CNPC Implications for UTM Separation Standards

Dr Terrence Martin & Dr Aaron McFadyen
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Research Motivation
Australian UTM BVLOS Trials

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Research Background
Australian UTM BVLOS Trials

RPAS Operators

Trial Management

UTM Providers

Novad Systems

Little Ripper LifeSAVER

V-TOL Aerospace

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Research Background

UTM Trial Take Aways

• Separation

• Sensor Referencing & Accuracy

• System Latency
Current UTM Designs support either point to point flight plans with no bounds on deviations OR Area segregation via polygon allocation with only basic proximity alerting functionality.
WON'T SCALE AS MORE AIRCRAFT COMPETE FOR SAME AIRSPACE

DOESNT CATER for PLATFORMS WANTING to FLY BVLOS from A to B
Introduction: Our Contribution

Part 1
Communication

Dr Terrence Martin
Examination of CNS role in separation and subsequent geofence parameters for UTM
Focusing on support to major distribution routes ie enroute

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Part 2
Geofencing

Dr Aaron McFadyen
Data-driven, risk-based ATM to establish safe and efficient volumetric separation principles to underpin geofencing boundaries
Focusing on the terminal and aerodrome environment
Introduction
QUT Contribution Part 2: Dr Aaron McFadyen

- Diminishing Operating Options once 3 NM Aerodrome and Controlled Airspace boundaries are factored in
- Large Commercial value in metropolitan areas for UAV supported supply chains
Introduction

QUT Contribution: A Prelude to Part 2
UTM Trial Take Aways: Suitable Separation Standards

- Trial environment needed procedural separation backup,
Cesium Graphics development support provided by Mr Tim Cervenjak, Nova Systems

Lateral Separation

Longitudinal Separation

Vertical Separation

And Obstacle Clearance
CNS, Separation and Reich

What's useful in traditional Airspace
Trial Take Aways: Sensor Accuracy

Striking variation in height referencing across RPAS and UTM Operators: feet/metres, referenced from takeoff, referenced from position, and smoothing

Prompted multiple discussions around sensor accuracy: Lat, Long and Vertical and impact on separation distance

Cesium Graphics development support provided by Mr Tim Cervenjak, Nova Systems
Collision Risk Model needs to acknowledge limits:

- Pitot Static
- GPS and geofence boundary coupling

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Pressure Range</td>
<td>$P_{\text{range}}$ Full Accuracy</td>
<td>450</td>
<td>1100</td>
<td></td>
<td>mbar</td>
</tr>
<tr>
<td>Extended Pressure Range</td>
<td>$P_{\text{ext}}$ Linear Range of ADC</td>
<td>10</td>
<td>1200</td>
<td></td>
<td>mbar</td>
</tr>
<tr>
<td>Total Error Band, no autozero</td>
<td>at 25°C, 700..1100 mbar</td>
<td>-1.5</td>
<td>+1.5</td>
<td>+2.0</td>
<td>mbar</td>
</tr>
<tr>
<td></td>
<td>at 0..50°C, 450..1100 mbar</td>
<td>-2.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>at -20..85°C, 450..1100 mbar</td>
<td>-3.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>at -40..85°C, 450..1100 mbar</td>
<td>-6.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Error Band, autozero at one pressure point</td>
<td>at 25°C, 700..1100 mbar</td>
<td>-0.5</td>
<td>+0.5</td>
<td>+1.0</td>
<td>mbar</td>
</tr>
<tr>
<td></td>
<td>at 10..50°C, 450..1100 mbar</td>
<td>-1.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>at -20..85°C, 450..1100 mbar</td>
<td>-2.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>at -40..85°C, 450..1100 mbar</td>
<td>-5.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Required Navigation Performance
Position Accuracy & Reporting Time

RNP expects you to:

- accurately know your position,
- **monitor** it and be **alerted** if you deviate,
- **Act** to correct it in a timely manner if you do deviate, and
- **communicate** with relevant people (ATC & other pilots), so they can respond.
Research Background

UTM Trial Take Aways

- Separation
- Sensor Referencing & Accuracy
- **System Latency**
  Unattributed Latency led to UTM system stalls: Telco, Platform or UTM?
- **Intervention**
- How much latency is permissible in comms and HMI

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Longitudinal Separation
Overtaking Conflict: Oceanic

How long before they converge?

What is the UTM Intervention Time ($\tau$)?

Reporting Period (T) Aircraft 2

Convergence in Separation

Time

Prediction Aircraft 2

Actual Position Aircraft 2

Actual Position Aircraft 1

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Derived from Example given in Fijito
Future RPAS CNPC Infrastructure

Handover to Standalone

Handover Between Standalones

Handover to SATCOM

Public Network

Inter Network Handover

Intra Network Handover

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Derived with Permission from Hee Wook Kim, ETRI Korea, RTCA SC-228 [16]:

Future RPAS CNPC Infrastructure

Copyright: Terrence Martin

Derived with Permission from Hee Wook Kim, ETRI Korea, RTCA SC-228 [16]:

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Derived with Permission from Hee Wook Kim, ETRI Korea, RTCA SC-228 [16]:
Research Background
UTM CNPC Infrastructure: Signal Quality and Altitude

- What will the altitude limitations be using LTE
- Availability, Continuity, Integrity
- How will this be substantiated

Source: LTE Tower Signal data generated by Stephen Dade at Nova Systems using STK
## Intervention
### Longitudinal Separation & C2

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time in Seconds ADS</th>
<th>Possible Time in LTE Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screen Update time/controller conflict recognition</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>Controller Message Composition</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Message Transfer (CPDLC, LTE, RF ??)</td>
<td>90</td>
<td>2*</td>
</tr>
<tr>
<td>Pilot Reaction</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Aircraft Inertia plus Climbs</td>
<td>75</td>
<td>10</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>240</strong></td>
<td><strong>82</strong></td>
</tr>
</tbody>
</table>

SOURCE: Table 4 Components of tau for normal ADS operations
Decomposition of tau for normal ADS Operations and proposed UTM
# Intervention
## The Old and the New

<table>
<thead>
<tr>
<th>Manned Oceanic</th>
<th>Reporting Period (T)</th>
<th>Reporting Period (T)</th>
<th>Reporting Period (T)</th>
<th>Intervention (τ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RNP 10</td>
<td>T=27 Mins</td>
<td>T=27 Mins</td>
<td>T=27 Mins</td>
<td>4-13 mins</td>
</tr>
<tr>
<td>Sy=50 NM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## UTM Transition

- Reporting Period (T) much smaller
- RNP 1?
- Prediction Error shrinks to ZERO

- HITL
  - τ
  - Still substantial

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CNS, Separation & the Reich Model
- ATM uses TLS of $5 \times 10^{-9}$ per dimension
- Assumes a collision is catastrophic
- Collision between 2 UAVs is not catastrophic,
  - The secondary effect may be!
- What TLS likelihood should we use?
- Went with an arbitrary $0.5 \times 10^{-6}$ per dimension

**Source:** FAA Safety Management System (SMS) and Acquisition Management System (AMS) Guidance Document
The Reich Model
In Simple terms

• An aircraft is represented by a box and collision is an overlap of 2 boxes. The collision rate is expressed as:

\[ F_x P_y P_z + F_z P_x P_y + F_y P_z P_x \]

Where:

• \( P_y \) is the probability that across track separation is less than \( \lambda_y \) (aircraft width)
  - \( P_x \) & \( P_z \) similarly defined

• \( F_x \) is the **expected frequency per unit of time** where the along track separation shrinks to less than \( \lambda_x \) (length)
  - \( F_y \) & \( F_z \) similarly defined

SOURCE: [1, 4]
The Reich Model

Probability Vertical Overlap: \( P_Z(0) \)

Expected # fatal accidents per flight hour

\[
E_y \text{ (same)} \left\{ \frac{|\Delta V|}{2 \lambda_x} + \frac{|\dot{y}(S_y)|}{2 \lambda_y} + \frac{|\dot{z}|}{2 \lambda_z} \right\} + E_y \text{ (opp)} \left\{ \frac{2|V|}{2 \lambda_x} + \frac{|\dot{y}(S_y)|}{2 \lambda_y} + \frac{|\dot{z}|}{2 \lambda_z} \right\}
\]

How often do the platforms move from different flights levels to to a coincident altitude

Linked to Altimetric Performance: Total Vertical Error (TVE)

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The Reich Model

Occupancies

How many laterally proximate pairs per unit time?

\[ E_y \text{(same)} \]

\[ E_y \text{(opp)} \]
The Reich Model

Probability Lateral Overlap \( (P_y(S_y)) \) & RNP

How close before this overlap probability is unacceptable?
The Reich Model

Implementation Subtleties: Lateral Separation

Expected # fatal accidents per flight hour

\[ P_y(S_y)P_z(0) \frac{\lambda_x}{S_x} \left[ E_y(\text{same}) \left\{ \frac{|\Delta V|}{2\lambda_x} + \frac{\|\dot{y}(S_y)\|}{2\lambda_y} + \frac{|\dot{z}|}{2\lambda_z} \right\} + E_y(\text{opp}) \left\{ \frac{2|\vec{V}|}{2\lambda_x} + \frac{\|\dot{y}(S_y)\|}{2\lambda_y} + \frac{|\dot{z}|}{2\lambda_z} \right\} \right] \]

Where:

- **Occupancies**: \( E_y(\text{same}) \) & \( E_y(\text{opp}) \)
- **Aircraft dimensions**: \( \lambda_x, \lambda_y, \lambda_z \)
- **Speeds**: relative (\( |\Delta V|, |\dot{z}|, \|\dot{y}(S_y)\| \)) and ground speeds (\( |\vec{V}| \))
- **Navigation Performance**: Nominal & GNEs: \( a_1, a_2 \) & \( \alpha \)
- **Nominal Separation**: Lateral (\( S_y \)), Longitudinal (\( S_x \)) + others......
The Reich Model
Longitudinal Separation & C2

Collision Rate

\[
\text{Collision Rate} = \left[ \frac{2}{T} \times HOP \left(T + \tau \right) \times P_z(0) \times \left\{ 1 + \frac{|\dot{z}|}{2\bar{\kappa}_z} \times \frac{\pi\bar{\kappa}_{xy}}{2V_{rel}} \right\} \right]
\]

MOST RELEVANT FOR THIS PRESENTATION

- \((T)\) : Reporting Period
- \((\tau)\) : Communication and controller intervention buffer
- \((HOP)\) : Horizontal Overlap Probability for pair AC during crossing

Others

- \(P_z(0)\) : probability of vertical overlap of aircraft nominally flying at the same flight level
- **Aircraft dimension** : length \((\bar{\kappa}_x)\), width \((\bar{\kappa}_y)\) & height \((\bar{\kappa}_z)\)
- **Speeds** : relative \((2V_{rel}^C, |\dot{z}|)\)
Modelling Effort
Experiments
Models Employed

• Longitudinal
  • ICAO Doc 9689 Appendix 1 [4]
  • Ryota Mori, 2014 [5]
  • Walton, SASP 2012 [9]
  • Andersen, RGCSP/10-WP/9, 2000, [7]

• Lateral & Vertical
  • EUR/SAM Corridor: 2016 Collision Risk Assessment, ARINC [8]
  • Risk Assessment of RNP10 & RVSM in the South Atlantic Flight Identification Regions” [6]
### Model Parameter Scaling

<table>
<thead>
<tr>
<th>Parameter Description</th>
<th>Manned ICAO 9689 []</th>
<th>UAV Extrapolation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft Width ($\lambda_y$)</td>
<td>193.12 feet</td>
<td>3.3 feet</td>
</tr>
<tr>
<td>Aircraft Length ($\lambda_x$)</td>
<td>174.45 feet</td>
<td>3.3 feet</td>
</tr>
<tr>
<td>Aircraft Height ($\lambda_z$)</td>
<td>55.43 feet</td>
<td>1.5 feet</td>
</tr>
<tr>
<td>Average Relative Longitudinal Speed $</td>
<td>\Delta \vec{V}</td>
<td>$</td>
</tr>
<tr>
<td>Average Relative Vertical Speed $</td>
<td>\dot{z}</td>
<td>$</td>
</tr>
<tr>
<td>Average Relative Lateral Speed $</td>
<td>\dot{y}</td>
<td>$</td>
</tr>
<tr>
<td>Aircraft Aircraft Speed $</td>
<td>\vec{V}</td>
<td>$</td>
</tr>
<tr>
<td>Relative Velocity Collision ($2V_{rel}^C$)</td>
<td>Range: 71-95</td>
<td>7 kts</td>
</tr>
<tr>
<td>$E_y (\text{same})$</td>
<td>Sect 3.4</td>
<td>Varied Traffic Levels under examination</td>
</tr>
<tr>
<td>$E_y (\text{opp})$</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

**SOURCE:** ICAO Doc 9689 Appendix A: GENERAL COLLISION RISK MODEL FOR DISTANCE-BASED SEPARATION ON INTERSECTING AND COINCIDENT TRACKS
## Model Parameter Scaling

### Vertical Risk

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Manned ARINC [x]</th>
<th>UAV Extrapolation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAD Typical Performance Parameter within DDE: A1</td>
<td>22.3</td>
<td>2</td>
</tr>
<tr>
<td>AAD Non-Nominal Performance Parameter within DDE: A1</td>
<td>123.9</td>
<td>12</td>
</tr>
<tr>
<td>AAD: Alpha</td>
<td>1.1e-5</td>
<td>1.1e-5</td>
</tr>
<tr>
<td>ASE Mixture Overall Mean</td>
<td>4.38 ft</td>
<td>0 ft</td>
</tr>
<tr>
<td>ASE Mixture Overall SD</td>
<td>44.14 ft</td>
<td>25 ft</td>
</tr>
<tr>
<td>( P_z(0) )</td>
<td></td>
<td>0.0393</td>
</tr>
</tbody>
</table>

And Many more……

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Parameter Selection
Tuning, Tuning and More Tuning

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Summary

- Separation by segregation is not scalable for any UTM which wants to be commercially viable
- Needs a separation standard: how far apart should we put UAV Traffic: in each dimension.
- Needs improved data on sensor performance variability, traffic projection, LTE network latency.
- What TLS? Will RNP and Height Keeping Standards Apply.
  - If not, what?
- Who will drive this standard? Will there even be one?
THE END
References

[10] RTCA DO-362, C2 Data Link Minimum Operational Performance Standards (Terrestrial), September 2017
[16] H.W Kim, “Presentation to RTCA SC-228 on CNCP Architecture”, ETRI Korea, 2017
[17]
[18]
[19] FAA Safety Management System (SMS) and Acquisition Management System (AMS) Guidance Document

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