Aerial Robotix
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A Practical Deconfliction Model for BVLOS RPAS Operations in Manned Airspace

An Operational Case Study from the Niger Delta

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Executive Summary

This paper demonstrates that safe and scalable BVLOS RPAS operations in manned airspace are achievable today using existing aviation systems. Based on over 4,000 flight hours and 390,000 km of incident-free operations in a high-density helicopter environment, it presents a proven deconfliction framework integrating cooperative surveillance, ATC coordination, and structured procedural controls. The approach is supported by empirical risk quantification, human factors analysis, and alignment with international regulatory principles. While UTM is recognised as a key future enabler of scale, this work shows that safe BVLOS integration does not depend on its immediate availability. Instead, it provides a practical, evidence-led model for regulators and operators to enable responsible expansion of BVLOS operations in mixed airspace today.

A Practical Deconfliction Model for BVLOS RPAS Operations in Manned Airspace

1. Introduction

This paper aims to demonstrate that safe BVLOS RPAS operations in manned airspace are achievable today using existing aviation infrastructure, and to provide an empirical basis for regulatory confidence and expansion.

The integration of Remotely Piloted Aircraft Systems (RPAS) into manned airspace remains one of the most critical challenges in modern aviation. While concepts such as UTM (Unmanned Traffic Management) continue to evolve, real-world operations—particularly in complex environments like oil and gas regions—require immediate, reliable, and scalable solutions.

This paper presents a **proven deconfliction framework** developed and executed by Aerial Robotix (ARX), supporting long-range BVLOS operations in the Niger Delta since September 2022.

Operating in airspace heavily utilized by crew-change helicopters, ARX has successfully flown **over 390,000 km (equivalent to ~10 circumnavigations of the Earth)** without incident, using a layered and cooperative surveillance model.

2. Operational Environment

The Niger Delta presents a uniquely challenging airspace environment:

- High density of **low-level helicopter traffic** (oil & gas crew changes)
- Limited radar coverage in certain regions
- Mixed equipage of manned aircraft (primarily Mode S, TCAS II)
- Dynamic and often uncontrolled airspace structures

Helicopters typically operate with:

- **Mode S transponders**
- **TCAS II systems**
- **No ADS-B In capability**

This creates an asymmetry:

- RPAS can see manned aircraft (ADS-B In), but
- Manned aircraft cannot directly see RPAS via ADS-B Out.

3. ARX Deconfliction Architecture

ARX employs a **multi-layered cooperative surveillance and procedural deconfliction model**, combining onboard systems, ground-based awareness, and ATC integration.

3.1 Airborne Systems

- **Mode S Transponder (RPAS)**
- Ensures visibility to Secondary Surveillance Radar (SSR)
- Enables ATC tracking and integration into controlled airspace
- **ADS-B Out**
- Broadcasts RPAS position to cooperative systems
- **ADS-B In (Onboard)**
- Provides real-time situational awareness of surrounding traffic
- Enables remote pilot level tactical deconfliction

3.2 Ground-Based Surveillance Layer

- Dedicated **ADS-B receivers at each RPAS base**
- Independent traffic awareness layer
- Redundancy to onboard systems
- Supports GCS operators with wider situational picture

3.3 ATC Integration

- Coordination with **Port Harcourt Air Traffic Control**
- RPAS visible via SSR due to Mode S
- ATC provides:
- Traffic information
- Strategic separation
- Vectoring support where required

This creates a **hybrid surveillance model**:

- RPAS sees traffic (ADS-B In)
- ATC sees RPAS (SSR)

- ATC manages manned aircraft (TCAS / Mode S environment)

3.4 Procedural Deconfliction Measures

- **NOTAM publication** prior to operations
- **24-hour flight plan distribution** to:
- Oil & gas operators
- Helicopter service providers
- Local aviation stakeholders
- Defined operational corridors and altitude blocks
- Pre-coordination with frequent airspace users

3.5. Human Factors Consideration (Crew Awareness Asymmetry)

A key characteristic of the operational environment is the asymmetry in airborne traffic awareness and alerting.

ARX RPAS are equipped with Mode S transponders and are therefore electronically conspicuous to Secondary Surveillance Radar (SSR) and interrogable by TCAS II–equipped aircraft. However, in practical terms, TCAS II alerting performance against small RPAS may be limited by system thresholds, relative geometry, and operational flight profiles. As a result, flight crews cannot be assumed to receive consistent or timely Resolution Advisories (RA) or Traffic Advisories (TA) relating to RPAS operations.

This introduces a human factors consideration whereby the cockpit crew may not be reliably alerted to RPAS presence through onboard systems alone.

Mitigation Strategy

The ARX operational model addresses this through layered, human-centric barriers:

- **ATC Traffic Information**
    - Primary real-time crew awareness mechanism
    - RPAS visibility via Mode S enables ATC-mediated deconfliction
- **Strategic Awareness**
    - NOTAM publication
    - 24-hour flight plan distribution
    - Known operating areas and corridors
- **Operational Predictability**

  - Defined altitude blocks
  - Repeatable mission profiles

Safety Position

ATC traffic advisory therefore functions as a **tactical backstop rather than the primary defence layer**.

Primary separation is achieved through:

- Strategic deconfliction
- Procedural coordination
- Remote pilot situational awareness

This approach reduces reliance on:

- TCAS alerting behaviour
- Time-critical cockpit response under workload and ensures that separation is maintained through **predictable, layered, and system-supported mechanisms**.

4. Deconfliction Model: Layered Safety Concept

The ARX system is built on **defence-in-depth principles**, combining:

Layer 1 – Strategic Deconfliction

- NOTAMs
- Flight plan sharing
- Stakeholder coordination

Layer 2 – ATC Tactical Oversight

- SSR tracking via Mode S
- ATC traffic advisories and vectoring

Layer 3 – Operator Situational Awareness

- ADS-B In onboard RPAS
- Ground-based ADS-B monitoring

Layer 4 – Pilot/Operator Decision Making

- Real-time avoidance actions
- Procedural separation minima

4.1 Defence-in-Depth Validation (Single Failure Analysis)

Failed Layer	Remaining Mitigation	Residual Capability
ADS-B In (RPAS)	ATC + ground ADS-B + procedures	Maintained separation via ATC + strategic deconfliction
Ground ADS-B	Onboard ADS-B + ATC	Local awareness reduced, overall system intact
ATC (loss of comms)	ADS-B + procedural separation	Tactical avoidance by remote pilot
NOTAM / planning failure	ATC + ADS-B	Tactical deconfliction remains effective
Mode S failure	ADS-B + procedural separation	Reduced ATC visibility, mitigated by awareness layers

5. Operational Performance

Since September 2022:

- **>390,000 km flown BVLOS**
- **Total hours flown: >4,000**
- **Operations up to 100 km from GCS**
- **Zero airprox or mid-air incidents**
- **Data current as of: May 8, 2026**
- Continuous operations in **manned helicopter-dense airspace**

This demonstrates that **cooperative surveillance + procedural discipline + ATC integration** can deliver safe BVLOS operations today—without reliance on fully developed UTM ecosystems.

5.1. Empirical Air Risk Quantification

The ARX operational record provides a quantifiable basis for assessing air risk:

- **Total Distance Flown:** 390,000 km
- **Total Flight Hours:** 4,000
- **Recorded Airprox / Collision Events:** 0

Using a conservative statistical approach, the absence of observed collisions can be used to estimate an **upper-bound probability of collision**.

Applying a standard approximation for zero-event observations:

Upper bound probability of collision ≈ 3 / N

Where:

- **N = total exposure (flight hours)**

This yields:

Upper bound collision probability ≈ 3 / 4,000 = 7.5×10^{-4} per flight hour

Interpretation

This represents a **conservative upper bound**, not an observed rate.

- It assumes the next event could occur immediately
- It does not account for:
  - Layered mitigations
  - ATC integration
  - Strategic deconfliction

As operational exposure increases, this upper bound will reduce proportionally.

Contextual Benchmark

Relative to helicopter operations in Nigeria, which involve:

- Low altitude operations
- High traffic density
- Variable weather conditions

the ARX operational model demonstrates:

An empirically bounded air risk that is trending toward, and expected to fall within, the range of acceptable manned aviation risk levels as operational exposure increases.

Safety Position

The absence of airprox or collision events over 4,000 flight hours in a high-density, mixed-use airspace environment provides:

Strong empirical evidence that the ARX layered deconfliction model is effective in maintaining safe separation from manned aircraft.

This value represents a conservative statistical upper bound derived from zero observed events and does not reflect the true operational risk rate. Continued accumulation of flight hours will reduce this bound proportionally.

6. Comparison with UTM Concepts

Aspect	**ARX Operational Model**	**Typical UTM Concept**
Deployment	Operational today	Largely developmental
Infrastructure	Uses existing SSR + ADS-B	Requires new digital infrastructure
Airspace Integration	Fully integrated with ATC	Often parallel/unintegrated
Scalability	Proven in high-risk environment	Pre-operational in most regions
Manned Aviation Integration	Direct (ATC + Mode S)	Indirect or evolving

Key Insight: The ARX model demonstrates that **UTM is not a prerequisite for safe BVLOS operations**. Instead, UTM should enhance—not replace—proven aviation-based deconfliction methods.

This comparison does not seek to diminish the future role of UTM as a key enabler of scalable RPAS operations. Instead, it reflects the current operational reality that, in many environments, BVLOS integration must be supported by existing aviation systems and established procedural controls.

7. Key Lessons Learned

1. **Mode S remains critical** → It bridges RPAS into the existing ATC ecosystem.

2. **ADS-B In is a force multiplier** → Provides operator-level situational awareness even when manned aircraft cannot see RPAS.
3. **ATC integration is essential** → Not optional in mixed airspace environments.
4. **Procedural discipline reduces risk significantly** → NOTAMs and flight plan sharing are highly effective in oil & gas ecosystems.
5. **Layered systems outperform single solutions** → No single technology (including UTM) is sufficient alone.

8. Conclusion

ARX's operational experience demonstrates that **safe, scalable BVLOS operations in manned airspace are achievable today** using:

- Existing aviation infrastructure (SSR, Mode S)
- Cooperative surveillance (ADS-B)
- Strong ATC integration
- Robust procedural frameworks

Rather than waiting for fully implemented UTM systems, regulators and operators should consider adopting **hybrid models** that leverage proven aviation tools while incrementally integrating UTM capabilities.

Position Statement: UTM should be viewed as an **enhancement layer**, not a replacement, for established aviation deconfliction systems.

ANNEX A — REGULATORY ALIGNMENT (EASA / NCAA / SORA 2.5)

A1. Alignment with EASA Framework

The ARX deconfliction model aligns closely with the intent of the **EASA Specific Category** regulatory structure:

- **Article 11 (Risk-Based Operations)** → ARX operations demonstrate a fully risk-assessed, mitigated BVLOS model
- **Operational Authorisation Basis** → The layered architecture reflects required mitigations for:
- Air risk
- Ground risk
- Operational complexity
- **U-Space Compatibility** → The ARX model can integrate directly into U-space services:
- Strategic deconfliction → U-space planning services
- Real-time awareness → U-space tactical services

Key Position: ARX represents a **"pre-U-space operational model"** already compliant in principle with EASA's future ecosystem.

A2. Alignment with Nigerian Civil Aviation Authority

Within the Nigerian regulatory environment:

- Operations align with **Nig CARs (RPAS provisions)** requiring:
- ATC coordination
- Airspace integration
- Safety case justification
- The ARX model directly supports NCAA expectations for:
- **BVLOS operational control**
- **Airspace situational awareness**
- **Third-party risk mitigation**
- Use of:

- Mode S
- ATC integration
- NOTAMs

…demonstrates **compliance with conventional aviation safety principles**, not just emerging RPAS frameworks.

Key Position: ARX operations provide a **benchmark case study for NCAA BVLOS approvals in complex airspace**.

A3. Mapping to SORA 2.5

The ARX model aligns strongly with SORA methodology, particularly:

A3.1 Air Risk Class (ARC) Mitigation

- High helicopter density → **ARC C/D environment**
- Mitigations applied:
- Mode S visibility to ATC
- ATC tactical separation
- ADS-B situational awareness

Equivalent to **robust Strategic + Tactical Mitigation**

A3.2 Tactical Mitigation Performance (TMP)

- **Onboard ADS-B In → Tactical awareness**
- **ATC vectoring → External mitigation layer**

Combined system exceeds typical **TMP expectations**

A3.3 Strategic Mitigation

- NOTAMs
- 24-hour flight plans
- Stakeholder coordination

Strong alignment with **SORA Strategic Mitigation (M1/M2)**

A3.4 Operational Safety Objectives (OSOs)

The ARX system contributes directly to:

- **OSO #05 – Airspace Awareness**

- **OSO #06 – Traffic Separation**
- **OSO #07 – Collision Avoidance**
- **OSO #08 – External Services (ATC Integration)**

A3.5 Residual Risk Position

Based on applied mitigations:

- Air risk reduced from **high intrinsic risk → tolerable residual risk**
- Achieved through:
- Multi-layer detection
- Procedural barriers
- ATC integration

A3.6 Ground Risk Characterisation (GRC Determination)

Operational Environment Characterisation

The ARX BVLOS operational corridor within the Niger Delta is predominantly characterised by:

- **Open water environments** (rivers, creeks, offshore areas)
- **Mangrove terrain** with **very low population density**
- Limited presence of:
    - Urban settlements
    - Public gatherings
    - High-density infrastructure

As a result, operational routing is deliberately designed to maximise overwater and low-density terrain exposure wherever practicable.

RPAS Impact Energy Consideration

The RPAS platforms utilised by ARX:

- Are **significantly lower in mass** than manned aircraft
- Operate at **controlled altitudes and speeds**
- Present **limited kinetic energy at impact** relative to conventional aviation hazards

In the event of a loss of control, the combination of:

- Low population exposure
- Reduced impact energy

results in a **substantially reduced ground risk profile**.

Ground Risk Class (GRC) Position

Based on:

- Environmental characteristics (low population density)
- Operational design (controlled corridors)
- RPAS physical properties

the intrinsic Ground Risk Class (GRC) is assessed as:

Low to Moderate, prior to application of additional mitigations.

Applied Mitigations

Ground risk is further reduced through:

- **Route selection** prioritising:
    - Water bodies
    - Unpopulated terrain
- **Controlled launch and recovery areas**
- **Operational containment procedures**
- **Defined emergency response protocols**

Conclusion

The combination of environmental conditions and operational controls results in a **ground risk profile that is inherently low and consistent with SORA 2.5 expectations for BVLOS operations in sparsely populated areas.**

A4. Regulatory Positioning Statement

The ARX operational model demonstrates that:
A layered, aviation-integrated approach using existing surveillance systems (Mode S, SSR, ADS-B), combined with procedural and ATC-based mitigations, can meet or exceed the intent of modern RPAS regulatory frameworks including EASA Specific Category and SORA 2.5.

A5. Strategic Implication for Regulators

- UTM/U-space should **augment**, not replace:
- ATC integration
- Cooperative surveillance
- Procedural aviation discipline
- Proven operational models such as ARX should be used as:
- **Reference cases for regulatory evolution**
- **Validation inputs for SORA refinement**
- **Benchmark for BVLOS approvals in complex environments**

ANNEX B — ICAO RPAS Integration Alignment

The ARX operational model demonstrates practical implementation of ICAO guidance for the integration of RPAS into non-segregated airspace.

ARX operations demonstrate that ICAO-aligned RPAS integration is achievable today without reliance on future UTM systems, through the effective use of Mode S surveillance, ATC integration, and distributed detect-and-avoid methodologies.

This alignment is demonstrated through application of:

- ICAO Doc 10019
- ICAO Annex 19

B1. Integration into Air Traffic Management (ATM)

ICAO requires that RPAS operations integrate into existing Air Traffic Management (ATM) systems rather than operate as parallel or segregated structures.

The ARX model achieves this through:

- **Mode S transponder equipage**
    - Ensures visibility to Secondary Surveillance Radar (SSR)
    - Enables integration into controlled airspace
- **ATC coordination**
    - Continuous interaction with Air Traffic Control
    - Traffic information and tactical deconfliction
- **Shared airspace operations**
    - RPAS operate alongside manned aircraft under standard aviation frameworks

Position:

ARX operations are fully integrated into the existing ATM environment, consistent with ICAO principles.

B2. Detect and Avoid (DAA) Implementation

ICAO guidance recognises that Detect and Avoid capability may be achieved through a combination of:

- Airborne systems
- Ground-based systems
- Procedural mitigations

The ARX system implements a **distributed DAA model**:

DAA Function	ARX Implementation
Traffic detection	ADS-B In (onboard) + ground receivers
Traffic awareness	GCS + remote pilot
Separation	ATC + procedural controls
Avoidance	Remote pilot decision-making + ATC vectoring

Position:

The ARX model satisfies ICAO DAA intent through layered and complementary systems rather than reliance on a single onboard solution.

B3. Cooperative Surveillance

ICAO promotes the use of cooperative surveillance systems to support airspace integration.

ARX implements:

- **Mode S transponders**
    - Visibility to SSR and ATC systems
- **ADS-B (Out and In)**
    - Broadcast of RPAS position
    - Receipt of surrounding traffic information

Position:

ARX leverages established aviation surveillance infrastructure, ensuring compatibility with existing manned aviation systems.

B4. Human Factors and Crew Awareness

ICAO recognises that human performance and situational awareness are critical components of safe airspace integration.

In the ARX operating environment:

- RPAS are electronically conspicuous via Mode S
- However, **cockpit alerting via TCAS II cannot be assumed to be consistent or reliable**

The ARX model mitigates this through:

- ATC traffic information (primary crew-side awareness mechanism)
- Strategic awareness (NOTAMs, flight planning)
- Predictable operational profiles

Position:

Crew awareness is supported through layered mechanisms, reducing reliance on real-time cockpit alerting and aligning with ICAO human factors principles.

B5. Safety Management (Annex 19 Alignment)

The ARX operational model reflects the principles of ICAO Annex 19:

Safety Risk Management

- Identification of:
  - High-density helicopter traffic
  - Mixed surveillance environments
- Implementation of mitigations:
  - Mode S integration
  - ATC coordination
  - Procedural deconfliction

Safety Assurance

- 390,000 km BVLOS operations
- 4,000 flight hours
- Zero airprox or collision events

Safety Promotion

- 24-hour flight plan distribution
- Stakeholder coordination
- Transparent operational intent

Position:

ARX demonstrates a practical implementation of ICAO Safety Management principles within BVLOS RPAS operations

B6. Strategic Positioning

The ARX operational model demonstrates that:

Safe integration of RPAS into manned airspace can be achieved today through the application of ICAO-aligned principles, including cooperative surveillance, ATC integration, and distributed detect-and-avoid methodologies.

B7. Relevance to Nigerian Regulatory Context

Given that the Nigerian Civil Aviation Authority derives its regulatory framework from ICAO standards:

The demonstrated alignment of ARX operations with ICAO principles provides a strong basis for regulatory confidence in BVLOS operations within Nigerian airspace.

Conclusion and Call to Action

This paper demonstrates that safe and scalable BVLOS RPAS operations in manned airspace can be achieved today through a layered deconfliction framework grounded in procedural control, strategic coordination, and validated operational experience.

The absence of fully mature or universally deployed UTM services should not, in itself, preclude responsible BVLOS integration where alternative mitigations have been shown to be effective and proportionate to the operational risk.

This framework is intended as a practical, evidence-led reference for regulators, operators, and airspace stakeholders to support the safe expansion of BVLOS operations in mixed airspace while maintaining safety for all users and enabling operational capability at scale.

UTM remains a critical future enabler of scalable RPAS integration. This work does not seek to replace that trajectory, but to address the present operational reality: that safe BVLOS operations must, in many environments, rely on existing aviation systems and established procedural controls.

The experience presented contributes to the evolving global understanding of RPAS integration into manned airspace, demonstrating how current aviation infrastructure can support safe operations today while complementing the continued development of future traffic management frameworks.