Flow management without en route capacity limitations by pre-tactical trajectory compatibility determination
Purpose of the Research

The research’s aim is to reduce the current ATC capacity limitation by pre-tactical trajectories compatibility determination
Presentation structure:

• Paradigm shift in ATM
• Capacity versus Predictability
• First Approach:
  ➢ Assumptions
  ➢ Example
  ➢ Conclusions
Paradigm shift in ATM

- Current Air Traffic Management (ATM) system shows clear signs of saturation (traffic expected to double by 2030)
- Increased environmental awareness calls for more efficient operations
- ATM based on principles introduced more than 50 years ago
Paradigm shift in ATM

- Tactical actions taken by controllers have been identified as the main bottle neck for today’s ATM system

61.3%

* Proportion of ATFM delay in July 2011

• USA and European initiatives towards a Paradigm Shift in ATM:

FROM
Sector based Management

TO
Trajectory based Management
SESAR Innovation Days

Paradigm shift in ATM

FROM Sector Management

http://www.cranfield.ac.uk
SESAR Innovation Days

Paradigm shift in ATM

FROM Sector Management

http://www.cranfield.ac.uk
• Airspace divided into sectors handled by one executive ATCo able to control a **limited number of aircraft**
• To attend increase of traffic demand the number of available sectors is proportionally increased, but this also has a limit
• Future ATM will require decision support tools providing conflict-free trajectories in advance
• ATCO workload reduced by this high degree of automation
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Paradigm shift in ATM

FROM
Sector Management

TO
Trajectory Management

Capacity=45

Capacity=50

d

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Paradigm shift in ATM

- Strategic: It is not known in advance if the traffic is going to have any conflict
- Tactical: The potential conflicts must be avoided by the ATCO
- The capacity limitation is a human limitation

Capacity=45

Capacity=50
Paradigm shift in ATM

- Strategic: The trajectory is only allowed if there is not any foreseen conflict
- Tactical: The amount of possible conflicts is radically reduced
- The capacity is not limited by the human
Under which conditions can two trajectories be declared as compatible? Trade off between capacity and predictability

- **Capacity**: demanded number of tactical interventions (en route capacity)
- **Predictability**: degree of compliance between planned and actual a/c positions, affecting total system safety
Nowadays

- Max. Number of aircraft per hour: sector capacity
- Trajectory compatibility determination: capacity not exceeded in any of the sectors involved
Real data (Maastricht UAC)

- 600 mov/sector/day
- 50% of conflicted a/c
- 75 potential conflicts/sector/day
  - 5 NM minimum horizontal distance
  - 1000 ft minimum vertical height
• Trajectory Based Operations (prediction time)
• Trajectory deviation uncertainties:
  ➢ Lateral
  ➢ Vertical
  ➢ Longitudinal
Trajectory Based Operations

- Business Trajectory, Shared BT, Reference BT

Trajectory compatibility determination
PBN concept:
- Aircraft navigation system requirements
- Operation in a particular airspace supported by the appropriate infrastructure

Total system error \(\pm 1\text{NM}\)

(PBN 1)

(Accuracy Requirements 95%)
Two different cases:
1. Aircraft established at a flight level

- Total vertical error \( \pm 200 \text{ft} \)
- (Accuracy Requirements 3 \( \sigma \))
Two different cases:

2. Aircraft climbing or descending
   • Aircraft vertical profile evolution with $T \gamma \rho$
   • Wind variation with altitude
Wind prediction errors are the largest source of trajectory prediction errors.

Individual vector errors larger than 10 m/s are 3% overall. RMS value for wind error about 6 m/s.
First Approach: Horizontal Movement Uncertainties

Intruder AC (j)
Reference AC (i)

IMPACT PLANE

vji

Z

Y

X

Reference AC (i)

CPAp

Z₁

Y₁

Reference AC (i)
First Approach: Assumptions

- En route phase of flight
- Only horizontal components considered (two aircraft established)
- Aircraft position lateral error negligible (PBN may give values as low as 0.1NM, 95% of the time)
First Approach: Expression obtained

\[ \sigma = t_{CPA} \cdot a \cdot \sigma_w \]

<table>
<thead>
<tr>
<th>( \sigma )</th>
<th>Standard deviation for CPAy coordinate estimation</th>
</tr>
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<tbody>
<tr>
<td>( t_{CPA} )</td>
<td>Time to CPA</td>
</tr>
<tr>
<td>( a )</td>
<td>Geometrical factor (depending on aircraft and wind angles, and speeds ratio)</td>
</tr>
<tr>
<td>( \sigma_w )</td>
<td>Standard deviation for wind error estimation</td>
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</table>
• Geometrical factor $a$ depending on the geometry of the encounter: $\vec{v}_i, \vec{v}_j, \theta_w$

• Speeds ratio and trajectory angles, known through the flight plan (different configurations presented), wind angle unknown (worst case for any configuration chosen for the analysis).
### Example

\[ \sigma = t_{CPA} \cdot \alpha \cdot \sigma_w \]

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<tr>
<td>( \alpha )</td>
<td>variable with different encounter geometry configurations</td>
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<tr>
<td>( \sigma_w )</td>
<td>6 m/s (Gaussian distribution)</td>
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Example:
Maximum "α"
Example
Probability density functions for CPA_\psi coordinate
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Example

Standard Separation (5NM) | “D” NM
Aircraft i | Aircraft j

Conflicts Probability Assumption

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Research’s Aim

Under which conditions can two trajectories be declared as compatible? Trade off between capacity and predictability

- **Capacity**: demanded number of tactical interventions
- **Predictability**: degree of compliance between planned and actual a/c positions, affecting total system safety
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**Example**

**Capacity:** demanded number of tactical interventions

Real data (Maastricht UAC)
- 600 mov/sector/day
- 75 potential confl/sector/day

**Future**
- 1800 mov/sector/day
- 6 potential confl/sector/day

**Predictability:** degree of compliance between planned and actual a/c positions, affecting total system safety

Probability of conflict assumed

\[ 3 \cdot 10^{-3} \]

http://www.cranfield.ac.uk
Standard Separation (5NM)  "D" NM

Aircraft i  Aircraft j

3 \cdot 10^{-3}
Conclusions

\[ \sigma = t_{CPA} \cdot a \cdot \sigma_w \]

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**Probability of conflict**

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<td>Probability of conflict</td>
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<td>Tactical interventions /sector/day</td>
<td>6</td>
</tr>
<tr>
<td>Minimum distance between aircraft to be declared as compatible</td>
<td>12NM</td>
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• Vertical movement and other possible uncertainties inclusion (estimated time of departure)
• Algorithm for trajectory compatibility determination
• Evaluation of the impact on Flow Management capacity
QUESTIONS ?