Collision Risk Assessment Methodology for Parallel Approach Operations

Modelling and Simulation in Air Traffic Management

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Agenda

- Context and Motivation
- Background
- Assessment Methodology Overview
- Scenario: Blundering Aircraft
- Scenario: Loss of Separation
- Scenario-based Validation
- Outlook
Context and Motivation

- SESAR Goals (by 2020)
  - Increase Capacity and safety
  - Decrease Environmental impact and costs
- SESAR Solution PJ.01-03 – Dynamic and Enhanced Routes and Airspace
  - Thread 1: Improved parallel approach operations supported by PBN
- Safety Assessment Metrics:
  - Probability of separation infringements and collisions
Independent Parallel Approach Environments

- ICAO allows independent approach operations to parallel runways spaced at least 3,400 ft
- At intercept, separation between aircraft on adjacent approach tracks is required: 3 NM lateral or 1,000 ft vertical
Assessment Methodology Overview

• Threats considered for safety assessment
  ▪ Blundering aircraft on final approach
  ▪ Blundering aircraft during intercept
  ▪ Loss of separation during intercept

• Those make up „scenarios“ for the simulation and calculations
ABMS Framework

- Agent-based Monte Carlo simulation
- Entities
  - Aircraft (physical body, point mass model)
  - FMS (flight planning)
  - Pilot (reaction time)
  - Radar (traffic surveillance)
  - ATCO (monitoring / controlling)
- Fast-time capable
  - Successfully ran on HPC cluster at TUD
Blundering aircraft

- Blunder = aircraft unintentionally diverges from approach path
- Not a result of navigation tolerances

General blunder case: ATCO detects blunder, issues breakout commands, aircraft obey

Worst-case blunder: Blundering aircraft does not react to ATCO commands

Source: ICAO
Scenario: Blundering Aircraft

- **Goal:** Determine Probability of (near mid-air) collision
- **Inputs:**
  - Runway System, Route structure, infrastructure
  - Radar: Location, Update period, azimuthal accuracy
  - Navigation Tolerances
  - Blunder: probability, angle, WCB rate
  - Reaction Times
  - Aircraft Speeds (Traffic Mix)

Source LOC tolerances: ICAO
In case, slant range at CPA falls below minimum, a FAA test criteria violation (TCV) is recorded.

Calculate risk of a TCV per approach:

\[ P(TCV) = \frac{N_{TCV}}{2 \cdot N_{Events}} \cdot P(Blunder) \]

- \( P(TCV) \): Probability of test criteria violation
- \( N_{TCV} \): Number of recorded TCV
- \( N_{Events} \): Number of events simulated
- \( P(Blunder) \): Probability of a blunder to occur
- 2: Number of aircraft (approach procedures) involved in an event

Source: FAA blunder scenarios
Scenario: Loss of Separation

- What is the probability of a separation infringement between aircraft on adjacent approaches during intercept?
- Assumption: Normal operation (no blundering), in-trail separation is granted
- ICAO Constraint: 1,000 ft vertical / 3 NM lateral required on intercept

Source: ABMS model, TU Dresden
Loss of Separation - Inputs

• Runway System, Route structure, infrastructure
• Navigation Tolerances
• Traffic Mix (speed)
• Intercept behaviour
  ▪ Distance from FAF
  ▪ Angle

Source ABMS model, TU Dresden
Loss of Separation - Simulation

• Combine Monte Carlo Simulation with probabilistic risk assessment
  ➢ Generate nominal flight path
  ➢ apply probability functions on top (XTT, ATT, VTT)
• Probability functions can be obtained from statistical analyses of radar data (equals TSE)
• Therefore we call them ANP (actual navigation performance)

Source; Thiel C. und H. Fricke, Collision risk on final approach - a radar data based evaluation method to assess safety, ICRAT 2010
Loss of Separation – Probability Computation

• Probability calculation is done:
  ▪ For each pair \((m, n)\) of aircraft on adjacent approach tracks
  ▪ Separately for all 3 dimensions in space

• Cross-correlation (difference between two random variables):

\[
p_{m,n,d}(S_d) = \int_{-S_d}^{S_d} \int_{-\infty}^{\infty} g_{A_d,m}(u) \cdot g_{A_d,n}(u + s) \, du \, ds
\]

• \(g_{A_d,k}\) denotes the ANP of Aircraft \(k\) in dimension \(d \in \{x, y, z\}\)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(p_{m,n,d}(S_d))</td>
<td>Probability for loss of separation</td>
</tr>
<tr>
<td>(S_d)</td>
<td>Required separation</td>
</tr>
<tr>
<td>(u, s)</td>
<td>Integration variable, along dimension’s axis</td>
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</tbody>
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Transformation of ANP functions

- Problem: ANP functions (so-called XTT, ATT, VTT) are defined in aircraft-local coordinate system (non-PBN operation)
- Solution: transform ANPs into an earth-fixed coordinate system
- ANP shapes according to Thiel, C. et al, 2010:
  - ANP functions are Normal / Gaussian distributions
  - ANP functions are independent
- Transformation Method:
  - derive Bivariate Normal Distribution from XTT and ATT
  - rotate according to aircraft heading
  - Derive marginal distributions for x and y dimension (in earth-fixed coordinate system, this time)
Scenario-based Validation (1)

Configure an ICAO-like blunder on final approach scenario with data from ICAO SOIR regulatory document:

- Runway spacing 4,300 ft / 3,400 ft
- Blunder
  - Probability: $\frac{1}{2,000}$, WCB: $\frac{1}{100}$ of those
  - Angle: 30°
- Radar
  - Update period: 5 s / 2.5 s
  - Azimuthal Accuracy (1 sigma): 0.3° / 0.06°
- Speed: 150 kn
- XTT: 150ft at 10NM, linearly decreasing towards threshold
- Delay of ATCO reaction, communication with pilot, pilot reaction: 8 s
- NTZ width: 2,000 ft
- Test criterion: slant range of 500 ft

Source: ICAO
Scenario-based Validation (2)

- Necessary Assumptions
  - Radar Position: between runway thresholds
  - No Vertical Components (no climb/descent, no VTT)
- ICAO result: 1 TCV in 56 million approaches
  \[ 1.8 \times 10^{-8} \text{ per approach} \]
- Our findings:
  - 3,400 ft runway spacing scenario: \( 8.3 \times 10^{-8} \)
  - 4,300 ft runway spacing scenario: \( 8.8 \times 10^{-8} \)
- Same magnitude (important for safety researches)
- Not all input data of ICAO simulations are known
Outlook

• Currently Ongoing:
  ▪ Definition of additional setups / configuration for further model verification and validation

• Prepare for PBN procedures

• Revise regulations on separation requirements and NTZ definition
Contact

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