Using PBN for Terminal and Extended Terminal Operations

Navigation Performance Data Analysis and its Effect on Route Spacing

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- Validation of methodology
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- Navigation Performance distribution
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BACKGROUND AND OBJECTIVE
Background

- Variety of navigation specification and procedures

Example: 95% deviation < 0.85NM
(P-RNAV route spacing study, 2003)
Navigation Data Collection

- Data sources:
  - LVNL – Amsterdam Schiphol Airport (EHAM)
  - NATS – London Heathrow Airport (EGLL)
  - DSNA – Paris Charles de Gaulle Airport (LFPG)

<table>
<thead>
<tr>
<th></th>
<th>LVNL</th>
<th>NATS</th>
<th>DSNA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Duration</strong></td>
<td>April-Sept 2014</td>
<td>Jan-March 2014</td>
<td>Jan-Dec 2014</td>
</tr>
<tr>
<td><strong>No. of SIDs</strong></td>
<td>22</td>
<td>4</td>
<td>35</td>
</tr>
<tr>
<td><strong>No. of STARs</strong></td>
<td>9</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td><strong>No. of Approach Transitions</strong></td>
<td>7</td>
<td>0</td>
<td>7</td>
</tr>
</tbody>
</table>
Data filtering – Step 1
Determination of route segments for reference procedure
Data filtering – Step 2
Automatic filtering of the tracks for defined segments
Data filtering – Step 3
Visual inspection of each individual track
Data filtering – Step 3
Visual inspection of each individual track
VALIDATION OF METHODOLOGY
Validation of method: 1 – cumulative distribution for each method
COMPUTATION OF CROSS TRACK DEVIATION
Computation of cross-track deviation

Transition area definition

- Reference procedure
- Start and end points of Fly-by turns (DO-236C)
- Fly-by transition boundary (DO-236C)
- Recorded Track (after filtering)
- Circle fit in turns (to determine radius)
DATABASE SIZE AND FLEET COMPARISON
# Database size

<table>
<thead>
<tr>
<th></th>
<th>Number of tracks</th>
<th>Number of tracks after filtering</th>
<th>% Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LVNL</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SID</td>
<td>64 130</td>
<td>9 213</td>
<td>14.37 %</td>
</tr>
<tr>
<td>STAR</td>
<td>62 694</td>
<td>3 876</td>
<td>6.18 %</td>
</tr>
<tr>
<td>Transition</td>
<td>4 438</td>
<td>2 248</td>
<td>50.65 %</td>
</tr>
<tr>
<td><strong>DSNA</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SID</td>
<td>209 422</td>
<td>14 716</td>
<td>7.03 %</td>
</tr>
<tr>
<td>STAR</td>
<td>73 771</td>
<td>2 978</td>
<td>4.04 %</td>
</tr>
<tr>
<td>Transition</td>
<td>151 636</td>
<td>47 726</td>
<td>31.47 %</td>
</tr>
<tr>
<td><strong>NATS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SID</td>
<td>12 605</td>
<td>7 237</td>
<td>57 %</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>578 696</td>
<td>88 099</td>
<td>15 %</td>
</tr>
</tbody>
</table>
Influence of Navigation Sensors

- Mixture of navigation sensors (EHAM)
  - With GNSS (89% tracks)
  - Without GNSS (11% tracks)

Aircraft with GNSS
- 95% < 0.09NM straight
- 95% < 0.18NM turn

Aircraft without GNSS
- 95% < 0.15NM straight
- 95% < 0.27NM turn
NAVIGATION PERFORMANCE DISTRIBUTION
Navigation Performance Distribution

- Cross track deviation influenced by:
  - Groundspeed
  - Track angle change

- Data of cross-track deviation was organized into the following subsets of the combined LVNL-NATS-DSNA dataset:
  1) straight segments, high groundspeed (>350kts)
  2) straight segments, low groundspeed (<=350kts)
  3) turns with 30-60° track change, high groundspeed (>350kts)
  4) turns with 30-60° track change, low groundspeed (<=350kts)
  5) turns with 90° track change, low groundspeed (<=300kts)
## Navigation Performance Distribution Parameters

<table>
<thead>
<tr>
<th>No. of data points</th>
<th>Cross-track deviations (NM)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>95%</td>
</tr>
<tr>
<td><strong>Straight Segments Low Groundspeed (&lt;=350kts)</strong></td>
<td>1297549</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Straight Segments High Groundspeed (&gt;350kts)</strong></td>
<td>825264</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Mid Turn 30-60° Low Groundspeed (&lt;=350kts)</strong></td>
<td>267099</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Mid Turn 30-60° High Groundspeed (&gt;350kts)</strong></td>
<td>48672</td>
<td>0.04</td>
</tr>
<tr>
<td><strong>Mid Turn 90° Low Groundspeed (&lt;300kts)</strong></td>
<td>32579</td>
<td>-0.03</td>
</tr>
</tbody>
</table>
Navigation Performance Distribution
Mid turn 30° - 60° track change at low ground speed
Navigation Performance Distribution
Mid turn 90° track change at low ground speed
Collision Risk Modelling

- The computed navigation performance distributions were used in a Collision Risk Model (CRM) for the computation of route spacing and associated risks for a set of route configurations.

- Reference documentation
ROUTE CONFIGURATION AND SPACING EXAMPLES
# Route configurations and spacing examples

<table>
<thead>
<tr>
<th>Route Configuration</th>
<th>Description</th>
<th>Sample route spacings and risks based on the Collision Risk Model</th>
</tr>
</thead>
</table>
| 1. Parallel tracks. Same direction Both aircraft in level flight. | ![Diagram](image1.png) | Combined LVNL, NATS, and DSNA straight-segment data  
Applicable TLS: 4 x 10^{-9} fatal accidents per flight hour (f.a.f.h.) |
| Groundspeed 450kts |  
Spacing used in CRM: 3 NM  
(see Key Points 1, 2 and 3) |  
\( N_{ay\text{-best}} = 3.69 \times 10^{-11} \) (f.a.f.h.) |
| Groundspeed 220kts |  
Spacing used in CRM: 3 NM  
(see Key Points 1, 2 and 3) |  
\( N_{ay\text{-best}} = 1.07 \times 10^{-11} \) (f.a.f.h.) |
| 2. Converging Tracks. Joining a parallel path with a 90° fly-by turn. Both aircraft in level flight. | ![Diagram](image2.png) | Combined LVNL, NATS, and DSNA straight segment and 90 degree turn angle data  
Applicable TLS: 4 x 10^{-9} fatal accidents per flight hour (f.a.f.h.) |
| Groundspeed 220kts |  
Spacing used in CRM: 5 NM  
(see Key Points 1, 2 and 3) |  
\( N_{ay\text{-best}} = 3.78 \times 10^{-10} \) (f.a.f.h.) |
| 3. Converging tracks. Joining a parallel path with a 45° fly-by turn. Both aircraft in level flight. | ![Diagram](image3.png) | Combined LVNL, NATS, and DSNA straight segment and 30 – 60 degree turn data  
Applicable TLS: 4 x 10^{-9} fatal accidents per flight hour (f.a.f.h.) |
| Groundspeed 450kts |  
Spacing used in CRM: 4 NM  
(see Key Points 1, 2 and 3) |  
\( N_{ay\text{-best}} = 2.34 \times 10^{-10} \) (f.a.f.h.) |
| Groundspeed 220kts |  
Spacing used in CRM: 4 NM  
(see Key Points 1, 2 and 3) |  
\( N_{ay\text{-best}} = 6.68 \times 10^{-11} \) (f.a.f.h.) |
Route configurations and spacing examples - Key points

- A limitation of using radar surveillance as a mitigation of risk is that the spacing between two routes cannot be the same or less than the radar separation minima. → Minimum of 4-5 NM route spacing in an environment using 3 NM radar separation.

- No published spacing results can be considered for direct application without performing local pre-implementation analysis.

- The resolution of the radar display (a function of ATC sector size) is a determining human factor which forms part of the post-CRM implementation safety analysis to determine the acceptable (final) route spacing.
CONCLUSIONS
Conclusions

- 95% lateral navigation Total System Error for straight line segments is in the order of magnitude of **0.11 NM** (for high groundspeed >350kts) and **0.06 NM** (for low groundspeeds <350kts) from the route centerline.

- 95% lateral navigation Total System Error for low groundspeed (<350kts) and with a track change of 90° is in the order of magnitude of **0.28 NM**.

- Using a CRM with assumed risk of $10^{-10}$ fatal accidents per flight hour, yielded the following acceptable route spacing values:
  - Parallel routes: route spacing of 3 NM
  - Converging tracks using fly-by: route spacing of 4-5 NM

Note: dependent on track change angle and groundspeed.
Cross track deviation – LVNL data set
Cross track deviation – LVNL data set