Deconfliction and Separation Management: Manned-Unmanned and Unmanned-Unmanned

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Overview

Part A – Manned-Unmanned Separation

- Problem Definition
- Methodology and Example Results

Part B – Unmanned-Unmanned Separation

- Problem Definition
- Methodology and Example Results
Part A
Manned-Unmanned Separation
Problem Definition

Simplified Exclusion Zones
LAANC-like Systems/Zones
AEC/ARC (JARUS)

Implicit Collision Risk Modeling:
- Non-uniform/subjective (harmonization)
- Time-consuming/costly (manual)
- Communication/transparency

Part A

Strategic Separation

What separation/buffer

Results in how much collision risk

And therefore, what safe altitude in each region?

Airport, Heliport

Manned Traffic
(1 Day)
Proposed Solution

Part A

ICAO, Manual on airspace planning methodology for the determination of separation minima, Doc 9689, 1998
Traffic Modelling

- Runway
- Aerodrome Ref. Point

Surveillance Data A
Surveillance Data B
Known/ATC Expert

Manned Traffic Flow

Part A
Traffic Modelling

- Runway
- Aerodrome Ref. Point
Traffic Modelling

- Runway
- Aerodrome Ref. Point
\[ f_{r,\theta}(h) \]

Manned Trajectories

\[ D_{r,\theta} \]

Polar grid (radial and azimuth bins)

Crossing Rate

Manned Altitude

\[ f_{r,\theta}(\lambda) \]

\[ f_{r,\theta}(h) \]
Given a UAS altitude and nav. performance, what is the likelihood the vertical displacement between manned and unmanned is less than a specified separation buffer?

\[
f_{r,\theta}(h), \quad \text{Manned Altitude}
\]

\[
x_{r,\theta}(h), \quad \text{Unmanned Altitude}
\]

\[
n_{r,\theta}, \quad \text{Manned Crossing Rate}
\]

\[
g_{s,r,\theta}(h), \quad \text{Vertical Overlap}
\]

\[
p(v) @ \text{Separation 1}
\]

\[
p(v) @ \text{Separation 2}
\]

\[
\int_{-\infty}^{s_2} g_{s,r,\theta} \, dz = p(v)
\]

NB: Horizontal Overlap = 1 (thus worst case)
Separation Analysis – Example A (Aerodrome Cells)

\[ \mu_u = 400 \text{ (UAS Nom. Alt.)} \]
\[ \sigma_u = 30 \text{ UAS (UAS Alt. Error)} \]
\[ s_z = 200 \text{ (Sep./Buffer)} \]
\[ n = 1, 25 \text{ (crossing rate)} \]
Separation Analysis – Example B (Runways)

Department Splay

Approach Splay

Departure Splay

\[ \mu_u = 400 \text{ (UAS Nom. Alt.)} \]

\[ \sigma_u = 30 \text{ UAS (UAS Alt. Error)} \]

\[ s_z = 500, 350, 100 \text{ (Sep./Buffer)} \]
Separation Analysis – Example C (Aerodrome Points)

Collision Likelihood

$10^{-2}$  $10^{-3}$  $10^{-4}$  $10^{-5}$  $10^{-6}$

NB: Preliminary Results (limited data/unverified, no crossing rate addition)
Given a separation buffer \( s_z \) and UAS nav. perf., what is the max. UAS altitude such that the likelihood that the vertical displacement between manned and unmanned being less than \( s_z \) is equal to a specified TLS?

\[
\frac{-\ln(1 - TLS)}{n_{r,\theta}} = p_{r,\theta}^*(v)
\]

\( n_{r,\theta} \) - Set (Parameters)

\( f_{r,\theta}(h) \) - Manned Altitude

\( g_{r,\theta}(h) \) - Separation + Unmanned Variance

\( x_{s,r,\theta}(h) \) - Unmanned Altitude - \( H^* \)

\[
\int_{-\infty}^{-H^*} x_{s,r,\theta} dz = p_{r,\theta}^*(v)
\]

\( H^* @ TLS, \text{ Separation} 2 \)

\( H^* \) - Calculate Max. Alt. Associated with Separation

\( H^* \) - NB: Horizontal Overlap = 1 (thus worst case)
Airspace Encounter Models / Max Altitude Determination

Max Safe Altitude

Example A: Medical Centres.

Example B: App/Dep Splays

Risk-based facility maps

TLS $1 \times 10^{-4}$
Risk-based facility maps

TLS $1 \times 10^4$
Airspace Structure - Example B (Aerodrome Cells)

Risk-based facility maps  \( TLS \times 10^{-4} \)

Aerodrome Analysis/Facility Map

No Data/Zero Point

5nm

MAP NOT TO SCALE – NOT FOR NAVIGATIONAL PURPOSES
Key Points:

- Volpe/FAA Report does not apply uniform risk to each grid location (TLS varies between grid). See over (blue) and under (yellow) conservative grids.

- Removal of data not constitute ‘risk adjustment’ as no risk is calculated/known.

- Can conclude that the Volpe/FAA method gives values between $10^{-3}$ and $10^{-5}$ (roughly).
Part B
Unmanned-Unmanned Separation
Problem definition

Part B

What separation/buffer results in how much collision risk and therefore, what is required nav. performance?
Proposed Solution

Given a UAS nav. performance, scaled velocity/params and a TLS, what is the required lateral displacement (separation) between unmanned aircraft on parallel tracks?

Separation Analysis - Method

Part B

Method/Model

Separation Analysis - Example A (Two Parallel Tracks)

**Strategic Separation**

**Separation Surface @ \( TLS = 10^{-2} \)**

- Sub 10 metre track separation
- Dominated by nominal navigating UAS. Proportion of poorly navigating UAS \( \alpha \) and degree \( \alpha_2 \) has limited impact.

**Separation Surface @ \( TLS = 10^{-6} \)**

- Sub 100 metre track separation if proportion of poorly navigating UAS \( \alpha < 1/10,000 \).
- Dominated by nominal navigating UAS \( \alpha_1 \) for \( \alpha < 1/10,000 \).

\[
\Delta V = 0.8 \text{ m/s} \\
V = 20 \text{ m/s} \\
|\dot{y}| = 1.77 \text{ m/s} \\
\lambda_{y,x} = 0.3 \text{ m}, \lambda_z = 0.2 \text{ m}
\]
Strategic Separation

Separation Curves

Compares the separation standards ($S_y$) for $10^{-2}$, $10^{-4}$ and $10^{-6}$ target levels of safety ($Ny$ in the figure).

Highlights the importance of maintaining a low proportion of poorly navigating aircraft.

Exact TLS for unmanned operations is not clear, but results can be used to investigate navigation requirements and separation for different types of unmanned operations (i.e. packages vs people).

$$\Delta V = 0.8 \text{ m/s}$$
$$V = 20 \text{ m/s}$$
$$|\dot{y}| = 1.77 \text{ m/s}$$
$$\lambda_{y,x} = 0.3 \text{ m}, \lambda_z = 0.2 \text{ m}$$
Manned-Unmanned Separation Development

- Method to **quantify vertical collision risk** (terminal areas) aligned to manned aviation practise that can be used for multiple analysis types (separation/segregation standard/buffer, navigation perf. etc.)

- Method to **derive max safe altitudes** (terminal areas) that explicitly considers navigation perf., separation/segregation standard/buffer, data error via collision risk modelling.

Unmanned-Unmanned Separation Development

- Method based on manned approaches to investigate navigation perf. requirements and associated separation standards/buffers.

General

- Useful for ANSP’s, regulators and operators alike - with applications in airspace design (low-level/UTM/U-Space) and development of navigation perf. requirements/definitions/standards.

- Software (**semi-automated**) created and being further extended, tested and validated

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Thanks!