DroneHome-2
Autonomous Return-to-Home and Landing

ESA NAVISP-EL2-232

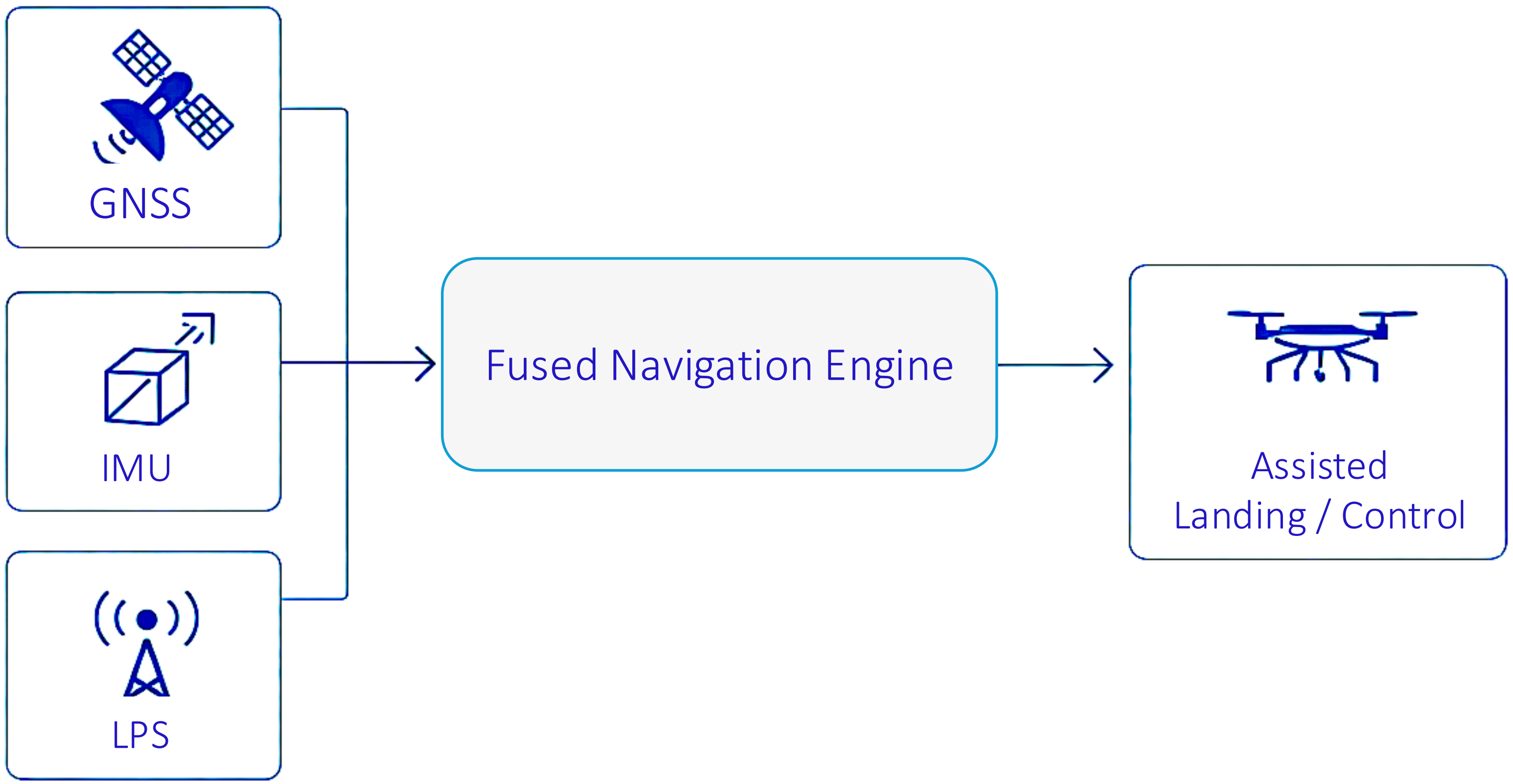
Contract No. 4000147462/25/NL/MP/dg

Project Completion Presentation - 26 February 2026

Autonomy in GNSS-Degraded Environments

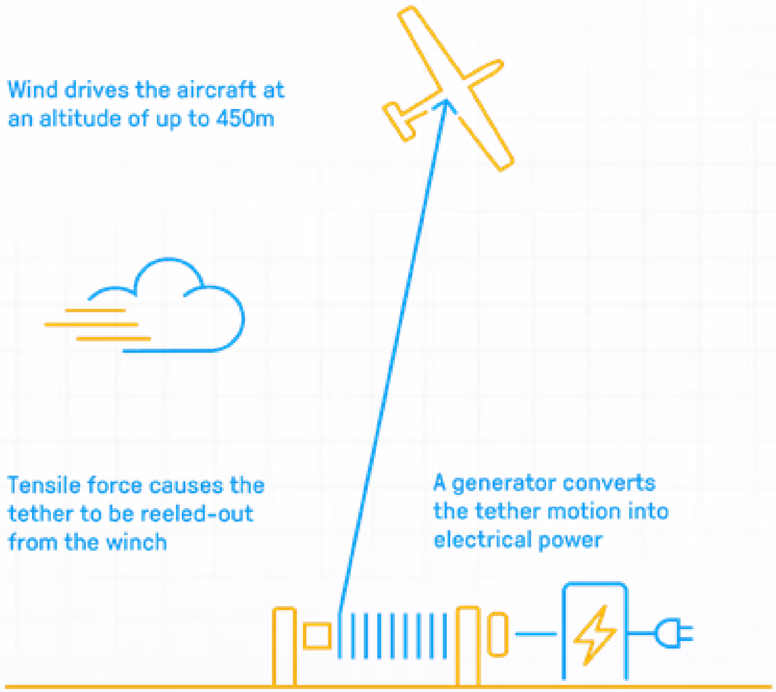
- GNSS multipath and obstruction occur near vessels and infrastructure
- Landing and return-to-home are safety-critical phases
- GNSS degradation can destabilise fused navigation
- Bounded, deterministic behaviour must be maintained

Engineering Response to GNSS Degradation



- Multi-sensor fusion (GNSS, IMU, LPS)
- Explicit estimation of clock bias and drift
- Bounded stability under degraded GNSS conditions

Programme Lineage and Transition to DroneHome-2



- DroneHome originated within NAVISP as part of AWES landing studies
- Initial activity focused on system specification and feasibility
- Programme suspension in 2022 interrupted the transition to validation
- DroneHome-2 transitions from specification ambition to quantified performance validation

Integrity Through Sensor Fusion

Issue	Mitigation Strategy
Loss of single GNSS constellation	Multi-constellation reception (GPS, GLONASS, Galileo)
Failure of single receiver	Redundant receiver architecture with voting logic
Loss of single band (jamming/interference)	Dual-band operation (L1/L2)
Design or implementation error in receiver software	Independent receiver implementation
Temporary loss of all navigation signals (e.g. extreme flight dynamics)	High-grade IMU with extended-state fusion
Loss of GNSS / RTK during approach or landing	Integrated Local Positioning System integration (**DroneHome**)

Integrity achieved through complementary sensing and state estimation

DroneHome-1 to DroneHome-2

Continuity and Completion

DroneHome-1

(AWES Application Context)

2021-22

- Integrated system architecture specified
- Navigation and LPS integration defined
- Feasibility testing preparation underway

Programme Transition

2023-24

- External industrial partner change
- Original application pathway discontinued
- Core architecture retained

DroneHome-2 (NAVISP EL2)

2025-26

- Architecture stabilised and validated
- Explicit clock modelling implemented
- Performance envelope quantified

Engineering continuity maintained; focus shifted from specification to quantified validation

DroneHome-2 Objectives

Technical Objectives

- Integrate the Local Positioning System within the navigation stack
- Explicitly model clock bias and drift behaviour
- Characterise geometry-dependent performance

Validation Objectives

- Conduct field-based flight simulations and trials
- Evaluate GNSS-enabled and GNSS-disabled scenarios
- Quantify the achievable performance envelope

Key Technical Challenges

UWB Range

- UWB Regulations
- UWB Chip power output and sensitivity

Architecture

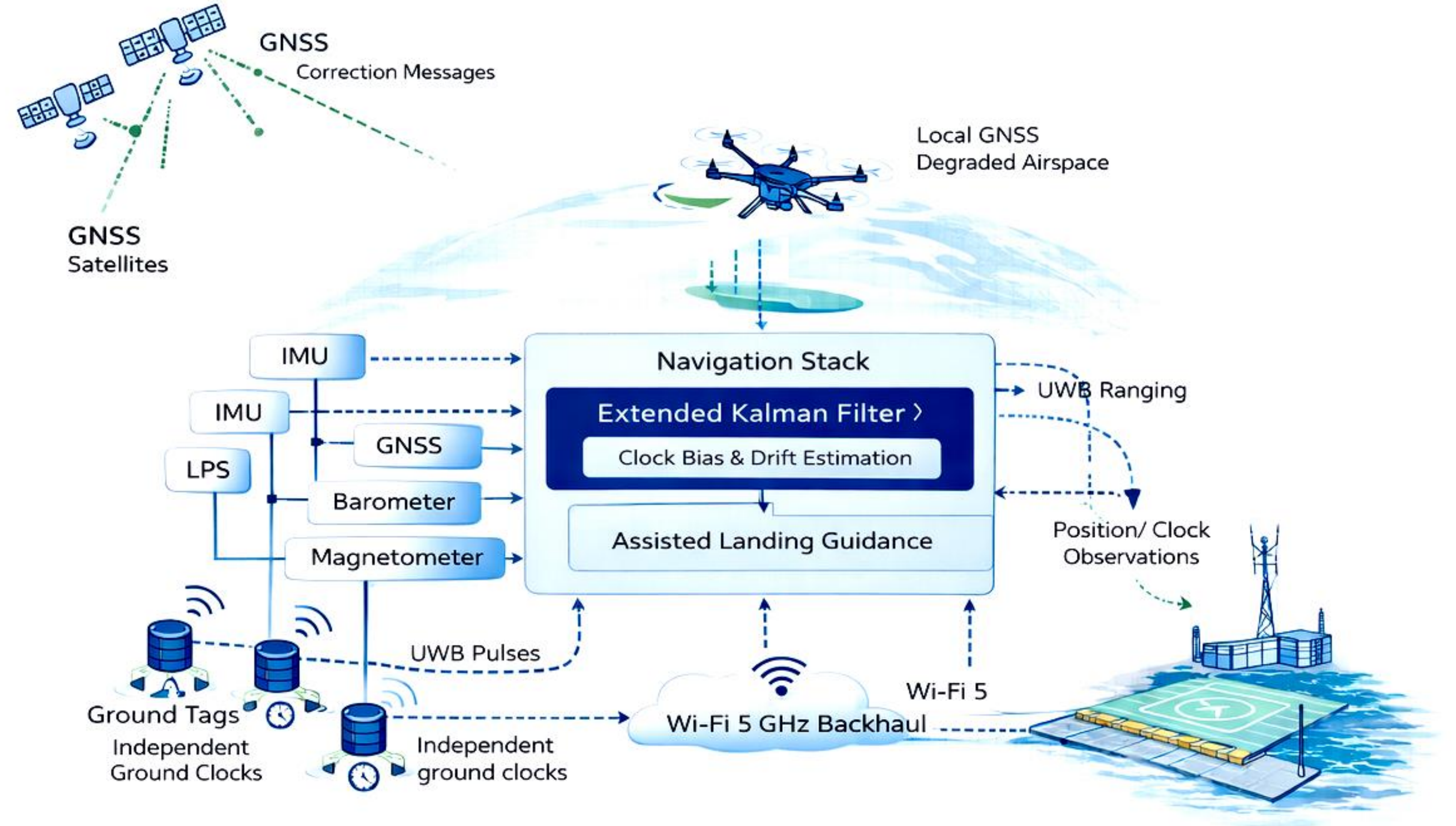
- Switch from typical high-volume, low update (5-8s) to small system, high update (sub seconds)
- Separate timing and positioning algorithms
- An aligned, current, clock model from Ground Tags
- One-way UWB transmissions to RPA

Test and Analysis

- Developing data visualisation and analysis tools
- Changing to from RPA to Drone (copter) for testing (adapting to different inputs and sensors)

DroneHome-2
Validated and Extensible Navigation Architecture

Integrating GNSS, IMU and local positioning to enable resilient GNSS-degraded operations



Introduction to Local Positioning System (LPS)

Ground station nodes are georeferenced in any chosen coordinate frame, and the LPS server configured accordingly.

Active nodes take it in turn to broadcast two (or more) "chirp" messages spaced apart in time that is less than the coherence window . These chirps carry a payload that includes node identity, Time of Departure (ToD) and other supplementary data.

Any active nodes receiving the broadcast message from a neighbour measure the ToA (local clock) and send a report containing measurements

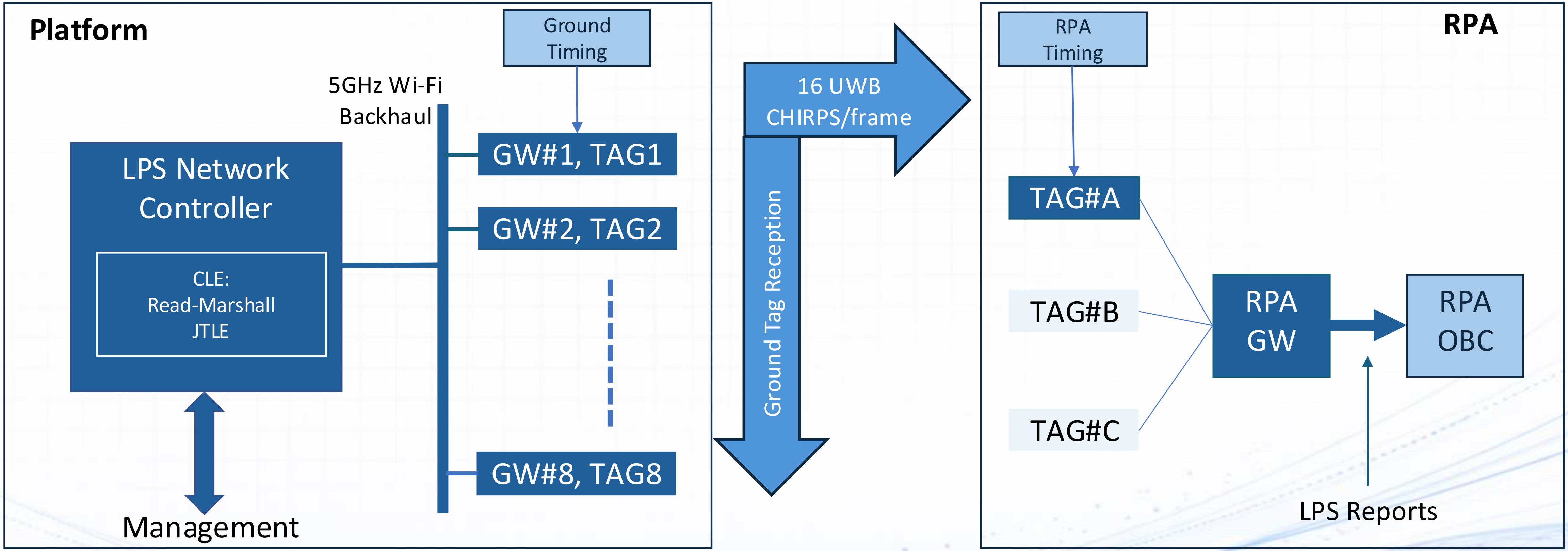
For Ground tags the TOD/TOA results are reported to a LPS network controller	RPA (Remotely Piloted Aircraft) tags report the results to the RPA gateway

On the LPS Network controller, JTLE (Joint Timing and Location Engine) application maintains a Timing Model of the system clock offsets for all the Ground tags

The UWB clocks are not synchronised, but the clock model is shared such that the ranging algorithm can consider the Ground Tags as having synchronised clocks.

To comply with UWB radio regulations the Drone operates in receive only mode

LPS System Architecture



RPA: Remotely Piloted Aircraft
LPS: Local Positioning System
CLE: Cluster Location Engine

UWB Regulations (2021)

Generic UWB

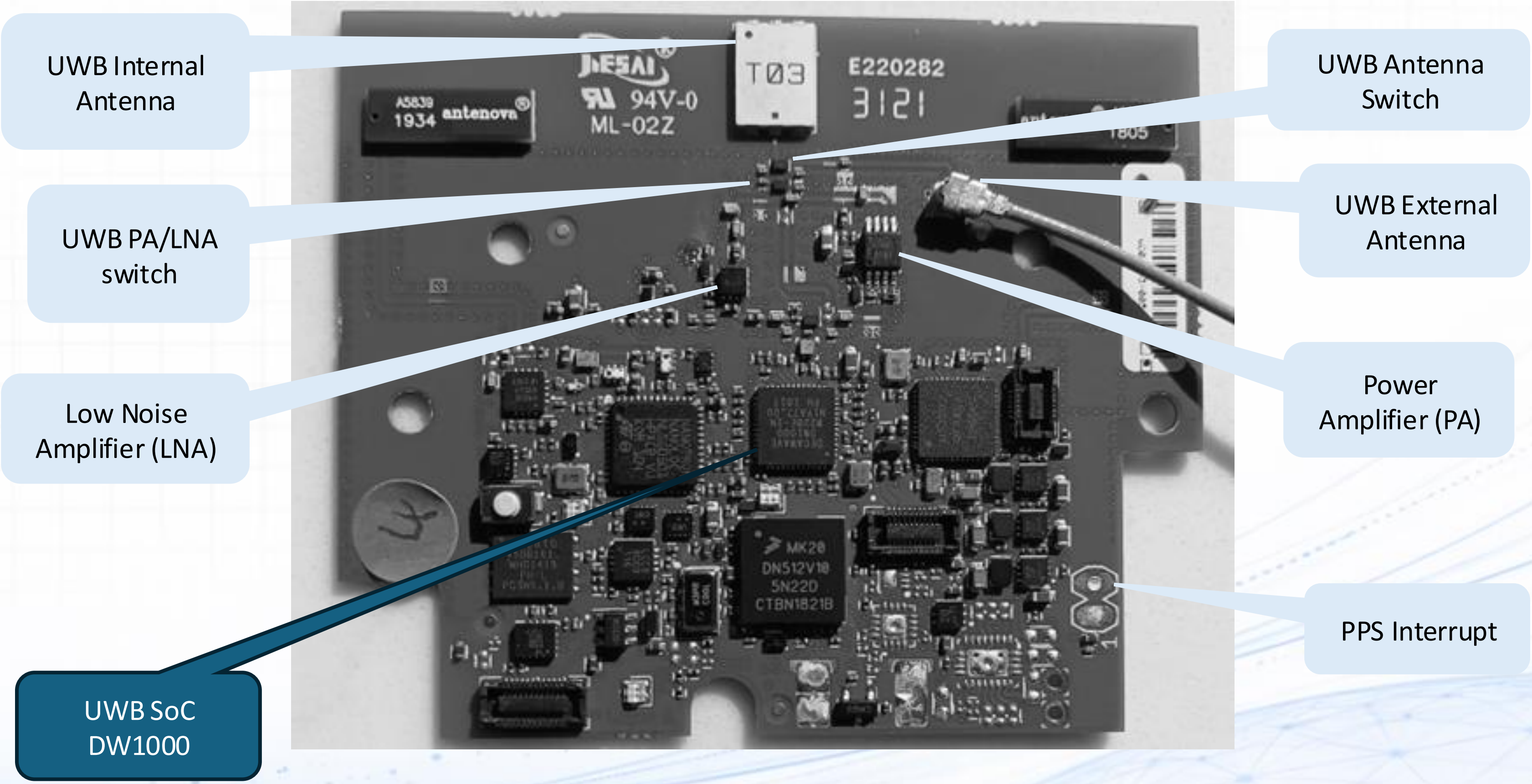
- UWB used on a ‘non-interference and non-protected basis’ means that no harmful interference may be caused to any radiocommunication service
- UWB airborne transmission is not allowed
- Equipment used outdoors cannot be attached to a fixed installation, a fixed infrastructure, or a fixed outdoor antenna.
- Unlicenced limits the Max Mean Spectral Density -41.3dBm/MHz

EU Category	Licencing	EIRP dBm/MHz	Fixed Infrastructure	Example Report Separation
Generic UWB	Unlicenced	-41.3	No	n/a
Location Tracking Systems (LT2)	Individual Authorisation (per deployment)	-41.3 (Low Duty Cycle) -70.0 >4.8GHz	Allowed outdoor	To FS – case by case To FSS – 2.6Km
Location Tracking Emergency and Disaster (LAES)	Yes. Services or Agencies responsible for Public Safety	-21.3 (3.4 to 4.2GHz) -70.0 >4.8GHz	Expected mobile/portable and temporary outdoors	To FSS 20Km/12.3Km

Created a white paper outlining the findings above and the requirements for LPS in AWE to work with Regulators

Technical Innovations: GCN535 with LNA and PA

- Enhanced an established S500 device with new RF sub-system
- Measured gain from Power Amplifier (PA) 16.6dB
- Low Noise Amplifier gains measured 4.8dB
- Over 240m range measured in field tests
- Updated TCXOs



Technical Innovations: Software

Device Firmware

- Over 100 firmware updates were implemented,
- Introducing new commands for UWB configuration, special operating modes, and optimisations to maximise measurement update rates.
- The firmware now supports functional mask flags for operational control, including software updates and switching between low and high-power UWB modes.
- Ground tags transmit message to include aligned ToD
- UWB chirps containing location, quality, and timing information, enabling more sophisticated processing on the RPA.

LPS Server Software

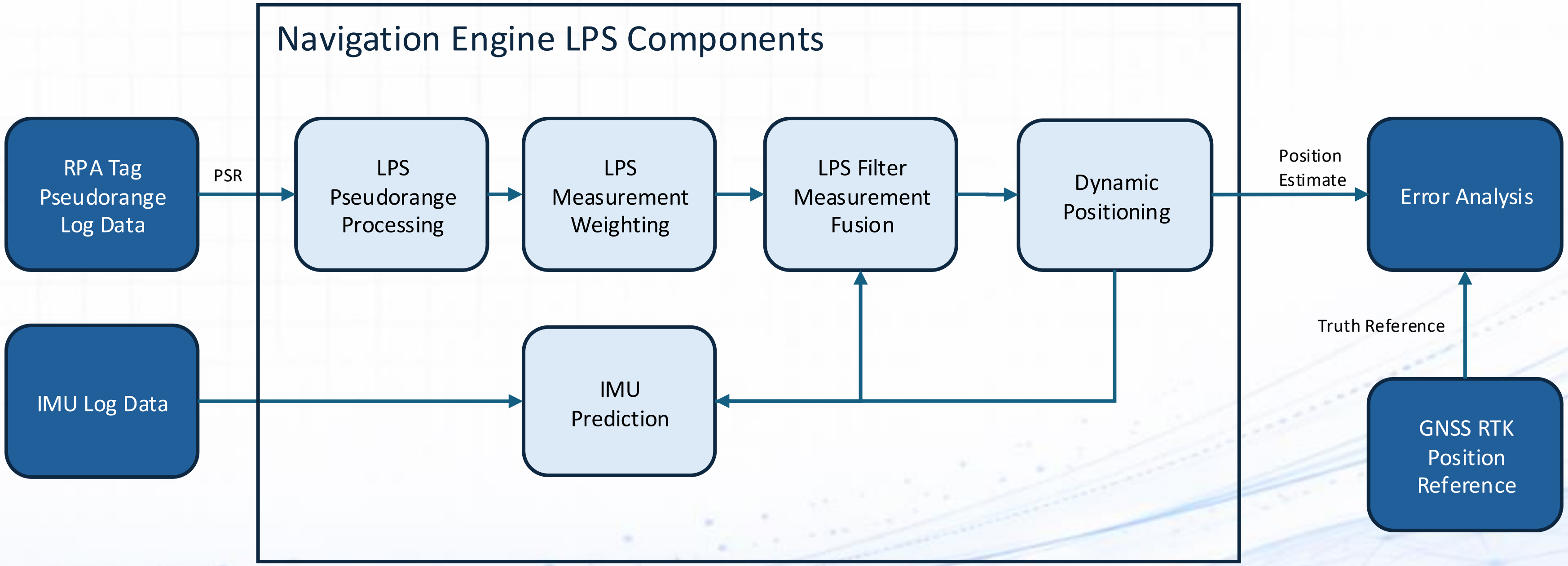
- A critical innovation was the introduction of a new Timing Model ('TM4') in the LPS server software calculating clock offsets and corrections (drift, drift rate) for Ground Tags
- New messaging protocols between the LPS server and ground tags facilitate the sharing of timing models, position information, quality metrics, and antenna delays, all of which are essential for correcting measured pseudoranges and ensuring accurate positioning
- Accommodate Device specific antenna delay settings
- Frame processing optimisation to increase update rate

LPS Fusion to Nav Engine

The navigation filter with the IMU, GNSS, magnetometer and barometric altitude was tuned for the PX4 sensors first.

The navigation filter implementation uses a state vector with 20 states:

- Position ECEF (3 states)
- Velocity ECEF (3 states)
- Quaternion Representing Body to ECEF Rotation (4 states)
- Gyro Bias (3 states)
- Accelerometer Bias (3 states)
- **LPS Clock Bias (1 state)**
- **LPS Clock Drift (1 state)**
- Pressure Altitude Bias (1 state)
- Magnetometer Bias (1 state)



Pilot Execution and Validation

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Model Tuning Datasets

- Capture error characteristics of the sensors
- Limited characterisation compared to AP3 sensors
- Tuning based on data gathered and appropriate over-bounding

LPS Tests

- External antenna delays
- LPS Timing Model Bias vs Update Rate
- Range Bias

Six Approach runs

- From 200m to the landing zone
- G1,G2,G3 (start-stop, constant velocity)
- G10,G11,G12 (start-stop-start)

Navigation Replay Results

- Results with GNSS
- Results with GNSS Denial
- Results with LPS Clock Bias Removed
- Results with Updated Ground Node Distribution

Comparison of Navigation Model (DH) and Drone Data (PX4)

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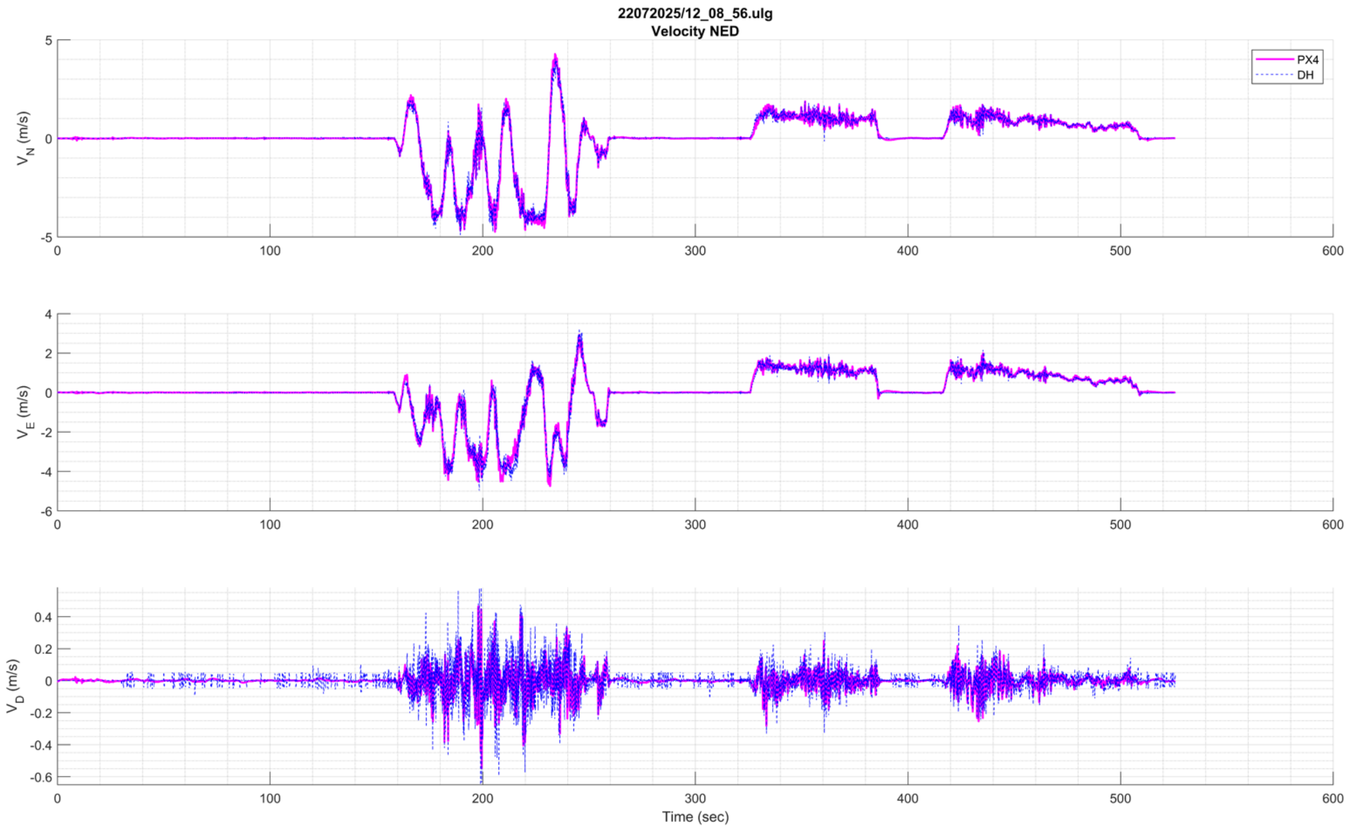
PX4 solution exhibits greater yaw drift and velocity settling time relative to the DH navigation solution.

- PX4 yaw angle drifts, DH is yaw is stable
- Velocity is tighter in the DH solution compared to PX4. When the vehicle comes to a stop the PX4 solution takes additional time to settle to zero
- In some cases (not shown here), the PX4 height is wrong by > 100 m

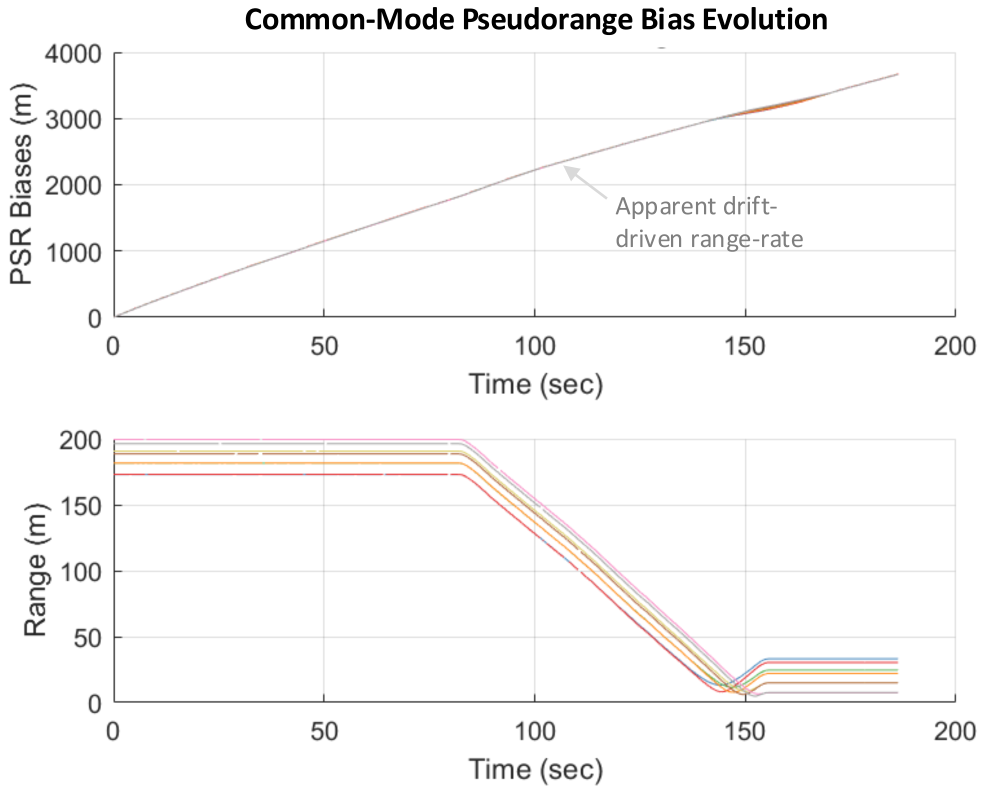


Conclusion: the DH navigation solution is compatible with the sensor data and the solution is usable for DH purposes

Navigation Model: LPS Data Analysis

Key Observations

- RPA UWB clock not synchronised to ground clock ensemble
- Clock drift rate ~7 × 10^{-8}
- Equivalent to ~20 m/s apparent range-rate error
- Pseudorange errors common-mode across beacons
- Bias behaviour varies with deployment geometry



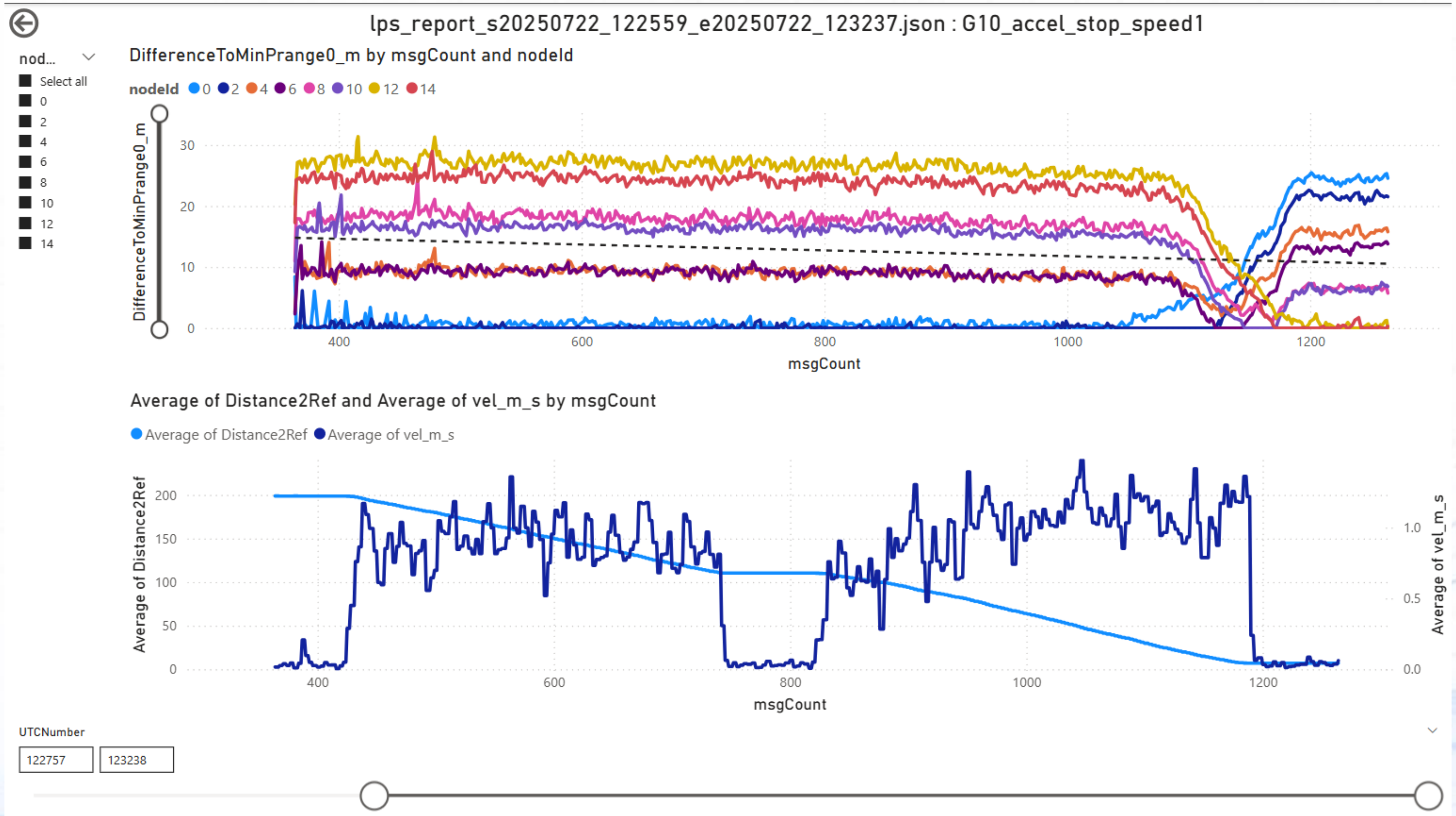
Engineering Implications

- Clock bias and drift must be explicit filter states
- Accurate initialisation required during alignment
- Simple averaging insufficient due to time-varying clock drift
- Kalman filtering implemented to estimate drift rate

Explicit clock and bias modelling is essential for stable GNSS-degraded fusion.

Example Analysis:
LPS Pseudorange Difference to MinPrange

- LPS reports have no external range or positional information
  - Distance and velocity added from GNSS just for analysis
- Compare difference in Pseudorange vs the shortest Pseudorange per report/frame
- Some noise in plot due to missed chirps particularly at distance
- Within landing zone radial velocity differences are significant as move past forward ground beacons



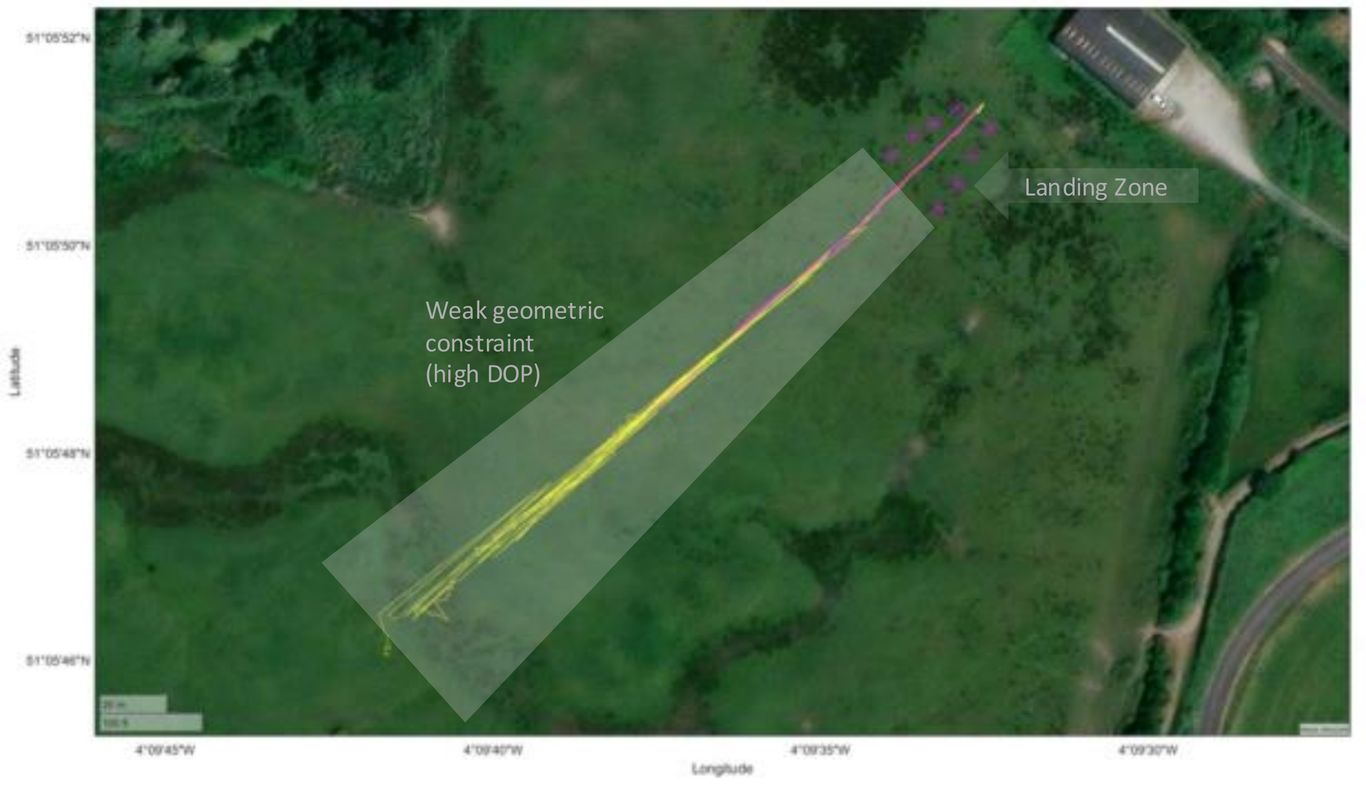
LPS Clock Ground Tag Timing Model - Clock Drift

- Ground Tag UWB clocks are continuously running but unsynchronised
- Each frame the UWB chirps captured by Ground Tags are collected by the LPS server and the independent clocks are resolved to an aligned (common) clock model
- New/updated clock model is distributed to the Ground Tags
- Ground tags apply the model to report a unified ToD included in the UWB Chirp
- *RPA clock drift is a combination of the 'common' Ground clocks and the individual RPA UWB clock*

Navigation Geometry: Dilution of Precision (DOP)

Key Observations

- DOP increases when beacons are near-collinear
- Radial displacement can be compensated by pseudorange bias adjustment
- Position solution weakly constrained along radial axis
- Low DOP requires beacon “surround” geometry



Engineering Implications

- Achievable performance envelope is geometry-dependent
- Deployment configuration must enforce surround geometry
- DOP-driven beacon placement strategy
- Operational landing zone must maintain surround geometry

Deployment geometry governs bounded performance.

Example G12-Updated Node Positions

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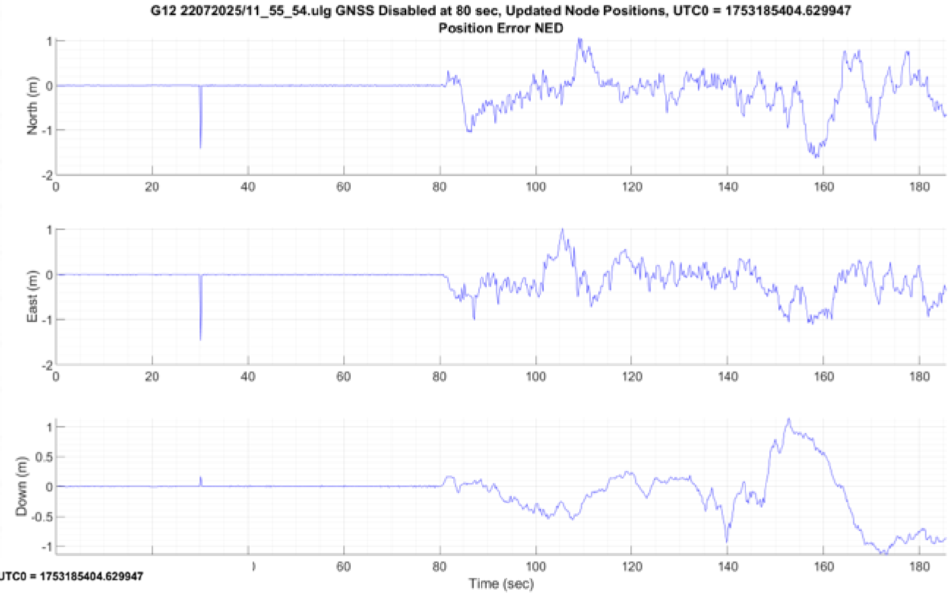
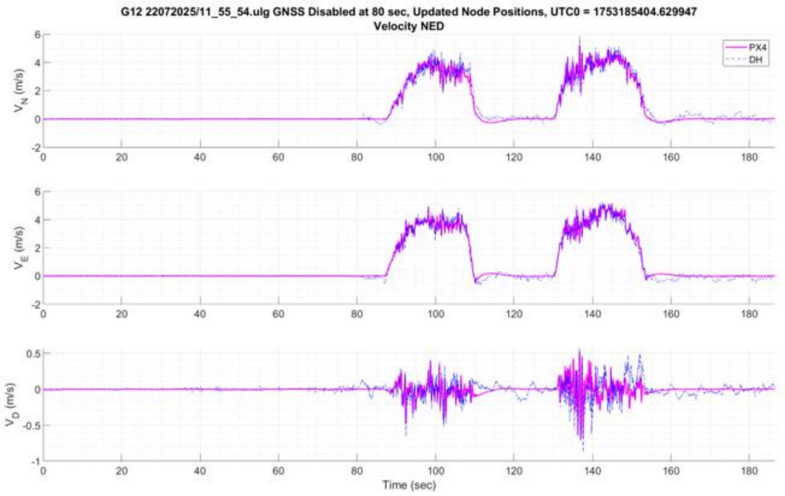
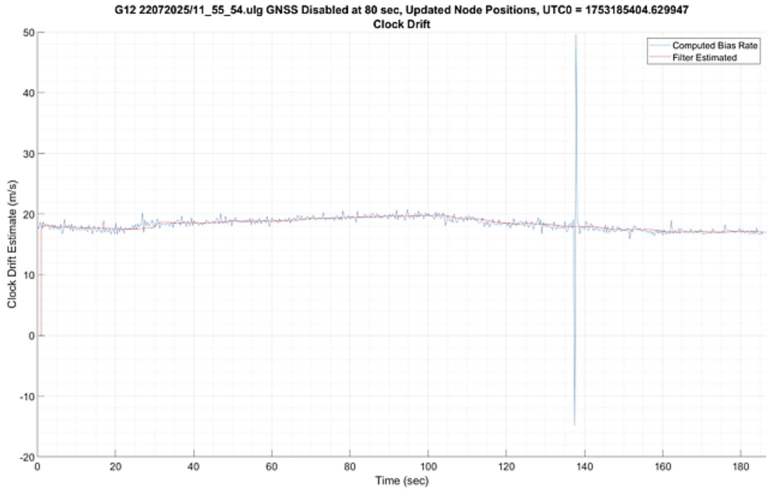
GNSS Disabled at 80s



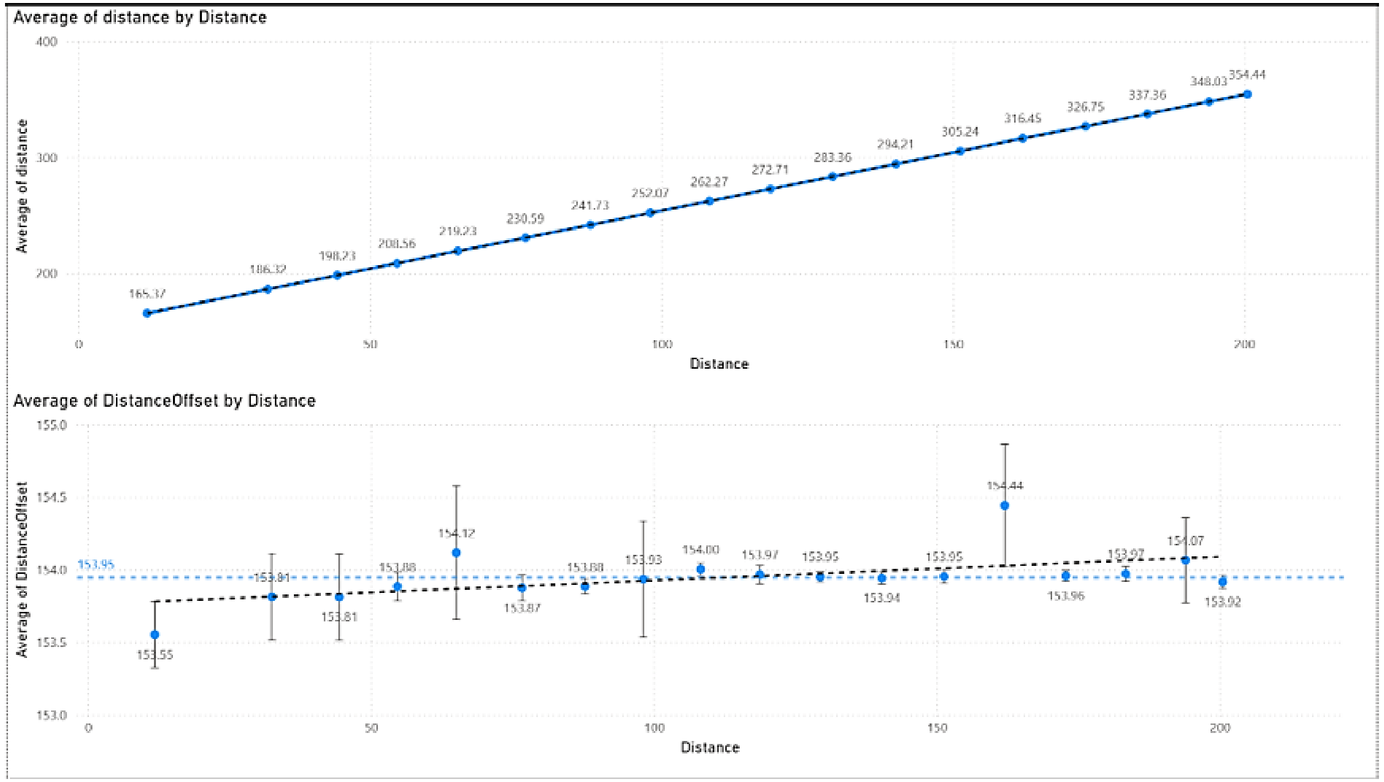




This shows that the LPS Pseudoranges can be employed in concert with the GNSS and other sensor inputs

UWB Range Bias

- Range bias was evaluated using Symmetrical Double-Sided Two-Way Ranging (DW-TWR) with RTK GNSS reference.
- A signal-strength-dependent timestamp bias was observed, decreasing below ~100 m.
- Magnitude ~0.4 m — small but significant for bias minimisation.



Validated Performance Envelope

Operating Regime	Typical Performance	Notes
GNSS-Supported (Assisted)	RTK-supported regime: cm-class reference Assisted GNSS landing: <20 cm	Stable convergence
GNSS-Denied	30–50 cm (validated bounded regime)	Bounded and stable Dependent on beacon configuration

Interpretation

- Assisted GNSS-supported regime better than 20 cm accuracy
- GNSS-denied performance remains stable and bounded
- Geometry and clock stability govern achievable accuracy
- The performance envelope is now **explicitly characterised**

Performance values derived from structured field-based flight simulations and trials under controlled validation conditions.

Technical Outcomes and Engineering Levers

Technical Outcomes

- Stable LPS–IMU–GNSS fusion demonstrated
- Airborne clock bias and drift successfully modelled
- Performance envelope quantified and governing constraints explicitly identified

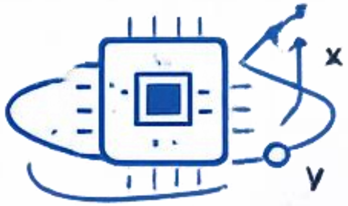
Defined Engineering Levers for Performance Improvement

Clock and Timing Refinement

- Higher-stability oscillator integration
- Improved synchronisation modelling

Beacon Geometry Optimisation

- Deployment configuration refinement
- DOP-driven placement strategy



Sensor and Fusion Enhancement

- Higher-grade inertial integration
- Extended state refinement

Pathway from Validation to Operational Deployment

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Validated Architecture

- Multi-sensor fusion demonstrated
- Airborne clock behaviour explicitly modelled
- Performance envelope quantified under structured validation

Refinement and Optimisation

- Targeted clock and synchronisation enhancement
- Deployment geometry optimisation for performance scaling
- Sensor and fusion refinement aligned to application needs

Operational Integration

- Adaptable architecture for multiple autonomous platforms
- Performance scaling to application-specific requirements
- Structured pathway to mission-level validation

Structured validation provides a defined and manageable maturation pathway toward operational deployment.

From Technical Capability to Application Opportunity

DroneHome-2 has established a robust multi-sensor navigation architecture capable of maintaining bounded performance in GNSS-degraded and GNSS-denied conditions. The capability is configurable across multiple autonomous deployment contexts.

Application Domains

UAS Return-to-Home and Landing

Autonomous landing in GNSS-degraded or obstructed environments

Maritime and Vessel Landing

Relative navigation and bounded approach performance

Urban and Corridor Operations

Navigation continuity across indoor–outdoor transition zones

Ground and Hybrid Platforms

Deployable positioning support for mixed-environment autonomy

Deployment Priorities and Market Focus

UAS Return-to-Home and Landing
Autonomous landing in GNSS-degraded or obstructed environments

Maritime and Vessel Landing
Relative navigation and bounded approach performance

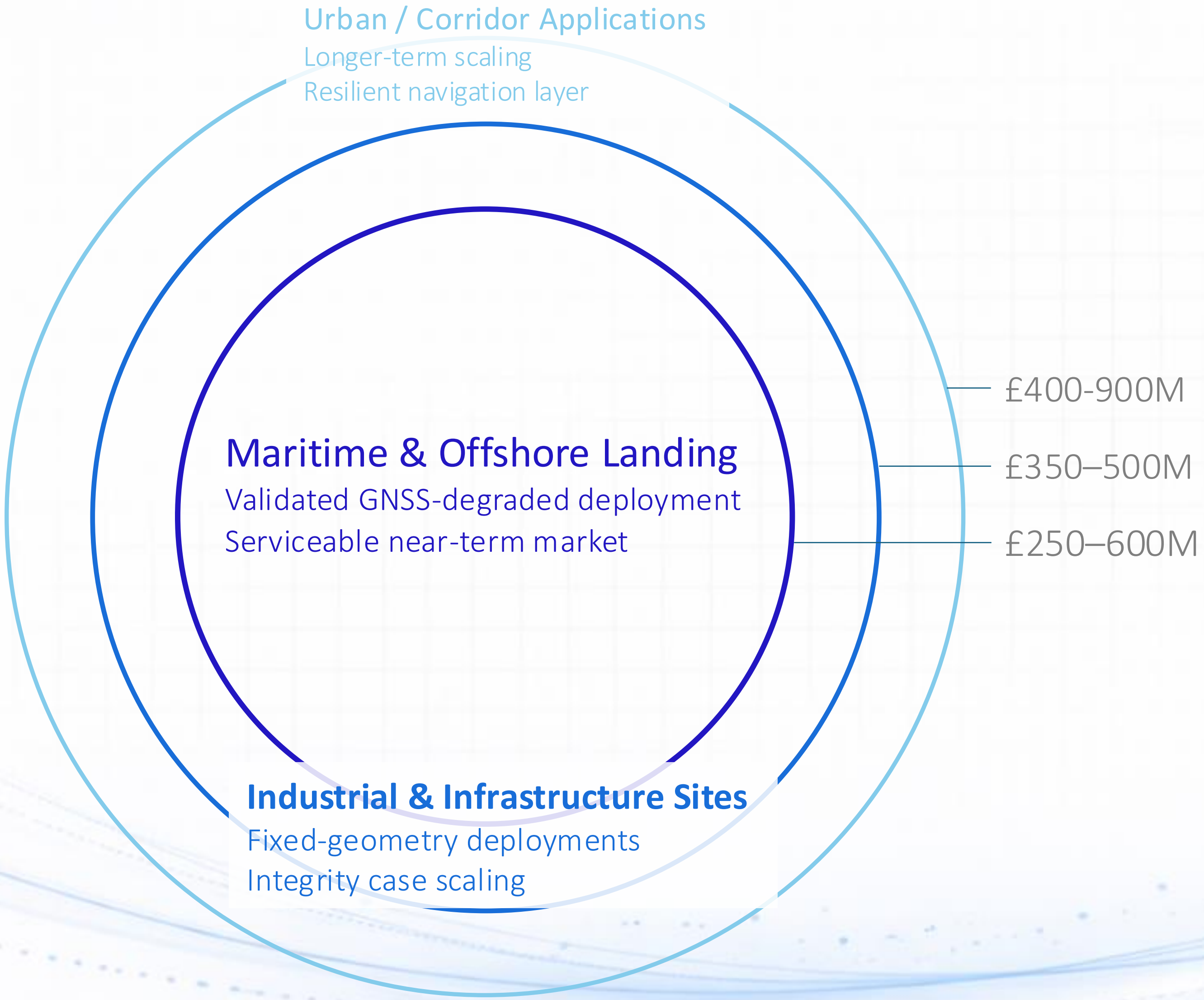
High readiness, bounded performance requirement, near-term integration pathway

Urban and Corridor Operations
Navigation continuity across indoor–outdoor transition zones

Ground and Hybrid Platforms
Deployable positioning support for mixed-environment autonomy

Aligned with technical maturity and partner engagement strategy.

Addressable Opportunity & Validation Pathway



Phase 1 – Maritime Pilots

Controlled GNSS-degraded landing trials
≤30–50 cm bounded performance validation

Phase 2 – Industrial Sites

Fixed-geometry deployment templates
Integrity case development

Phase 3 – Urban Transition

Rooftop & corridor integration
Indoor–outdoor continuity

Phase 4 – High-Integrity Systems

Advanced autonomous operations
Certification-aligned architecture

Figures derived from 2024–2025 industry analyses; resilience navigation layer estimated at 3–10% of relevant drone deployment infrastructure segments.

Market Modelling Assumptions & Stakeholder Refinement

Modelling Assumptions and Scope

- Early-adopter deployment focus (not full-system replacement)
- Application-specific integration model
- Resilience layer estimated at 3–10% of relevant deployment infrastructure segments
- Scaling aligned with regulatory and autonomy expansion

Stakeholder Engagement and Model Refinement

- Webinar feedback and structured questionnaire
- Direct early-adopter engagement
- Iterative refinement of addressable segment assumptions

Addressable opportunity model iteratively refined through stakeholder engagement.

Minimum Viable Deployment Pathway

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Defined Minimum Viable Deployment Package

- Core LPS and multi-sensor fusion integration framework
- Geometry-configurable beacon deployment architecture
- Application-specific calibration framework
- Structured performance validation methodology

Focused on bounded-performance approach operations in prioritised domains.

Platform Integration

Integration with partner navigation stack and system architecture

Joint Validation Campaign

Representative environment performance verification

Mission-Level Demonstrator

Operational deployment within defined early-adopter context

Structured basis for targeted ESA follow-on activity aligned with operational deployment.

Strategic Summary

Validated Architecture

- Stable LPS–IMU–GNSS fusion demonstrated
- Airborne clock bias and drift explicitly modelled
- Performance envelope quantified under structured validation

Defined Deployment Pathway

- Prioritised high-readiness application domains
- Defined minimum viable deployment package
- Structured early-adopter integration pathway

Strategic Positioning

- Extensible architecture across autonomous platforms
- Aligned with resilient PNT demand in GNSS-degraded environments
- Structured basis for targeted ESA follow-on activity

Stakeholder Engagement and Next Steps

Structured Engagement Mechanism

- Webinar discussion and technical feedback
- Structured stakeholder questionnaire
- Direct early-adopter engagement
- Website relaunch supporting structured stakeholder dialogue

Questionnaire Focus Areas

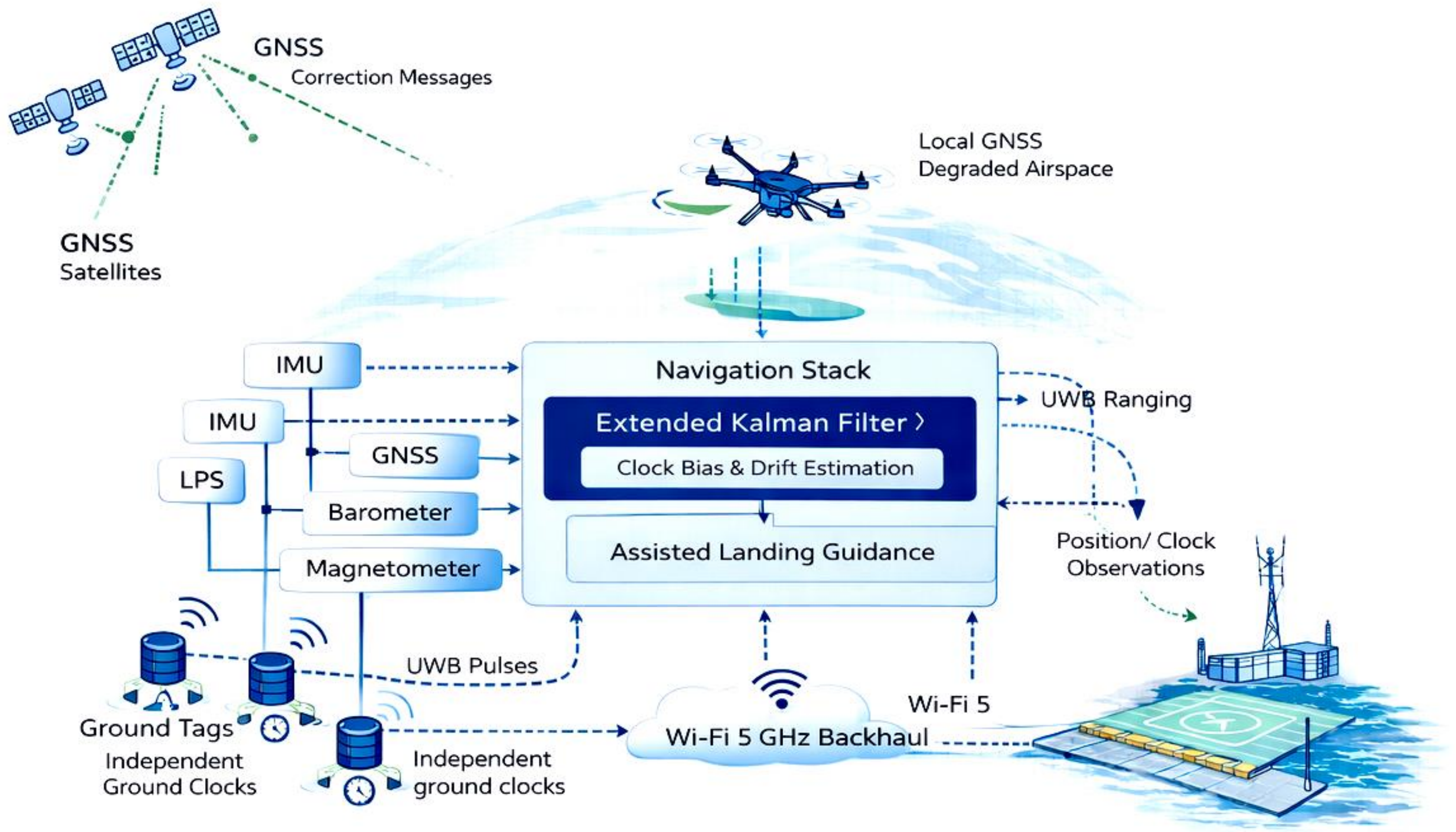
- Deployment context and operational constraints
- Accuracy and resilience requirements
- Integration pathway and architecture considerations
- Prioritised application domains

Stakeholder input form
forms.gle/KrdSJYPTr1MWxiKQA

Stakeholder input will inform ongoing refinement of deployment priorities and addressable opportunity modelling.

DroneHome-2
Validated and Extensible Navigation Architecture

Integrating GNSS, IMU and local positioning to enable resilient GNSS-degraded operations



Value and Lessons from NAVISP Collaboration

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Value Delivered through NAVISP Support

- Funding support enabled dedicated engineering and modelling effort to validate one-way TOA-based ranging with embedded Time-of-Departure (ToD) timing estimation in operationally representative conditions.
- Transition from conceptual architecture to experimentally verified performance envelope
- Independent technical review and programme oversight strengthened validation rigour and credibility

Lessons Learned

- Transition from specification ambition to quantified performance validation
- Integration of integrity modelling (clock bias, geometry constraints) strengthened system design
- Phased validation pathway reduces deployment risk pathway (controlled pilots → operational scaling)
- Programme continuity enables completion of complex validation programmes

NAVISP enabled the transition from conceptual architecture to validated performance envelope.

Thank You — Questions & Discussion

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We welcome discussion on validation and next-stage collaboration.

We gratefully acknowledge ESA's support through NAVISP and the continued guidance of:

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Stakeholder input form
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