Trawl-Net Technology for Timely Precise Air Traffic Controller Turn-To-Base Commands

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Flight Legs for Approaching Aircraft

Turn to base is a timely critical phase during approach

Screenshot of prototypic DLR controller display RadarVision
Current Situation

- Feeder controller joins inbound traffic
- Sequencing takes wake vortex separation minima into account (currently ICAO matrix)
- Turn-To-Base “as usual” for controllers if aircraft exactly on downwind
Trajectory Calculation with Trombone Pattern

Arrival Manager (AMAN) is able to calculate turn-to-base starting points (flight route exactly on trajectory)
Support Concepts (1)

- Countdown for initiating turn-to-base
  - At the label
  - Advisory in a stack

- Area of attention
- ‘Jumping‘ or disappearing digits in case of replanning
- Cognitive transfer between time and distance
Support Concepts (2)

Current supporting concepts with virtual centerline positions:

Credeur et al. (NASA), 1993: displaying start points is better than target points
Trawl-Net Regarding the Calculated 4d-Trajectory
Idea: Visual Assistance for Timely Precise Turn-To-Base Commands

- Aircraft or Ghost on the centerline with a supposed target position as a successor drags a “trawl-net"

- Mouse over tooltip for corresponding aircraft to trawl-net line

- Smooth adaptation in case of replanning

- Disappears if one of the following conditions hold
  - (1) succeeding aircraft is on centerline
  - (2) predeceasing aircraft is too close to runway (final approach fix)
  - (3) predeceasing aircraft is too far away from “base” area

- Preferences for e.g. two trawl-net lines

- Support for controllers in time-based flight guidance
Concept of the Trawl-Net

Future A/C Position $A^*$
Future A/C Position $B_n^*$
A/C $A$
Target $B'$

Runway

$C_R = \frac{(270° - \alpha) \cdot \pi}{180°}$

$C_x = \frac{v(B)}{v(A)} \cdot \pi r - AB'$

$C_y = 2r$

$T(B_1)$
$T(B_2)$
$T(B_3)$
$T_{max}$
$T_{min}$

Centerline $l_C$
Downwind $l_{D,South}$

5 NM
5 NM
5 NM

0
5
10
15
20

[NM]

[Image 0x0 to 720x56]
Equation for the Trawl-Net Line Calculation

\[
C_x = \frac{v(B)}{v(A)} \cdot \pi r - AB'
\]

\[
C_y = 2r
\]

\[
C_R = \frac{(270^\circ - \alpha) \cdot \pi}{180^\circ}
\]

\[
\begin{pmatrix}
T_x \\
T_y
\end{pmatrix} = \begin{pmatrix}
A_x - \left(\frac{v(B)}{v(A)} \cdot \pi r - AB'\right) \cdot \cos\left(\frac{(270^\circ - \alpha) \cdot \pi}{180^\circ}\right) + 2r \cdot \sin\left(\frac{(270^\circ - \alpha) \cdot \pi}{180^\circ}\right) \\
A_y - \left(\frac{v(B)}{v(A)} \cdot \pi r - AB'\right) \cdot \sin\left(\frac{(270^\circ - \alpha) \cdot \pi}{180^\circ}\right) + 2r \cdot \cos\left(\frac{(270^\circ - \alpha) \cdot \pi}{180^\circ}\right)
\end{pmatrix}
\]
Equation for the Trawl-Net Poly Bezier Arc

\[
\begin{align*}
(SC_{x1}) &= (A_x) \\
(SC_{y1}) &= (A_y) \\
(SC_{x2}) &= (A_x + 2 \cdot \cos(C_R)) \\
(SC_{y2}) &= (A_y - 2 \cdot \sin(C_R)) \\
(SC_{x3}) &= (T_{\text{min},x} + 2 \cdot \cos(C_R)) \\
(SC_{y3}) &= (T_{\text{min},y} - 2 \cdot \sin(C_R)) \\
(SC_{x4}) &= (T_{\text{min},x}) \\
(SC_{y4}) &= (T_{\text{min},y})
\end{align*}
\]
Trawl-Net Video
Several Trawl-Nets with Straight Connectors

Screenshot of prototypic DLR controller display P-HMI with trawl-net for parallel runways
Trawl-Net Pre-study Concept

- Briefing and explanation of concept
- Demonstration on display and non-interactive simulation run
- Questionnaire with 10 questions for rating on Likert scale („0-5“)
- One open remark question
Trawl-Net Pre-study participants

- 3 female and 19 male controllers as study participants
Result Significance: Dexter One Sample Size t-Test

- Scale average
  \[ \mu_0 = \frac{0+1+2+3+4+5}{6} = 2.5 \]

- Null hypothesis
  \[ H_0 : \mu \leq \mu_0 \quad \text{rejection (negative)} \]

- Alternative hypothesis
  \[ H_1 : \mu > \mu_0 \quad \text{affirmation (positive)} \]

- t-value
  \[ t = \frac{\overline{X} - \mu_0}{\sigma} \cdot \sqrt{n} \]

  \( n \): sample size, \( \sigma \): standard deviation, \( \overline{X} \): arithmetic average, significance level \( \alpha=0.05 \), confidence interval: 95%, \( n-1 \) freedom degrees

- \( n \) sometimes less than 22, but \( t > 1.9 \) indicates positive affirmative significance in all cases
Results of Trawl-Net Evaluation: T01-T03

<table>
<thead>
<tr>
<th>Question number</th>
<th>Understanding trawl-net lines</th>
<th>AMAN trajectory</th>
<th>Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>T01</td>
<td>4.73</td>
<td>3.36</td>
<td>3.90</td>
</tr>
<tr>
<td>T02</td>
<td>5.00</td>
<td>3.36</td>
<td>3.90</td>
</tr>
<tr>
<td>T03</td>
<td>4.73</td>
<td>3.36</td>
<td>3.90</td>
</tr>
</tbody>
</table>

Average Rating:
- T01: 4.73
- T02: 3.36
- T03: 3.90
Results of Trawl-Net Evaluation: T04-T07

<table>
<thead>
<tr>
<th>Question number</th>
<th>Use</th>
<th>Effectivity</th>
<th>Time precision</th>
<th>Negative effects</th>
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<tbody>
<tr>
<td>T04</td>
<td>3.50</td>
<td>3.84</td>
<td>3.90</td>
<td></td>
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<tr>
<td>T07</td>
<td>2.00</td>
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Average Rating 3.50, 3.84, 3.90, 2.00
Results of Trawl-Net Evaluation: T08-T10

<table>
<thead>
<tr>
<th>Question number</th>
<th>Concept general</th>
<th>Time-based step</th>
<th>Display integration</th>
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</thead>
<tbody>
<tr>
<td>T08</td>
<td>3.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T09</td>
<td></td>
<td>3.61</td>
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<tr>
<td>T10</td>
<td></td>
<td></td>
<td>3.28</td>
</tr>
</tbody>
</table>

Average Rating: 3.45, 3.61, 3.28
Results of Trawl-Net Evaluation: Controller Remarks

- “Accurate and conflict-free AMAN calculation important”
- “Sometimes trawl-net line may force too early turns in current implementation”
- “Semicircle turn trajectory should be replaced by dog curves”

- “Missing wind input”
- “Demands of the tower”
- “Pilot’s reaction embodies non-influenceable time parameter”

- “Nice idea”
- “Offers good orientation for best turn-points”
- “Additional human estimation still required”
Results of Trawl-Net Evaluation: Further Ideas

- Alternative idea for connector:
  linked with planned target position in a TargetWindow

- Colored fan instead of single line

- More restrained trawl-net line design

- Dynamically adapting line leg lengths

- Two different trawl-nets (north and south) for different aircraft to enable possible sequence change
Summary and Benefits

- Time-based control via distance-based display

- HMI enhancement showed basic acceptance, usability and advantages for controller’s work

- Idea and prototypic implementation
  → actual feedback encouraged for further work and enhancement

- No solution for today, but for future growing complexity
  - RECAT(-2), dynamic pair-wise separation
  - Noise variation paths

- Even better results with future environment?
Outlook

- Including more influences
  - Wind
  - Given controller commands
  - Turn capabilities of aircraft types
  - Usual headings and ILS intercept degrees

- Real-time simulation with controllers and pseudo-pilots
  - Nine topics with sixty questions in baseline- and trawl-net scenario
    - Situation awareness
    - Workload
    - Usability
    - User acceptance
    - Distrust
    - Trust
    - Usefulness
    - Ease of use
    - Further notes
Thank you for your attention.

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