UK Space Based Augmentation System (UKSBAS) Testbed

ESA Public Presentation

03 Dec 2024

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Agenda

1. Context and rationale for the development of the project
2. Outcome of the project
2. Contribution of the project to national strategy
3. Technology gaps or developments still required, if any
4. Approach to sustain the activity (e.g. exploitation plan for a national laboratory)
5. Benefits of working with ESA

UKSBAS Context & Project Outcomes

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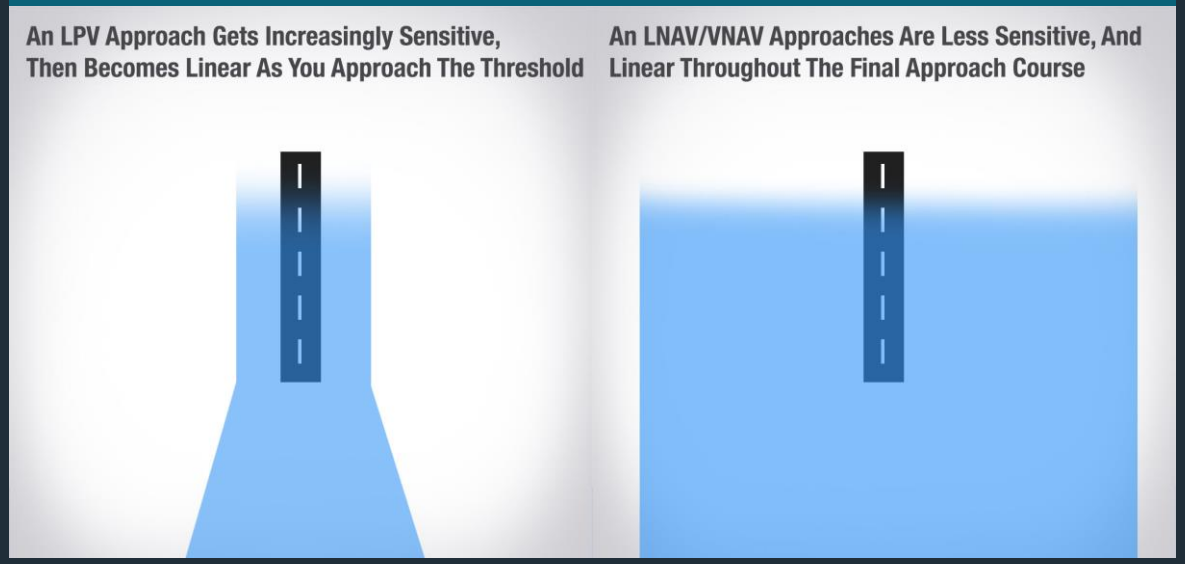
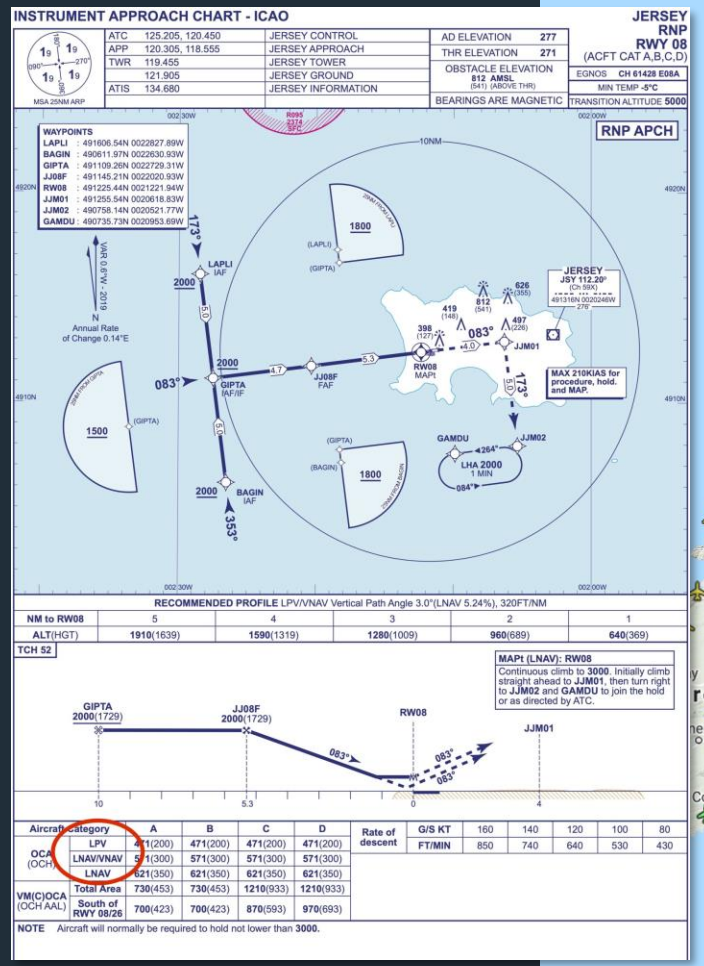
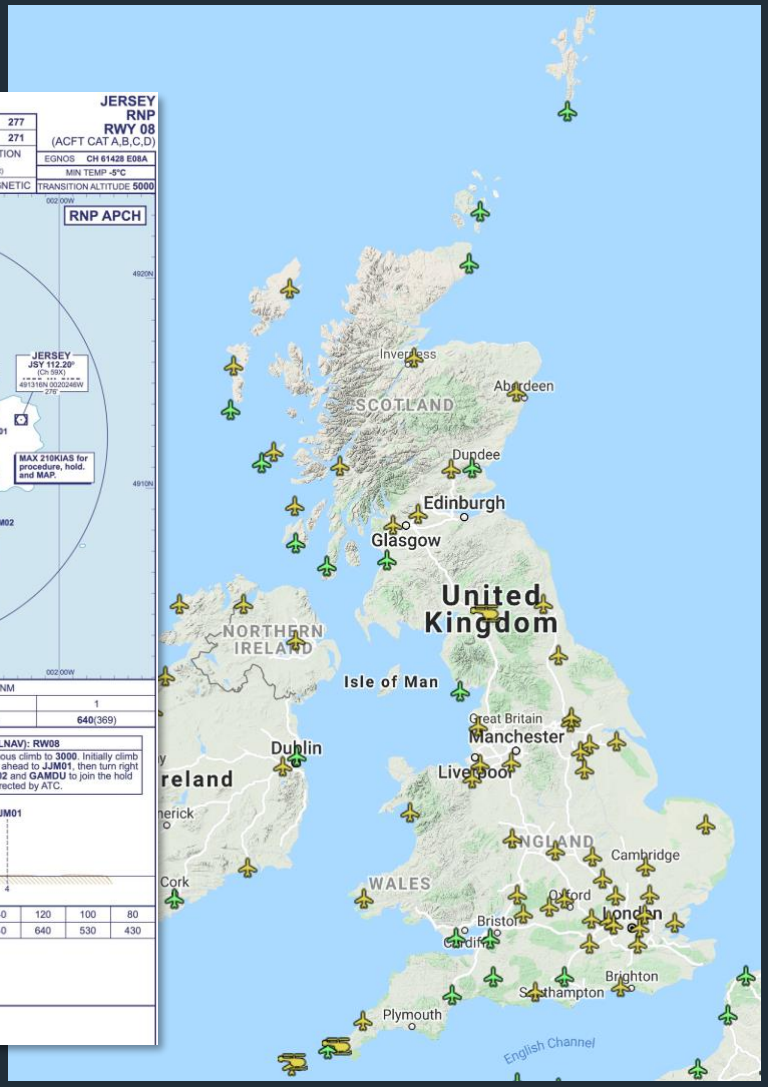
UK SBAS Testbed context

Rapid setup of testbed to broadcast UK SBAS Test Signal-In-Space (SIS)

- 25-JUN-21: EGNOS Working Agreements with ESSP are suspended/terminated: UK has withdrawn from EGNOS programme
  - LPV approach procedures are unavailable
  - LNAV or LNAV/VNAV minima unaffected



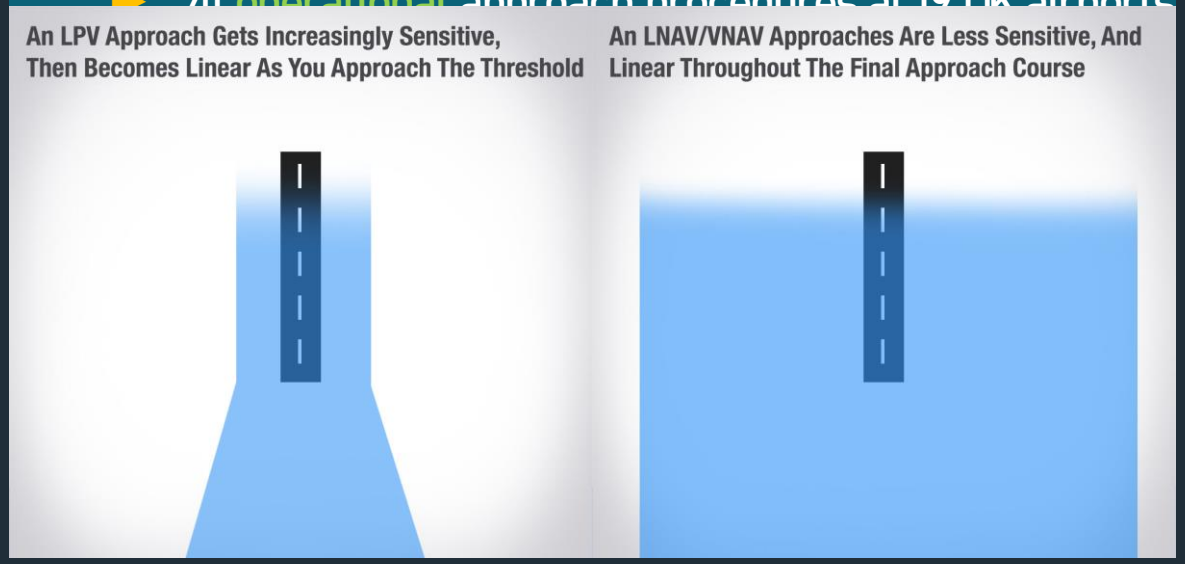


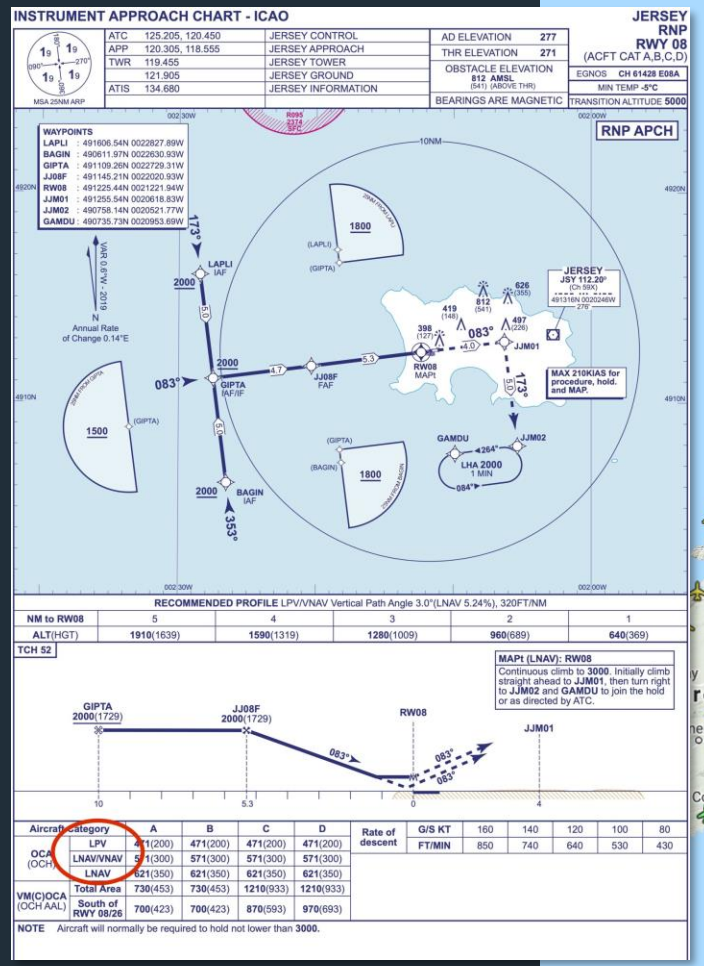


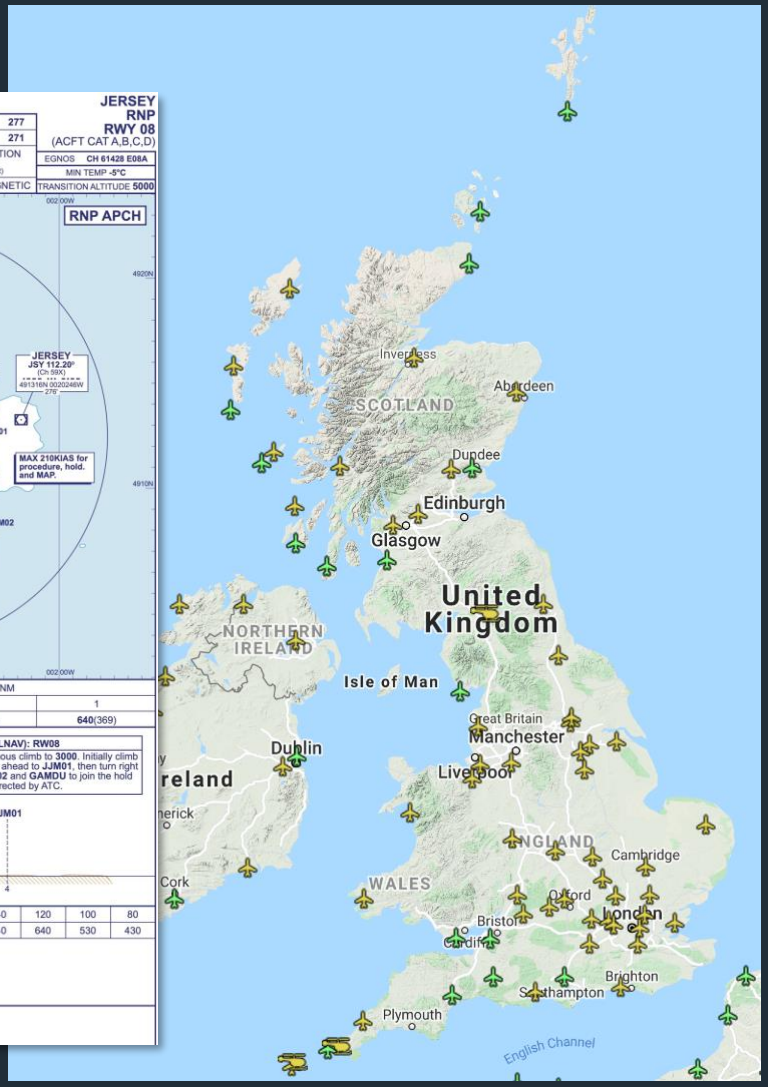
UK SBAS Testbed context

Rapid setup of testbed to broadcast UK SBAS Test Signal-In-Space (SIS)

- 25-JUN-21: EGNOS Working Agreements with ESSP are suspended/terminated: UK has withdrawn from EGNOS programme
  - LPV approach procedures are unavailable
  - LNAV or LNAV/VNAV minima unaffected
- UK Airports: pre-2021 baseline
  - 41 operational approach procedures at 19 UK airports







UKSBAS Testbed Context

Consortium Roles

- Project Prime, System and Service Concepts, Satellite Operator, Demonstration Event Coordination

- Ground Segment Testbed Development, SBAS message generation and performance assessment, use case trials

- Safety and Security Roadmaps

- Ground Uplink Station Provider

- Provider of ground monitoring data

UK SBAS Results and Objectives

Phase 1	Phase 2A	Phase 2B
Rapid setup of testbed to broadcast UK SBAS SIS	Define UKSBAS future system architecture options and conduct live trials in Maritime and Aviation	Define/update UKSBAS future system architecture options and conduct live trials in Road, Rail
Oct 21 to Dec 22	Jan 23 to April 24	April 24 to Nov 24

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Work Breakdown

Work Stream 1

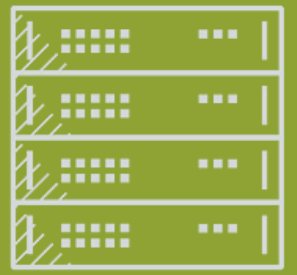
Future System and Services Definition

Work Stream 2

Core Infrastructure

Work Stream 3

Demonstration Platforms



Work Stream 4

User Trials Activities

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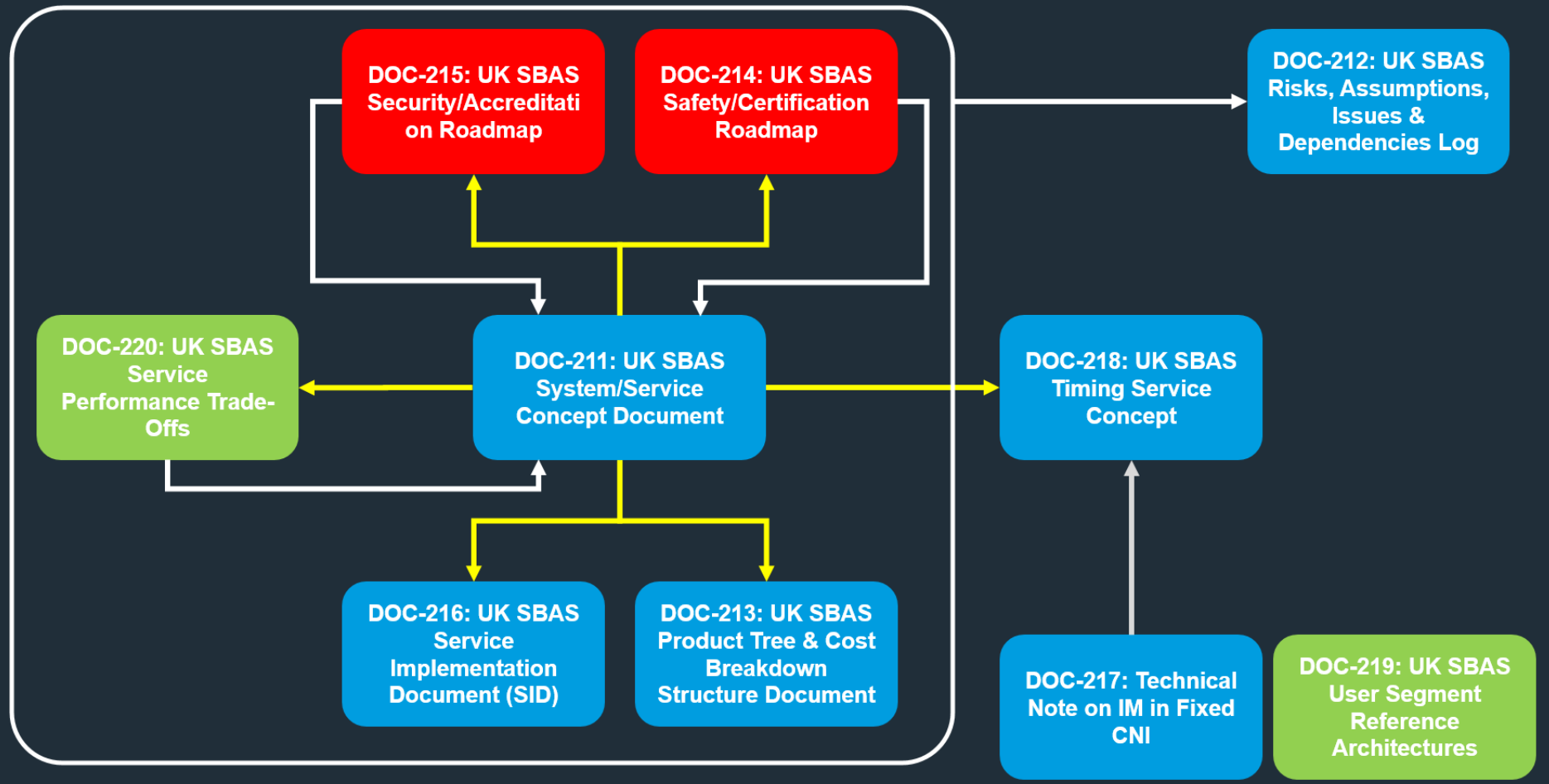
Future System and Service Architecture Document Logic



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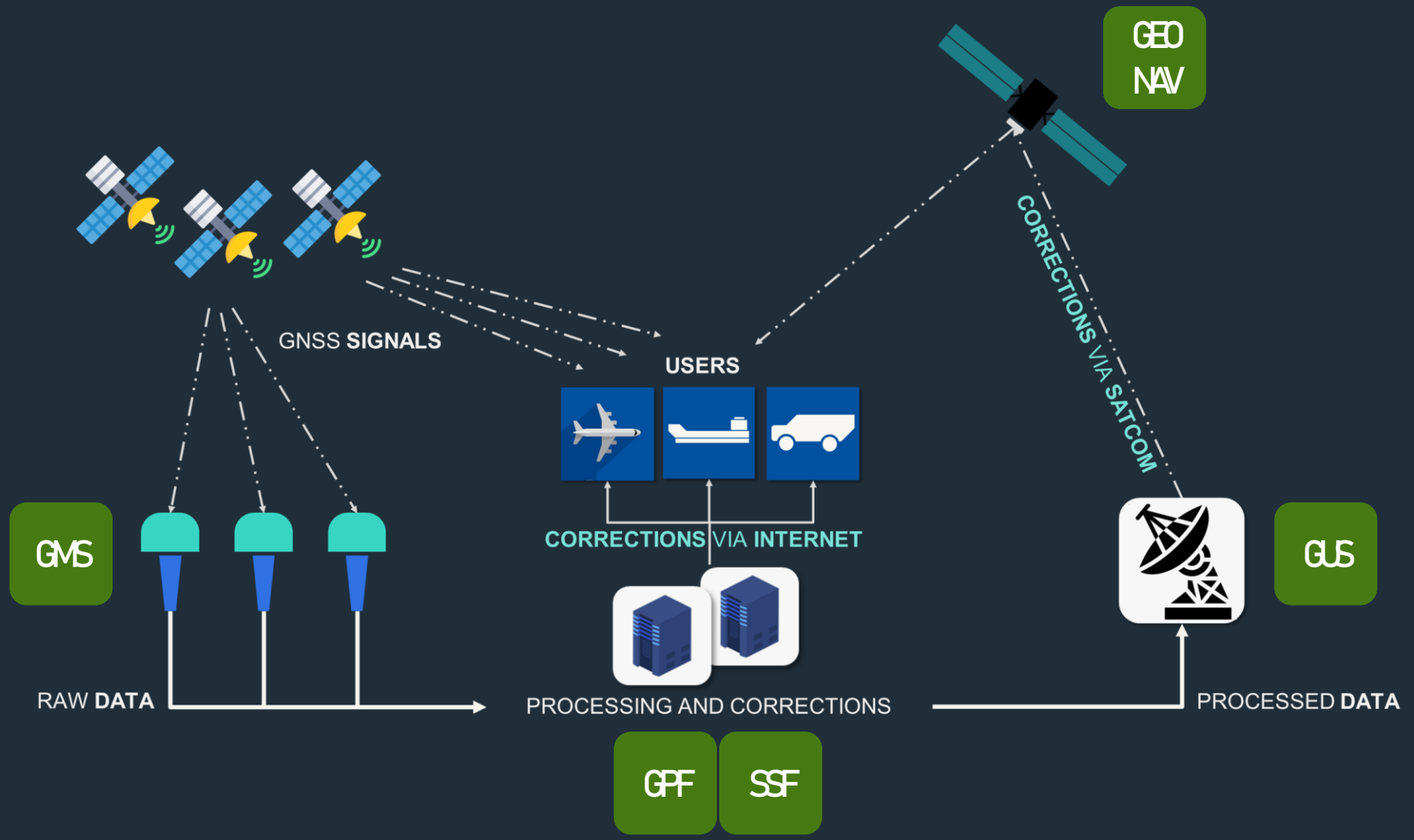
UKSBAS system architecture



UKSBAS Service Options Under Consideration

Safety of Life (SoL)
- L1 SoL Service
- DFMC SoL Service

Open UKSBAS Service
- OS L1
- OS DFMC

UKSBAS-PPP
- E5b

UKSBAS Data Augmentation Services (UKDAS)

UKSBAS Timing Service (TBC)

Safety Roadmap - CGI

Task

- Identify the currently applicable legislation, regulation and standards affecting the formal approval of the UK SBAS service for commercial aviation, maritime, rail and road
- Confirm the organisational, functional and performance requirements which affect the service definition
- Consult with CAA and GLA
- Create the roadmap defining key activities and milestones required for development, certification and operations
- Perform a preliminary safety assessment of the preliminary system design

Findings

- The landscape is most mature in the aviation and maritime sectors.
- Purely from the safety perspective, there is little formal regulation which would be applicable to the use of an SBAS service in any other domain.

Conclusion/Recommendation

- The major conclusion/recommendation to be taken forward is that many of the responsibilities, including the application for certification/recognition, must be owned (though could be delegated) by the service operator so it would be beneficial if that organisation could be set up early in the process.

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Security Roadmap - CGI

Task

- Define a roadmap for Stakeholders to identify and manage Threats, Security Goals and Objectives, and to determine their Risk Appetite for UK SBAS including threats from the supply chain.
- Identify applicable development Security & Privacy Standards for stakeholders.
- Make recommendations for development and operational certification and possible system accreditation.

Findings

- The UK SBAS Mission statement needs to be defined.
- Regulatory domain – applicable legislation is and will evolve over time. UK SBAS needs to ensure the programme and its suppliers keep themselves aligned with the changes.
- Risk Management – there is no one RM framework that is designed for UK SBAS specific needs.
- Security approvals – as with the regulatory domain, the various schemes underpinning the various security approvals for the programme will evolve over time. UK SBAS needs to ensure the programme and its suppliers keep themselves aligned with the changes.
- System Architecture – there are a several existing systems that deliver SBAS services but typically these are more safety focused.

Conclusion/Recommendation

- The contracting authority should,
  - survey the various published Threat Landscape reports;
  - survey of all RM frameworks available;
  - perform a periodic Gap Analysis review of the legislative and regulatory landscape;
  - issue documents that include mandatory security requirements, a programme security classification guide (SCG) and a Security Aspects Letter (SAL);
  - mandate the development and operation of the system to utilise NCSC Cyber Assurance services;
  - require the various businesses, organisations (and those supporting) to adhere to specific standards

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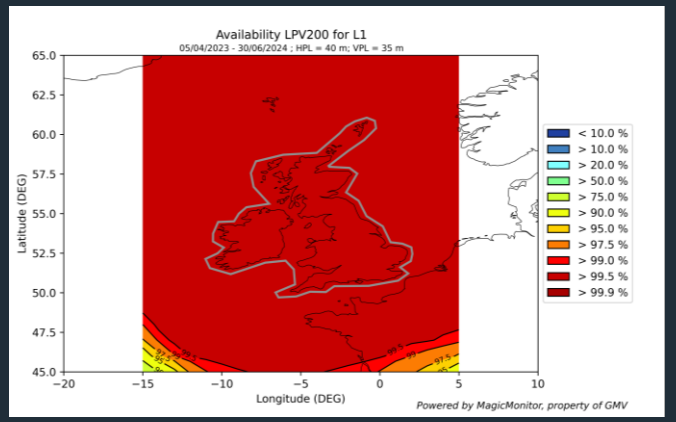
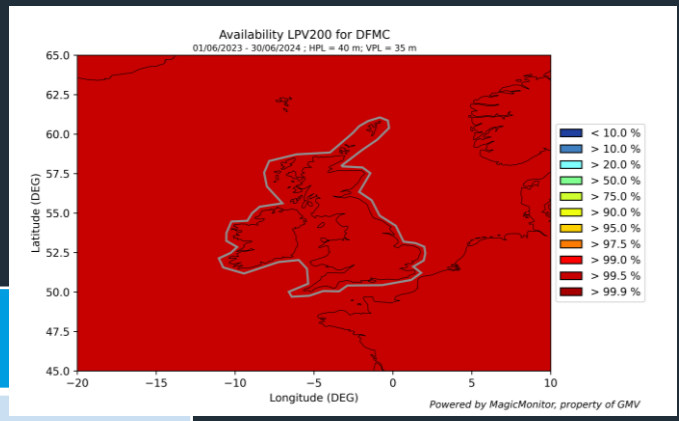
GMV Work Achieved

- Continuous provision of testbed services over the last 2 years:
  - **UKSBAS L1 SiS** since May 2022, delivered by Viasat 3F5 satellite and through SiSNET.
  - **UKSBAS DFMC** (over GPS L1/L5 & Galileo E1/E5a frequencies), delivered since June 2023 through SiSNET.
  - **UKSBAS PPP** active since October 2023, delivered over NTRIP.
- Crucial support to a wide range of user trials in different environments.
- Service maintenance on a daily basis.
- Delivery of SBAS/PPP monthly performance reports addressing broadcast status, CORS ground segment health, APV-I/LPV-200 service volume availability and accuracy statistics.
- **SiS live** and successfully tracked from UK landmass **over 99% of the time.**
- Outstanding **Performance Level** achieved.



UKSBAS L1 LPV-200 availability at message generation level during Phase 2



UKSBAS DFMC L5 LPV-200 availability at message generation level during Phase 2

	UKSBAS L1	UKSBAS DFMC	UKSBAS PPP
Station Accuracy	95 cm (HPE@95%) 175 cm (VPE@95%)	70 cm (HPE@95%) 92 cm (VPE@95%)	10 cm (PE@95%) Sub-minute convergence to 25 cm
Orbit & Clock Accuracy (PE95%)	85 cm (WUL, @95%)	76 cm (GPS, WUL, @95%) 54 cm (GAL, WUL, @95%)	2.3/1.9 cm (GPS, RMS orbit / avg clock) 3.3/1.6 cm (GAL, RMS orbit / avg clock)
Availability	> 99% (LPV-200, message generation level)	> 99.9% (LPV-200, message generation level)	> 99%

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GMV Work Achieved – User Trials

Static Aviation Trials

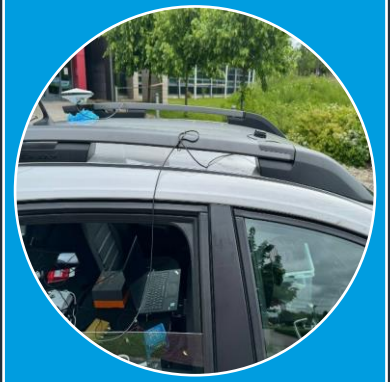
- **Static data collection at 4 distributed airports** to assess SiS tracking and post-processed performances.
- Signal-In-Space correctly received in open-sky conditions.
- LPV-200 service level fulfilled in terms of accuracy / availability.
- Comparable performance to EGNOS.
- Significant improvement of SBAS DFMC over legacy service.

Dynamic Aviation Trials

- Two separate data collection campaigns, with Skybus aircraft and support to Cranfield demonstration event.
- To test signal reception from an aeronautic environment and end user performances.
- Improved accuracy over standalone GNSS.
- Preserved integrity and LPV-200 availability while airborne.

Maritime Trials

- **Data collection on-board a vessel** performing round trips.
- Performance compatible with coastal operations (HAL < 25m) with effective overbounding.
- Shown benefits with dedicated maritime-specific interfaces (MISI L1/DFMC) to accommodate integrity risk.
- Proved synergies combined with autonomous integrity solutions (MGRAIM/MRAIM) to improve the reliability of user alarms.

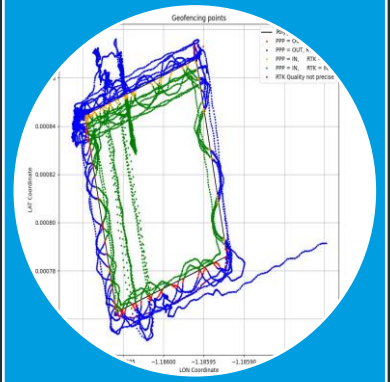


Public Road Trials

- 3 days of data collection with dedicated setup using PPP + IMU solution, and SBAS RT and post-processed solutions with SiSNet.
- PPP solution achieves horizontal accuracy (95%) < 50 cm, matching the most demanding accuracy requirement applications.
- SBAS L1 improves accuracy moderately, while DFMC increases noise. Multipath levels challenge integrity.

Rail On-board Trials

- GNSS + IMU data collected on-board a train provided by Network Rail to compute GNSS vs SBAS solutions.
- Non-system errors (multipath, NLOS, obstruction) are significantly dominant to SiS corrections, challenging for SBAS standalone augmentation.
- Simple IMU propagation (dead reckoning) proved useful to extend positioning availability.



Trackside Worker Geo-fencing Trials

- **Assess PPP performances for trackside workers wearable safety devices**, contributing to Network Rail safety case.
- Static and dynamic trials in different conditions.
- Quick solution reconvergence (few seconds) when passing under tunnels.
- Comparison between RTK and PPP solutions in dm level of error.
- Captured benefits from PPP wide-area corrections.

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GMV Work Achieved – System & Services Contribution

WSB17 – User Segment Reference Architecture

Transport Domain	Key Use-Cases	Performance Requirements	Key Standardisation documents	Related reviewed projects/initiatives	Challenges
Maritime	SBAS for maritime users	MASS reqs. For Ocean / Coastal / Port Navigation HPE95% < 1-10m HAL<2.5-25m, TIR = 10-5/3h	IMO Resolutions (A.915, A.1046, MSC.401, MSC.1575)	MarRINav SEASOLAS INSPIRE ESMAS	Environmental multipath, pending consolidation of integrity definition, SiS obstruction
UAS	Geo-awareness Remote ID Unmanned Traffic Management	Depends on misión risk (SAIL) Accuracy@95% = 1-50m HAL/VAL= 40/50m to 2.5/4m TIR = None to 4.2*10-7 Availability > 99.8%	RTCA MOPS DO-229 CAA CAP 722, CAP 2610	EGNSS4RPAS SUGUS EUGENE	Standardisation maturity, usage in urban environments, Resilience to spoofing/jamming
Road	L5 Autonomous Driving	HPE95% < 10-50cm to 10m Availability > 99 to 99.9% TIR = 10-7/hour TTA ~ 20ms	Automated Vehicle Bill (2024) ISO 26262, ISO 21448, ISO 21434	IMPACARS ITHACA GIROADS GINA	In PPP: integrity layer, resilience in urban environment In SBAS: local error treatment /overbounding, SiS obstructions
Rail	ETCS Class 3	HPE95% < 1-10m TIR = 10-9 Availability > 99.98% TTA < 7s	ERTMS GNSS Application in the Railway Domain Guidelines	CLUG GRAIL-2 ERTMS with GNSS EGNSS-R	SBAS message dissemination/reception, treatment of environmental errors, stringent integrity risks, complex hybridised architectures

- Analysis of the implications of different ground segments for UKSBAS SBAS & PPP testbed services.
- Minimum station trade-off over SBAS L1 & DFMC stations to cover UK with > 99% LPV-200 availability.

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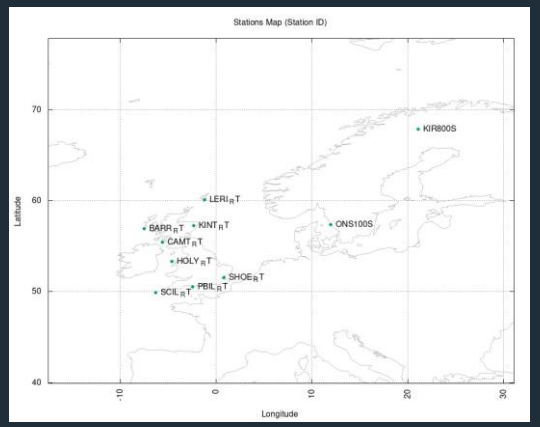
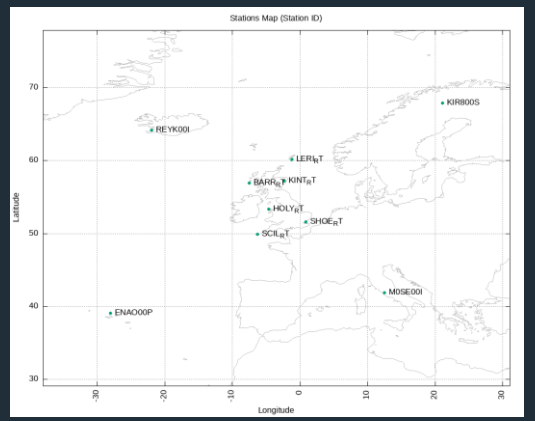


UKSBAS L1 <	UKSBAS DFMC >



Key Findings

- UKSBAS L1 Signal-In-Space broadcast over PRN158 has supported a wide range of user focused trials in the maritime, aviation, road and rail domains.
- Despite being a testbed with non-dedicated reference stations, results computed over 18 months show that UKSBAS achieves impressive performance levels (in terms of accuracy and availability) comparable to current operational legacy SBAS such as EGNOS, compatible with LPV-200 service level. Next-generation L5 DFMC SBAS providing augmentation over GPS and Galileo constellations in dual-frequency has shown remarkable improvement over legacy SBAS L1 augmentation at system and user level. The PPP service has also shown outstanding results in terms of accuracy and convergence time.
- Value has been found in a PPP corrections service in the road/automotive sector, through a road-specific technological solution that achieves decimeter-level positioning accuracy without expensive equipment, compatible with preliminary autonomous driving accuracy requirements. Furthermore, the potential value towards ensuring safe operations for rail trackside workers has been demonstrated as a cost-effective wide area alternative to RTK.
- The economic impact of the UK's withdrawal from EGNOS for small and medium sized airport operations has raised the need to recover an operational SBAS service over the United Kingdom, where UKSBAS has demonstrated the potential to support landing procedures over United Kingdom airports and on-board aircraft, with successful SiS tracking, fully compliant with LPV200 service levels and preserving positioning integrity.
- Effort is being completed in the maritime domain to standardize SBAS for improved navigation in oceanic and coastal operations, with potential to be employed not only standalone, but as a key subsystem that safely over-bounds the SiS error contribution in more complex and advanced architectures, involving local barriers such as Receiver Integrity Autonomous Integrity (RAIM) algorithms, and other ranging sources and sensors. A dedicated Maritime Integrity Service Facility has been developed, demonstrating adapted and flexible maritime solutions to optimize SBAS L1 and DFMC availability.

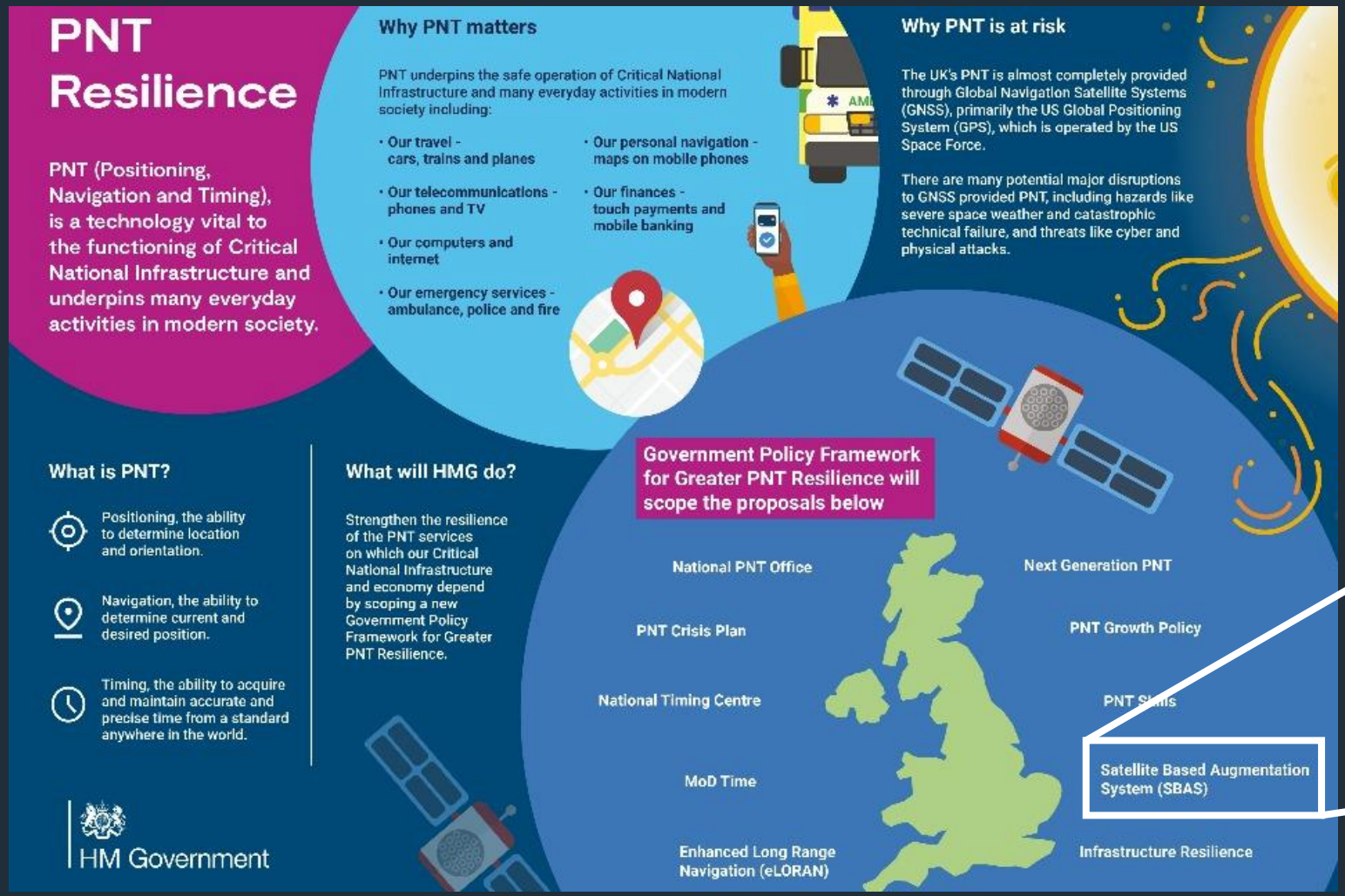
Key Findings

- In the road and rail domain, SBAS has major challenges ahead to deal with the inherent limitations of terrestrial applications. Protection against multipath degradation and signal blockages raise the opportunity for sensor-fusion algorithms and alternative approaches to deliver integrity. In the latter, SBAS systems are regarded as key enablers for complex positioning in On-Board Units on trains that can help to reduce the cost of expensive trackside safety equipment through scalable architectures where integrity is assured in the pseudorange domain.
- The UAV domain is expected to absorb aviation regulations for critical missions, and arising concepts that emerge in current regulations, such as geo-awareness or remote IDs, can potentially open new markets for SBAS and PPP where safe and reliable aerial navigation is enforced through regulation.
- The implications of dimensioning a ground segment for UKSBAS L1, DFMC & PPP services have been reviewed: regional stations are critical for SBAS L1 ionospheric monitoring and PPP reduced convergence times. Overseas stations are required for SBAS services to provide coverage in the eastern boundaries.
- From the CORS Ground Segment used for this testbed, a RIMS trade-off has been carried out, identifying two 10-station candidate distribution for UKSBAS L1 and UKSBAS DFMC services respectively that help to provide initial cost estimates to the business case. Sets of CORS added on top of a RIMS ‘core segment’ have been studied, identifying potential performance benefits.

Recommendations

- The maritime regulatory and technological landscape is evolving at present. Special interest has been taken with regards to the definition of the EGNOS Safety of Life assisted services for maritime users (ESMAS), in order to consolidate the relevant user algorithms.
- The use of SBAS on-board trains has been identified to have potential to be a key-enabler in the subsystem for ETCS Level 3. As a suggested upgrade from the completed trials, the mounting/installation of a high-grade rail approved GNSS antenna and SBAS equipment on-board a train would enable further demonstrations, providing higher fidelity results and the assessment of real-time SiS performances and post-processed SBAS DFMC solutions. More advanced processing techniques are recommended, such as tightly-coupled sensor fusion architectures, integration of digital track maps for error projection on the railway, as well as coasting simulation between the deployed Eurobalises.
- The UAV regulatory landscape is expected to accommodate demands from civil aviation authorities. The conduction of dedicated trials in line with the proposed plans would help to better understand the achievable performances of SBAS and PPP services in the domain and linking them to target requirements.
- The demonstration of PPP capabilities through performance assessments on public roads have shown interesting results in terms of accuracy. Further demonstration and evaluation of their performance at application level, involving automated vehicle interventions in a controlled environment, can serve as a consolidated proof of concept.
- For the adaptation of SBAS solutions beyond the baseline aviation algorithms based on RTCA/EUROCAE MOPS, effort has been spent in proposing domain-specific solutions to be integrated into the UKSBAS post-processing tool as part of the different demonstration platforms. The main driver for these evolutions is the proper characterization of the degraded local environment. Further development/improvement to the UKSBAS post-processing tool could be recommended, involving the treatment of unsmoothed transitory measurements and associated error characterization.
- A RIMS station trade-off has been simulated for UKSBAS L1 & DFMC ground segments to provide a minimum distribution. Consolidation of more candidate station distributions is suggested as way-forward, using flexible service volume tools over longer scenarios and addressing impact of various degradation modes.
- The possibility of using CORS as part of UKSBAS ground segment has been discussed in the context of the testbed as a cost-effective alternative. A more thorough analysis of the safety and security implications of using CORS in a ground segment is recommended.

Contribution of the project to national strategy



- **UK SBAS:** develop a proposal for a UK Precise Point Positioning Satellite-Based Augmentation System to replace the UK's use of the European Geostationary Navigation Overlay Service, monitor GNSS and enable GNSS dependent high accuracy Position for autonomous and precision uses

Satellite Based Augmentation System (SBAS)

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Technology Gaps

- How Continuously Operating Reference Stations (CORS) can be used in a Safety of Life (SoL) service
  - Requires further evaluation on the impact of using CORS
  - Software development on detecting integrity values and anomalies
- The test and evaluation of live over-the-air DFMC/DFSC services

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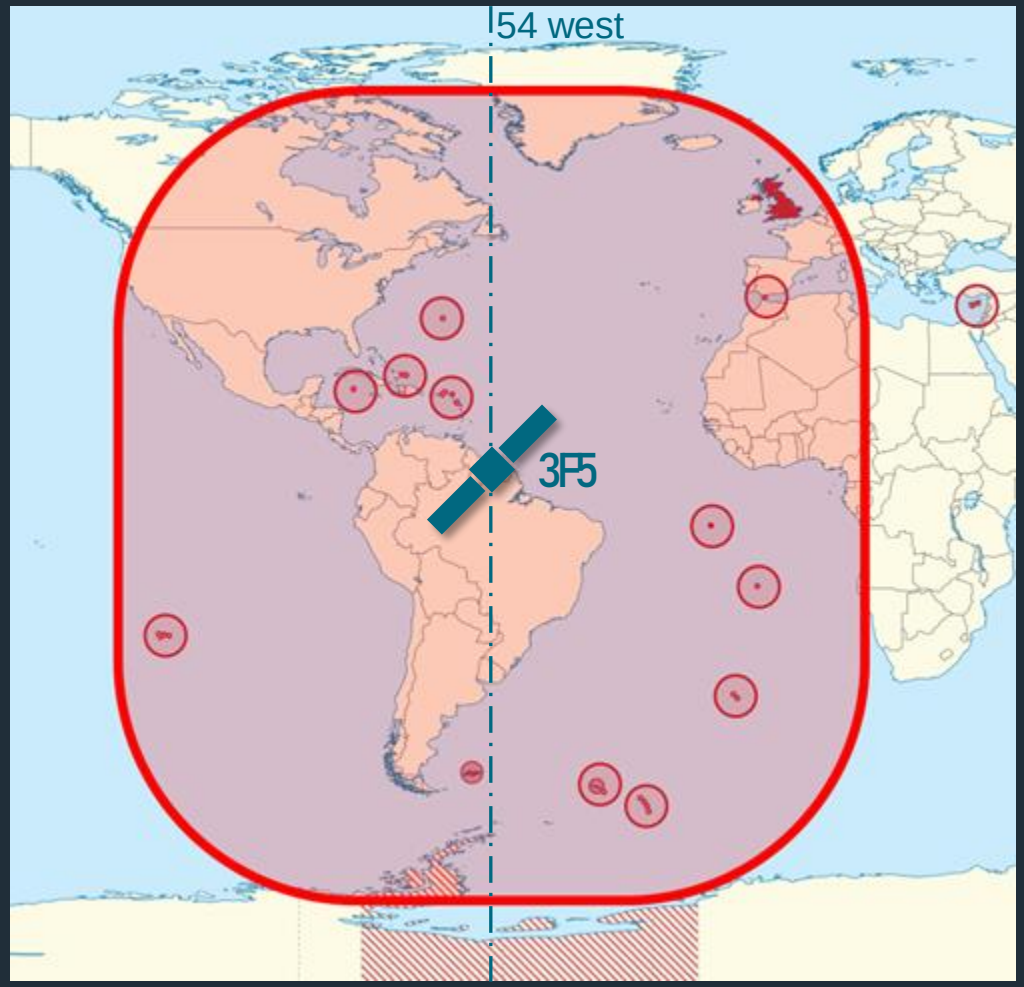
Approach to sustain the activity

- Pivot towards and fund a UK national platform to assess and evaluate the "globalized" provision of DFMC/DFSC SBAS services
  - UKSA still has use of PRN158
  - Inmarsat-3F5/54W transponder remains available, as a UK asset, for broadcasting SBAS messages
  - GMV servers/equipment and GES facilities (C-band 9-metre antenna) remain in-situ at the uplink station.
  - SBAS market is growing with Middle Eastern, African, Asian and Latin American nations commencing or evaluating new SBAS programmes
  - 3F5 has a GBA covering LATAM, part of Africa, and 12 of the 14 British Overseas Territories
- Evaluate and demonstrate LPV200 and PinS capabilities at “point/sub-regional locations” within the GBA
- Partly-supported by the UKSBAS initiative, Viasat took the decision to deploy a further THREE (3) SBAS payloads on satellites of the I-8 class due in orbit in 2028 at 178E, 64E and 54W GEO slots providing global coverage



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Benefits of working with ESA

- Technical and operational know-how in the domain of SBAS systems and services
- Application of robust verification and validation methodologies to enable the deployment of a test SBAS capability intersecting with operational (EGNOS and WAAS) safety-of-life services
- Programmatic coordination support at inter-governmental and institutional levels, e.g. with FAA, EU/EC

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Acknowledgements

- **Aviation**
- Civil Aviation Authority
- Cranfield National Flying Laboratory
- PildoLabs
- Isle of Scilly Travel - Lands' End Airport
- Skybus
- Regional and City Airports - Exeter Airport
- Regional and City Airports - City of Derry Airport
- Regional and City Airports - Norwich Airport
- Highlands & Islands Limited - Inverness Airport

- **Maritime**
- General Lighthouse Authority
- Isle of Scilly Travel - Isles of Scilly Steamship Group

- **Rail**
- Satellite Applications Catapult
- Network Rail
- Thales Group – Ground Transportation Systems

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Questions

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Stakeholder Statistics

Single Operator Flight Disruptions

62.5 Days
Disrupted Flying

→

50 Days
Due to Fog, Low Cloud, Low Visibility

→

26 Days
Could have flown is SBAS was available

52 %

1028 Flights
Cancelled due to Weather

→

14392 Pax
Affected by the cancellation

→

535 Flights
Could have flown is SBAS was available

→

7484 Pax
Could have completed their journey

971 Flights
Delayed due to Weather

→

13594 Pax
Affected by the delays

→

Significant number of delays could also be avoided or reduced

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