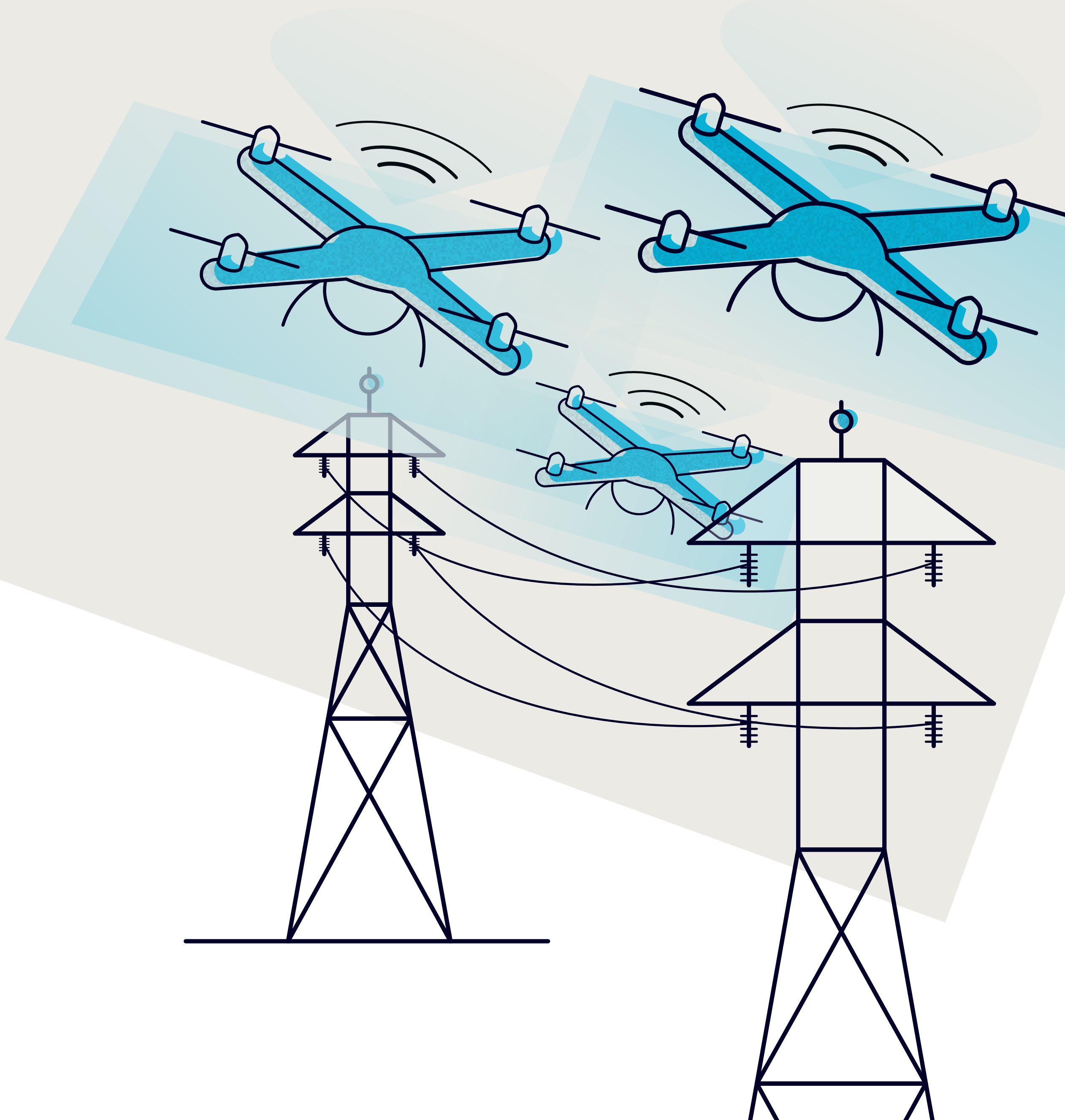
Innovation briefing

Collaborative autonomous drone fleets for next-level UAS operations



cambridgeconsultants
Part of Capgemini Invent

CC in three your key notes to take away

1. A ground-breaking application of autonomy is ready to accelerate the public acceptance and commercial viability of UAVs, transforming safety, reliability and trust

2. Advances in AI have unlocked a new paradigm of collaborative autonomous drone fleets able to share tasks and respond to dynamic environments through a dynamic hierarchy of command and control

3. The unprecedented levels of teamwork will elevate current commercial applications and unleash a new generation of novel use cases offering significant business advantage

Introduction: the business opportunity

The commercial prospects for uncrewed aircraft systems (UAS) are currently limited by persistent issues around safety. Cracking the conundrum of regulatory obstacles – related to societal acceptance – offers the keys to the future. CC strongly believes that the answer lies in a new generation of **automated, collaborative uncrewed aerial vehicle (UAV) fleets** with pilots on the loop, not in the loop. In fact, we are sure of it – and we've invested in a live working demo to support the thesis.

This Innovation Briefing reveals details of that demonstration as well as some exciting prospective commercial use cases. Our breakthrough in collaborative drone autonomy is a world first that advances the state of the art and has the potential to propel the UAS industry to the next level. Services based on single drones and piloted operation will still have their place for appropriate applications of course, but we believe our vision represents additional business opportunity for ambitious operators.

The challenge: overcoming hurdles and inefficiencies

Commercial drone operations have reached a pivotal point. The UAVs themselves are maturing, along with key systems infrastructure such as traffic management. So too is the potency of initial breakthrough use cases like inspection and delivery. The industry urgently needs to accelerate public and regulatory acceptance of UAVs.

The current economics of operations are based on UAS missions using semi-autonomous drones with autopilot and supervision from a human operator in the loop. The model of homogenous drones working identically and independently of each other is costly, inefficient, lacks adaptability and limits use cases. Our vision of a collaborative autonomous fleet model would transform economic viability. With oversight from a single human operator (on the loop), more would be achieved in less time – and much more safely. This is the way to greater societal and regulatory acceptance.

This article unpacks more of our reasoning why collaborative autonomous drone fleets with a dynamic hierarchy of command and control will help ambitious companies seize the future.

The answer: many hands make light work

Many hands make light work. This timeless truism is the essence of our innovation breakthrough. Undertaking missions with a collaborative autonomous fleet is the way to commercial advantage. Teamwork trumps all – and there are some cases that can *only* be achieved with multiple collaborating drones. Autonomous fleets will unlock those cases and allow missions to be:

- More efficient, because more than one UAV can cover a greater area or a larger physical linear asset
- More resilient, because the mission can be completed if one of the member of the fleet fails (the fleet can provide a mesh for communications and control)
- More effective, because the payload and mission activity for each UAV in the fleet can be different (each can have a unique sensor to execute a different task)
- Safer, because autonomy removes the human element that is subject to error, inconsistency and bias

A compelling commercial case

Most of the world's infrastructure sits on the earth's surface within an average space of no more than 500 square meters – think buildings, masts, towers and so on. So, there is an obvious need to have an aerial platform to install, access, measure and fix them. Other applications, to deal with inaccessibility caused by distance, environmental factors or hazardous conditions, add to the compelling case for UAS.

A collaborative autonomous proof of concept

Safety of UAS operations is of course paramount. It is also critical that the fantastic record of safety inherited from general aviation is maintained. Solving the related regulatory question requires a multifaceted initiative driven by national and international effort – and infused with bold technology innovation. It is this backdrop that spurred a multidisciplinary team of scientists, engineers and designers here at CC to seek a way forward.

Working in our multiple labs across the world we set about conceiving and implementing an appropriate system that creates a unique foundational technology to offer our clients. Now, we have a unique working fleet of collaborative autonomous drones. This proof of concept is an enabler to achieving Level 5 autonomy (the highest possible) with beyond visual line of sight (BVLOS) capability. We have a way to go to fully realise all aspects of safety, regulatory demands and operational robustness, but our viable far-reaching goal has been set.

Video 1. The CC collaborative autonomous UAV fleet shown at Amsterdam Drone Week. Watch video: https://cmcn.uk/k5s

Unpacking the live demo

1. Training the AI with reinforcement learning

The collaborative autonomous drone fleet operates in a dynamic and changing operating space and must change its spatial configuration to deal with obstacles, avoid hitting other fleet members, and cope with other non-cooperating UAVs. The fleet UAVs are flying without a pilot. We do not set a flight path, that is determined dynamically. We simply provide a target destination. Everything else is sensed and responded to autonomously. (see Figure 1.)

The mission is accepted by the fleet leader, which makes the macro decisions necessary to achieve success and to coordinate its members. Let's take a simple example of the fleet passing through an aperture which is too narrow for a normal wide formation. We believe our system is better suited to this goal than individual drones acting independently. Each would eventually get through by following basic rules like 'don't hit anything'.

The collaborative approach is much more effective. The macro level of AI makes the decisions for the fleet and provides the interim goals for the individual members. In simple terms, the fleet leader determines the optimal strategy and relays this to the followers so that they pass through the aperture efficiently.

This is achieved by using reinforcement learning (RL) to train the AI. To be specific, the RL control policies are trained using the widely successful proximal policy optimisation (PPO) algorithm. Effectively the AI exists at two levels: every fleet member uses RL for obstacle avoidance, the fleet leader is another layer of RL that determines the overall fleet strategy. The RL is trained in simulation where agents undertake many flights as members of fleets and are rewarded for achieving the goal while avoiding obstacles (including one another).

As it develops, this multi-level approach is applied to increasingly complex missions. The system's learning becomes increasingly effective, and it becomes able to deal with different situations exponentially.

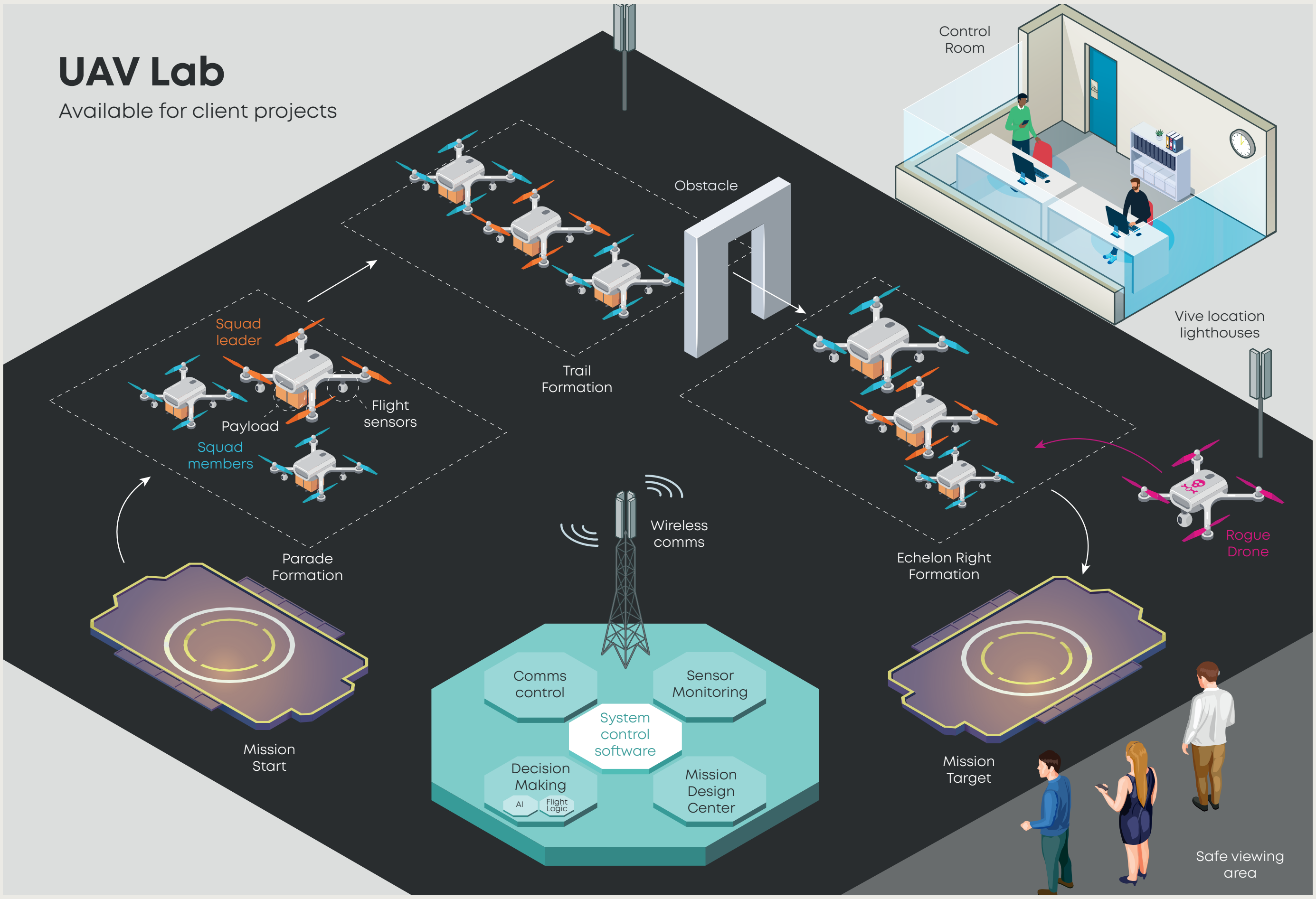


Figure 1. ConOps for our collaborative autonomous drone fleet concept

2. The UAV lab and platform

Our purpose-built UAV lab is where our live fleet demonstration takes place. It is also the platform for our continuing investigations, research, and testing. The team applies its competencies in AI, communication, embedded and cloud native computing, digital services, sensor fusion and mechanical systems. To provide a safe, secure and effective solution it is vital to achieve an integrated operational system that fuses the best of emerging technologies with robust engineering.

The lab allows us to learn by 'doing'. The harsh reality of flying autonomous drones in an enclosed space can only be learnt by experience – invaluable for our current and future clients.

We decided on an indoor lab to provide a more controlled environment for experiments. Custom made drones give us an airframe and a modular onboard computing and communication system that can be fully controlled remotely. Our indoor location tracking system provides UAV positions with millimetre accuracy. We have an efficient wireless communications system between each UAV and the ground control station (GCS) based on our optimisation of the PX4 stack and using the ROS operating system. This is the command and control (C2) interface.

We simulate LiDAR communications in the model. The RL trained algorithms are used to control the UAVs using the wireless communications system with a feedback loop to the indoor positioning system. We have implemented a mission control interface that allows the minimal parameters necessary to initiate and oversee the flight.

To improve the productivity of the flight testing and AI learning we also have a 3D simulated model of the UAVs and flying space. This allows us to use the full software stack deployed on the real hardware to be run and tested in real time with simulated motors and sensors, with full simulated physics and 3D rendering. All the lab software is run in the same way as the real hardware, except with simulated hardware for the UAVs. This allows faster, safer and cheaper development and testing of the system before needing to deploy it on real hardware. It's also faster, easier, and more convenient to do end-to-end testing of the system software and algorithms.

While the indoor approach is valid, we know that the system must be operated outside to satisfy the real use cases of clients. This will mean adapting the system for other wireless communication such as 5G or satcom, while using real sensors and dealing with weather conditions. We are also preparing to deal with macro meteorological forces like storms, as well as localised effects such as sheer winds around buildings.

Video 2. A 3D simulated model of the UAVs passing through an aperture efficiently. Watch video: https://cmcn.uk/n6w

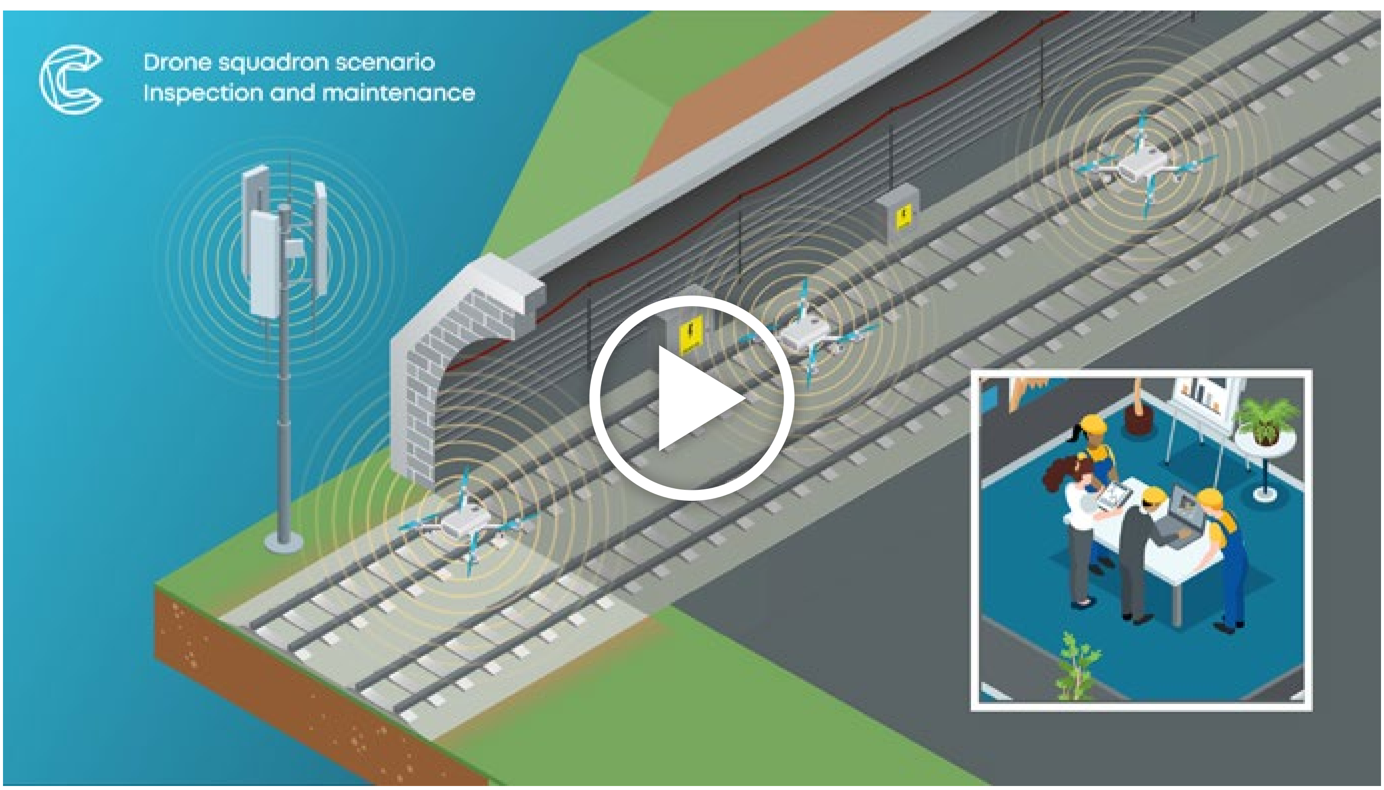
Potential commercial use cases

Infrastructure asset inspection

We are working on the assumption that many drones make light work, but how does that translate into potential use cases? Linear infrastructure asset inspection is a prime area for UAV fleets to exploit. Examples include railway lines, pipelines, electricity power lines, offshore windfarms and building cladding to name a few. These assets are not inspected regularly enough, leaving them exposed to potential failure. Further, power lines are currently subject to proximity visual inspection by helicopter. Blades and cables don't mix, so dangerous work that demands expensive, highly skilled pilots.

Our vision is shown in Video 3. In this scenario the drone fleet is inspecting a dark and potentially dangerous railway tunnel. There are many kilometres of track to check and high voltage lines overhead. Crucial safety checks should ideally be carried out without impacting passenger or goods services.

- The fleet navigates to the site and within the closed environment
- The tunnel is a comms-denied space so one drone stays at the mouth of the tunnel to retain wireless communications and relay it via intra-UAV mesh wireless communications to the fleet
- Each fleet member has a different sensor and role in the overall inspection
- Roles could include using a thermal camera to check any hot spots in electrical panels or using ultrasonics to look for rail cracks
- Information is streamed in real time to human inspectors who adjust the mission accordingly
- Larger data sets such as 4D image capture can be stored locally on the UAVs and taken to base for the creation of immersive digital twins

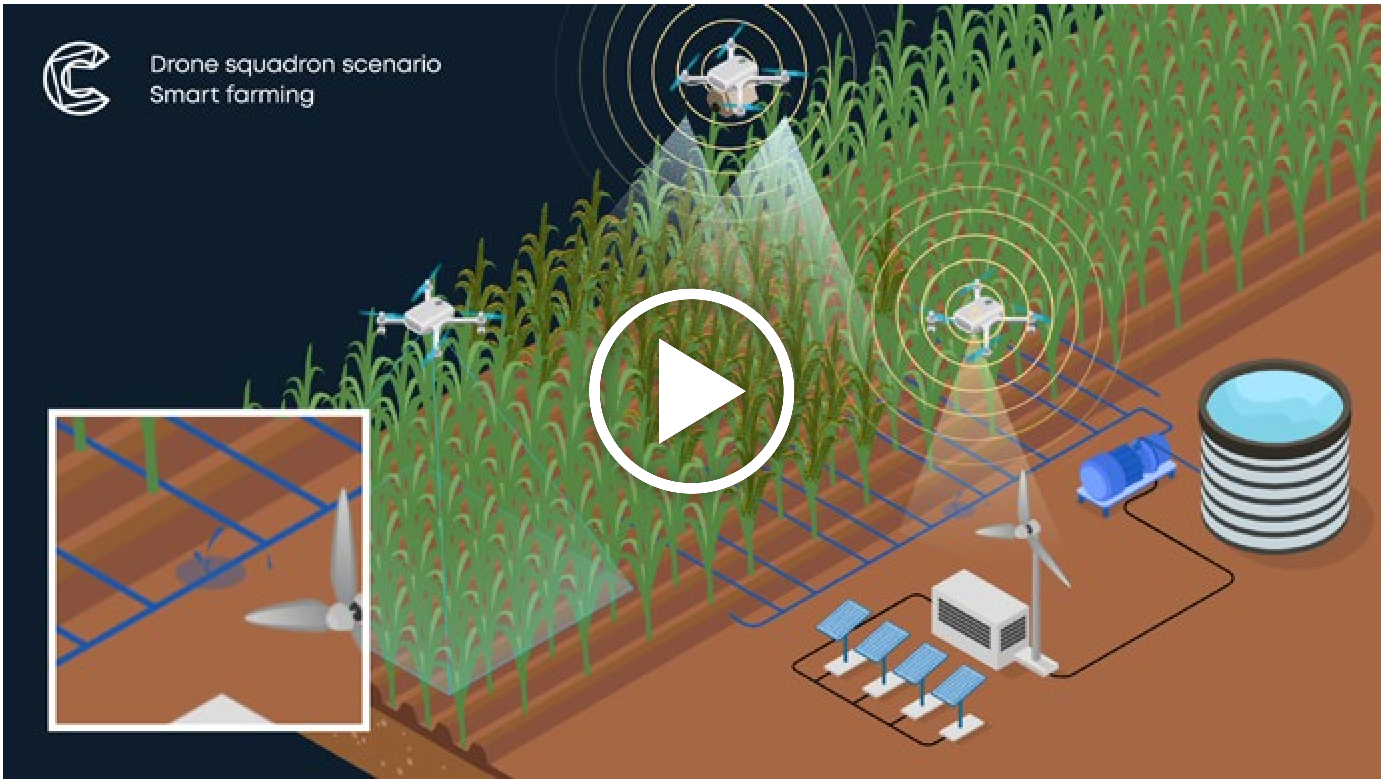


Video 3. Use case - Rail infrastructure inspection. Watch video: https://cmcn.uk/ofb

Smart farming applications

Collaborative autonomous fleets could bring transformative benefits to smart farming, when vast areas of crops need to be inspected. A fleet leader could identify undernourished or infested areas. Rather than having to schedule a follow-up mission, the fleet could treat affected soil or plants immediately. One member could deliver targeted insecticide or fertiliser. Another could check on irrigation systems.

Such an approach is in-keeping with the commercial advantages of precision farming. It amplifies the benefits of moving away from expensive and unnecessary large-scale crop treatment and intensive use of machinery on the soil. The collaborative fleet has inbuilt obstacle avoidance, so it can work very closely to objects. This provides the potential for not just conducting non-contact inspections, but for using a tool to make contact. (Taking a soil sample in a smart farming application, for example.)



Video 4. Use case - Smart farming. Watch video: https://cmcn.uk/fw9

Search and rescue

Even before the introduction of autonomous UAVs, drones were used to save lives in 68 instances by one vehicle manufacture alone between 2017 and 2022. In our imagined scenario, a snowboarder with a passive RECCO® searchable reflector gets buried in an avalanche.

- With speed of response vital, avalanche detection automatically triggers the UAV fleet to launch a search
- The fleet is able to cover a vast area rapidly. Once a fleet member picks up the reflector and spots the snowboarder it alerts mountain rescue
- A drone initiates ground-penetrating radar to gauge geography and the stability of the hillside
- Another projects a visual marker onto the snow to guide the helicopter and show rescue teams where to dig

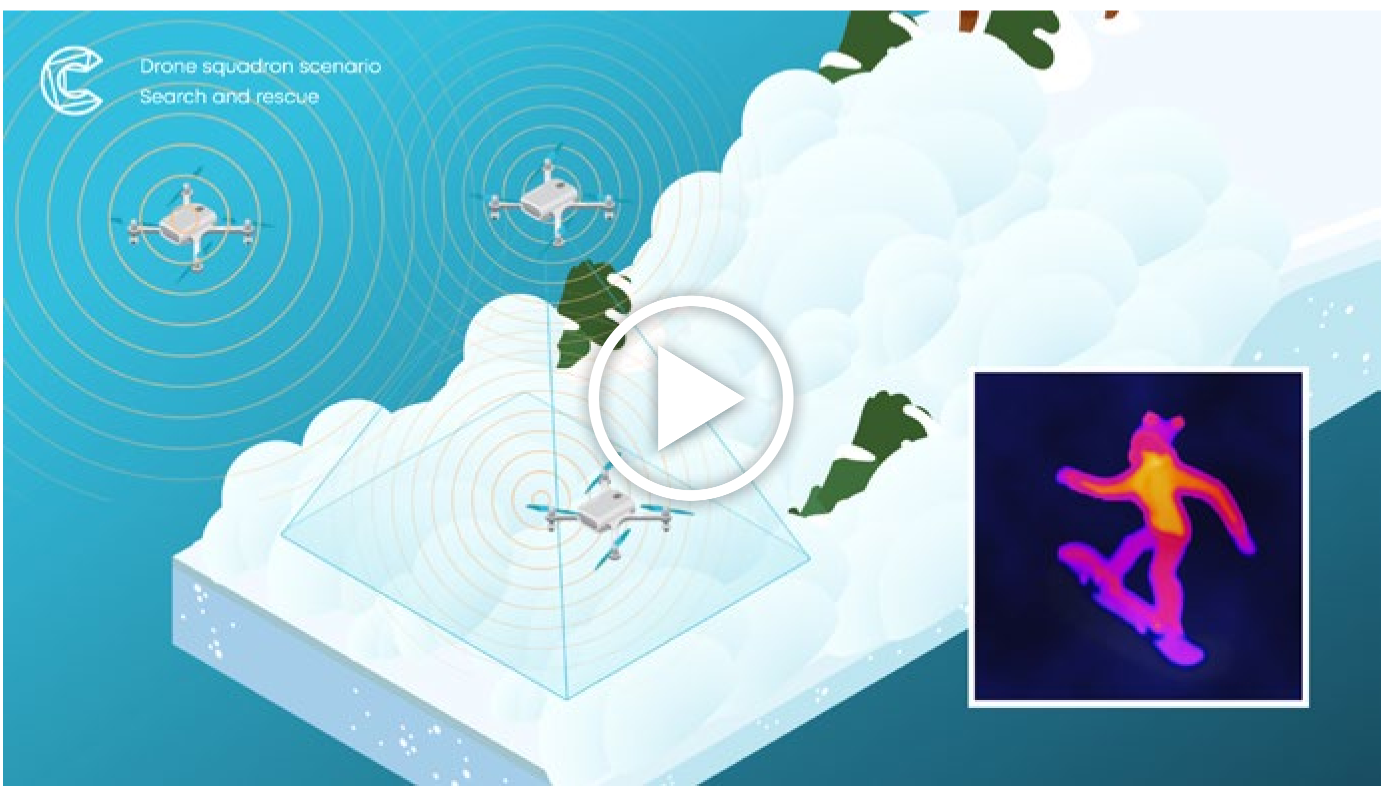
Such rapid coordinated activity could help save many lives. Variations of our example use case could extend to countless search and rescue operations.

A platform, and a springboard to the future

We believe that our unique collaborative autonomous fleet approach adds many benefits to the seed use cases that industry commentators have already identified. As is usual with technology advances, a host of further possibilities will open once techniques mature and the burden of regulation is lifted. That will certainly be the case if entrepreneurial businesses have access to a highly capable autonomous fleet platform.

Often the fleet mission will be to collect data. This is likely to be extremely valuable and obtained from otherwise inaccessible sources. Establishing the status of suspended high voltage cables or photographing remote places, for example. Such data is the fuel of digital services – and it can be processed into valuable insights by data analytics and machine learning.

Rather than the data itself being the value it's the insights or more importantly the improved outcomes that are valuable. The ability to conduct predictive maintenance to avoid failure. Being able to have accurate estimates of likely harvest levels to determine crop prices. The autonomous AI controlled squadron is then an arial data acquisition platform and fits into an overall service design approach.



Video 5. Use case - Search and rescue. Watch video: https://cmcn.uk/i9i

Cool not creepy, benevolent not malicious

Not every UAV use case will need BVLOS and full autonomy, so the collaborative fleet approach is another tool in the toolkit to be used in the appropriate way. UAVs working in hostile places such as offshore wind farms are great for removing danger from humans. But an autonomous, pilotless police drone investigating a crime scene has too much of the dystopian nature of the 'I Robot' movie for most of us. All autonomous systems should augment human effort, remove burden, ease repetitive and dangerous tasks – and ultimately deliver end user convenience and elevate the value of human endeavour.

Complications to be resolved

Our innovation has progressed the state of the art. But we are aware of further challenges to achieving wide-scale deployment and commercial success. Recognised barriers to large scale adoption lie in resolving the air flight regulations as UAVs join the single airspace alongside many other actors. Closely linked to this is societal acceptance of the benefits of UAVs. Most surveys show that people in the main recognise the benefit UAS will bring – but they expect safety and security not to be jeopardised..

To that end, we already exploring how an AI assurance framework can be applied to ensure correct mitigations are built into each stage of a transparent AI development lifecycle, a topic cover in more depth in our recent Innovation Briefing – AI assurance: protecting next-gen business innovation.

While our system has object avoidance, a trial or commercial service will need to integrate with a uncrewed aircraft traffic management (UTM) system and work with a coordinated detection and avoid system for flight deconfliction. Each UAV will need to provide electronic conspicuity (EC) so that it can be identified. We also need to determine how information from Notice to Air Missions (NOTAMs) are integrated into the mission operation.

The International Civil Aviation Organization (ICAO) regulation insists on a 'pilot being in command'. The pilot does not necessarily have to be onboard, and there now needs to be a debate with legal organisations if the pilot must be a human and, if not, where legal responsibility resides. Collaborative autonomous fleets offers new solutions to respond to the safety and security considerations and new challenges to move to an integrated airspace.

Conclusion: many hands make light work

Our development work is continuing. We believe that autonomy answers the challenges and opportunities of safe and successful commercial flights. This investment is a foundation to help clients achieve their ambitions and move beyond current thinking. Our in-house digital service innovation team stands ready to develop a commercial mission. We're well placed to further evolve the initial AI approach, as well as the communication and sensor-based systems, to cope with the ever-changing complexity and unpredictability of mission environments.

The approach has been applied to UAVs but will work with any autonomous moving system – be it ground or marine based robots – and we are already reusing our algorithms for other autonomous system initiatives.

If you'd like to discover more about collaborative autonomous drone fleets, would like help with an aspect of aerospace innovation, do please get in touch with Martin Cookson, Director of Digital Service Innovation.

martin.cookson@cambridgeconsultants.com

Why CC?

Cambridge Consultants (CC), part of Capgemini Invent, is a global team of 800 bright, talented people – united by the ambition to turn brilliant and radical ideas into technologies, products and services that are new to the world. We expand the boundaries of technology innovation by tackling the tough, high-risk challenges that bring sustained competitive advantage and market leadership for clients. We are trusted by some of the world's biggest brands and most ambitious start-ups to realise their critical technology-based aspirations – and we've been doing it for 60 years.

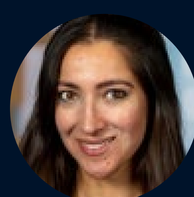
Authors and contributors

Martin Cookson,
Director of Digital Service Innovation

Sam Turner,
Associate Director,
Wireless and Digital Services

Stewart Marsh,
Head of Aerospace

Joe Smallman,
Technical Lead, AI and Algorithms



Kiran Ikram,
Senior AI Engineer

Chris Bourbeau,
VP of North America Aerospace

cambridge consultants
Part of Capgemini Invent

UK — USA — SINGAPORE — JAPAN

www.cambridgeconsultants.com

Cambridge Consultants is part of Capgemini Invent, the innovation, consulting and transformation brand of the Capgemini Group. www.capgemini.com

Lit-IB-008 v0.6 '2023_UAVs_Innovation_Briefing'