The Drone: A Building Block for the Network in the Sky

Many people in our industry dislike the term "drone". It implies something that is cheap, dumb and disposable – the exact opposite of traditional Aerospace. We're a high-tech industry and we defend the idea that we can build vehicles with capabilities that no-one else can.

However, those people might be missing the point. That word, drone, coming from bee colonies, tells us that something much bigger is going on. We may be considering a single vehicle, but it is part of a network. A network, which may soon have the ability, if some of the fast-moving developments of the Digital Technology industry continue, to decide autonomously how best to achieve its given objective and therefore begin to be more important than any of its individual parts.

Information networks with some form of airborne element have been around for almost as long as the Royal Aeronautical Society. But at the moment, we're at the start of an exciting ride of linking all our existing innovations together and joining up with the exponential trends of the entire Digital Tech Sector – including Distributed Computing, Artificial General Intelligence, Sensor Fusion and others.

This is our first peak at our own future and we're going to have to change our thinking, and our partnerships, to keep up.

It's Not About The Vehicle

So, what is a drone? On first hearing that word, one might think about an armed, military combat aircraft. Or possibly a teenager's toy. Or, how about a weather satellite?

Ultimately, a drone is simply a node in a network, specifically one which can take to the air. The Aerospace industry – especially in the UK – has mastered the business of getting into the air. We can design, build and fly aircraft in any part of the flight envelope all the way up to space and are still setting endurance records. We have a wide choice about which technologies to put together into a vehicle – from electric engines to ramjets, blimps to rotorcraft. You could argue that, as an industry, we have achieved our remit and everything is now just optimisation:

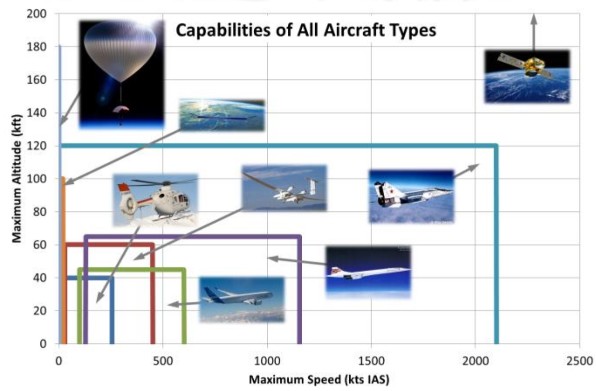

Fig. 1: Capabilities of Aircraft Types

However, if you think about the vehicle – or the "node" – from the network's point of view, there are just 6 attributes that actually matter:

- Location (where is it in x, y and z)
- Velocity (how rapidly it can relocate)
- Endurance (how long can it be there)
- Connectivity (how it interacts with network)
- Environmental (can it survive the weather)
- Certification (is it allowed to be there)

There are many examples in Aerospace history of trying to make one node do multiple different tasks. But time has told us that this is a quick route to runaway expense and compromised capability. This is why Systems Engineering brings success – it ensures that Engineers focus on the function and not on the means, allowing us to use many different solutions in parallel to solve problems efficiently.

So when we start thinking about designing a system, rather than the vehicle, some interesting solutions start to appear. For instance, in the Digital Tech industry at the moment there are three huge Aerospace projects with the same operational requirement – to deliver wireless broadband internet to consumers in 2020. But the vehicles in the network couldn't be more different:

Facebook's solution is a fleet of their Aquila solar-powered fixed wing aircraft, developed from QinetiQ's Zephyr platform, slowly orbiting at 60 to 90,000 feet. Google is also competing for use of the stratosphere but their aircraft are 15m wide disposable helium balloons. Meanwhile, a company called OneWeb believes that the solution should be in space and proposes a constellation of over 600 satellites in Low Earth Orbit.

Fig. 2: Facebook Aquila, Google Loon, OneWeb

But there is no benefit unless different vehicles can collaborate through a network – a network in the sky….

A Network In The Sky

During my career in Engineering, I've discovered that when you're designing a system, there is a fundamental difference between the types of components you want one of, components you want two of (for symmetry or sharing), and components where many are required and an optimum just needs to be found. For instance, a passenger airliner has one cockpit for good reason, two wings are necessary for balance, yet does it really matter how many wheels there are in the undercarriage system?

What's important is that as soon as you have more than two things interacting, you need a network – a way for them to relate to one another in a many-to-many relationship. This could be a structural network, an information network, a power network or any other type of connectivity. The network between the wheels in the undercarriage is a complex set of axles and bearings, load-carrying elements, dampers and actuators – but together they make up a system which acts in unison to support the aircraft on the ground.

Thinking back to internet drones, communicating with large parts of the globe simply cannot be accomplished by just one vehicle and therefore many are required. Constraints of size, cost and mission duration also infer that these aircraft cannot be manned. However, if you have large numbers of unmanned vehicles, it's difficult and inefficient to coordinate their actions centrally, requiring constant ground-to-air communication.

Instead, these vehicles must be able to collaborate between themselves as part of their own network. This substantially reduces the power and amount of communication needed and allows the drones to share tasks such as clustering over an area with high data needs or regrouping if one of the nodes malfunctions.

This networked decision-making is known as distributed computing and, along with ever-decreasing weight and power requirements of computers, is an emerging trend from the Digital Technology sector that is an enabler for countless technologies including smart traffic lights, cellular networks, driverless cars and water distribution systems.

For Aerospace, the advent of distributed computing in the sky is going to change the sorts of aircraft that we need to build, opening up new requirements for aircraft as new applications for aerial networks become possible Luckily, we're in a position to benefit from the other industry's very rapid developments and exploit them in our own.

Generally speaking, technology progression like this follows recognisable patterns. Whether we're looking at the thermal capabilities of turbine blades or the sequencing rate of DNA, we see a breakthrough that leads to rapid progression before ultimately delivering diminishing returns – and then the next breakthrough comes. These are known as S-curves.

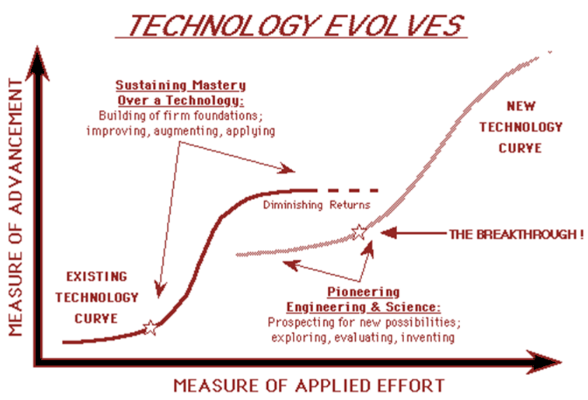

Fig. 3: S-Curves describe technology improvement

My own experience working with unmanned systems makes me feel that we could be reaching diminishing returns from using individual drones, as we find fewer and fewer applications where a single drone can do something new for us. It's been nearly 20 years since the Global Hawk first flew, paving the way for remote operations anywhere in the world, however now is the time for the network to take over. This will allow us to progress from the constraint of building one, super-effective vehicle and controlling it directly, to designing systems of drones which can collaborate.

There is also no need for all the nodes in a network to be truly the same. Swarm Systems, a UK-based defence drone company, proposes a future system of warfare where entire battalions of drones, including solar-powered scouts, armed attack drones and heavy lift logistic drones, can be airdropped into a battlefield and decide amongst themselves how best to lead their human allies into enemy territory.

But a network and its nodes cannot function without intelligence…

The Role of Artificial Intelligence

What is a robot? According to researchers, it is simply a machine which has three main functions:

- Sense (monitor environment, detect change)
- Think (decide how to respond)
- Act (effectors to make a change in response)

Take away 'think' and you are left with a mechanism; alternatively, take away 'act' and you simply have a computer.

So, if we are designing a system to solve the problem of distributing internet across the globe, it helps to think about the network as a whole as being the 'robot'. This robot is solving the vague objective of giving the best internet access to its customers – meanwhile the vehicles themselves are its mobile sensors and effectors, performing the main act of relaying communications whilst autonomously taking care of their own needs of location control, energy management and damage tolerance. And in a truly distributed network, the vehicles are all co-ordinating amongst themselves to decide how to solve the wider objective.

Autonomy of any type requires a degree of intelligence. A robot network needs to autonomously to find the best solution to a large number of simultaneous problems of different scales and therefore make use of advanced intelligence. This is exactly what humans are great at and machines, until now, have struggled with…

Artificial Intelligence comes in many flavours but there are currently considered to be three main categories:

1. Artificial Narrow Intelligence (ANI): A machine is specialist in one area.

2. Artificial General Intelligence (AGI): A more general mental capability that can reason, solve problems, think abstractly and learn from experience

3. Artificial Superintelligence (ASI): An intellect that is much smarter than the best human brains in practically every field including scientific creativity, general wisdom and socially.

We are living in a world surrounded by ANI; examples include the system that decides which gate an airliner goes to, websites which generate automated product recommendations and voice recognition software. We can build complex systems by stacking technologies together.

At the moment, we're just reaching the stage where we could deploy a large network of aircraft which can effectively decide how to achieve a task and also deal with failures. But, it might not be long before such a network can look after itself better than any dream team of our top air traffic controllers, pilots and network administrators:

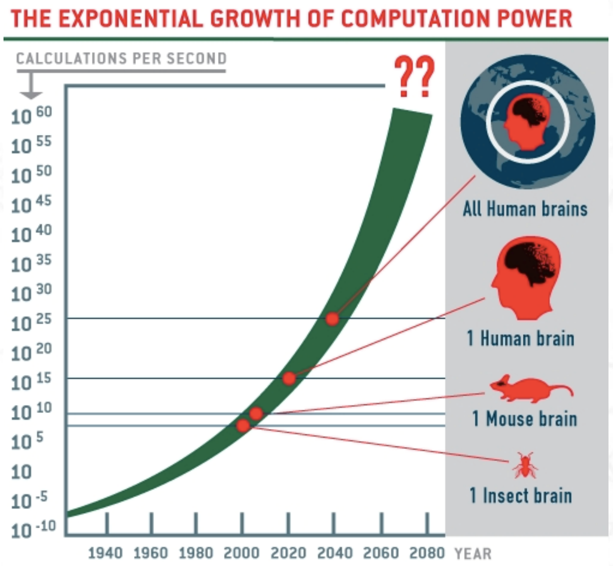

Fig. 4: Predicted Growth of A.I.

So – putting the three building blocks together gives a network of drones the chance to achieve true teamwork:

True Teamwork

If we look at Engineering in general, our greatest achievements are the products of teams working together, people co-ordinating their work and compounding their strengths. No longer are the big breakthroughs achieved by soloists with extraordinary skills.

To mirror that in the world of drones, we are just starting to see applications emerge for airborne teams of autonomous aircraft. No longer should drones only given the Dull, Dirty and Dangerous jobs to do – I'd like to share some of the latest concepts with you from around the globe:

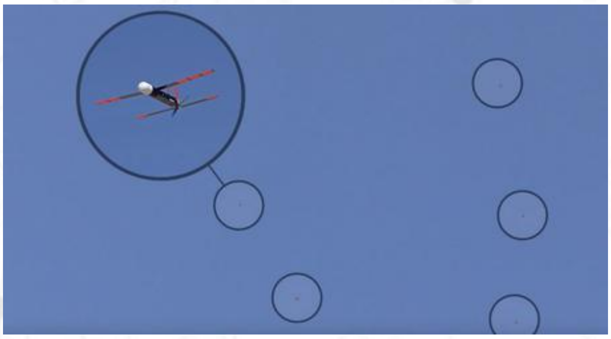

Fig. 5: US Navy LOCUST drone swarm

In Defence, trailblazers as ever, the US Navy have been trialling their LOCUST programme – a swarm of lightweight drones that co-ordinate amongst themselves and send individuals to investigate a target while the others regroup to attack. Fired from tubes, their wings unfold and once they've got their bearings, collaborate in groups of a dozen or more.

Fig. 6: Delft Ambulance drone

Of more direct interest to public health, the University of Delft have designed a drone to lie in wait until someone has urgent need – of a defibrillator. This node of the healthcare network can also communicate directly with a first aider until the ambulance arrives.

Fig. 7: Drones for Agriculture survey

For a civilian solution to tackle drought and decreasing returns from farming, thanks to Vijay Kumar's lab at Penn State University, a group of quadcopters can now work together, each with different sensors, to map out and investigate the health of entire orchards, providing farmers with recommendations on how to treat individual trees.

Fig. 8: Facebook Aquila on maiden flight

And, as mentioned earlier, Facebook Aquila is using high-altitude UAVs to connect the most isolated communities into a truly world wide web. These vehicles are rapidly advancing towards readiness with a planned entry into service within the next decade.

So why are high-tech companies increasingly using networks and distributed computing to solve problems? By spreading the functionality out among multiple modes, you have the opportunity to lower the cost (by mass-producing simpler vehicles), improve the robustness (by ensuring redundancy) and giving a holistic approach (spreading sensors and actuators over a wider area) than can ever be possible with one vehicle.

The challenges of designing such systems are many and include significant advancements which need to be made in the fusion of many sensor inputs; extracting meaning and patterns from large volumes of data; distributing the processing efficiently around the network; extracting energy from the environment. However, these challenges being addressed throughout the Digital Tech industry and we can build on their exponential growth and achievements, much like mobile phone batteries enabled the electric car. These challenges are not those of Aerospace!

But how well is the UK positioned to take part in this?

A Role for UK Aerospace

In the UK, we have key strengths that allow us to partner with these big Tech developments and provide drone solutions for the networks of the future. The Civil Aviation Authority is recognised for being forward-thinking and pragmatic in UAS regulations. Our world-renowned Universities are expert in rapid design / manufacture systems. We have a strong, established Aerospace industry capable of developing and certifying any size and application of aircraft. We also have a government which supports innovation, entrepreneurship and the advancement of science.

However, we face challenges to being able to grow our own big Tech companies. For instance, there are few UK role-models who think big in Tech – who's our Elon Musk? There is the growing complexity of collaborating with Europe on digital business, coupled with protectionism growing in the USA which limits foreign involvement. British venture investors are traditionally conservative and react too slowly to make high impact investments. We also have an industry of Aerospace companies aligned strongly with their traditional markets and preoccupied with innovating to reduce cost, rather than expand into new markets.

As an industry, I believe that we should therefore focus on delivering solutions to any airborne requirement that the global Tech industry can throw at us. We need organisations which can swiftly partner up to deliver aircraft and systems regardless of scale – for instance, which can provide power from 2 Watts to 200 Megawatts, in a vehicle that may fly, flap or float. We should be able to take any requirement for location, duration and connectivity and be bold enough to find the best way to fulfil it.

This may require the setup of a new interface for the Aerospace industry as a whole – a front page through which any potential partners in the Digital Tech industry can find aerial solutions to their networking problems. Such consortia have been set up before, for instance SMMT in the Automotive Industry – the Royal Aeronautical Society could help this happen.

We already have successes to celebrate; For instance, Amazon has chosen to partner with the UK industries to trial its home delivery network. This should excite everyone in the industry and we should embrace this type of change and not give in to easy apathy or pessimism in this respect.

So, let's stop focussing on the vehicle and start thinking about the network. Let's embrace the word drone.

Colin Field MRAeS

Bristol, July 2017

Visual Presentation:

https://prezi.com/nm-g7htnrstc/uavs-and-ai-what-next/

Inspiration:

RAeS Blog: *AirbusDS FCAS Brief*

Wired: *How Drone Swarms Will Change The Face Of Modern Warfare*

Wait But Why: *The AI Revolution*

Facebook: *Building Communications Networks in the Stratosphere*

Ministry of Defence: *SDSR 2015*

BBC News: *Tech Talent: Mapping the Route to a 'UK Google'*

P.W. Singer: *Wired For War (2010)*

Yuval Noah Harari: *Homo Deus – A Brief History Of Tomorrow (2015)*

David Hambling: *Swarm Troopers (2016)*

Stephen Crampton of Swarm Systems Ltd

Nigel Gifford of Ozoneering

TED Talks by Vijay Kumar

The ASTRAEA Project

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Fig. 5: Office of Naval Research Youtube channel

Fig. 6: TU Delft Applied Labs

Fig. 7: L'Atelier (BNP Paribas), Penn Engineering

Fig. 8: Facebook / engadget.com

And with many thanks to Andy Haasz, Rolls-Royce plc, for his mentoring throughout this process.