Probabilistic Aircraft Conflict Detection and Resolution Considering Wind Uncertainty

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Outline

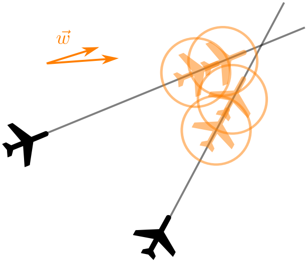
- Introduction
- Conflict characterization
- Probabilistic CDR
- Application - Results
- Summary - Final remarks

Motivation

- Understanding/ managing uncertainty is key to provide **better decision support**. Procedures to **integrate uncertainty information** into the ATM planning process must be developed.
- In particular, **weather prediction uncertainty**.
- It is expected that by considering the weather prediction uncertainty, the **safety and efficiency** of the air traffic may be improved.
- Project TBO-Met (H2020 Ref. 699294)
  Meteorological Uncertainty Management for Trajectory Based Operations.
  SESAR 2020 Exploratory Research; Topic: Meteorology.

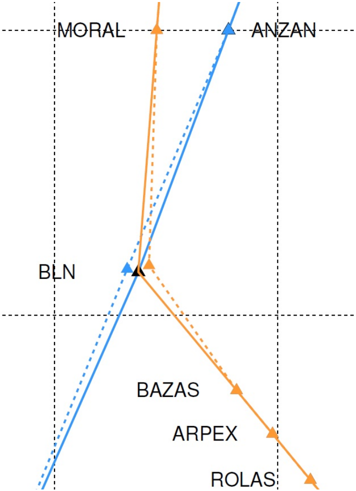
Case study

- **Problem**: Probabilistic Conflict Detection and Resolution
- **Uncertainty source**: Wind



- **Objective**: Resolve the conflict in such a way that its probability be smaller than a given threshold
  (in this work $P_{con} \leq 0.1\%$)

Results preview



Nominal scenario

$P_{con} = 70.4\%$

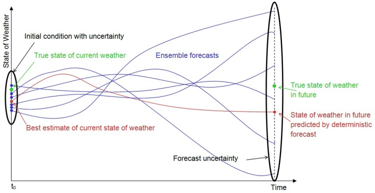
Deconflicted scenario

$P_{con} = 0.1\%$

Ensemble weather forecasting

- Weather uncertainty is defined by **Ensemble Weather Forecasts** (EWF's).

- An EWF is obtained by
  - slightly **altering the initial conditions** and/or physical parameters, and/or
  - considering time-lagged or **multi-model** approaches.



- An EWF constitutes a **representative sample** of the possible realizations of the **potential weather outcome**.

- The **uncertainty information is in the spread** of the various forecasts of the ensemble.

Conflict characterization (1)

Indicators

- Conflict intensity
- Conflict imminence
- Conflict duration
- Conflict probability

Info provided

- Risk of collision
- Urgency
- Expected workload
- Priority

They define the **severity** and **criticality** of the conflict

Conflict characterization (2)

Indicators

- Conflict intensity
- Conflict imminence
- Conflict duration
- Conflict probability

Supporting metrics

- Minimum distance between a/c
- Starting time of conflict
- Duration of loss of separation
- $P[d_{min} \leq D]$

  (D - **given separation requirement**)
  (in this work D=5 NM=9260 m)

Assumptions

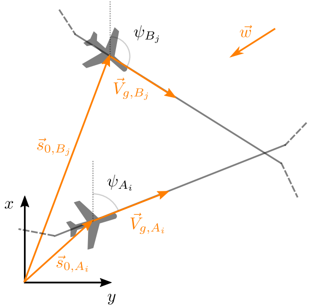
- Two aircraft, A and B, fly with approaching trajectories at the same altitude, with constant known **airspeeds** (V_A and V_B).
- The **initial separation** between aircraft is greater than D .
- The aircraft **courses** in segments i and j resp. (ψ_{A_i} and ψ_{B_j}) are constant and known.
- The aircraft are affected by the same **uncertain constant wind ($\vec{w}(w_x, w_y)$)**.
- The **ground speeds (V_{g,A_i} and V_{g,B_j})** are uncertain.

Conflict scenario

- Aircraft motion (**segments** i, j)

$$\vec{s}_{A_i}(t) = \vec{s}_{0,A_i} + \vec{V}_{g,A_i} t \qquad \vec{V}_{g,A_i} = \vec{V}_{A_i} + \vec{w}$$

$$\vec{s}_{B_j}(t) = \vec{s}_{0,B_j} + \vec{V}_{g,B_j} t \qquad \vec{V}_{g,B_j} = \vec{V}_{B_j} + \vec{w}$$



- Relative motion

$$\vec{s}_{ij}(t) = \vec{s}_{B_j}(t) - \vec{s}_{A_i}(t) = \left(\vec{s}_{0,B_j} - \vec{s}_{0,A_i}\right) + \left(\vec{V}_{g,B_j} - \vec{V}_{g,A_i}\right) t$$

$$\vec{s}_{ij}(t) = \vec{s}_{0_{ij}} + \vec{V}_{g_{ij}} t$$

relative initial position $\vec{s}_{0_{ij}}$ (uncertain)

relative ground speed $\vec{V}_{g_{ij}}$ (uncertain)

Conflict definition

- Distance between the two aircraft:

$$d_{ij}(t) = \left\| \vec{s_{ij}}(t) \right\| = \sqrt{s_{0_{ij}}^2 + 2\vec{s}_{0_{ij}} \cdot \vec{V}_{g_{ij}} t + V_{g_{ij}}^2 t^2}$$

- Minimum distance

$$d_{min} = min\{(d_{min})_{ij}\} = g(w_x, w_y) \quad (\text{uncertain})$$

- Conflict existence

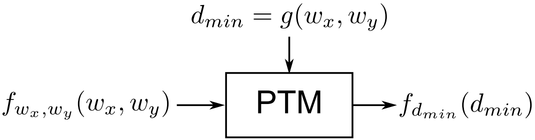
$$d_{min} \leq D \quad (\text{D - given separation requirement})$$

- Probability of conflict

$$P_{con} = P[d_{min} \leq D]$$

Probabilistic approach

- **Probabilistic Transformation Method (PTM)**



- The expected value, standard dev. and probability of conflict are given by

$$E[d_{min}] = \int_{-\infty}^{\infty} \rho f_{d_{min}}(\rho) \mathrm{d}\rho$$

$$\sigma[d_{min}] = \left[\int_{-\infty}^{\infty} \rho^2 f_{d_{min}}(\rho) \mathrm{d}\rho - (E[d_{min}])^2 \right]^{1/2}$$

$$P[d_{min} \leq D] = \int_{-\infty}^{D} f_{d_{min}}(\rho) \mathrm{d}\rho$$

Conflict resolution

- **Modify both trajectories (vectoring) in such a way that the probability of conflict be smaller than a given threshold δ, and the deviation from the nominal trajectories be minimum**
- The coordinates of the modifiable waypoints are collected in the vector $\mathbf{x}$. The nominal trajectories are considered as the preferred ones and they are denoted by $\mathbf{x}^n$
- **Parametric optimization problem**

$$\text{minimize} \sum_{k=1}^{q} \left[(x_k - x_k^n)^2 + (y_k - y_k^n)^2 \right]$$

$$\text{subject to } P_{con}(\mathbf{x}) \leq \delta$$

(q is the number of modifiable waypoints)

Application (1)

Probabilistic wind

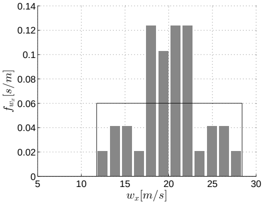
- EPS: Météo France PEARP (35 members).
- 6:00 on 05-May-2016 in the Southeast of Spain (38°N, 2.5°W); Forecast horizon of 0 hours.
- PDF: w_x, w_y — uniform distribution

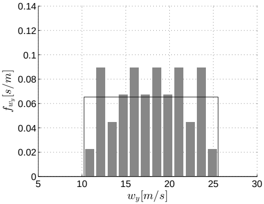
$$f_{w_i}(w_i) = \begin{cases} \frac{1}{2\delta_{w_i}}, & w_i \in [\bar{w}_i - \delta_{w_i}, \bar{w}_i + \delta_{w_i}] \\ 0 & \text{otherwise} \end{cases}$$

where $i \in x, y$, and supposed to be statistically independent:

$$f_{w_x,w_y}(w_x, w_y) = f_{w_x}(w_x) \cdot f_{w_y}(w_y)$$

- Meridional wind: $\bar{w}_x = 20.08$ m/s, $\delta_{w_x} = 8.33$ m/s
- Zonal wind: $\bar{w}_y = 17.89$ m/s, $\delta_{w_y} = 7.65$ m/s

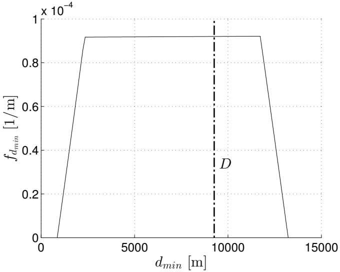




Application (2)

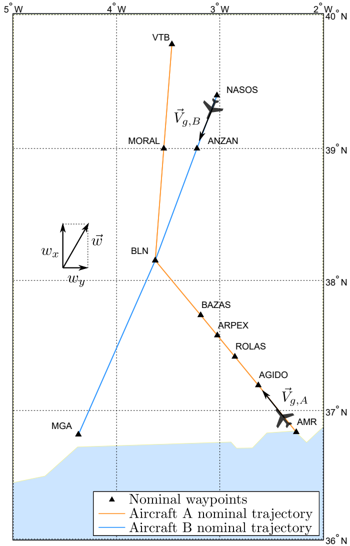
Nominal scenario

- aircraft following RNAV routes UM192 and UN869
- $V_A = 240$ m/s, $V_B = 230$ m/s



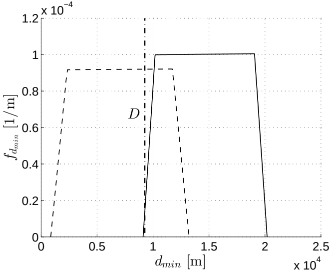
$$E[d_{min}] = 7044 \text{ m}, \ \sigma[d_{min}] = 3170 \text{ m}$$

$$P_{con} = 70.4\%$$



Application (3)

Deconflicted scenario



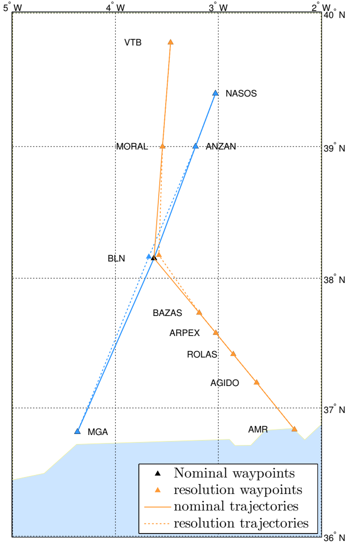
$E[d_{min}] = 14329$ m, $\sigma[d_{min}] = 2897$ m

$P_{con} = 0.1\%$

Max deviation a/c A: 4826 m (@BLN)

Max deviation a/c B: 5029 m (@BLN)

(Resolution cost: 6973 m)



Application (3)

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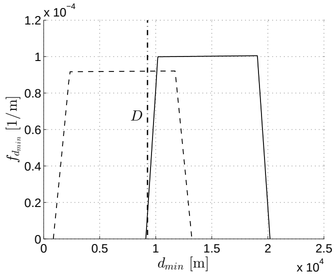

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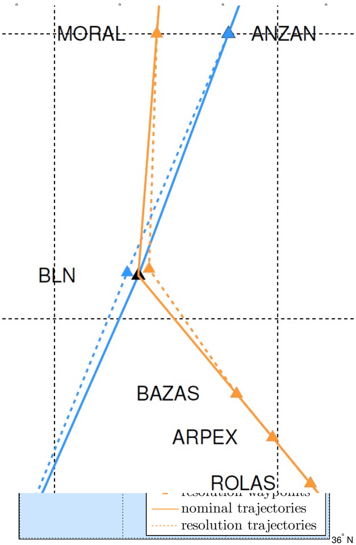

Summary - Final remarks (1)

- We have addressed an **important topic** for the future of TBO.
- The **probabilistic methodology** presented
  - is able to **quantify** the probability of conflict,
  - is able to **resolve the conflict**, generating new trajectories that lower the probablity of conflict to small acceptable levels,
  - is very flexible with respect to the weather input: it can take as input any type of wind distribution derived from **any weather data source**..
- The **indicators** defined can be of interest for ATC, because they provide relevant information about the conflict, and, therefore, **support for better decision making**.

Summary - Final remarks (2)

- Application foreseen: **Medium Term Conflict Detection (MTCD).**
  - **Notification of conflicts** to ATC according to their **probability**; reduction of missed and false alerts.
  - **Evaluation of the viability** (in terms of conflict probability) of proposed **resolution maneuvers**; strategically deconflicting the air traffic.
- Future Work
  - different types of wind distribution
  - variable, correlated wind fields
  - altitude and speed changes (**for TMA analysis**)

Acknowledgements

THANK YOU

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