CAELUS

A roadmap to a national medical drone logistics network

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Innovate UK

CAELUS

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INTRODUCTION

The CAELUS project is developing what will be the UK's first national distribution network to use drones to transport essential medicines, blood, organs and other medical supplies throughout Scotland. The project is part funded by Innovate UK's Future Flight Challenge.

Project CAELUS: why? The vision of CAELUS is for NHS Scotland and wider society to reap the benefits of drone technology, particularly in remote and rural areas of Scotland. The Future Flight challenge is positioning the UK as a global leader in advanced aviation solutions with drone delivery central to this.

Project CAELUS: what? The CAELUS project is working to deliver what will be the first national medical drone logistics network that can transport essential medicines, bloods and other medical supplies throughout Scotland including to remote communities.

Project CAELUS: how? To achieve the CAELUS vision of a national drone logistics network a foundation of aircraft, infrastructure, supporting services, funding models, etc will be needed.

Why do we need a CAELUS roadmap? A roadmap is defined as "a structured visual chronology of strategic intent"[1].Put simply it is a visual guide to the steps needed to achieve a desired outcome that also shows how those steps relate to each other in time. Future flight related roadmaps such as the future flight vision and roadmap, and the future of flight working group action plan have been published and focus on specific aspects related to technology and regulation. Because a medical drone logistics network involves sectors including aviation but also healthcare, and logistics, a roadmap specifically for CAELUS is necessary to bring together the key elements from all these sectors.

Where does CAELUS want to get to? The vision for CAELUS is a comprehensive national network, realising the potential of drones to revolutionise medical logistics in the UK, scaling to achieve an efficient, economic service. This will involve a range of aircraft both large and small alongside multiple service offerings to support the needs of the diverse regional and national health boards within Scotland. A phased approach is proposed to achieve the development of the network and these phases are reflected in the roadmap.

Where are we now? Trials of services are being undertaken across Scotland testing concepts developed by the consortium partners. Alongside this there is engagement with regulators, key stakeholders including airspace users, NHS staff, and the public, to ensure the CAELUS vision aligns with these key stakeholders.

How do we realise the vision of CAELUS?

We need technology developments, investment, regulatory change and societal support to come together at the appropriate points in the next five to ten years to ensure that momentum is maintained and the CAELUS vision can be realised. This roadmap starts the process of identifying the key elements and the points in time when they need to align.

1 C. Kerr and R. Phaal, "Roadmapping and Roadmaps: Definition and Underpinning Concepts," in IEEE Transactions on Engineering Management, 2022

PHASED DEVELOPMENT

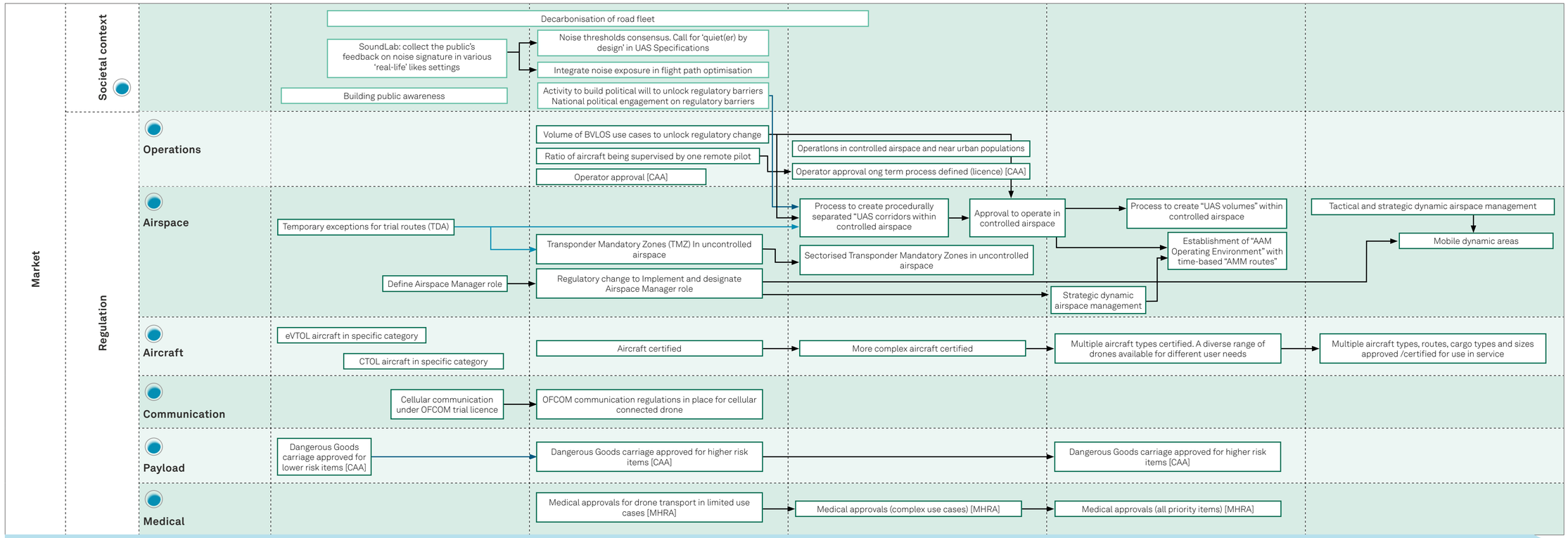
The CAELUS vision will be realised with phased development from the demonstrations within the current project to small scale services deployed initially in certain areas building up to comprehensive services at a regional level and ultimately a comprehensive national service across Scotland and beyond.

The phases underpinning the CAELUS roadmap are:

Minimum viable service	Comprehensive but geographically limited service	Comprehensive regional service	Comprehensive national service
Type of network: Single hub (major hospital), 3-10 spokes (smaller hospitals, GPs)	**Type of network:** 1-2 Hubs, 5-15 spokes	**Type of network:** 5+ hubs, major drone port, 30+ spokes	**Type of network:** National hub network, several major drone ports, intermediate charging locations where needed
Routes: 3-10 single hop routes	**Routes:** 5-15 single hop routes, assessment of multi-hop routes	**Routes:** 10+ single hop routes, optimised multi-hop routes	**Routes:** Optimised routing with multiple types of route
Payloads: 2-3 different types (lower risk) and small volumes (e.g. <5 samples)	**Payloads:** 3-5 different types increasing in complexity (e.g. stricter monitoring requirements)	**Payloads:** 5-10 different types increasing in complexity (e.g. multiple dangerous goods approvals)	**Payloads:** 10+ different types (all the highest priority payloads)
Service type: Scheduled (max two per day per route) and responsive (as needed)	**Service type:** Scheduled (min two per day per route) and responsive (as needed)	**Service type:** Responsive and scheduled	**Service type:** responsive and scheduled
Automation: Limited, significant staffing levels required	**Automation:** limited, significant staffing levels required	**Automation:** Significant flight automation, increased ratio of routes/services to staff	**Automation:** significant automation of majority of activities (flight, payload management)
Airspace: Flights limited to trial areas in controlled airspace and Transponder Mandatory Zones in uncontrolled airspace	**Airspace:** Flights integrated in procedurally separated volumes in controlled airspace and Transponder Mandatory Zones in uncontrolled airspace for UAS. New IFR routes for RPAS	**Airspace:** Shared airspace comprised of pre-defined reconfigurable volumes in controlled airspace and network of Transponder Mandatory Zones in uncontrolled airspace	**Airspace:** Highly dynamic reconfigurable volumes in controlled airspace and in uncontrolled airspace TMZs removed and a nationwide EC mandate introduced
Aircraft: 2-4 aircraft in operation (1-2 types)	**Aircraft:** 3-5 aircraft in operation (varied capabilities)	**Aircraft:** 5-10 aircraft in operation (multiple of each aircraft type)	**Aircraft:** Fleet suitable for the breadth of routes, conditions and payloads

How to Use the Roadmap

This roadmap has been designed to be interactive. Clicking on the illuminated buttons next to each sub-category in the roadmap will provide further detail on the right-hand panel which has been gathered as part of the CAELUS project through literature review, stakeholder engagement and input from domain experts.



Technology (see next page)

		Demonstrator - 2022-24	Minimum viable service	Comprehensive but geographically limited service	Comprehensive regional service	Comprehensive national service
Services	Operations		**Type of network:** Single hub (major hospital), 3-10 spokes (smaller hospitals, GPs) **Routes:** 3-10 single hop routes **Payloads:** 2-3 different types (lower risk) and small volumes (e.g. <5 samples) **Service type:** Scheduled (max 2 per day per route) and responsive (as needed) **Automation:** Limited, significant staffing levels required **Airspace:** Flights limited to trial areas in controlled airspace and Transponder Mandatory Zones in uncontrolled airspace **Aircraft:** 2-4 aircraft in operation (1-2 types)	**Type of network:** 1-2 Hubs, 5-15 spokes **Routes:** 5-15 single hop routes, assessment of multi-hop routes **Payloads:** 3-5 different types increasing in complexity (e.g. stricter monitoring requirements) **Service type:** Scheduled (min 2 per day per route) and responsive (as needed) **Automation:** limited, significant staffing levels required **Airspace:** Flights integrated in procedurally separated volumes in controlled airspace and Transponder Mandatory Zones in uncontrolled airspace for UAS. New IFR routes for RPAS **Aircraft:** 3-5 aircraft in operation (varied capabilities)	**Type of network:** 5+ hubs, major drone port, 30+ spokes **Routes:** 10+ single hop routes, optimised multi-hop routes **Payloads:** 5-10 different types increasing in complexity (e.g. multiple dangerous goods approvals) **Service type:** Responsive and scheduled **Automation:** Significant flight automation, increased ratio of routes/services to staff **Airspace:** Shared airspace comprised of pre-defined reconfigurable volumes in controlled airspace and network of Transponder Mandatory Zones in uncontrolled airspace **Aircraft:** 5-10 aircraft in operation (multiple of each aircraft type)	**Type of network:** National hub network, several major drone ports, intermediate charging locations where needed **Routes:** Optimised routing with multiple types of route **Payloads:** 10+ different types (all the highest priority payloads) **Service type:** Responsive and scheduled **Automation:** Significant automation of majority of activities (flight, payload management) **Airspace:** Highly dynamic reconfigurable volumes in controlled airspace and in uncontrolled airspace TMZs removed and a nationwide EC mandate introduced **Aircraft:** Fleet suitable for the breadth of routes, conditions and payloads
Resources	Commercial	CAELUS2 Macro-economic Impact Assessment CAELUS2 Value Case	Operational costs reduce due to back up transport use, and pilot to aircraft ratio, reducing Research, development and innovation (RDI) funding Commercial funding Outline Business Models for service, infrastructure (e.g. multi-purpose Full business case for procuring comprehensive service Template business case for other areas and use cases Low rate initial production of aircraft Routes limited by supporting commercial services e.g. insurance, aircraft providers	Investment case for scale up Sufficient demand to unlock investment for all BVLOS operations Informed Business Case for regional service – prioritising use case groups with evidence Aircraft manufacturing scales with reducing cost Increasing options for supporting commercial services e.g. insurance providers	Coverage and utilisation increases – reducing cost per trip Commercial funding Diversify business models for service and infrastructure providers Export of knowledge and expertise into other sectors Demonstrate value to key healthcare stakeholders Mature marketplace for supporting service options e.g. insurance providers	Return on investment

Technology

Aircraft Technology

Reliability and availability

- Reliability and availability requirements captured e.g. number of completed deliveries
- Minimum reliability requirements met
- Severe weather capability improved e.g. can operate in most annual weather conditions in operating area
- Comprehensive reliability and availability requirements met locally
- Severe weather capability e.g. can operate in 97% of annual weather conditions in region
- Comprehensive availability requirements met nationally
- Severe weather capability e.g. can operate in 99% of annual weather conditions nationally

Automation

- Automated flights with remote pilot supervision
- Aircraft to remote pilot ratio increases
- Flight automation – "conditional automation"
- Deconfliction without a pilot in the loop

Energy Storage

- Manual charging / battery swap
- Charging Automation
- Aircraft powertrain constrains trial/demonstration routes (range)
- Duplicate aircraft available to mitigate for charging time
- Increased availability and coverage due to higher capacity energy storage and faster charging

Detect and Avoid

- Transponder Mandatory Zone requirements met
- Certified on-board detect and avoid system
- Automated detect and avoid

Payload

- Limited aircraft load. Use cases dictated by drone payload capability
- Additional payload requirements captured
- Payload capacity improved
- Operations include multiple payloads based on drone design
- Manual payload load/unload
- Payload loading automation requirements captured
- Payload load/unload automated

Noise

- Noise requirements understood
- Quiet by design

Physical Infrastructure

Physical Infrastructure

- Process for infrastructure planning applications, building warrant approval and SER certification at each stage - increasing in complexity but learning from each stage and improving designs, processes etc to aid efficiency.
- Multi-modal infrastructure
- Standardised process for infrastructure planning applications, building warrant approval and SER certification.

Staff

- Maintenance undertaken by the dedicated drone supplier staff on ad hoc basis
- Maintenance requirements developed
- Maintenance support developed. On call maintenance specialists available. Teams of support at hub locations.
- Maintenance service developed. Maintenance service optimised for needs e.g. dedicated maintenance team at hub locations
- Personnel involved in NHS drone logistics scale-up requirements
- Personnel scale-up implementation

Power

- Prototype automated charging / battery swap
- Production automated charging / battery swap system
- Standardised automated charging / battery swap system
- Power requirements assessed.
- Power requirements monitored, assessed and scale up strategy developed.
- Scale up of existing infrastructure as per requirements and scale up strategy
- Power infrastructure developed capable of supporting comprehensive drone services

Landing

- CAELUS Phase 1 Infrastructure Concept
- Market engagement with ground infrastructure product manufacturers
- Temporary landing, charging and drone storage infrastructure
- Capture infrastructure requirements for a range of drones and develop a flexible common infrastructure
- Tiered landing infrastructure
- Improved landing, charging and drone storage infrastructure options at Drone ports.
- Landing and charging infrastructure as per service requirements at the Drone Hubs and charging and landing infrastructure at most of the destinations.
- Comprehensive landing, charging, drone storage and maintenance infrastructure options at Drone ports.
- Landing and charging infrastructure at Drone Hubs and destinations to support the full service.
- Standardised landing, charging, storage and maintenance infrastructure options.

Payload

- Payload infrastructure security requirements captured
- Payload infrastructure security requirements embedded in design
- No dedicated payload infrastructure.
- Manual Payload infrastructure
- Payload infrastructure as required by use case and location
- Comprehensive payload storage infrastructure to support the service and automated delivery system.

Digital Infrastructure

Communication

- Demonstration using existing cellular communications infrastructure alongside Satellite Communication. Findings to inform future infrastructure requirements
- Minimum communications infrastructure with redundancy
- Comprehensive comms infrastructure in service area
- Regional comms infrastructure
- National comms infrastructure capable of supporting service

Navigation

- Higher granularity Shuttle Radar Topography Mission (SRTM) data
- Assured GNSS with smaller variation in position

Surveillance

- The BVLOS UAS used is electronically conspicuous to detect and be detected.
- The aircraft used is equipped with obstacle avoidance technology - video/LIDAR/transponders
- 95% of vehicles globally shall be electronically conspicuous with certified technology.
- 99% of vehicles globally shall be electronically conspicuous with certified technology.
- Low level coverage (below 500ft) should be present within a volume in which UAS are operating

Uncrewed Traffic Management

- Demonstrate linking UTM with Air Traffic Management stakeholder
- Integrating CAELUS services into the existing UTM system. Interoperability tests
- Digital Flight Information Service
- Foundational UTM services deployed
- Overall airspace management approach
- UTM-ATM integration
- Digital Infrastructure integrated into Shared Airspace where all aircraft are conspicuous
- Digital infrastructure to support high density, high complexity operations.
- Airspace Management consisting of separate airspace managers with ATM, UTM and Flight and traffic information provided in uncontrolled airspace

INTRODUCING A COMMON THREAD THROUGH CAELUS

The CAELUS roadmap is a common thread that runs through the project, with work across the consortium using the roadmap phases to frame their outputs. Work from across the consortium has also fed back into and shaped the roadmap.

The Airspace Integration Concept of Operations developed by NATS with consortium partners is the backbone of the regulatory and technology streams of the roadmap. This Concept of Operations has been validated with key stakeholders and cross-checked for alignment with the roadmap phases.

The trials being undertaken in the project provide evidence for the regulatory change required to enable the CAELUS vision. In addition to the trials, the public engagement via the Commonplace platform will increase local public awareness and allows communications with the community. This developing of the CAELUS concept with local communities is crucial for the realisation of the roadmap.

Noise is a key aspect related to societal acceptance and this is highlighted in early phases of the roadmap. Public engagement specifically on the topic of noise from a drone delivery service is the focus of work by project partner Arup.

It is expected that the requirements for the medical drone delivery service will evolve at each phase of the roadmap and feed into subsequent phases. For example, requirements such as those related to weather tolerance may differ across locations and therefore as operations expand into new areas of Scotland the requirements must develop.

The CAELUS Value Case report aligns with the phased approach of the roadmap, focusing on minimal viable services initially. Building up the service in phases with investment decisions supported by evidence from earlier phases aligns with UK government best practice on programme and project management.

The economic modelling supports the commercial stream of the roadmap in identifying the service arrangements to support the early phases of the roadmap and the need to scale the service to ensure value for money for the public sector.

To ensure the smooth expansion of the service towards a comprehensive national network will require detailed planning and the use of virtual simulations of different network configurations will be key to this. The digital twin capability developed by the University of Strathclyde with support from ANRA Technologies provides a foundation for simulating networks configurations virtually.

SUMMARY

The CAELUS roadmap reflects the diverse set of partners contributing to the project and the roadmap is intended to raise awareness of the cooperation needed between different sectors to realise the vision of a national drone logistics network. The societal acceptance of medical drone deliveries is key to the realisation of the CAELUS vision. Public engagement and working with local communities is critical to ensuring the vision is developed with and embraced by communities.

Regulatory change is required to enable the early phases of the roadmap which rely on efficient approval of beyond visual line of sight operations. Further regulatory change is required to enable the later phases of the roadmap where varied airspace users are integrated in airspace.

The technology underpinning the CAELUS vision is core to the roadmap but its development should consider the evolving social, commercial and regulatory context to ensure the right technology is developed at the right time.

The commercial context is critical to the realisation of the CAELUS vision. While funding for research, development, and innovation is needed to mature the technology, attention is needed on the business models and procurement mechanisms to support the early phases on the roadmap.

The roadmap presents a vision for the development of a national medical drone delivery service. The real world often presents unforeseen barriers to realising such a vision and so the roadmap should be questioned, challenged, and reviewed regularly to ensure it is robust and a reliable guide.

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