Analysis of Conflict Resolution Methods for Manned and Unmanned Aviation Using Fast-Time Simulations

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Review of CR Models

- Europe had 11 million manned flights in 2018 and may expect a constant increase until 2025 [1].

- Unmanned Aerial Vehicles (UAVs) must have Sense & Avoid capability to be allowed in the civil airspace [2].

- No direct comparison between researched CR models.

- No standardized simulation tool, scenarios → results are not comparable.

Minimum Separation

• Manned Aviation: most CD&R studies use ICAO's [1] definition of 5NM horizontal separation and 1000ft vertical separation.

• Unmanned Aviation: no pre-defined standard separation distance; although 50 m is a value commonly used in research [2].

## Conflict Resolution Models (2-D)

- **Velocity Obstacles Theory:**
  1. MVP
  2. SSD
  3. Coordinated Resolution
  4. Centralized Cost Solution

<table>
<thead>
<tr>
<th>Planning</th>
<th>Tactical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>Decentralized</td>
</tr>
<tr>
<td>Coordination</td>
<td>Implicit</td>
</tr>
<tr>
<td>Conflict Resolution</td>
<td>Pairwise</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MVP</th>
<th>SSD</th>
</tr>
</thead>
</table>
Conflict Resolution Models

|-------------------|--------------------|--------------------|


Conflict Resolution Models (2)

**Coordination [1]**

- Start
- Conflict Detected
- Ownship Broadcasts Maneuver
- Ownship Receives Intruders’ Maneuvers
- Conflict Resolution Cycle
- Feasible solution?
  - Yes
  - End
- No

**Cost [2]**

\[
F = w_I \Delta P_L + w_v \Delta V + w_d D_{th} + \delta P \\
w_I + w_v + w_d = 1
\]

- $\Delta P_L$ - variation of total path length
- $\Delta V$ - variation of velocity
- $D_{th}$ - distance to threats
- $P$ - penalty for crossing an intruder’s $PZ$
- $w$ - weight coefficients


Previous Research

- **MVP, SSD [1]:**
  - Blueksy [2]
  - Densities: 9 – 27 aircraft / 10 000 $NM^2$ [2]
  - Instantaneous aircraft: 93 – 277 aircraft
  - LosS: < 20
  - Conflicts: MVP < 15000; SSD < 8000

- **Coord [3]:**
  - Safe separation of 48 UAVs in a space of 22 $NM^2$ [2]

- **Cost [4]:**
  - Safe separation for 5 manned aircraft in a 54 $NM^2$ scenario [3]

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Experiment

• BlueSky - The Open Air Traffic Simulator
Experiment (2)

- Boeing 747-400
- DJI Mavic Pro

<table>
<thead>
<tr>
<th>Traffic Density (aircraft / 10000 NM²)</th>
<th>Instantaneous Aircraft</th>
<th>Spawned Aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Min Flight Distance [NM]</strong></td>
<td><strong>Max Flight Distance [NM]</strong></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>32</td>
<td>648</td>
</tr>
<tr>
<td>Medium</td>
<td>37</td>
<td>768</td>
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<tr>
<td>High</td>
<td>45</td>
<td>911</td>
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<tr>
<td><strong>Unmanned</strong></td>
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<td></td>
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<tr>
<td>Low</td>
<td>12000</td>
<td>1080</td>
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<tr>
<td>Medium</td>
<td>13856</td>
<td>1247</td>
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<tr>
<td>High</td>
<td>16000</td>
<td>1440</td>
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</table>
Experiment (3)

<table>
<thead>
<tr>
<th></th>
<th>Manned</th>
<th>Unmanned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation Area</td>
<td>202500</td>
<td>900</td>
</tr>
<tr>
<td>Experiment Area</td>
<td>405000</td>
<td>1800</td>
</tr>
<tr>
<td>Altitude [ft]</td>
<td>36000</td>
<td>300</td>
</tr>
</tbody>
</table>
Results (Safety - Conflicts)

Manned Aviation

Unmanned Aviation
Results (Safety – Losses of Separation)
Results (Safety – Time in Conflict)

**Manned Aviation**

**Unmanned Aviation**

![Graphs showing time in conflict for manned and unmanned aviation with different levels of safety and time intervals.](image-url)
Results (Safety – Intrusion Severity)

Manned Aviation

Unmanned Aviation
Results (Efficiency – Extra Flight Distance)

Manned Aviation

Unmanned Aviation
Results (Efficiency – Extra Flight Time)

Manned Aviation

Unmanned Aviation
Discussion

• A standardized simulation library should be developed so CD&R models can be fairly tested under the same conditions.

• No disparity found between manned and unmanned environment. Smaller minimum separation and velocities in unmanned aviation help prevent losses of separation.

• VO based methods showed better results safety-wise. **MVP:** minimum path deviations for CR reduced the effect of resolution maneuvers on flight efficiency while still guaranteeing minimal losses of separation.

• The efficiency of CR models depend on the aircraft performance limits, trajectories and simulation environment.
Thank you!