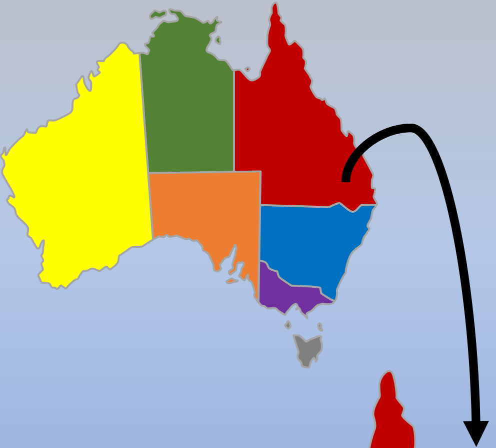
CNPC Implications for UTM Separation Standards

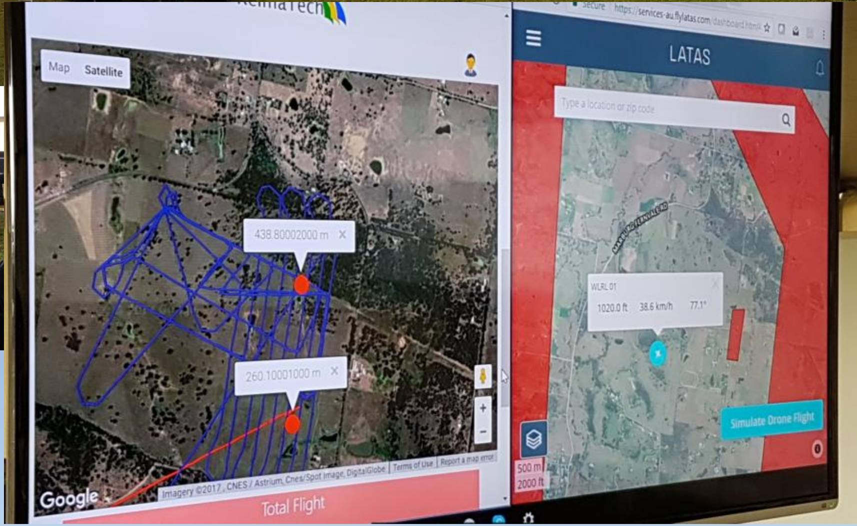
Dr Terrence Martin & Dr Aaron McFadyen

ICAO Unmanned Aircraft Systems (UAS) Industry Symposium
22-23 September 2017

Research Motivation

Australian UTM BVLOS Trials





Research Background

Australian UTM BVLOS Trials

RPAS Operators

SCOUT aerial media & surveying

Little Ripper LifeSAVER ...to the rescue

V-TOL AEROSPACE AUTONOMOUS ROBOTIC INTELLIGENCE

Trial Management

Nova Systems — Experience Knowledge Independence

lgis Local Government Infrastructure Services

UTM Providers

LATAS FLY SAFER

AIRMAP

SKYVUE from agi

SIAM Secure Integrated Airspace Management

QUT

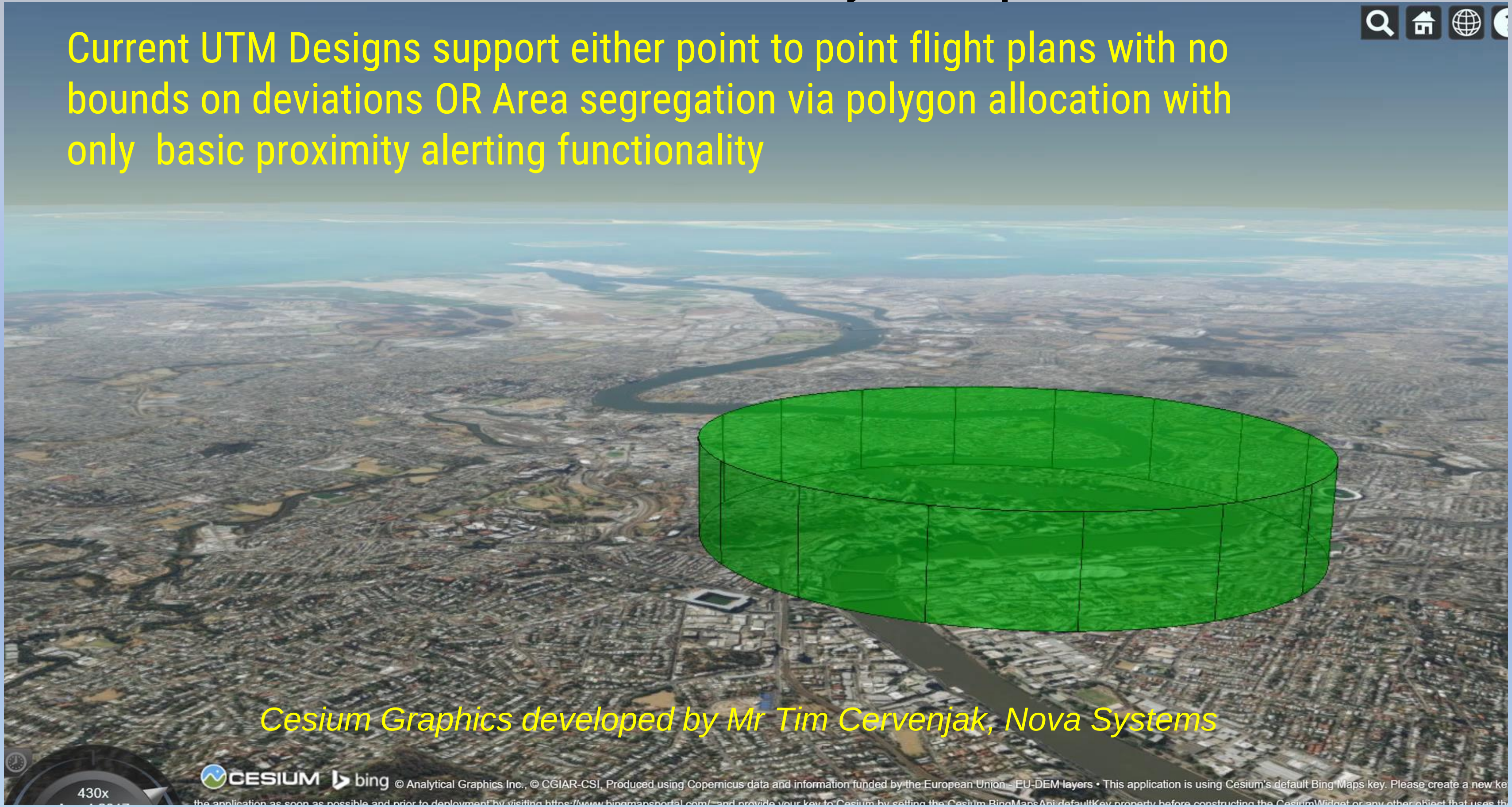
Research Background

UTM Trial Take Aways

Nova Systems
Experience Knowledge Independence

- Separation
- Sensor Referencing & Accuracy
- System Latency

Research Background
UTM Trial Take Aways: Separation



Nova Systems

Experience Knowledge Independence

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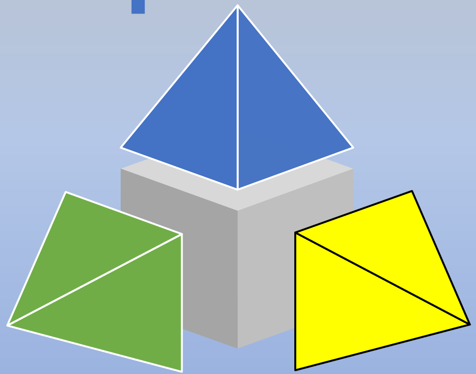
WON'T SCALE AS MORE AIRCRAFT COMPETE FOR SAME AIRSPACE

DOESNT CATER for PLATFORMS WANTING to FLY BVLOS from A to B

Introduction: Our Contribution

Nova Systems
Experience Knowledge Independence

Separation



Part 1 Communication

Part 2 Geofencing

Dr Terrence Martin

Examination of CNS role in separation and subsequent geofence parameters for UTM

Focusing on support to major distribution routes ie enroute

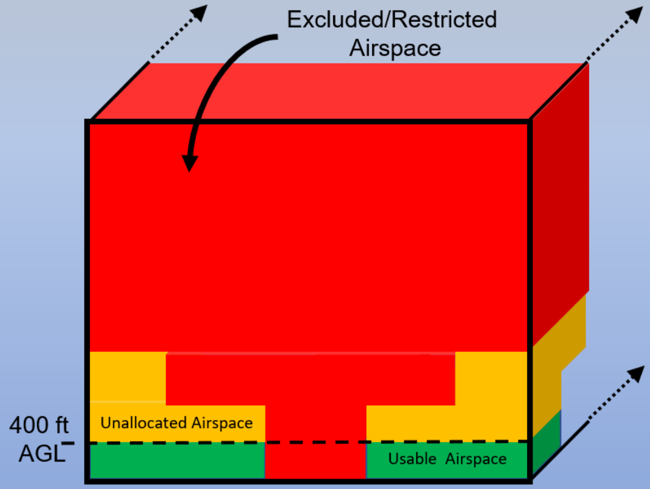
Dr Aaron McFadyen

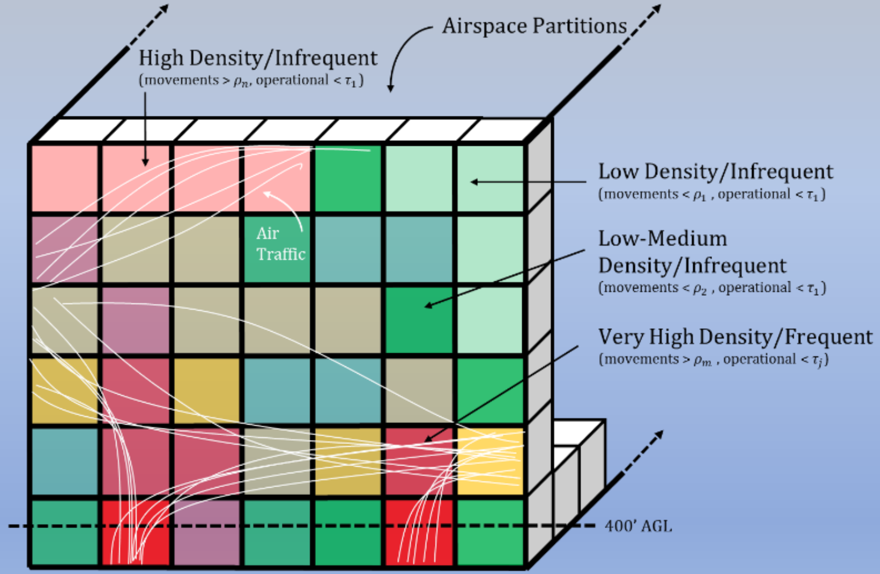
Data-driven, risk-based ATM to establish safe and efficient volumetric separation principles to underpin geofencing boundaries

Focusing on the terminal and aerodrome environment

Introduction

QUT Contribution Part 2: Dr Aaron McFadyen



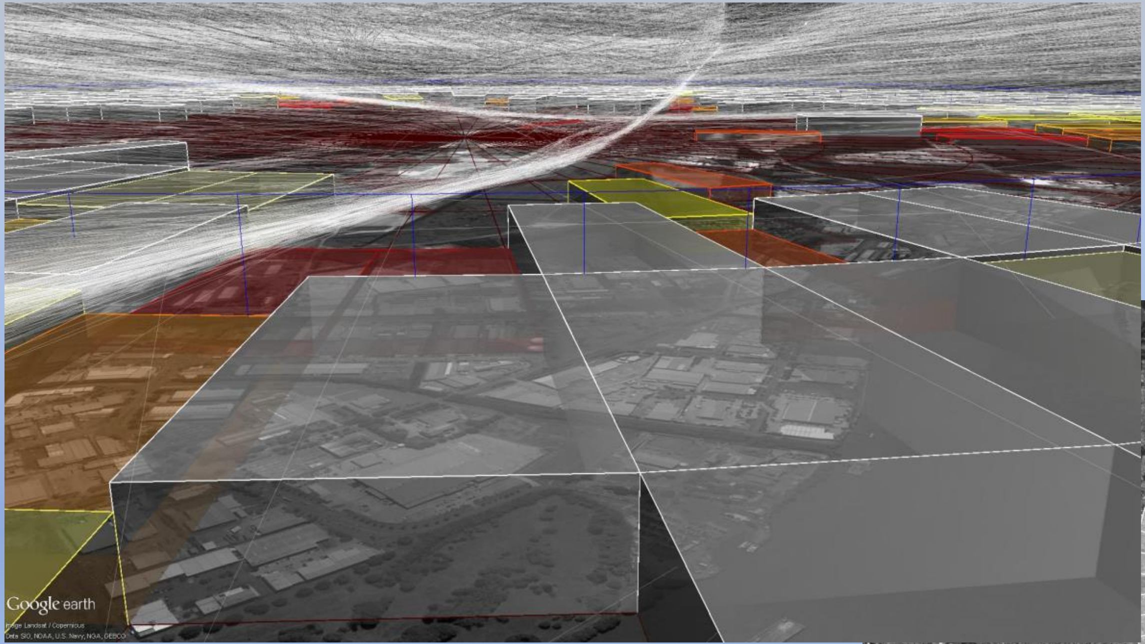


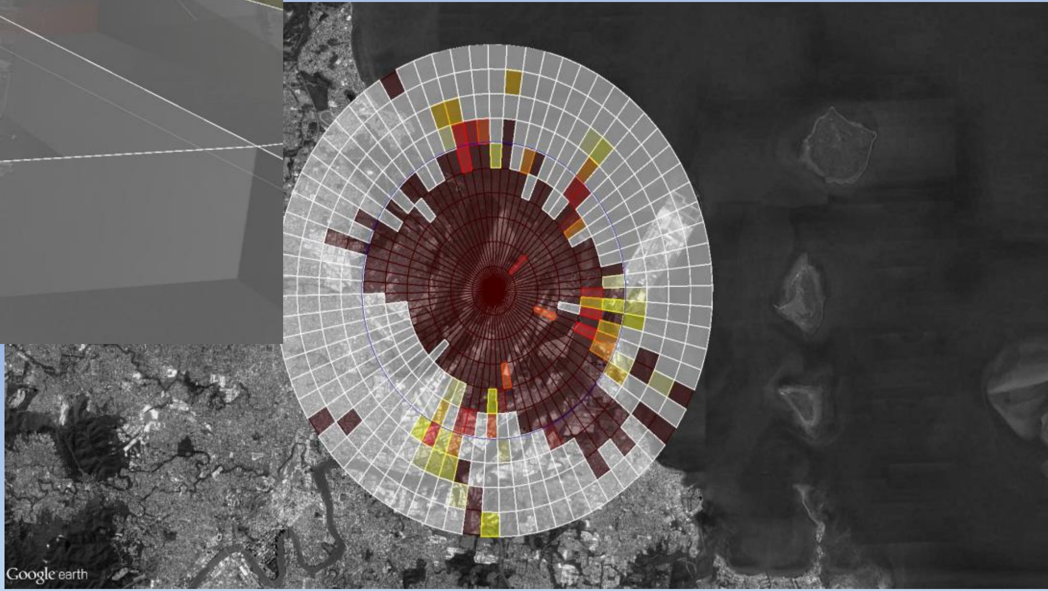
(b)

- 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





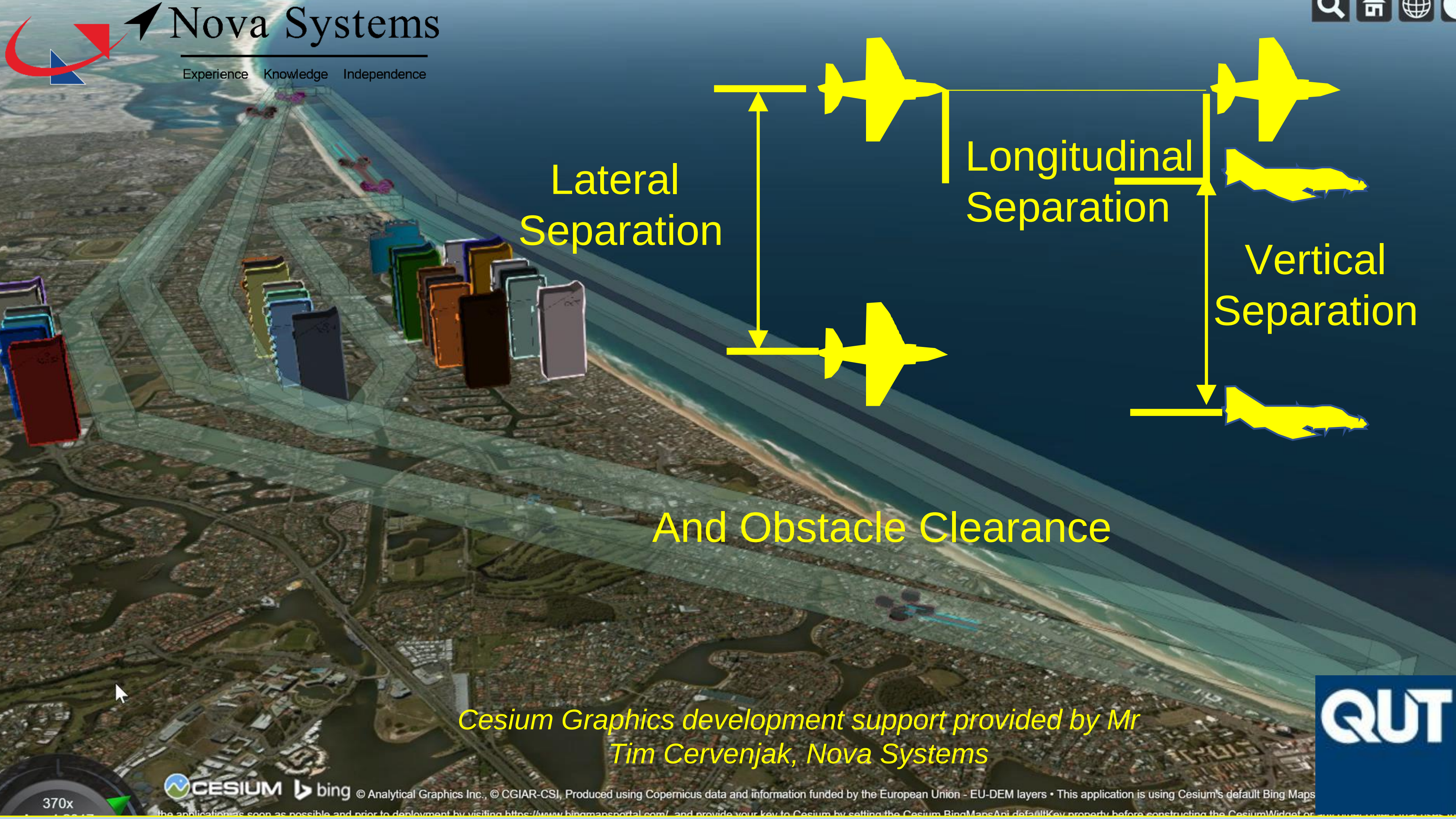
Nova Systems
Experience Knowledge Independence

UTM Trial Take Aways: Suitable Separation Standards

- Trial environment needed procedural separation backup,

Cesium Graphics development support provided by Mr Tim Cervenjak, Nova Systems

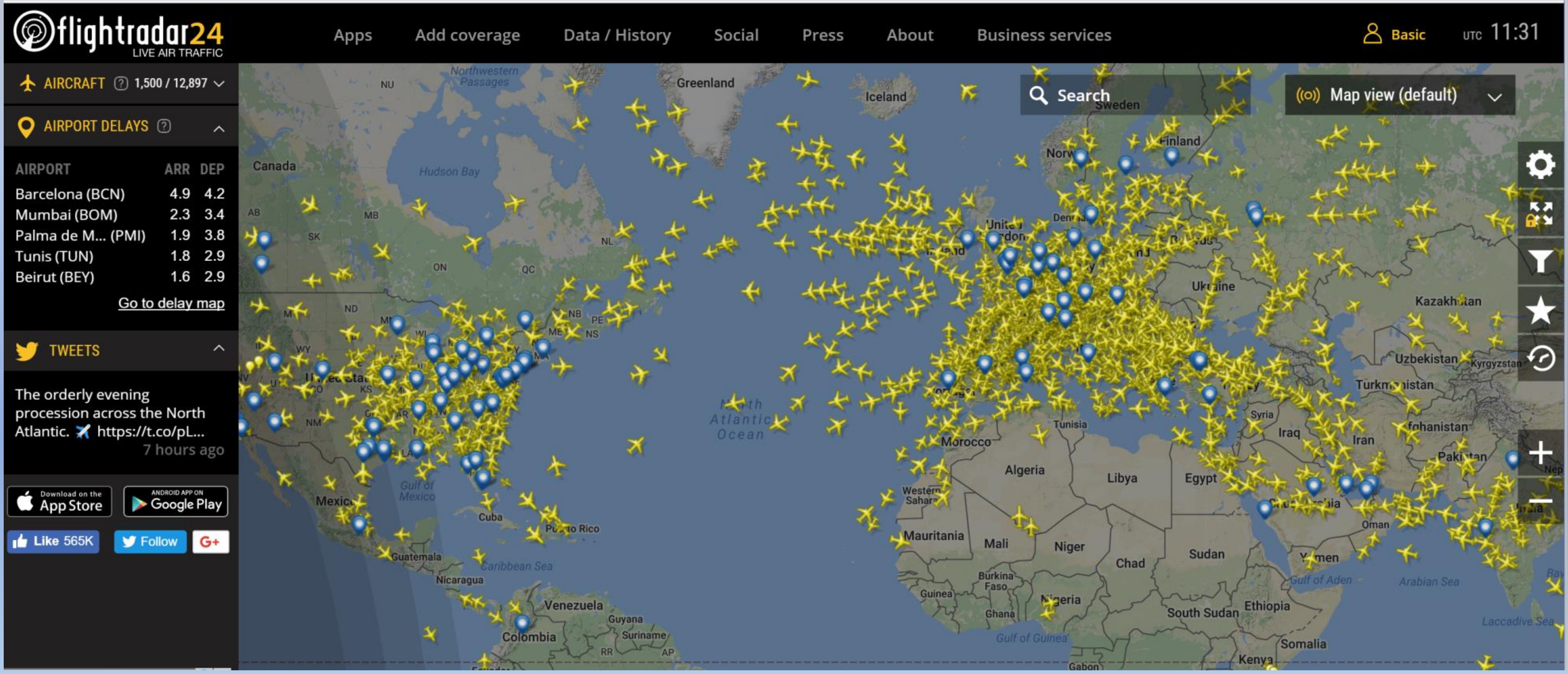
QUT



Nova Systems
Experience Knowledge Independence
Lateral Separation
Longitudinal Separation
Vertical Separation
And Obstacle Clearance
Cesium Graphics development support provided by Mr Tim Cervenjak, Nova Systems
QUT
CESIUM
bing
© Analytical Graphics Inc., © CGIAR-CSI, Produced using Copernicus data and information funded by the European Union - EU-DEM layers • This application is using Cesium's default Bing Maps
370x

CNS, Separation and Reich

Whats useful in traditional Airspace



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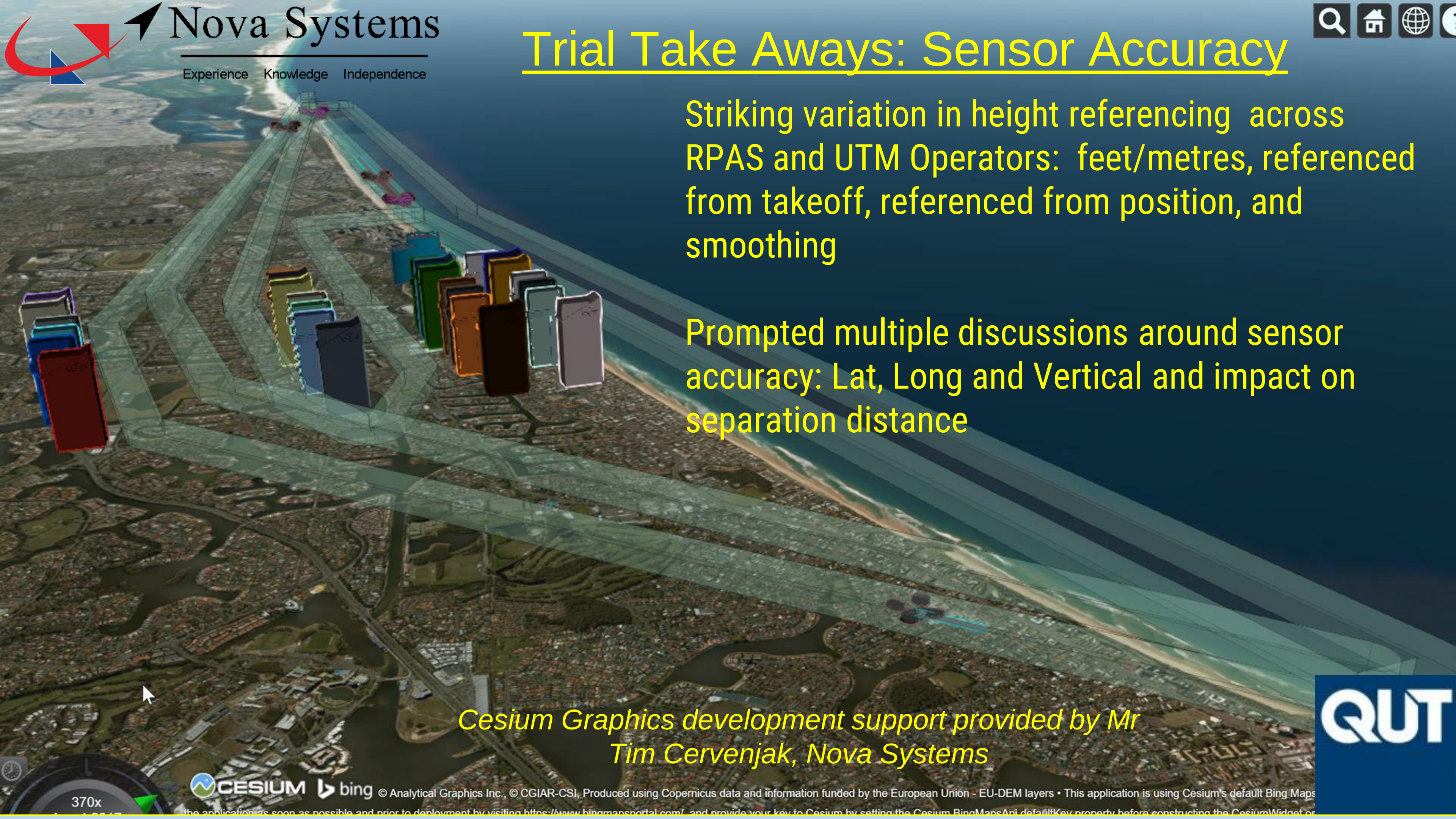
Trial Take Aways: Sensor Accuracy

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

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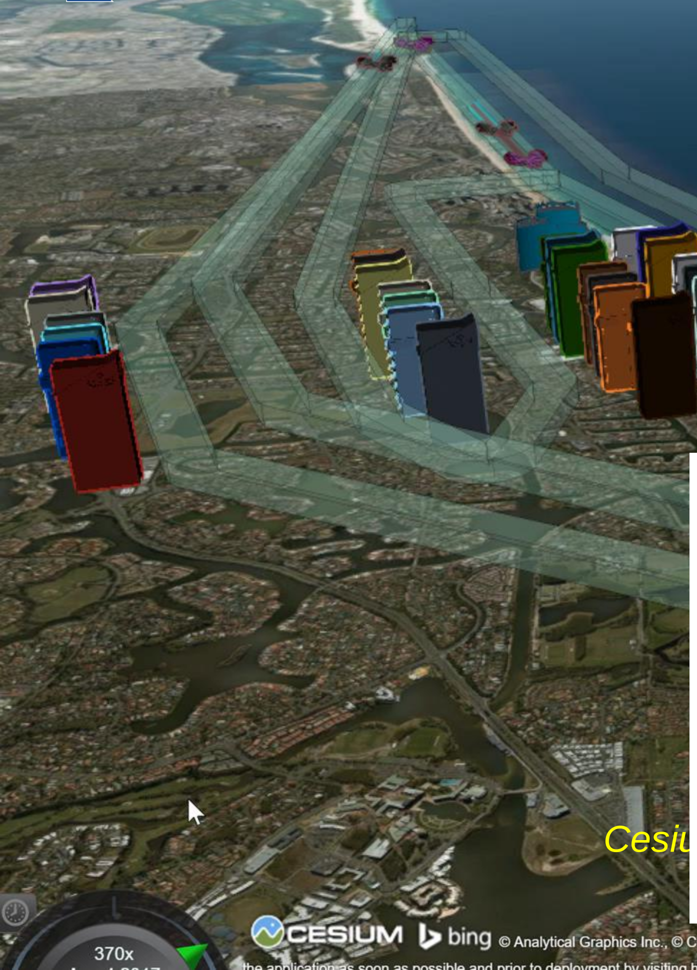
Experience Knowledge Independence

Collision Risk Model needs to acknowledge limits:

- Pitot Static
- GPS and geofence boundary coupling

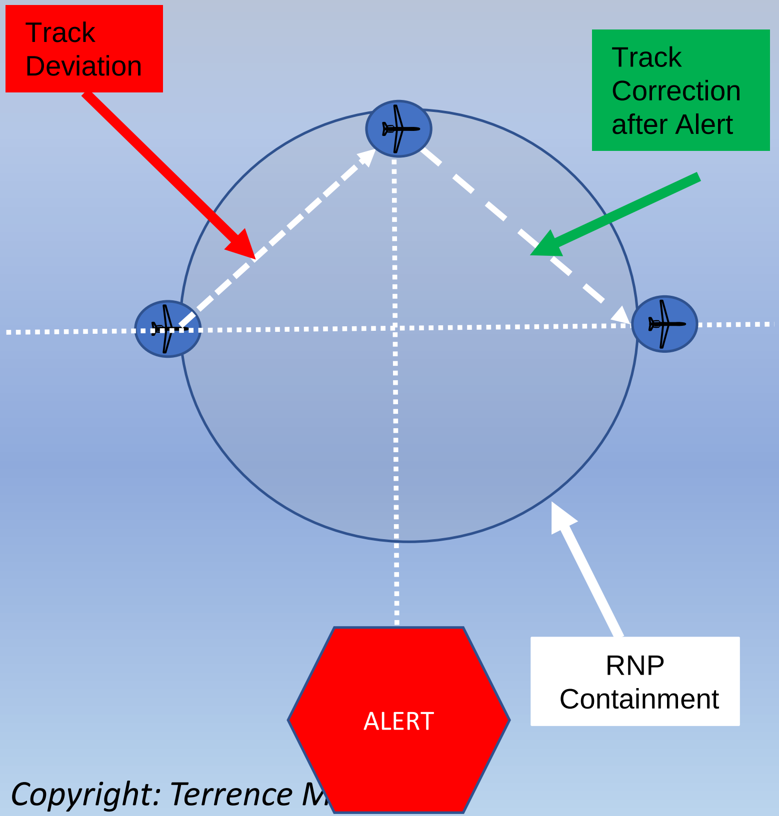


PRESSURE OUTPUT CHARACTERISTICS (V_{DD} = 3 V, T = 25°C UNLESS OTHERWISE NOTED)

Parameter	Conditions		Min.	Typ.	Max	Unit
Operating Pressure Range	P_{range}	Full Accuracy	450		1100	mbar
Extended Pressure Range	P_{ext}	Linear Range of ADC	10		1200	mbar
Total Error Band, no autozero	at 25°C, 700..1100 mbar at 0..50°C, 450..1100 mbar at -20..85°C, 450..1100 mbar at -40..85°C, 450..1100 mbar		-1.5 -2.0 -3.5 -6.0		+1.5 +2.0 +3.5 +6.0	mbar
Total Error Band, autozero at one pressure point	at 25°C, 700..1100 mbar at 10..50°C, 450..1100 mbar at -20..85°C, 450..1100 mbar at -40..85°C, 450..1100 mbar		-0.5 -1.0 -2.5 -5.0		+0.5 +1.0 +2.5 +5.0	mbar

Required Navigation Performance

Position Accuracy & Reporting Time

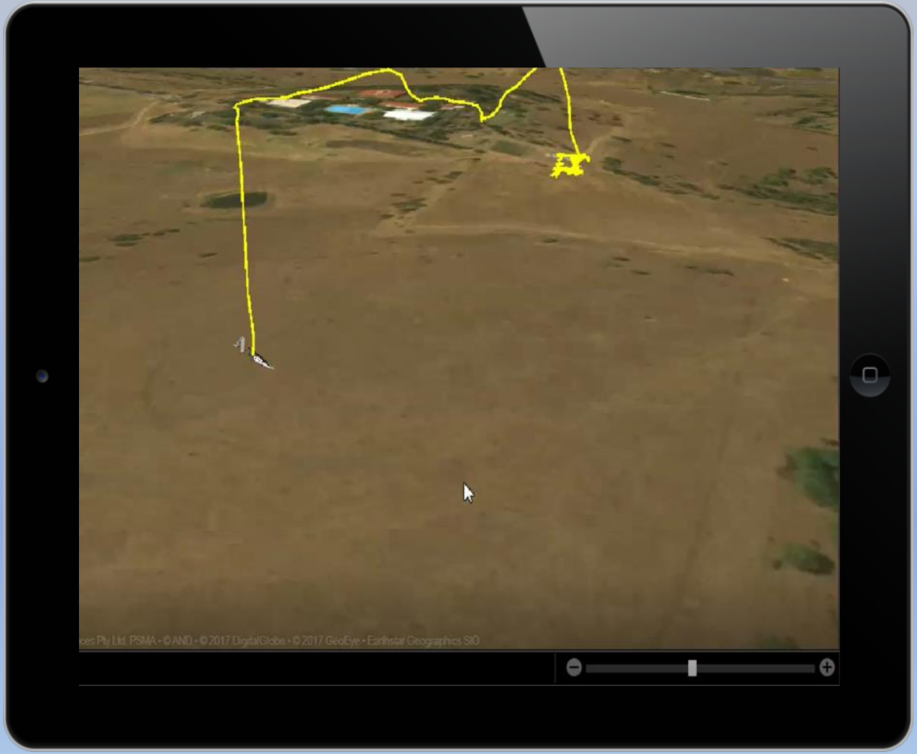


RNP expects you to:

- 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

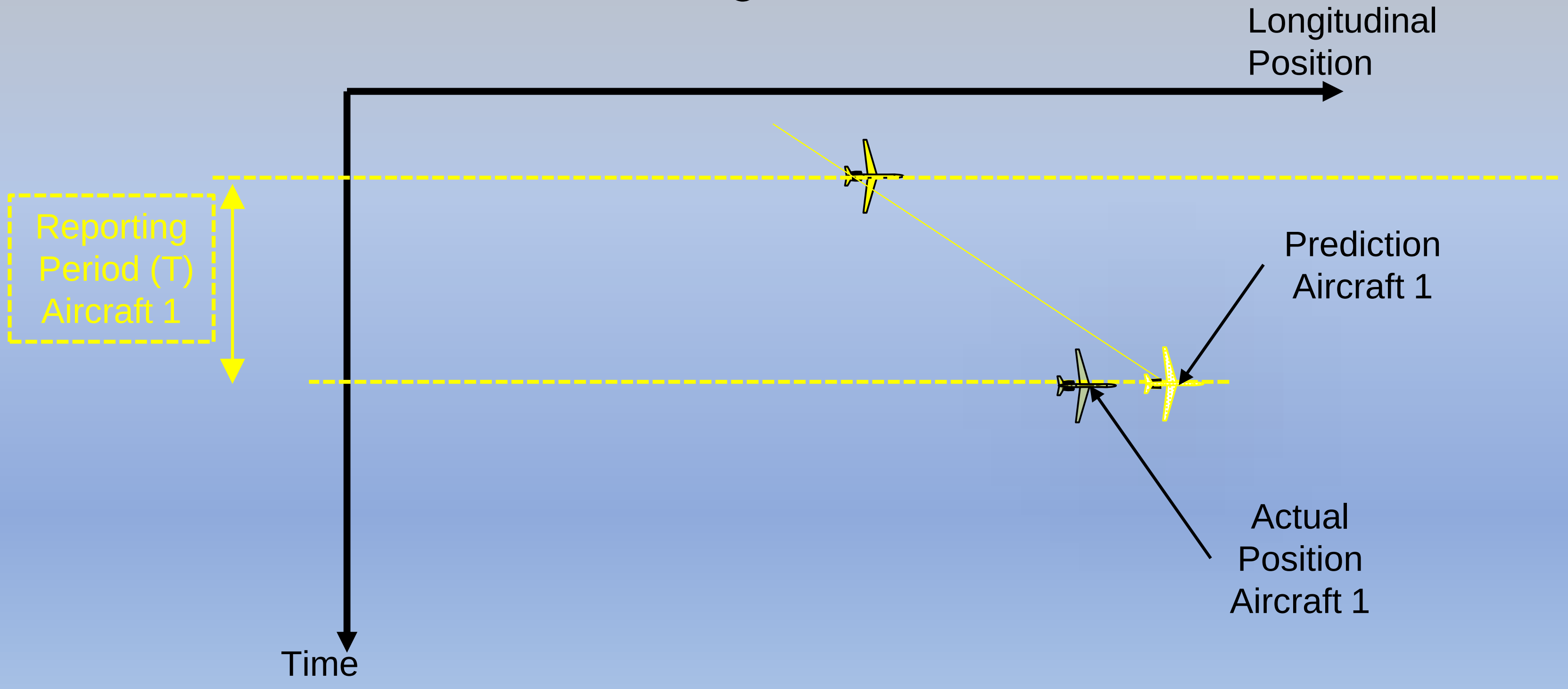
UTM Trial Take Aways



- 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

Longitudinal Separation

Overtaking Conflict: Oceanic



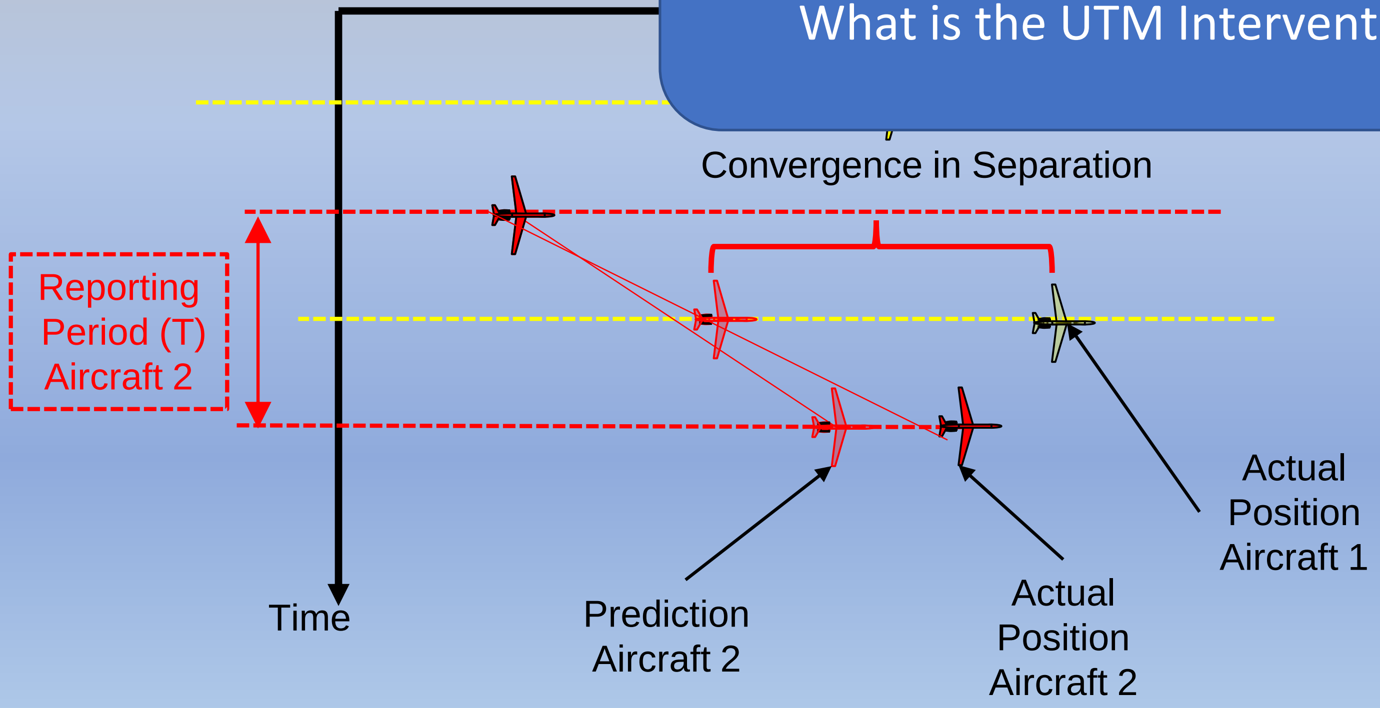
QUT

Longitu...

Overta...

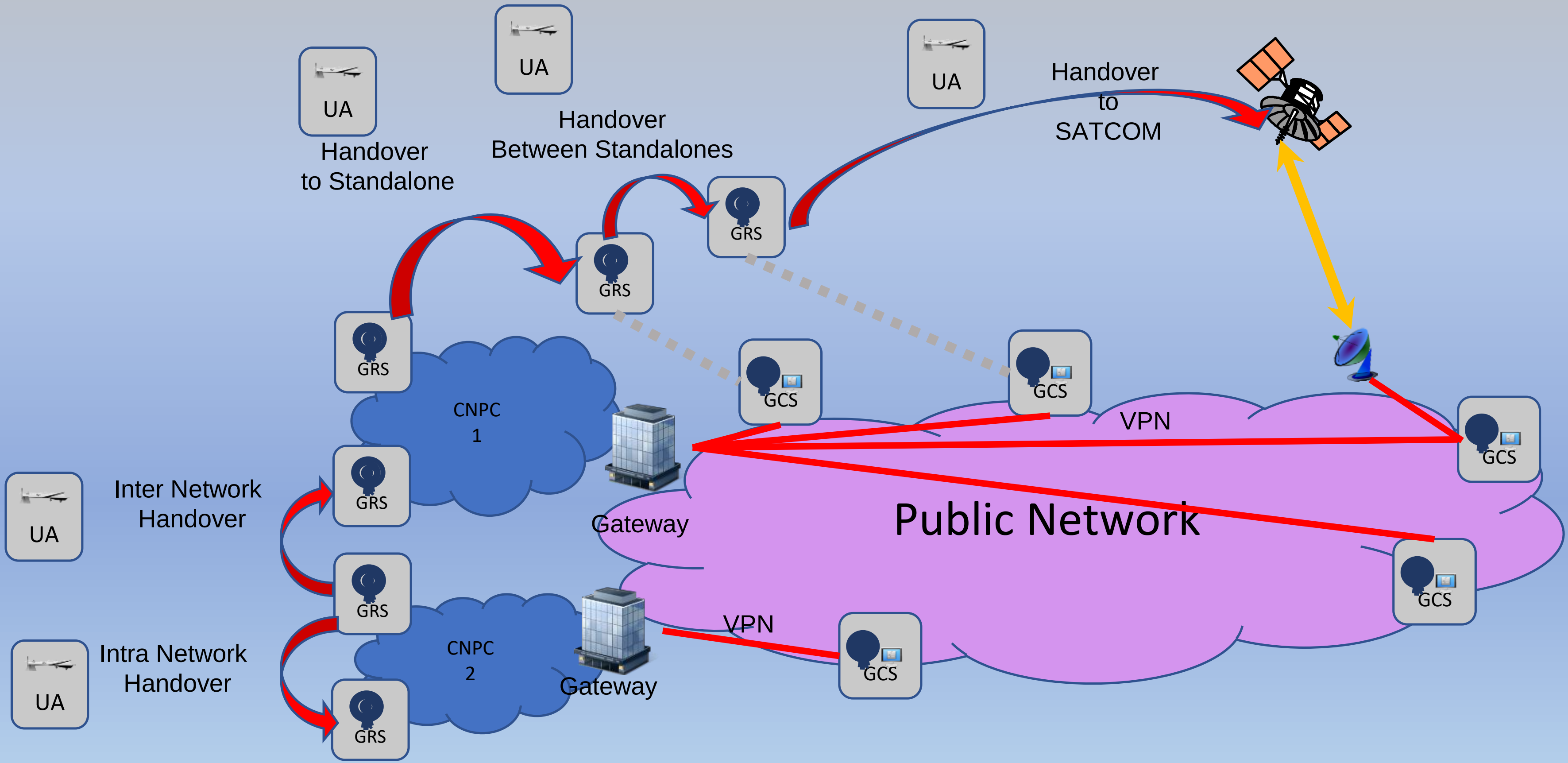
How long before they converge?

What is the UTM Intervention Time (τ)?



Derived from Example given in Fijito

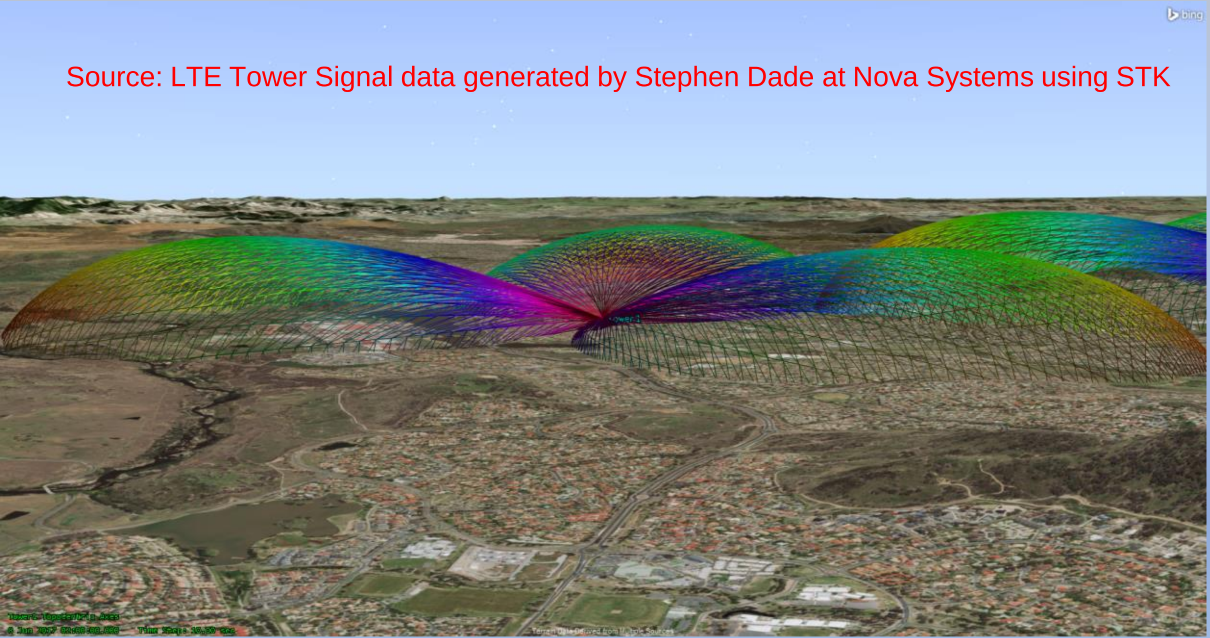
Future RPAS CNPC Infrastructure



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

Intervention

Longitudinal Separation & C2

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

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

Manned Oceanic

RNP 10
Sy=50 NM

Reporting Period (T)	Reporting Period (T)	Reporting Period (T)	Intervention τ
T=27 Mins	T=27 Mins	T=27 Mins	4-13 mins

UTM Transition

RNP 1?

Reporting Period (T) much smaller

2 mins

Prediction Error shrinks to ZERO

HITL
τ
Still substantial

CNS, Separation & the Reich Model

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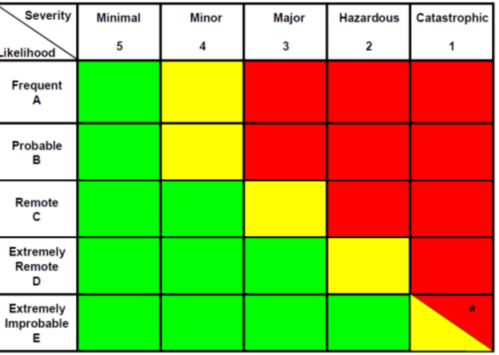
CNS and Risk

Nova Systems
Experience Knowledge Independence

Table 3.2-2: Likelihood Definitions

	NAS Systems & ATC Operational	NAS Systems		ATC Operational		Flight Procedures
	Quantitative	Qualitative				
		Individual Item/System	ATC Service/ NAS Level System	Per Facility	NAS-wide	
Frequent A	Probability of occurrence per operation/operational hour is equal to or greater than $1x10^{-3}$	Expected to occur about once every 3 months for an item	Continuously experienced in the system	Expected to occur more than once per week	Expected to occur more than every 1-2 days	Probability of occurrence per operation/operational hour is equal to or greater than $1x10^{-5}$
Probable B	Probability of occurrence per operation/operational hour is less than $1x10^{-3}$, but equal to or greater than $1x10^{-5}$	Expected to occur about once per year for an item	Expected to occur frequently in the system	Expected to occur about once every month	Expected to occur about several times per month	
Remote C	Probability of occurrence per operation/operational hour is less than or equal to $1x10^{-5}$ but equal to or greater than $1x10^{-7}$	Expected to occur several times in the life cycle of an item	Expected to occur numerous times in system life cycle	Expected to occur about once every year	Expected to occur about once every few months	Probability of occurrence per operation/operational hour is less than or equal to $1x10^{-5}$ but equal to or greater than $1x10^{-7}$
Extremely Remote D	Probability of occurrence per operation/operational hour is less than or equal to $1x10^{-7}$ but equal to or greater than $1x10^{-9}$	Unlikely to occur, but possible in an item's life cycle	Expected to occur several times in the system life cycle	Expected to occur about once every 10-100 years	Expected to occur about once every 3 years	Probability of occurrence per operation/operational hour is less than or equal to $1x10^{-7}$ but equal to or greater than $1x10^{-9}$
Extremely Improbable E	Probability of occurrence per operation/operational hour is less than $1x10^{-9}$	So unlikely that it can be assumed that it will not occur in an item's life cycle	Unlikely to occur, but possible in system life cycle	Expected to occur less than once every 100 years	Expected to occur less than once every 30 years	Probability of occurrence per operation/operational hour is less than $1x10^{-9}$



- ATM uses TLS of 5 x 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 x 10^{-6} per dimension

<u>Source:</u> *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 λ_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 λ_x (length)
  - F_y & F_z similarly defined

SOURCE: [1, 4]

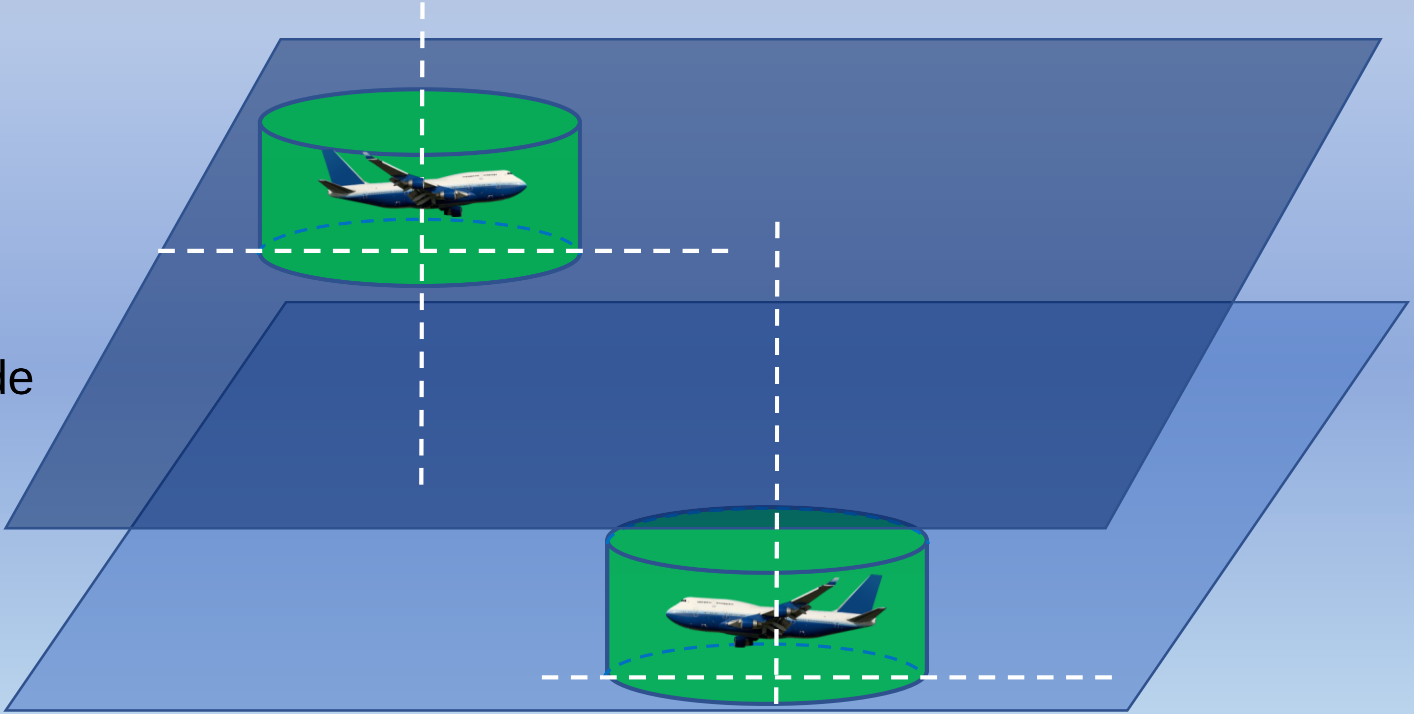
The Reich Model

Probability Vertical Overlap: $P_z(0)$

Expected # fatal accidents per flight hour

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

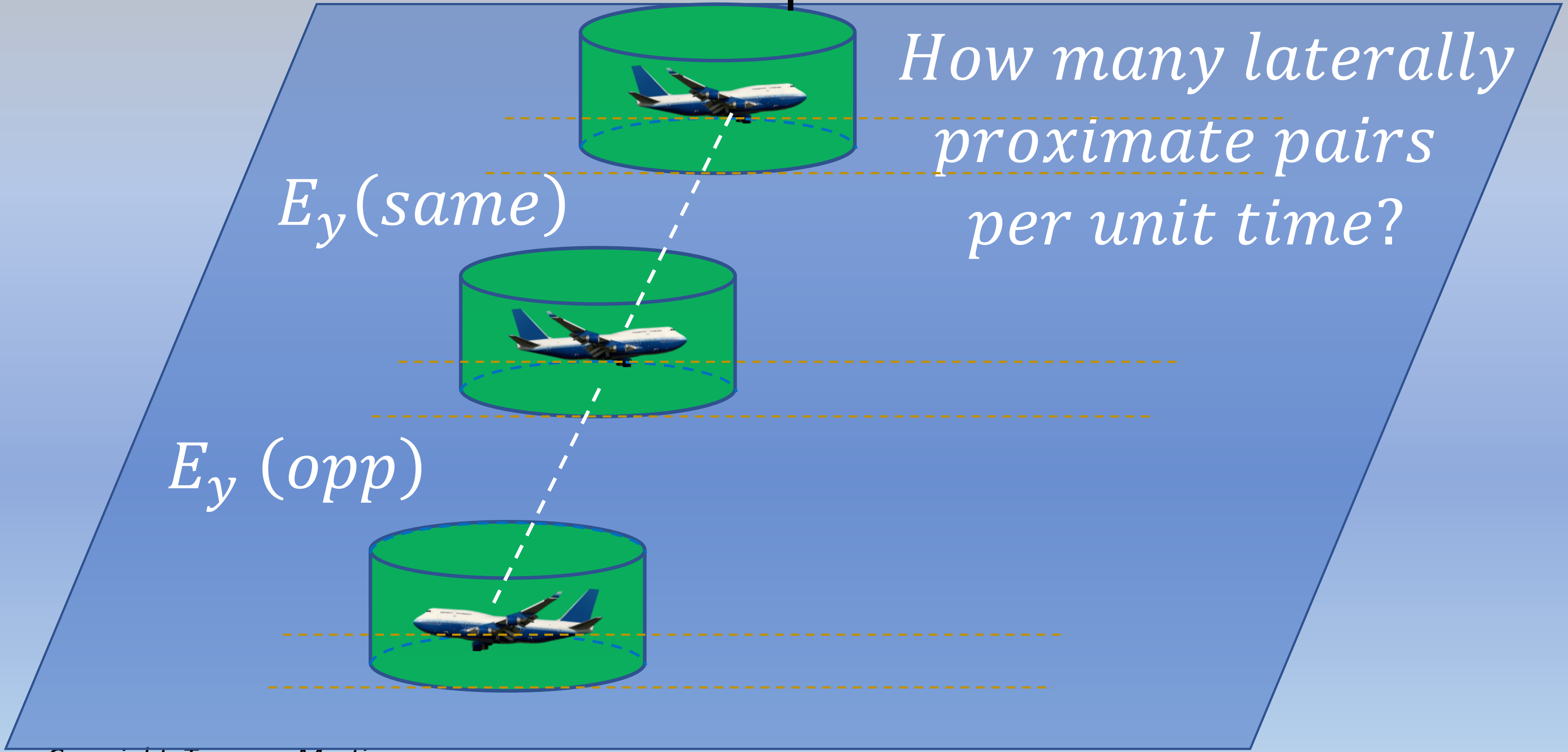
How often do the platforms move from different
flights levels to
to a coincident altitude



Linked to Altimetric Performance: Total Vertical Error (TVE)

The Reich Model

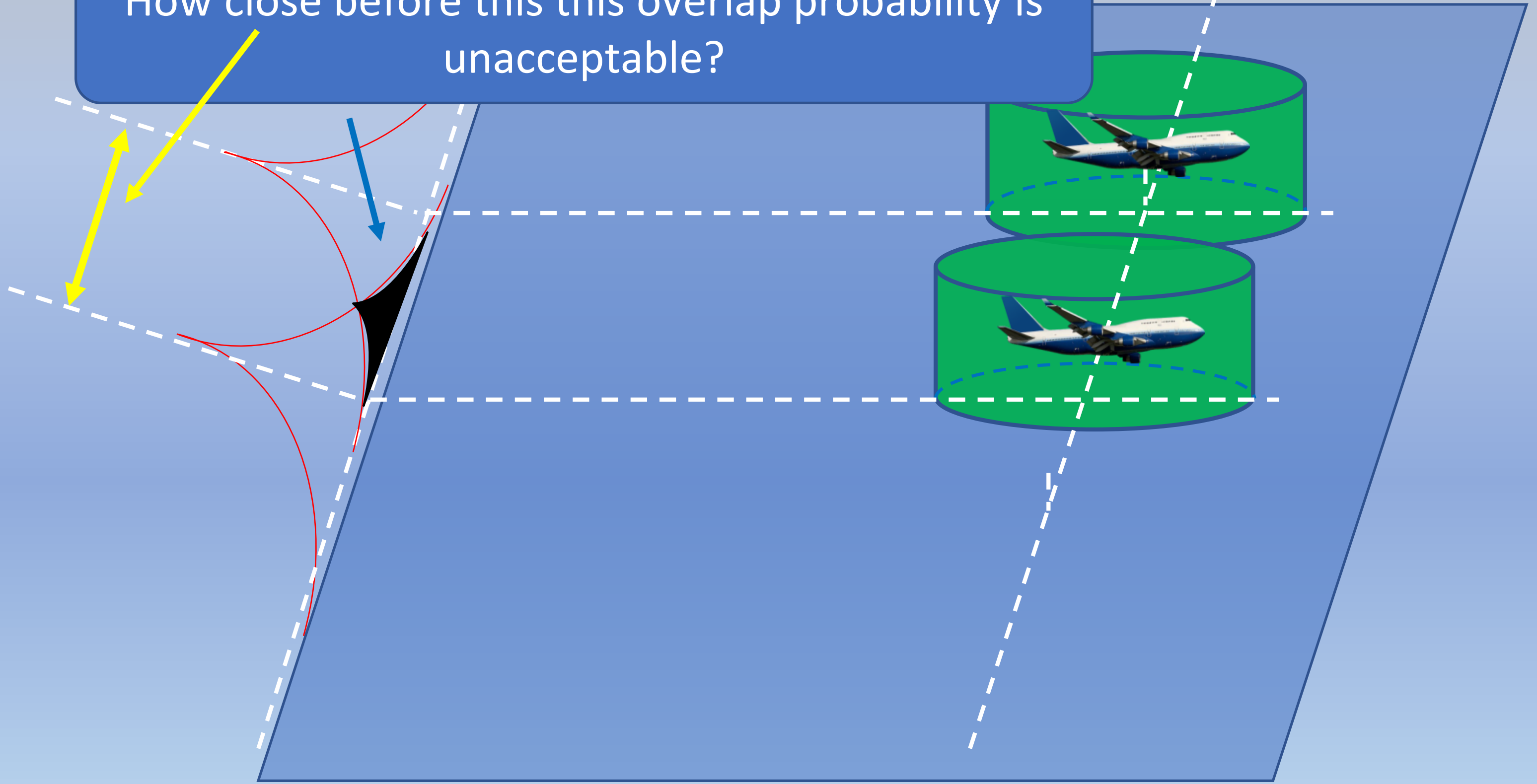
Occupancies



The Reich Model

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

How close before this this overlap probability is unacceptable?



The Reich Model

Implementation Subtleties: Lateral Separation

Expected # fatal accidents per flight hour $= P_y(S_y)P_z(0)\frac{\lambda_x}{S_x}\left[E_y(same)\left\{\frac{|\overline{\Delta V}|}{2\lambda_x}+\frac{|\overline{\dot{y}(S_y)}|}{2\lambda_y}+\frac{|\dot{z}|}{2\lambda_z}\right\}+E_y(\text{opp})\left\{\frac{2|\bar{V}|}{2\lambda_x}+\frac{|\overline{\dot{y}(S_y)}|}{2\lambda_y}+\frac{|\dot{z}|}{2\lambda_z}\right\}\right]$

Where:

$P_y(S_y)$ Prob. of Lateral Overlap at Separation (S_y)

$$= 2\lambda_y\left[\left(\frac{1-\alpha}{2a_1}\right)^2(a_1+S_y)\,e^{-\left|\frac{S_y}{a_1}\right|}+\left(\frac{\alpha}{2a_2}\right)^2(a_2+S_y)e^{-\left|\frac{S_y}{a_2}\right|}+\frac{\alpha(1-\alpha)}{2}\left\{\left(\frac{e^{-\left|\frac{S_y}{a_1}\right|}+e^{-\left|\frac{S_y}{a_2}\right|}}{a_1+a_2}\right)+\left(\frac{e^{-\left|\frac{S_y}{a_1}\right|}+e^{-\left|\frac{S_y}{a_2}\right|}}{a_1-a_2}\right)\right\}\right]$$

- **Occupancies**: $E_y(same)$ & $E_y(opp)$
- **Aircraft dimensions**: λ_x , λ_y , λ_z
- **Speeds:** relative ($|\overline{\Delta V}|$, $|\dot{z}|$, $|\overline{\dot{y}(S_y)}|$) and ground speeds ($|\bar{V}|$)
- **Navigation Performance**: Nominal & GNEs: a_1, a_2 & α
- **Nominal Separation:** Lateral (S_y), Longitudinal (S_x) + *others*…….

The Reich Model

Longitudinal Separation & C2

Collision Rate

$$= \left[\frac{2}{T} \times HOP\ (T + \tau) \times P_z(0) \times \left\{1 + \frac{|\dot{z}|}{2\Lambda_z} \times \frac{\pi \Lambda_{xy}}{2V_{rel}^{C}}\right\}\right]$$

MOST RELEVENT FOR THIS PRESENTATION

- **(T) :** Reporting Period
- (τ) : 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(Λ_x), width (Λ_y) & height (Λ_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

Nova Systems
Experience Knowledge Independence

	Manned ICAO 9689 []	UAV Extrapolation
Aircraft Width (λ_y)	193.12	3.3 feet
Aircraft Length (λ_x)	174.45 feet	3.3 feet
Aircraft Height (λ_z)	55.43 feet	1.5 feet
Average Relative longitudinal Speed $\lvert\overline{\Delta V}\rvert$	20 kts	2 kts
Average Relative Vertical Speed $\lvert\dot{z}\rvert$	1.5 kts (RNP 10)	0.15 kts
Average Relative Lateral Speed $\lvert\dot{y}\rvert$	20 kts	2 kts
Aircraft Aircraft Speed $\lvert\bar{V}\rvert$	475 kts	30 kts
Relative Velocity Collision ($2V_{rel}^{C}$)	Range: 71-95	7 kts
$E_y(same)$	Sect 3.4	Varied Traffic Levels under examination
E_y (opp)	0	

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

Model Parameter Scaling

Vertical Risk

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

And Many more……

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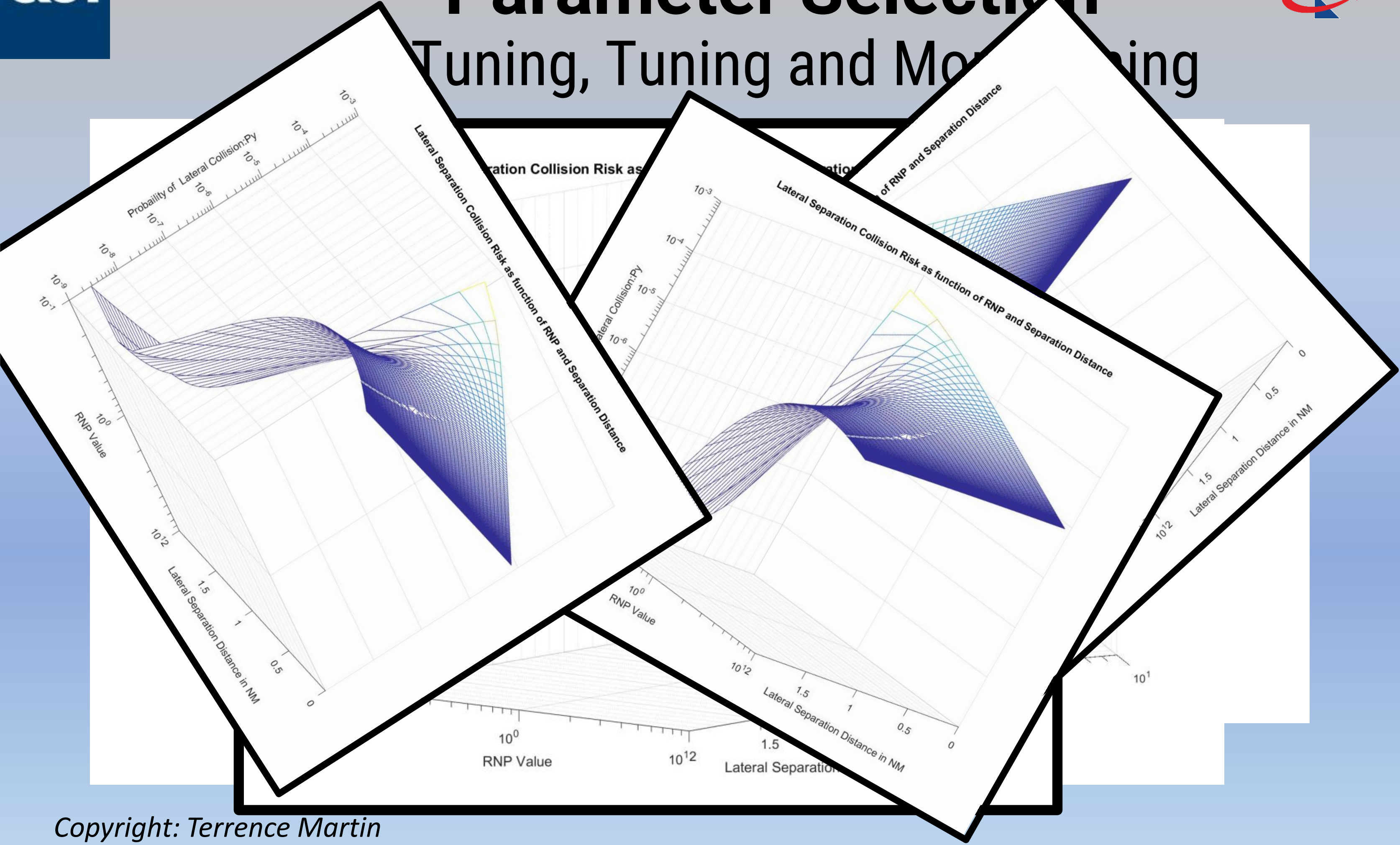
Parameter Selection

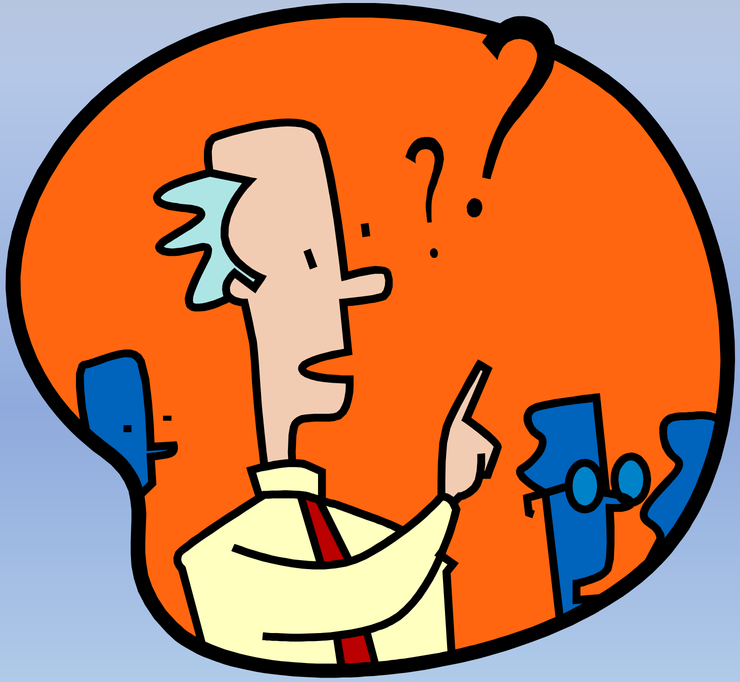
Tuning, Tuning and Mo ing



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



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[1] Reich P. G, "Analysis of Long-Range ATS Separation Standards - I, II, and III," *The Journal of (the Institute of) Navigation*, 1966
[2] S. Endoh, "*Aircraft Collision Models*", Flight Transportation Laboratory Report R82-2, 1982.
[3] ICAO Doc 9992, PBN Airspace Design Manual.
[4] ICAO Doc 9689, "*Manual on the Airspace Planning Methodology on the Determination of Separation Minima", 1998*
[5] Ryota Mori, "*Refined Collision Risk Model for Oceanic Flight Under Longitudinal Distance-Based Separation in ADS-C Environment",* The Journal of Navigation (2014), 67, 845–868.
[6] Geert Moek, Edward Lutz, William Mosberg, "*Risk Assessment of RNP10 and RVSM in the South Atlantic Flight Identification Regions",* ARINC Incorporated, *May 7, 2001*
[7] D. Anderson, Dr. X.G. Lin, "*An Extended Methodology for the Longitudinal Same Track Separation*", RGCSP/10-WP/9 11/4/00 10th MEETING Montreal, May 2000
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[18]
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