Paper #141: “Lateral Intent Error’s Impact on Aircraft Prediction”

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Presentation Overview

• Background - Motivation
  – Trajectory Based Operations
  – Trajectory Prediction Process Lateral Intent

• Flight Examples

• Lateral Deviation Metrics

• Measurements on ATC Operational Data

• Impact on Conflict Predictions

• Measurements on Airborne Operational Data

• Conclusions
Background and Motivation

• Trajectory Based Operations central to NextGen, SESAR, and Australian ATM Strategic Plan

• Trajectory Based Operations
  – “Requires precise management of aircraft’s current & future position”
  – Thus, trajectory prediction needs to be more accurate than today
  – Lateral intent is a key component of this TP process

*Flight Plan:* AAA123 B752 0450 310 XXX..ABC..DEF.BUC7.XYZ
Flight Example 1

- Commercial carrier flying a B737-300
- From Cleveland Ohio - To Denver Colorado
- Climbs to FL340 after a series of cleared steps
- Enters Denver en route center at FL 340
- Starts smooth descent into Denver airport after crossing radial distance 2 nm from AMWAY fix – follows SAYGE6 arrival
Flight Example 1 Continued
Flight Example 1 Continued

- Focused on arrival phase into Denver ARTCC

- ATC issues horizontal path stretch – not entered into ground automation

- Trajectory prediction exhibits large cross and along route errors
Flight Example 1 Continued

First Track Point, 83360s

Spatially Coincident Trajectory Point, 83625s

Time Coincident Trajectory Point, 83360s

<table>
<thead>
<tr>
<th>HORZ_ERR</th>
<th>LAT_ERR</th>
<th>LONG_ERR</th>
<th>VERT_ERR</th>
<th>CROSS_TRK_ERR</th>
<th>ALONG_TRK_ERR</th>
<th>TIME_ERR</th>
</tr>
</thead>
</table>

July 1, 2009
Flight Example 2

• Commercial carrier flight recorded in Washington ARTCC (ZDC)
• Origin: Dallas Fort Worth, Texas
• Destination: John F. Kennedy International Airport, New York
• Hand-off into ZDC at 20:14 UTC and outbound to New York ARTCC at 20:56 UTC during brief cruise at FL 240
Flight Example 2 Cont’d

- TP generated 34 trajectories
- Sampled 18 of the trajectories to produce 109 measurements
- Focus on trajectory build 74005 seconds (20:33:25 UTC) with 5 measurements below

<table>
<thead>
<tr>
<th>Sample Time</th>
<th>Measurement Time</th>
<th>Look Ahead Time</th>
<th>Horizontal Error</th>
<th>Cross-track Error</th>
<th>Along-track Error</th>
<th>Vertical Error</th>
<th>Clear Flag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seconds</td>
<td>Seconds</td>
<td>HH:MM:SS</td>
<td>Seconds</td>
<td>Nautical Miles</td>
<td>Nautical Miles</td>
<td>Nautical Miles</td>
<td>Feet</td>
</tr>
<tr>
<td>74040</td>
<td>74040</td>
<td>20:34:00</td>
<td>0</td>
<td>0.4</td>
<td>0.3</td>
<td>-0.3</td>
<td>0</td>
</tr>
<tr>
<td>74040</td>
<td>74340</td>
<td>20:39:00</td>
<td>300</td>
<td>0.1</td>
<td>-0.1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>74040</td>
<td>74640</td>
<td>20:44:00</td>
<td>600</td>
<td>1.2</td>
<td>-0.5</td>
<td>-1.0</td>
<td>0</td>
</tr>
<tr>
<td>74040</td>
<td>74940</td>
<td>20:49:00</td>
<td>900</td>
<td>2.1</td>
<td>-0.1</td>
<td>2.1</td>
<td>0</td>
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<tr>
<td>74040</td>
<td>75240</td>
<td>20:54:00</td>
<td>1200</td>
<td>34.6</td>
<td>11.9</td>
<td>-32.5</td>
<td>0</td>
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</tbody>
</table>
### Lateral Deviation Metrics

The image illustrates the calculation of lateral deviation metrics in aviation. The diagram shows a plane deviating from a cleared route, with symbols representing different distances and angles. The flowchart outlines the decision process for determining if a plane is in an inner, middle, or outer non-confirmation state based on the calculated distance and angle.

<table>
<thead>
<tr>
<th>Threshold</th>
<th>Value (units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_1$</td>
<td>0.5 (nm)</td>
</tr>
<tr>
<td>$D_2$</td>
<td>1.5 (nm)</td>
</tr>
<tr>
<td>$D_3$</td>
<td>1.0 (nm)</td>
</tr>
<tr>
<td>$P_1$</td>
<td>30 (deg)</td>
</tr>
</tbody>
</table>
Measurements from ATC Operational Data: United States En Route Facilities

- One day – seven hours of traffic
- All 20 ARTCCs
- 50,000 flights
- Over 8M measurements
Measurements from ATC Operational Data: Cluster Analysis Results
Measurements from ATC Operational Data:
Geography of Clusters
Measurements from ATC Operational Data: Precipitation Weather Map of Same Date
Measurements from ATC Operational Data: Distributions of Three ARTCCs
Measurements from ATC Operational Data: Three ARTCC’s Lateral Adherence States

Lateral Adherence Status within ARTCC

- innerInConf: 49%
- midInConf: 16%
- midNonConf: 9%
- outerNonConf: 25%
- innerInConf: 47%
- midInConf: 13%
- midNonConf: 8%
- outerNonConf: 32%
- innerInConf: 30%
- midInConf: 12%
- midNonConf: 9%
- outerNonConf: 49%

ZID: 49%, ZMP: 32%, ZMA: 49%
Measurements from ATC Operational Data: Lateral Deviation Statistics from Europe

• EUROCONTROL’s Flight Data Management Metrics Project published report July 2007

• Analyzed data set from November 2006
  – Approximately 27,000 flights from EUROCONTROL’s Central Flow Management Unit
  – Supplied by 31 European Air Traffic Service Providers (ANSPs)
  – Utilized a software tool called EUROCONTROL Flight Information Consistency Analysis Tool (EFICAT)

• Results for two dimensional route analysis
  – Grouped into major deviations > 50 nm off route and minor deviations between 20 and 50 nm
  – Of 27,300 sample measurements…
    • 19% - minor deviations with average lateral deviation of 30 nm
    • 3% - major deviations with average lateral deviation of 73 nm
### Impact on Conflict Predictions

<table>
<thead>
<tr>
<th>Alert State</th>
<th>Conflict Event Counts For Each Lateral Adherence State</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In</td>
<td>Out</td>
</tr>
<tr>
<td>Alert</td>
<td>106</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>111</td>
<td>97</td>
</tr>
<tr>
<td>No Alert</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>27</td>
</tr>
<tr>
<td>Totals</td>
<td>118</td>
<td>114</td>
</tr>
</tbody>
</table>

\[ \chi^2 = 5.04, df = 1; p-value = 0.025 \]

### Encounter Event Counts For Each Lateral Adherence State

<table>
<thead>
<tr>
<th>Alert State</th>
<th>Encounter Event Counts For Each Lateral Adherence State</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In</td>
<td>Out</td>
</tr>
<tr>
<td>Alert</td>
<td>232</td>
<td>212</td>
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<tr>
<td></td>
<td>137</td>
<td>307</td>
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<tr>
<td>No Alert</td>
<td>7413</td>
<td>6749</td>
</tr>
<tr>
<td></td>
<td>7508</td>
<td>6654</td>
</tr>
<tr>
<td>Totals</td>
<td>7645</td>
<td>6961</td>
</tr>
</tbody>
</table>

\[ \chi^2 = 84.742, df = 1; p-value = 0.000 \]

Both conflict and non-conflict predictions effected by lateral adherence state.

Beyond paper applied method to operational conflict probe.
Impact on Conflict Predictions: Sensitivity Analysis - Terms

• **Probability of Alert** – ratio of:
  - Number of conflict predictions (a.k.a. alerts) for min-max-ratio range to
  - Number of non-conflict events for same min-max-ratio range

• **Min-max-ratio**
  - Unit-less distance combines both dimensions of separation and
directly corresponds to standard separations.
  - Calculated on each position for each aircraft pair combo, such that:

\[ \lambda_i = \frac{\min_i \left[ \max(\lambda_i, \pi_i) \right]}{\delta_i} \]

\[ \pi_i = \frac{|z_i^a - z_i^b|}{\nu_i} \]

\[ \rho = \min_i \left[ \frac{\max(\lambda_i, \pi_i)}{k} \right] \]

where

- \( \delta_i \) = horizontal separation standard for the \( i \)th synchronized track data point;
- \( x_i^a \) = x position of the \( i \)th track point of aircraft a in nautical miles;
- \( x_i^b \) = x position of the \( i \)th track point of aircraft b in nautical miles;
- and \( y_i^a, y_i^b \) are the corresponding y positions
- \( \nu_i \) = vertical separation standard for the \( i \)th synchronized track data point;
- \( z_i^a \) = altitude position of the \( i \)th track point of aircraft a in feet;
- \( z_i^b \) = altitude position of the \( i \)th track point of aircraft b in feet.

\( i = \) current \( i \)th track point;
\( k = \) total number of track points
Impact on Conflict Predictions: Sensitivity Analysis

Sensitivity Analysis

Impact on Conflict Predictions:

Probability of Alert (#Alerts/#Encounters)

Min-Max-Ratio Separation Factor

- All
- InConf
- OutConf
- FitCurve(OutConf)
- FitCurve(All)
- FitCurve(InConf)
Measurements from Airborne Operational Data

• From Airservices Australia
  – ADS-C data
  – 778 flights
    • 58 flights of type Airbus A330-300
    • 168 flights of type Airbus A340-500
    • 258 flights of type Boeing 747-400
    • 294 flights of type Boeing 777-300
  – Avg. 34.4 reports/flight
## Measurements from Airborne Operational Data: Summary from Both U.S. & Australia

<table>
<thead>
<tr>
<th>Airspace Source</th>
<th>Sample Size</th>
<th>Percentiles (nm)</th>
<th>Mean (nm)</th>
<th>Std Dev (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>25&lt;sup&gt;th&lt;/sup&gt;</td>
<td>50&lt;sup&gt;th&lt;/sup&gt;</td>
<td>75&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>United States Airspace: ADS-C Data&lt;sup&gt;a&lt;/sup&gt;</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>U.S.</td>
<td>39012</td>
<td>-0.018</td>
<td>-0.002</td>
<td>0.007</td>
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<tr>
<td><strong>Australian Airspace: ADS-C Data</strong></td>
<td></td>
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<td></td>
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<tr>
<td>A.A.</td>
<td>26731</td>
<td>-0.019</td>
<td>-0.002</td>
<td>0.015</td>
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</tbody>
</table>
Conclusions

• TBO concepts will require accurate TP
• Missing *lateral intent* is significant TP error source
• Metrics defined to capture lateral intent state
• Large samples of ground automation measurements analyzed in both U.S. and Europe
  – U.S. reported lateral errors with an overall standard deviation of about 21 nm and IQR of 1.35 nm
  – Europe reported 19% of their flight sample had lateral errors of 30 nm on average
• Impact on conflict predictions significant
• Airborne ADS-C data measures from Australia and U.S. much more precise – 100 to 1000 times!
• Global challenge – needs global collaboration…