Adaptive Aerial Ecosystem Framework to support the Tactical Conflict Resolution Process

Flight Simulation Conference: Modelling and Simulation in Air Traffic Management

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Problem definition (I)

- Large-scale assessment of ATFCM within European airspace

Increased traffic demand: 50% increase in flights by 2035 comparing to 2012

Improper separation due to insufficient time leads to TCAS activation

Continuous pressure on Separation Management from ACC

Collision avoidance produces inefficient trajectory (vertical rate change)
Problem definition (II)

- Designed for operations in traffic densities of 0.3 ac/NM²
- Excellent performances for pair-wise encounters
- Operational logic drawbacks due to induced collisions in complex traffic scenarios
- Currently non-compliant with SM layer

TCAS II v 7.1

Need for a new concept supporting tactical level operations: aerial ecosystems
Problem definition (III)

Conflict for pairwise encounter - transition from SM to CA

ATC thresholds: MTCD & STCA; prediction moment to starting conflict moment
Problem definition (IV)

Focus on the conflict divergence; encounter geometries starting from the CPA – CP and CPA moments overlap.

Complex environment: 4 A/C - EDE positioning within the LAT and ET determination.
Problem definition (V)

Scenario evolution towards EDE – time windows

Rate of change in the number of resolutions: extra resolution capacity for time-critical system
Ecosystem concept (I)

- Goal: SESAR and NextGen joint initiatives towards future harmonization of air traffic operations through development of airborne and ground-based DMTs
- Response: project AGENT seeks for smooth and coherent transition between safety layers

- Centrally controlled ATC interventions (agent-centered approach)
- More efficient conflict avoidance operations (multi-agent approach)
Ecosystem concept (II)

- AGENT claims for a collaborative and proactive SM system considering a socio-technological approach, in which both human behavior and automation play important role.

- Def: relying on the multi-agent technology, given a set of aircraft inside a computed airspace volume, with the trajectory-amendment, decision-making capability, whose trajectories are causally involved in the safety event.
Ecosystem concept (III)

- DEF: relying on multi-agent technology, given a set of aircraft inside a computed airspace volume, with the trajectory-amendment, decision-making capability
- Predicted conflict between two aircraft whose trajectory segments are used for detection of surrounding traffic
- Identification of spatiotemporal interdependencies (STIs) as a combination of potential avoidance maneuvers between conflicting aircraft
STI identification and EDE computation (I)

Identification of two ST aircraft - A/C3 by left heading maneuver and A/C4 by climb amendment

Conflict interval for a single RBT applying a deflection angle of +30°
STI identification and EDE computation (II)

**Example of the STI structure**

<table>
<thead>
<tr>
<th>STI_ID</th>
<th>Interdependent aircraft IDs</th>
<th>Maneuvering combination</th>
<th>Conflict interval [sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>STI 1</td>
<td>A/C1 – A/C2</td>
<td>m₀ – m₂</td>
<td>tₛ₁ – tₑ₁</td>
</tr>
<tr>
<td></td>
<td>A/C1 – A/C2</td>
<td>m₀ – m₄</td>
<td>tₛ₂ – tₑ₂</td>
</tr>
<tr>
<td></td>
<td>A/C1 – A/C2</td>
<td>m₃ – m₂</td>
<td>tₛ₃ – tₑ₃</td>
</tr>
<tr>
<td>STI 2</td>
<td>A/C1 – A/C3</td>
<td>m₂ – m₃</td>
<td>tₛ₄ – tₑ₄</td>
</tr>
<tr>
<td></td>
<td>A/C1 – A/C3</td>
<td>m₄ – m₂</td>
<td>tₛ₅ – tₑ₅</td>
</tr>
</tbody>
</table>

\[
\text{LAT} = t_{CP} - t_{PM}
\]
\[
\text{ET} = t_{DE} - t_{PM}
\]
\[
I \leq \frac{N_A(N_A - 1)}{2} M^2
\]

\[
\text{TM}_A(t) = \frac{M^{N_A}}{\tau} (t_{CP} - t)
\]
\[
\text{CA}(t) = \frac{M^{(N_A - 2)}}{\tau} \sum_{k=1}^{I} [t_{EK} - \max(t_{SK}, t)]
\]

\[
\text{SA}(t) = \text{TM}_A(t) - \text{CA}(t) = \frac{M^{(N_A - 2)}}{\tau} (M^2 (t_{CP} - t) - \sum_{k=1}^{I} [t_{EK} - \max(t_{SK}, t)])
\]

\[
\text{SA}_{\text{max}} = \frac{M^{(N_A - 2)}}{\tau} (M^2 (t_{CP} - t_{PM}) - \sum_{k=1}^{I} [t_{EK} - t_{PM}])
\]

\[
M^2 (t_{CP} - t_{DE}) - \sum_{k=1}^{I} [t_{EK} - t_{DE}] = 0
\]
Simulation results (I)

Ecosystem 1 – trajectory segments

<table>
<thead>
<tr>
<th>flight ID</th>
<th>lat-1</th>
<th>long-1</th>
<th>alt-1</th>
<th>time-1</th>
<th>lat-2</th>
<th>long-2</th>
<th>alt-2</th>
<th>time-2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[°]</td>
<td>[°]</td>
<td>[ft]</td>
<td>[sec]</td>
<td>[°]</td>
<td>[°]</td>
<td>[ft]</td>
<td>[sec]</td>
</tr>
<tr>
<td>A/C1</td>
<td>50.498611</td>
<td>8.411389</td>
<td>25000.00</td>
<td>60629.00</td>
<td>49.932222</td>
<td>8.774444</td>
<td>32000.00</td>
<td>60927.00</td>
</tr>
<tr>
<td>A/C2</td>
<td>50.536087</td>
<td>8.527662</td>
<td>33000.00</td>
<td>60629.00</td>
<td>50.012420</td>
<td>8.791093</td>
<td>33000.00</td>
<td>60927.00</td>
</tr>
<tr>
<td>A/C3</td>
<td>50.119104</td>
<td>9.170007</td>
<td>36000.00</td>
<td>60629.00</td>
<td>50.273001</td>
<td>8.236522</td>
<td>36000.00</td>
<td>60927.00</td>
</tr>
</tbody>
</table>

Ecosystem 2 – trajectory segments

<table>
<thead>
<tr>
<th>flight ID</th>
<th>lat-1</th>
<th>long-1</th>
<th>alt-1</th>
<th>time-1</th>
<th>lat-2</th>
<th>long-2</th>
<th>alt-2</th>
<th>time-2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[°]</td>
<td>[°]</td>
<td>[ft]</td>
<td>[sec]</td>
<td>[°]</td>
<td>[°]</td>
<td>[ft]</td>
<td>[sec]</td>
</tr>
<tr>
<td>A/C1</td>
<td>39.660556</td>
<td>-8.246667</td>
<td>25000.00</td>
<td>66994.00</td>
<td>40.107527</td>
<td>-8.318823</td>
<td>29314.71</td>
<td>67212.49</td>
</tr>
<tr>
<td>A/C2</td>
<td>40.401960</td>
<td>-7.906300</td>
<td>40869.57</td>
<td>66994.00</td>
<td>40.032700</td>
<td>-8.271550</td>
<td>30314.71</td>
<td>67212.49</td>
</tr>
<tr>
<td>A/C3</td>
<td>40.303130</td>
<td>-7.782880</td>
<td>37000.00</td>
<td>66994.00</td>
<td>40.022940</td>
<td>-8.265890</td>
<td>29763.55</td>
<td>67212.49</td>
</tr>
<tr>
<td>A/C4</td>
<td>39.515320</td>
<td>-8.196740</td>
<td>26909.09</td>
<td>66994.00</td>
<td>39.82233</td>
<td>-7.800140</td>
<td>30000.00</td>
<td>67212.49</td>
</tr>
</tbody>
</table>

- time-1 = \( t_{PM} \) = 0 sec – for both ecosystems
- time-2 = \( t_{CP} \) = 298.00 sec – ecosystem 1
- time-2 = \( t_{CP} \) = 218.49 sec – ecosystem 2
Simulation results (II)

Ecosystem 1

Ecosystem 2
Simulation results (III)

Conclusions: a significance in providing time capacity for a set of certain maneuvers, when a severity of the conflict situation occurs very rapidly; with increased ecosystem size and diverse RBT geometries, STI structure becomes larger which produces less resolution capacity and shorter ecosystem time.
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Many thanks for your attention!

Questions?

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