td>Nb conflicts REF</td>
<td>1389</td>
<td>1389</td>
<td>1582</td>
</tr>
<tr>
<td>Nb conflicts OPT</td>
<td>1345</td>
<td>1372</td>
<td>1496</td>
</tr>
<tr>
<td>Same flow</td>
<td>303</td>
<td>298</td>
<td>357</td>
</tr>
<tr>
<td>Profit</td>
<td>25.0 %</td>
<td>22.7 %</td>
<td>28.0 %</td>
</tr>
</tbody>
</table>
Potential benefits (number of conflicts)

- Simulations show a decrease in the number of conflicts, provided the DMAN/AMAN schedule flights in a same flow.

- 3D-separation mainly benefits to upper airspace.

- The profit rate is not much related to:
  - the chosen method (global strategy, or 1 vs. n),
  - the detection mode,
  - the 3D-flows model.

- It is highly related to the amount of traffic handled on the 3D-airways:

<table>
<thead>
<tr>
<th>% traffic</th>
<th>Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 %</td>
<td>10 to 15 %</td>
</tr>
<tr>
<td>40 %</td>
<td>20 to 30 %</td>
</tr>
<tr>
<td>50 %</td>
<td>35 to 40 %</td>
</tr>
</tbody>
</table>
Concept assessment (over France only)

- Realistic 3D-flows model ==> needs more trajectories
  - UNIC (one airway per O-D): 40 % of the traffic on 70 airways
  - MULTI (several 3D-airways per O-D):
    30 % of the traffic on 139 airways

- What may be expected, with the most realistic model ?
  - 30 % of the traffic on a 3D-network of 139 airways.
  - 10 % to 15 % less conflicts, provided the scheduling on airways is made by DMAN/AMAN, or by coordination.
  - TOSCA WP3 : drastic decrease of the ground delays (divided by 7 ?)
    - if the new network has no incidence on the overall capacity,
    - and if the TOSCA results are still valid in the context of a 3D-network.
Application to Europe?

- Potential benefits of 3D-separation not assessed.
- We may expect similar results if a same amount of traffic can be handled on 3D-airways!!

- Airport-to-airport links = low concentration of traffic.
- We should consider TMA-to-TMA links, to expect significant benefits.
Conclusion

\* Algorithms:
  \* successfully applied to french and european traffic,
  \* current domain of application: 70 to 160 trajectories,
  \* Europe (star-shaped network): algorithms could be parallelized.

\* Concept assessment (french airspace only):
  \* significant potential benefits, with higher profit in upper airspace
  \* pending issues: DMAN/AMAN scheduling, real impact on capacity?

\* Check if the congestion/capacity problems are not transferred to
  \* the DMAN/AMAN scheduling,
  \* or to the airports!