Innovators

News and perspective from our
Research and Development teams

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Innovators contents

Click on the story title to take you to the relevant page

QR codes have been included within many of the articles. These will enable you to link through to further information.

BAE SYSTEMS

Driving integration across government and defence

Welcome to the next edition of Innovators, celebrating our most exciting technology projects and the people who make them possible.

The stories cover work in digital integration, operational advantage, manufacturing and sustainability. What's different this year is our focus on integration across domains. But it's not just the classic military domains of Land, Sea, Air, Cyber and Space – we're also integrating government databases to help stop crime, speed up border checks, protect vulnerable people and even identify disease outbreaks before they become pandemics.

While the concept of integrating across domains isn't new, it's been extremely difficult to achieve. Arguably, the technology has been available for a number of years, but behaviour change is definitely harder than solving the technical challenges.

One of the reasons it's so difficult to achieve an integrated force is the variety of different architectures and standards involved. That's why we're building a suite of capabilities that are designed to work across all domains, built on common NATO standards where they apply. These include: a multi-domain battle network called NetVIPR; a suite of autonomous vehicles using common architectures across land, sea, sub-sea and air; and a battle management system that will share data, enable command and control, and automate some aspects of mission planning.

We are designing our products using open systems, so that they can be more easily integrated with one another and with third-party products. In fact we're working with RUSI to help agree common standards and architectures that do even more to help our customers avoid being locked into just one system.

In BAE Systems we take great pride in working across land, sea, air, space and cyberspace, giving us a unique view over the systems that keep these domains in operation. It's our aim to help our customers to integrate across domains more securely, whilst also making it easier to add new capability from a range of suppliers.

Why are we doing this? Everyone you will meet at BAE Systems wants to help those who protect us. Ultimately we all want the men and women who are risking their lives on our behalf to be safer and better able to complete their missions.

If our customers can get access to all the data from all the sensors available, then they can use Artificial Intelligence (AI) tools to help make sense of it and aid decision makers in choosing their response. If, at the same time, they have control and oversight for every military asset, then they can fight more rapidly to the best effect, protecting lives and deterring enemies from even initiating conflict.

This integration extends beyond the battlefield, as you'll read about our manufacturing, synthetic training and simulation techniques. These are helping to make us more efficient and sustainable, as well as enabling training and testing outside of the permanent satellite-enabled gaze of our potential adversaries.

If you'd like to know more about anything in this book, please contact us at ctocomms@baesystems.com

Julian Cracknell,
Chief Technology and Information Officer

Return to Contents page

Future View

There's no doubt we're seeing a sudden increase in the public awareness of Artificial Intelligence (AI). While it's been discussed in scientific and engineering communities since the 1950s, the emergence of generative AI, with open public access, has inspired our collective imaginations to consider a future world that we have never previously imagined. Much like the Internet has become increasingly enmeshed into our lives since the 1990s, fuelled by ever increasing bandwidth of digital interconnectivity through the 2000s, AI is poised to change our experience of the world we will live in.

In the context of defence, I expect the AI revolution to be even more profound than these earlier digital examples. Our brains can only learn from the situations we are exposed to, at the rate at which life presents us with them. AI has the ability to learn from vast reservoirs of data, at a rate that is limited only by the computing power applied to the training.

How long does it take to train a human soldier? Around 20 years minimum, given the years of parenting, school and then military training. However, technologies such as deep learning and generative AI open up the possibility of AI-driven combat vehicles that constantly learn from operational environments. The ability to deliver combat mass becomes completely independent of population size or the need to sustain human forces.

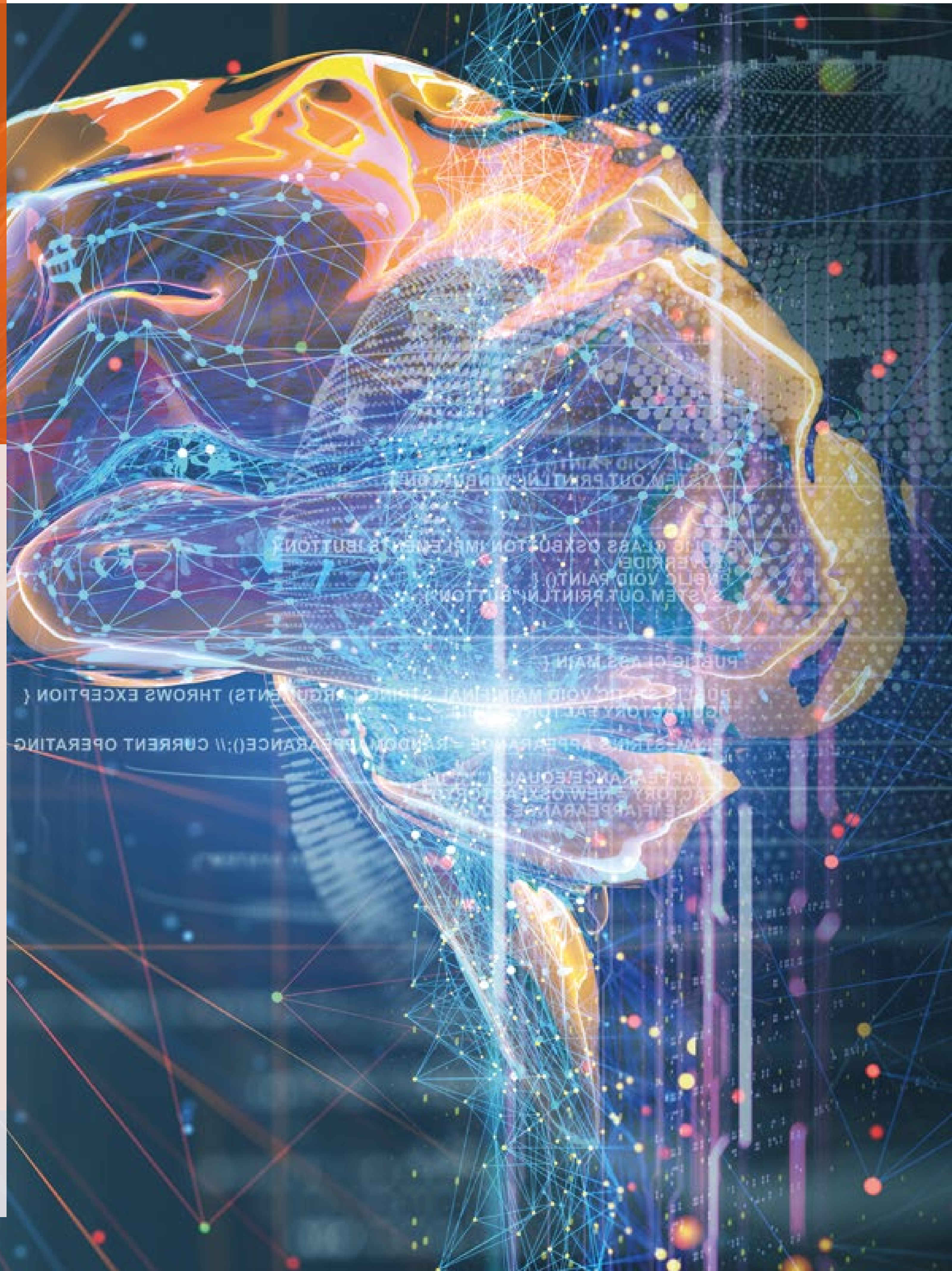
Now imagine a world where our ability to synthetically simulate real-life operational scenarios is so realistic, that these AI driven machines can learn, and test their learning, entirely within the virtual world. Countless scenarios could be rehearsed and trialled to optimise the algorithms that will provide machine speed decision-making on the battlefield.

We are a long way from these armies of self-learning, self-validating, autonomous vehicles, but given that many people think an international ban on developing military AI would be almost impossible to enforce, we need to consider how such a threat could be countered. AI will be a leading area of innovation in both civil and defence technologies, but it needs to be guided by moral and ethical imperatives. Like our customers, we firmly believe that there should be meaningful human input into the use of AI in defence, particularly in the weapon command and control chain. Our current focus is to develop AI that supports Command and Control, allowing machines to make allowable decisions within defined levels of operational authority, while helping humans choose the right responses to evolving situations, at pace, in the light of increasingly complex situations.

There are still major hurdles to overcome before AI is able to perform many of the functions carried out by humans today, but I doubt this will remain true forever. We need to embrace AI, allow it to become another tool in our everyday lives, and ensure we are prepared both to counter it, and to use it to complement our own decisions.

Our customers' goal – which makes it our goal – is to protect people from harm. We will continue to explore AI to understand both how others might use it, and how we can responsibly use it ourselves.

Rob Merryweather,
Technology Director



Digital Integration

According to Forbes, 70% of digital transformations fail because of the failure to implement new processes designed to best use digital technology.

A great example of this is General Electric, which realised in the early 2010s that digitising its massive corporation was essential to success. It formed 'GE Digital' in 2015 to create this new digital future, designed to help itself and its customers develop digital products and use the cloud to store and exploit data. They set up a huge organisation to 'carry out digital change' without having a clear roadmap as to what success looked like, and without buy-in from its constituent businesses. The company was forced to split up its business and lost billions of dollars.

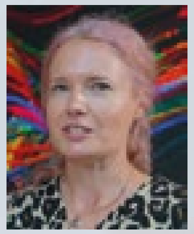
To avoid falling into this trap, it's important not to be seduced by the idea that simply installing a new digital system will solve your problems. Digital transformation is hard. You need to understand how your company operates now, think about how best to use digital technology, and then work out how to get there with strong leadership from the very top. Despite the difficulties, the rewards are massive.

In our work with the police to help identify vulnerable children, we've collaborated with officers to understand the current – largely manual – process for gathering information from various databases, then helped establish a new digital process that takes full advantage of an automated analysis of those same databases. This way, we were able to sit with the team doing this work, and make sure they agreed and saw the value of the new processes. I'm happy to say that this is now in use and has transformed the way that the police force does this important work, saving thousands of hours of manual work.

Another good example in this book is our AI dogfighter on p.28. This has been trained to win dogfights based on the optical and radar information that a pilot would have available in the real-world. Often in the past, similar AI systems have been fed 'perfect' information on adversaries' positions within that synthetic environment, which just isn't realistic. By understanding the context in which pilots operate, we've created a system that better reflects this environment.

When we turn to our military customers, the digital environment is a classic 'brownfield site'. Systems have been procured to fulfil a specific need – transferring video feeds from reconnaissance assets to their headquarters, for instance. This means there are multiple separate systems, which weren't originally designed to talk to each other.

These various systems now need to be integrated, but since we're not starting with a clean slate, we need to find a way to connect existing assets, whilst working across industry and our customers to choose a better way going forward – again, it'll be about people finding agreement before the digital technology can truly deliver a transformation.



Mivy James,
Digital Transformation Director

Return to Contents page

Working with Microsoft on an agile Combat Management System

The Combat Management System (CMS) is the brain of a ship. It brings together all of the on-board sensor data and external data sources, as well as giving secure access to the ship's weapons and countermeasures. It's a highly effective but also bespoke system, for which it's difficult and time-consuming to make changes – until now.

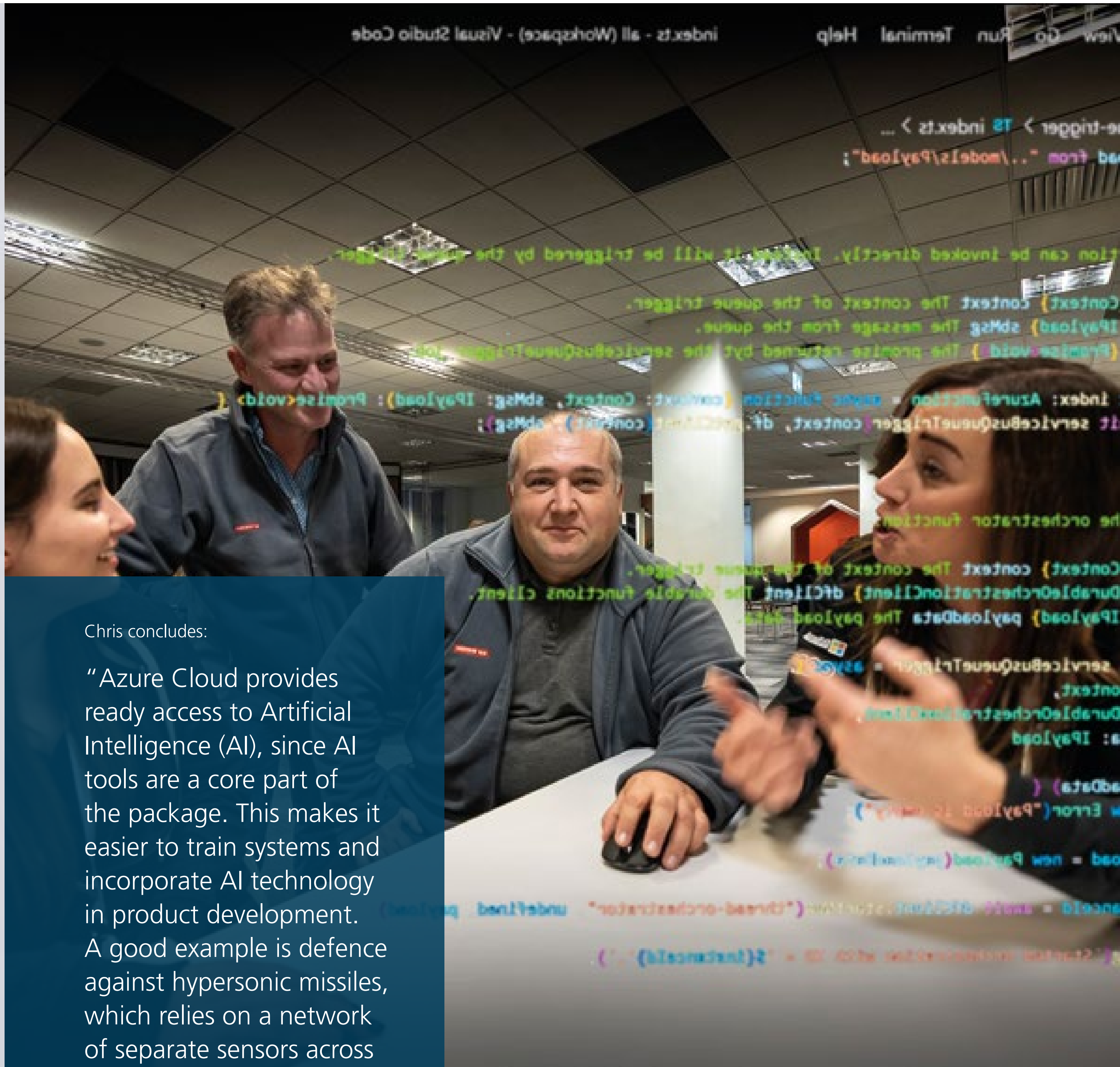
Working alongside Microsoft, we've now demonstrated a new cloud-based software application that supports a key component in the CMS – the 'Extended Range Surface Picture Compiler'. This draws data from a range of on-board sources including radar and optical sensors, then combines this with off-board intel such as open source maritime intelligence and satellite data. It analyses all of this information and presents this back to the operator, raising flags against anything suspicious.

Using Microsoft's Azure Cloud technology means that we could develop the system with common industry-standard tools, making it easier to find suitably qualified developers and to work with third parties. Being cloud-based, it also allowed us to give remote access to individual modules of code, allowing secure collaboration, in this case with the BAE Systems team in Australia.

Chris, Technology & Capability Lead, sets out the wider benefits: "Cloud technology helps us to work collaboratively with third parties, as we can then use common tools to build software modules with standard interfaces that work with the overall CMS. Our next step is to prove that cloud can be used for more sensitive information, because then our customers can use it to its full potential – even updating deployed ship systems wirelessly to address emerging threats."

Another advantage of using cloud is that it includes standard tools to automate the testing of new code. The integrity of developed software can be tested early and repeatedly, ensuring it will work as required. In this project, this was a key reason that we were able to go from concept to a tested demonstration in under three months.

We have brought together BAE Systems' knowledge of building complex digital systems for militaries and governments with Microsoft's approach to developing applications using its Azure Cloud platform.



Chris concludes:

"Azure Cloud provides ready access to Artificial Intelligence (AI), since AI tools are a core part of the package. This makes it easier to train systems and incorporate AI technology in product development. A good example is defence against hypersonic missiles, which relies on a network of separate sensors across land, sea, air and space to detect incoming threats. This means that a lot of interconnected data is generated, all of which needs to be analysed rapidly to determine the optimum countermeasure – something for which AI is ideally suited."

Chris,
Technology & Capability Lead

Return to Contents page

Ship in a cloud

Building a Digital Twin is more than just creating a visualisation or clever model – it allows us to reimagine our physical products, processes and systems in a virtual environment. Combined with the exponential increase in data and the pivot to hyper-scale cloud, there has never been a better time to get the full benefit from this approach. BAE Systems is now forging ahead with its transition to fully digital maritime platforms that exist in both the physical and virtual domains, through the development of Digital Threads and Twins.

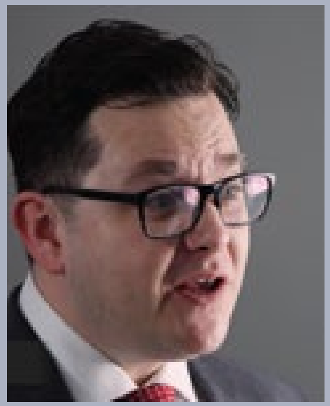
Rob, Head of Digital and Data, Maritime & Land explains what is new about the approach: "In the past, some Digital Twin projects have been overly ambitious and tried to model a huge system of systems from step one. In our approach, we're getting the data subsystems right first and building gradually to that full systems of systems digital model. The real value is then in connecting these different models together and seeing how they interact and 'talk to' one another, based on a Digital Thread that connects data through the life of our products."

Digital Threads are developed by mapping data flows modelled on existing components and processes that BAE Systems uses to design and build its platforms. These were developed further through a ground-breaking proof of delivery project with Microsoft, where we used the cloud and synthetic data to accelerate the integration of ship and support data. We also explored a more agile and efficient way to manage data from the ship in a way that maintains all of the interdependencies and configuration throughout its lifecycle – the Digital Thread itself.

Using this approach means we can then use smarter tools, including AI, to interrogate the data with confidence in its integrity and relevance. It means the Digital Thread is comprised of assured data that underpins decisions and actions, giving confidence in how changes to systems and equipment will impact across a wide and complex ecosystem – ultimately to optimise an asset's sustainability and availability.

We're now building a Digital Twin demonstrator of a critical system, allowing us to develop the people, process and technologies we need to build more Digital Twins and Threads. This will underpin a best practice approach across BAE Systems, built on the principle of 'start small, think big', allowing us to accelerate our digital interventions at pace and ultimately deliver and support digitally enhanced platforms through-life with our customers.

Rob,
Head of Digital and Data, Maritime & Land

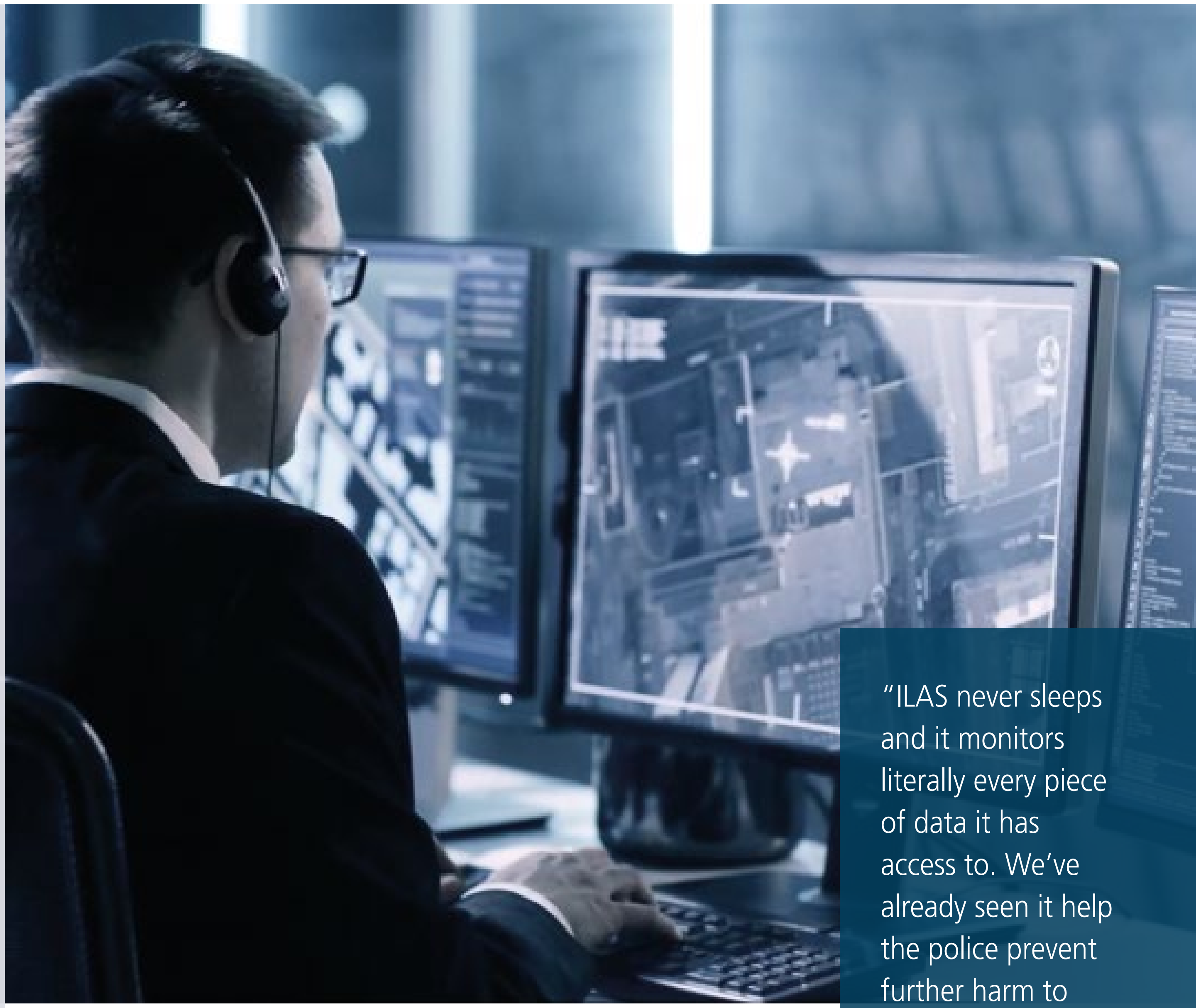


Rob outlines more about the ambition for this work: "Ultimately it's about connectivity, collaboration and interoperability. We have to develop a Digital Thread solution in partnership with our customers and other providers. There's limited value in a highly proprietary system that doesn't effectively integrate into the broader partner ecosystem."

"Our platforms are modern, complex systems of systems that need to be able to learn from and respond to the full spectrum of data they process. Only then can they effectively assist decision-making, inform asset management and start to unpick some of the most pressing challenges around sustainability, availability and multi-domain integration."

Automated intelligence – helping to protect children

Imagine if you could create thousands of extra police officers at the flick of a switch, dedicated to analysing all of the relevant available data to help protect vulnerable children and find criminal activity. That's the reason we created ILAS, the Intelligent Lead Assessment Service.



ILAS can scan and assess all available information as soon as it becomes available, cross-referencing it against the millions of pieces of data already held, finding connections that would take a human hundreds or even thousands of hours.

ILAS has been under trial with Dorset Police for the last year and has proven itself by identifying children at risk of harm, as well as those being exploited for moving and dealing drugs by criminals. With our recent enhancements, it can now assess the dynamics of risk, so instead of just showing the current picture of risk, it can identify emerging risks and help evaluate whether interventions are having a positive impact.

The police have access to more relevant data than ever before. While this sounds like a positive step, in practice it can be overwhelming – if not impossible – to stay on top of the data. Currently, thousands of hours of analysts' time is spent manually trying to spot connections in this data. ILAS takes on much of this work, freeing up analysts to assess and identify the response to the highest priority cases for intervention.

Richard, lead for ILAS at BAE Systems explains what the product can do: "Our Innovation team in Digital Intelligence came up with the idea for ILAS during a brainstorming session and rapidly took it from concept to initial prototype in just a few months. It was developed in close partnership with Ben, then a Chief Superintendent at Dorset Police and now part of the team."

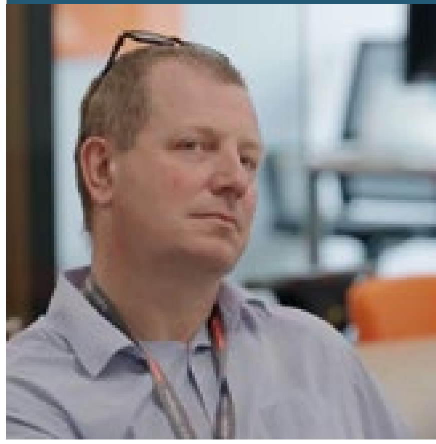
Ben explained the attraction of the product: "We've all seen horrific examples of crimes against vulnerable children, where afterwards it seems easy to work back and spot the signs – hospital referrals, social service reports and the like. However, it's much harder to spot those signs before an event happens, as those flags are buried in thousands of other pieces of data. ILAS never sleeps and it monitors literally every piece of data it has access to. We've already seen it help the police prevent further harm to children and now ILAS is being used to spot other crimes."

Another aspect of ILAS is its ability to explain why it identified a particular person or group as a risk, as it's able to trace its conclusions back to the underlying information, and explain in a human-readable way how a risk has been inferred from that information. This helps build user trust in the system, and supports rapid corroboration and decision-making based on information ILAS presents.

Richard also described how we worked closely with the police as we developed ILAS: "The police have their own 'tradecraft' – knowledge about how to spot criminal activity or vulnerable people. We worked closely with them to ensure we could capture the nuance and complexity of this tradecraft so that the ILAS product could use it to spot those high risk patterns of activity. ILAS isn't more intelligent than an analyst, but unlike a person, it can monitor for these patterns over millions of pieces of data, continuously. ILAS doesn't replace analysts – it allows them to focus on the highest value work such as decision making and identifying points of intervention."

"ILAS never sleeps and it monitors literally every piece of data it has access to. We've already seen it help the police prevent further harm to children and now ILAS is being used to spot other crimes."

Richard,
Bottom row middle of this picture, BAE Systems Digital Intelligence, with the ILAS development team.



Ben,
Domain Senior Specialist, BAE Systems Digital Intelligence.

Return to Contents page

The Intelligent Lead Assessment Service (ILAS) connects to multiple data sources and combines AI analysis with human tradecraft

Return to Contents page

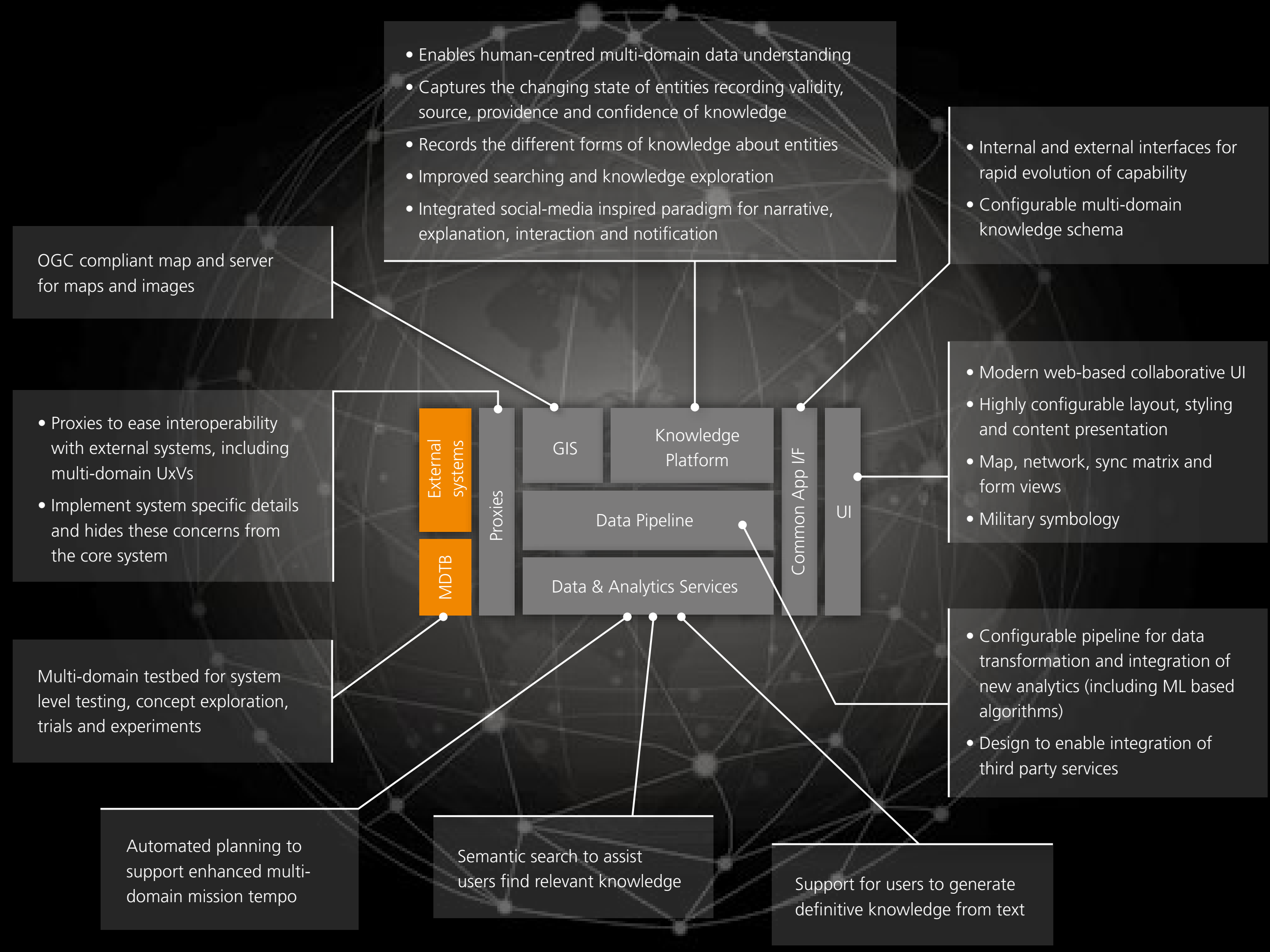
Our new Battle Management Information System

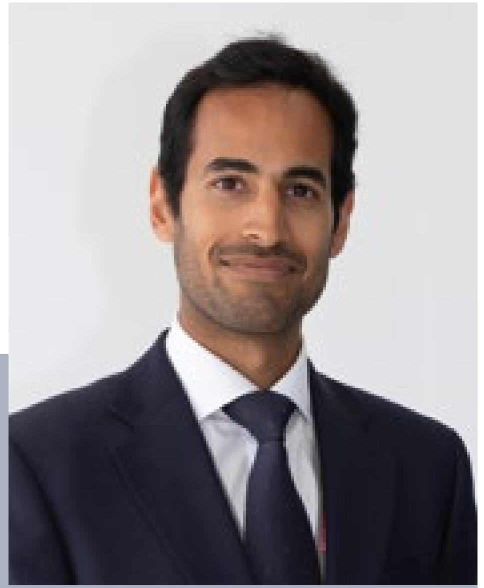
Most combat management systems today are designed to collate sensor data and give you a real-time picture of the battlefield, along with a way to communicate directly with your forces. Our newly announced Battle Management Information System (BMIS) adds advanced processing capabilities that automate and optimise many aspects of mission planning, as well as the ability to connect with assets across domains and even different nations' forces.

Pav, Project Engineering Manager for BMIS, gives an example of this capability in action: "Say you have identified a group of Ground Based Air Defences that you want to disable. At the moment you'd need to manually plan a huge amount of detail – fuelling levels, weapon mix, pilot assignment, waypoints and aircraft set up. We've created BMIS to automate much of that process, allowing the operator to check the plan it generates rather than starting from scratch. We've been able to create this system by complementing decades of experience working closely with our customers in mission planning, with research and the practical application of novel robotics techniques to mission planning."

BMIS provides a vital link in translating human commands into the control of local assets, by automatically generating a resourced plan in a data format that can be transmitted directly to a crewed or uncrewed vehicle." Pav continues: "As an example, if a commander needed to plan a mission to degrade enemy air defences, they could use information in BMIS to identify the desired targets and the assets available for the mission. BMIS would plan a set of tasks for the most appropriate assets, from fast jets to artillery to dismounted soldiers, to achieve the mission."

"The plan generator within BMIS can be optimised for different parameters to meet the priorities of the commander, such as minimising collateral damage, maximising probability of success or minimising resource consumption. It can also support the commander to dynamically repair or re-plan the mission in response to a changing situation, such as new pop-up targets, loss of resources or the need for re-engagement with a target. Think forward a few years, and BMIS becomes the perfect command interface for autonomous assets operating across land, sea and air, as well as planning space Intelligence, Surveillance and Reconnaissance (ISR) missions."





Pav,
Project Engineering Manager for BMIS

To allow BMIS to work across all domains and with a number of allies, the team has adopted an open, modular and proxy-based design to interoperability which allows it to use appropriate NATO standards as well as open, industry-standard best practice design patterns. BAE Systems is one of the few companies to operate across all five domains and has customers in the UK, US, Australia, Japan, the Middle East and other global locations. This experience provides the core knowledge and expertise from which to design our products for interoperability across a range of forces.

With any product that uses AI to support human decision-making, building user trust is a major consideration. BMIS achieves this through the use of a 'knowledge graph'. The knowledge graph uses military concepts derived from NATO's Multinational Operability Programme Information Model, to help users discover and exploit deep and complex relationships in a way that is explainable, and with quantifiable levels of confidence.

Pav concluded: "While BMIS handles huge volumes of complex data, it uses an intuitive graphical user interface designed to make it easier to understand a situation or plan a mission. We look forward to working with our customers to further enhance this and test it in real-world missions."

Agile software development for the Edge

As militaries around the world design new autonomous assets with better decision-making capabilities, what happens if the enemy updates its assets and yours are left a step behind?

We've been working with Microsoft on a system that can securely and rapidly update on-board software whilst in flight, which also brings other major benefits, as Dave, Head of Technology Environments, Air Labs explains:

"Updating the mission system for a UAV (Uncrewed Autonomous Vehicle) during flight, overseen by a human operator, is just the tip of the iceberg. What we've created with Microsoft is a new digital coding and deployment environment based on its Azure Cloud technology. The benefits are huge – not only can you collaborate securely with third parties on development, making it much easier to work with smaller non-defence companies, but it also allows us to exploit the latest available digital tools."

Pace has been the primary driver throughout this project. Making changes to digital products in defence is often a slow process due to the levels of testing required and complexity of the systems involved. However, in just three months we were able to create a new secure, collaborative coding environment and a process for deploying new code to deployed products. With the built-in tools in the Azure platform, augmented by our own engineers, it streamlined the code, build, testing and deploy process by using AI tools to do much of the work we'd otherwise have to do manually.

The new environment is also about connecting multi-domain assets more easily. By building systems to a common standard in the software industry, it will allow more interoperability (the ability for computer systems to exchange information) across things like mission systems, cockpit displays, software-defined radios and future capabilities that haven't yet been developed.

And the next step? Dave's answer: "This could be a real game-changer for our customers, providing a much faster way to safely and securely update their products, as well as much more flexibility in involving third-party suppliers in the process. There will always be a need for deep knowledge of the defence platforms themselves and how they're used operationally, but using a new environment like this, combined with our architectural approach, makes it much easier to securely 'plug in' new capability without worrying that it will adversely affect the rest of the system. If we can work with customers to move to new security approaches, built around the cloud, we can really accelerate future development."

BAE Systems and Microsoft have used the Azure Cloud approach to accelerate software design, development and testing of a system that can deploy new software on to an Uncrewed Air Vehicle (UAV) during flight. This approach to using the cloud could in future speed up the deployment of software to operational military platforms.

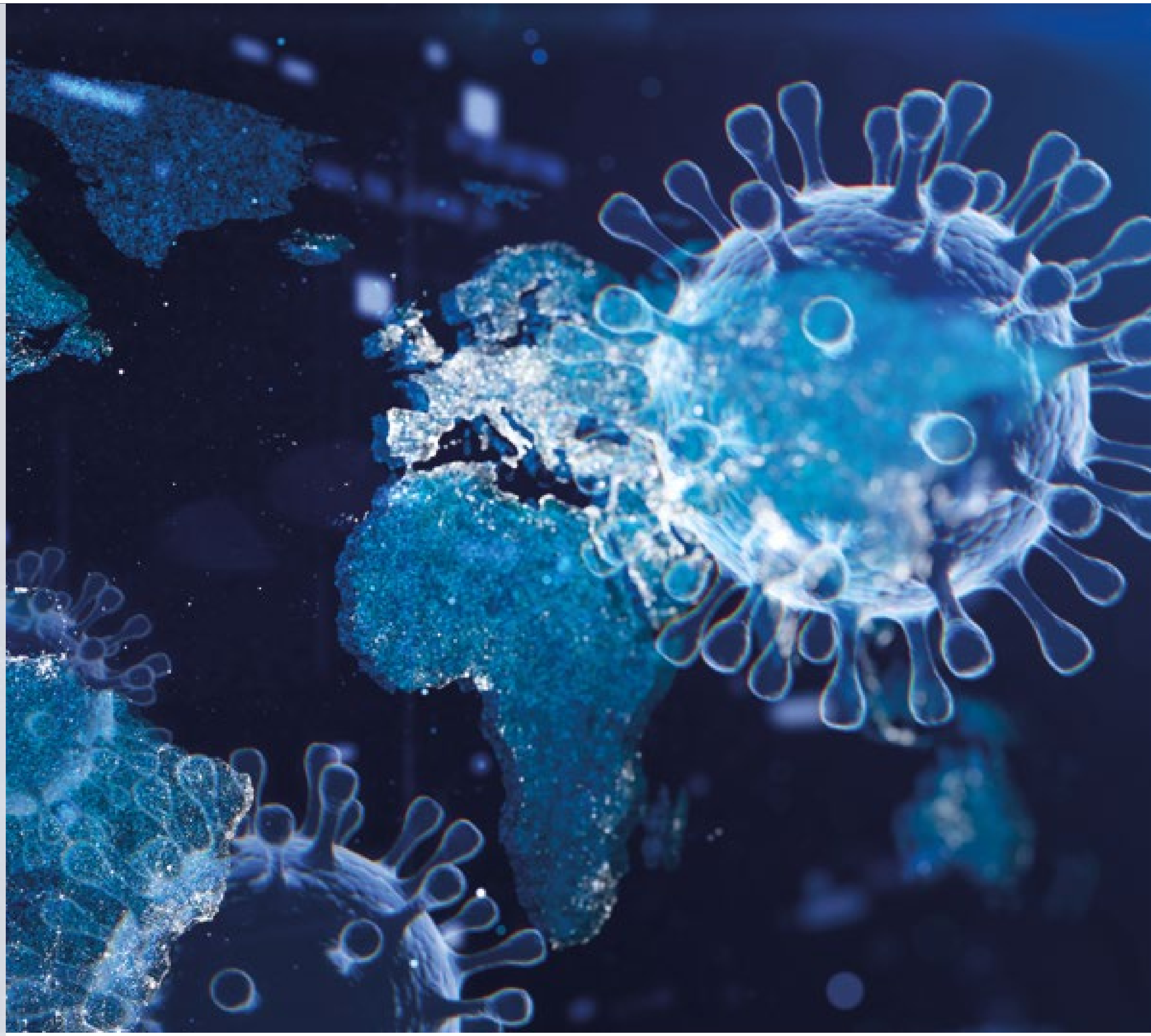
Dave,
Head of Technology Environments, Air Labs

Updating software capability at the Edge – we updated the firmware on this small UAV in flight, changing its behaviour in response to recognising a QR code. In the battlefield, this technique would be used to give products at the edge new capability to counter new threats. What underpinned this demonstration was a new agile coding environment that accelerates code development, testing and deployment, and allows secure collaboration in the cloud.

Return to Contents page

Covid data system adapted for emerging health issues

A data collation platform, which we built in just a few weeks in 2020 to 'join-up' Covid data, has provided the knowledge and engineering momentum for new data systems to analyse emerging disease outbreaks including Monkeypox, Avian Flu, Polio and Strep A.



The data platform, called the Environment for Data Gathering and Engineering (EDGE), was designed and built to give the Joint Biosecurity Centre access to disparate data sources to inform analysis about the spread of Covid during the pandemic. However, the team have used their Covid experience and specific engineering and data knowledge to develop new systems that allow data scientists and epidemiologists to analyse emerging health threats. Given that every pandemic starts as a localised outbreak, having a system that can quickly afford meaningful analysis early in the outbreak could also help slow the spread of any future highly contagious diseases.

Instead of building the platform on our own infrastructure to be deployed as a piece of 'black box' software within government, we deployed a team to work within the newly formed Joint Biosecurity Centre and the Department of Health and Social Care to leverage NHS infrastructure and networks. This had the double advantage of upskilling civil servants to understand and operate the system, as well as keeping sensitive government data on the existing government network and within its ownership and control.

One of the main challenges for the team who designed EDGE was to give it secure access to sensitive patient and personal data across a variety of government departments. One example showing why this was so important was in cross-referencing the impact of Covid on cancer patients, which is believed to be the world's first analysis of these cases, but has also remained the largest Covid-cancer study as of writing. Data on patients is highly sensitive, so keeping the entire system running within government infrastructure reduced the possibility of data leaks and garnered trust and engagement with health institutions and citizens alike.

As Adam, BAE Systems Account Manager for Health in Central Government explained:

"We didn't want to just provide another IT system that our customer would then need us to support in perpetuity. Instead, we wanted to help the government create a valuable capability which over time its own skilled team could support and be able to adapt for other uses in future."

Return to Contents page

AI projects speed up aircraft development time

Artificial Intelligence (AI) can massively increase the speed at which we make sense of data. As part of our AI Data Science Accelerator with the University of Manchester, we've developed AI systems that can simulate complex wind tunnel testing and can identify faults from X-rays of aircraft parts. This research project is now housed in our Air facility in North West England where testing continues to take place.

Andrew, Principal Engineer for New Technology in Air, explains why we formed this collaboration with the University: "AI techniques are being explored and developed across academia, and the University of Manchester is a leader in the field. Through the AI Data Science Accelerator, we can give researchers our most difficult data science challenges and work together to create an AI system to tackle it. This way we combine our deep technical knowledge of aerospace with the University's impressive research capability in AI."

Wind tunnel testing is essential in aerodynamics, but conventional testing requires a high use of energy and efforts are underway to reduce the carbon footprint of future testing. Working with the University of Manchester, we trained an AI Deep Learning Model on data from historic wind tunnel testing, allowing it to build a model of the way air moves at different speeds around aircraft panels. Now that we've proven that the model is accurate by comparing against real-world data, we've been able to rapidly increase the speed of design cycles, providing an alternative to a physical wind tunnel, setting up the test and then analysing the results to check the impact of a design change. This in itself creates a huge reduction in energy and time demand for future aerodynamic testing.

As well as design and testing, quality control is a fundamental part of aircraft manufacture. We have been using X-ray crystallography (a method of determining the atomic structure of a crystal) for a number of years, which allows us to check critical components of aircraft at the molecular level. As you would imagine, this technique produces a vast amount of data when checking an entire part, such as a blade in a jet turbine, where there are millions of atoms involved. Again, this required manual intervention for physical checking throughout the manufacturing process, but now we are incorporating AI techniques to automate the evaluation stage, rapidly improving the speed and even the accuracy of results.

Andrew, Principal Engineer for New Technology in Air, outlines the rationale for the AI accelerator:

"This is a really flexible collaboration, as we can very quickly carry out projects to consider new ideas before choosing whether to take them further. In addition to the specific projects described here, the University is also helping upskill our own people with regular seminars and courses."

AI can provide an alternative to physical wind tunnel testing, accelerating development, while also reducing costs and environmental footprint.

Andrew,
Principal Engineer for New Technology in Air in the collaboration laboratory at the University of Manchester's Engineering facility.

Operational Advantage

Soldiers, sailors and aviators across the globe will operate in an interconnected digital world where exchanging information, derived from vast and divergent data feeds, at the speed of relevance, will be vital for operational advantage. This modern force however, still needs to be a force – mixing hard and soft effects through a highly automated, human/machine integrated, multi-domain system of systems.

Our extensive work developing digital technologies sits hand-in-hand with the development of enhanced equipment, designed from the outset to meet the required pace of change and outmatch potential adversaries. Whether that's Autonomous Surface or Underwater Vessels that can carry out surveillance, protection and engagement missions, Uncrewed Air Systems capable of both vertical take-off and 300km+ endurance, or satellite clusters that use on-board processors to flag suspicious activity direct to the front line.

As the thresholds of conflict mix between state and non-state actors in both the virtual and physical worlds, traditional lines and boundaries are increasingly blurred and so create an evermore complex military environment. Therefore, decision-makers need simple, clear, actionable information. As an example, you'll read about our work on Commander Interfaces, bringing Augmented Reality to a ship's bridge and how we fuse information from multiple sources to identify, classify and display this next to objects – such as other ships – to synthetically enhance and improve visual lookout.

We're also developing a system to help untangle the data complexity of the modern battlefield by fusing cross-domain data sources, and presenting this to commanders as information in a single interface (p.18). This Battle Management Information System (BMIS) will also maintain a complete picture of a customer's assets, which it could use to automatically generate complex mission plans, from operational through tactical levels and down to asset types, payload requirements, route planning and even required fuelling levels.

Systems that work across domains need to be interconnected and so we're using common standards and open architectures, such as those defined by NATO, in our equipment to ensure they are highly interoperable. This will help those operating in support of front line military operations to integrate assets from a range of providers and suppliers into a system of systems; rather than trying to juggle a mix of separate non-compatible equipment types.

While NATO nations move quickly towards Multi-Domain Operations, that inextricably blend humans and machines together, this brings an increasing challenge for training and the maintenance of operational effectiveness. It's expensive and logistically difficult to physically bring together a broad range of land, sea, air and space assets, so we've recently opened an augmented reality training system that works across all those domains. This also brings the advantage of allowing training to replicate the speeds and complexities of modern warfare, but away from the ever-present gaze of satellite-enabled surveillance by potential enemies, preserving the ability to surprise them with novel tactics and capabilities.

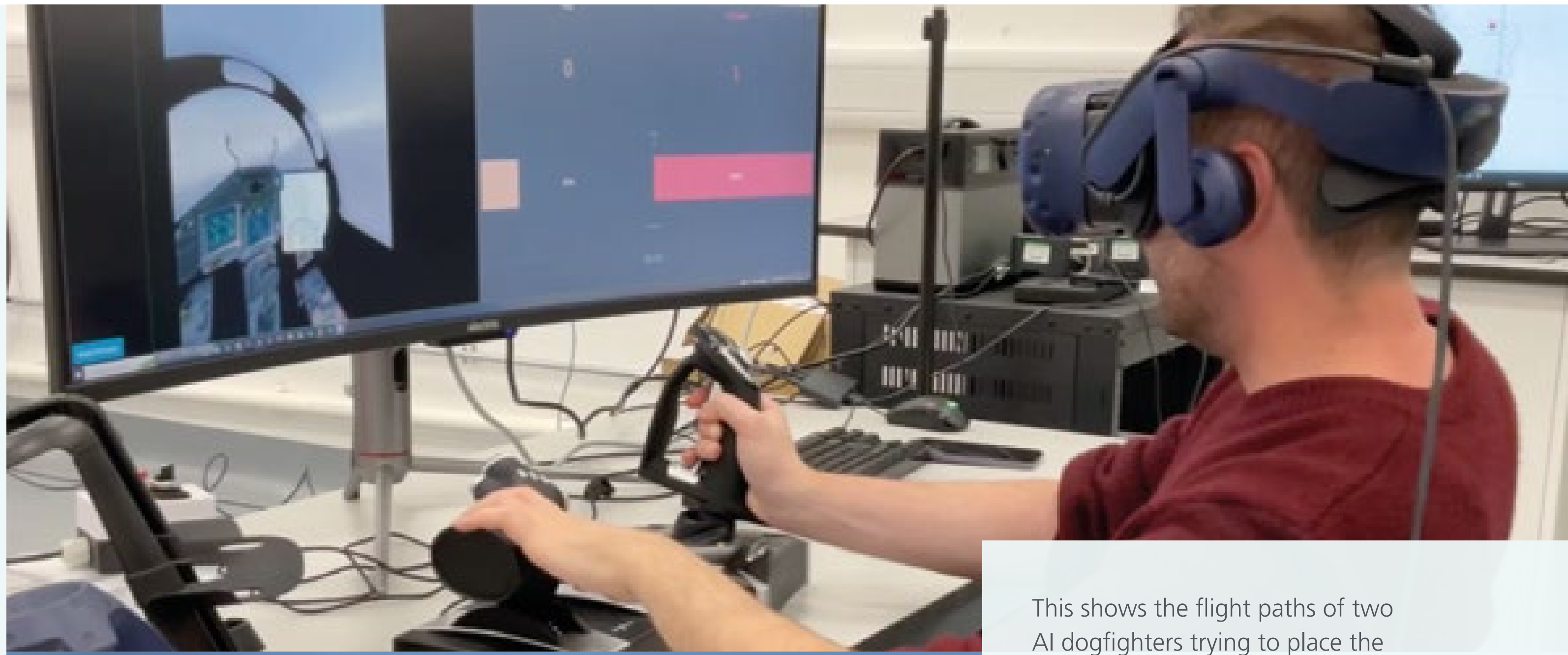
War in Europe is now a reality. This, together with the extension of the pacing threats building in the Indo-Pacific, means nations need to be more ready to deter their adversaries than they have in decades. BAE Systems remains determined to offer operational advantage to those whom we provide military capability – our valued customers.

Commodore Mike Knott CBE RN,
Maritime Capabilities Advisor

Return to Contents page

Digital dogfighters that can fight by sight and radar

We may not be a long way from all having self-driving cars, but we could be much closer than you thought to autonomous fighter aircraft capable of winning real-world dogfights (air-to-air combat). We've worked with one of our strategic partners, Cranfield University, to simulate what we believe is the world's most capable Artificial Intelligence (AI) powered fast jet fighter, to test a human's ability to out-manoeuvre it.



Nick, Principal Technologist in AI, Autonomy, and Disruptors for Air, explains our latest development: "In the past we've seen reports of AI dogfighters beating human opponents, but these were very different to real-world scenarios. Most of those demonstrations gave the AI 'perfect' information on their human opponents at all times – exact location, trajectory, speed and position. In actual combat, however, an autonomous fighter jet would only have the sensor data available from the aircraft's radar and visual sensors. We've now trained an AI to win dogfights based on that sensor data alone."

The AI pilot has also been integrated into a VR simulator and follows the dogfight visually, allowing human pilots to challenge it, or just sit in the cockpit while it's in control. It also means that you can watch the video of AI vs AI battles. Follow the QR code on this page to watch some of these dogfights.

Nick continues: "There's a very serious reason for doing this research. We expect human pilots to come up against AI pilots in the near future, so it's vital we understand what they're capable of and have the ability to maintain defence and counter them. In every human vs AI challenge we've tried on our system, the AI has won and won quickly, so we need to work with the technology to anticipate its actions and reactions and develop counter responses."

The team at Cranfield University has also created this system with much less computing power than many others have used in the past. Gokhan Inalhan, Professor of Autonomy and Artificial Intelligence at Cranfield University, runs the team we work with there: "The U.S. Defense Advanced Research Projects Agency (DARPA) ran a really interesting AI competition in 2020 called AlphaDogFight, inviting AI developers to fight one another in a virtual tournament. The winning team trained an AI to work out the best movement of the throttle and stick to get a bead on the opponent, essentially get them in the firing line for a gun. Because they chose that approach, to train the AI they had to go through four billion training cycles – missions from beginning to end – which took several weeks on a bank of really powerful computers."

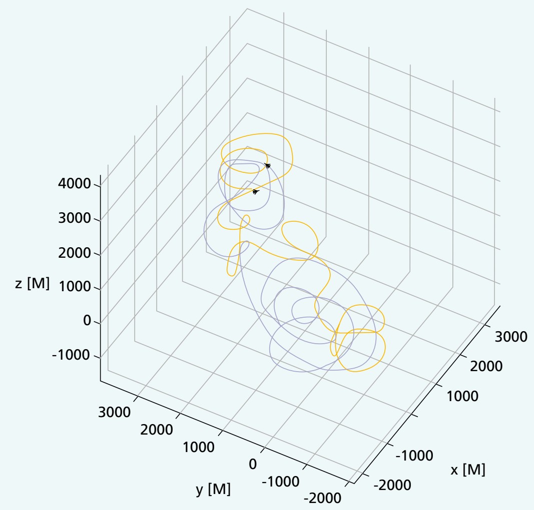
"Instead of our AI deciding how to move the throttle and stick to point at its opponent, we've made it look at distinct flight manoeuvres that will allow it to target its enemy quickly and long enough to defeat it. This is like looking at the actual chess moves rather than the movement of the arm and hand that moves the chess pieces. Because the AI is then looking at a much smaller set of data points, we've been able to train it in just one day on a fairly standard computer with only 80 million training cycles. Despite the lower training time, it also means that it's able to cope with a much greater range of scenarios, including multiple enemies. If this was ever used in the real-world, we would require human oversight of any decision to use force, once the AI had targeted an enemy."

Because the approach we've taken combines many small manoeuvres together to win the fight, it means the solution is scalable to any kind of vehicle – air, land or sea – which needs to perform pursuit or evasion tactics.

As well as being trained for combat, the AI can also estimate the chance of victory before engaging an enemy, helping it to fly away and live another day. In our simulations, we've also shown that the AI can still beat human opponents when it's in a significantly lower performance aircraft, so this will be a factor in predicting the odds.

Installing this AI system in a physical aircraft would be fairly straightforward, as it would feed its commands through the existing autopilot or flight control system. What will take longer is certifying that the AI will be a safe and reliable pilot, however, one of the benefits of the AI approach we have taken is that we can see why it made its decisions. This will help us to prove that it would be safe to take control of a physical aircraft in future and move the capability on from a test environment.

This shows the flight paths of two AI dogfighters trying to place the other 'on target'.



Nick,
Principal Technologist in AI, Autonomy, and Disruptors for Air

Return to Contents page

Azalea – our next generation satellite cluster takes shape

After announcing our new multi-sensor satellite cluster in 2022, we have now begun building the underlying hardware and testing software. This includes the Software Defined Radio at the heart of each satellite, which will provide communications both between the satellites in the cluster and ground stations.

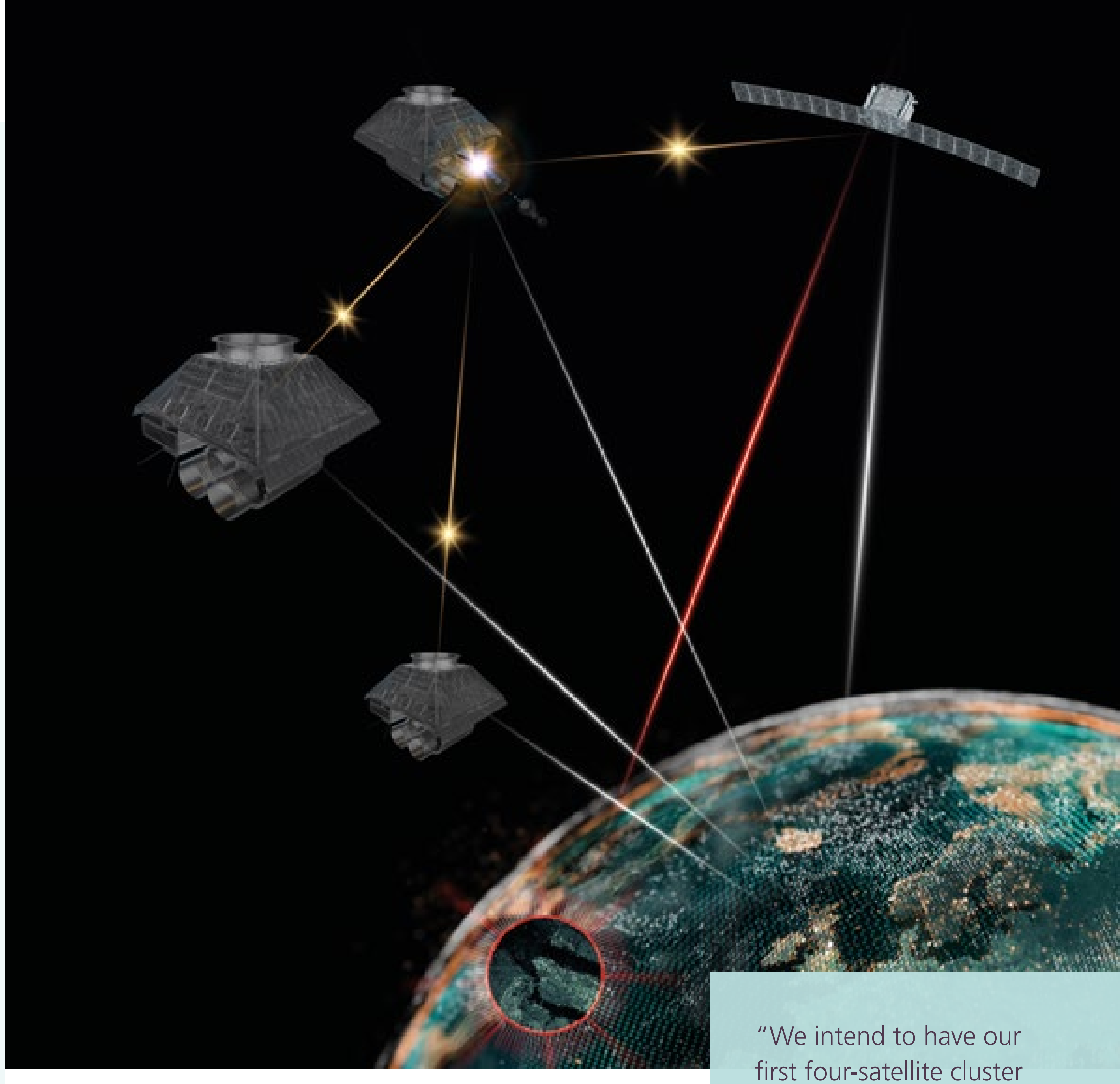
Elizabeth, Head of Space Strategy & Future Business, Digital Intelligence, explains the efforts underway: "We have built a large team to develop Azalea, who are building the payloads, writing software, developing Machine Learning techniques and doing all of the integration work to get these systems working together. We intend to have our first four-satellite cluster launch-ready by the end of 2024, which means we're on a tight schedule."

The purpose of Azalea is to create a transformational capability that not only collects data, but harnesses the power of edge processing and dynamic distribution of intelligence from Low Earth Orbit (LEO).

The initial cluster of four satellites will contain three optical and Radio Frequency (RF) satellites, with electro-optical imagers and multi-band RF capabilities. The fourth is an ICEYE Synthetic Aperture Radar satellite.

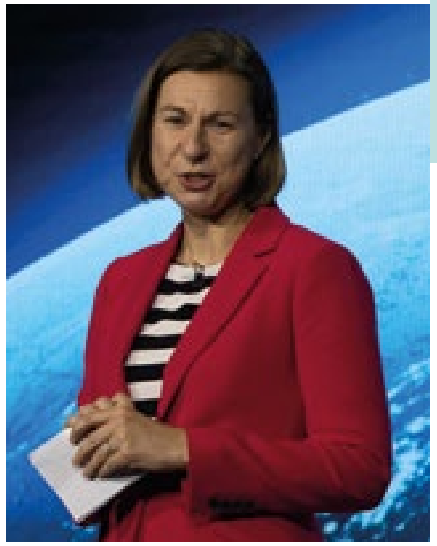
Looking to the future of LEO Intelligence, Surveillance and Reconnaissance (ISR), we are aiming to process captured data in orbit and deliver 'just in time' intelligence to the end user when and where it is needed. Our open architecture approach and the inclusion of reprogrammable on-board processing capabilities will allow customers to re-configure and upgrade the software payloads to deliver their specific mission requirements through-life.

As well as the team focused on getting the first cluster operating in space, we are also exploring multiple options to launch and operate a full constellation of multiple clusters in partnership with our Government customers. This full constellation would provide resilience, persistence and short revisit times required for tactical ISR missions, and enable other capabilities such as alternative Position, Navigation and Timing and communication services.



"We intend to have our first four-satellite cluster launch-ready by the end of 2024, which means we're on a tight schedule."

Our next generation satellite cluster can process data in space, flagging relevant activity and sending this directly to the front line.



Left:
Jessica,
Project Manager, Digital Intelligence

Right:
Elizabeth,
Head of Space Strategy & Future Business, Digital Intelligence

Return to Contents page

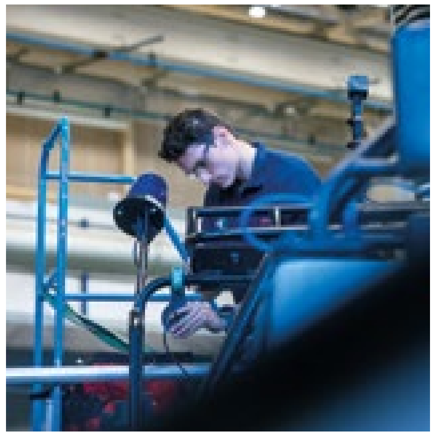
Our autonomous control system powers third-party boat

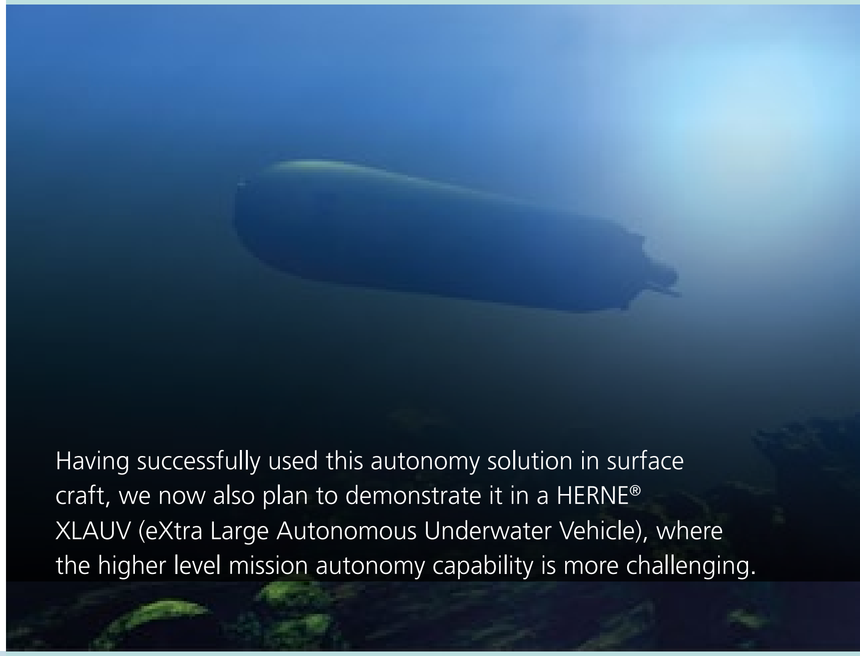
Our Autonomous Pacific 24 (AP24) uncrewed surface vessel, which was the first military vessel to achieve Lloyds Register Unmanned Marine Systems Certification, has already been demonstrated in trials with the Royal Navy and during multi-force NATO trials. Now we've shown that our new autonomy system can just as easily be integrated into a third-party vessel.

After seeing successful demonstrations of the Autonomous Pacific AP24, an international boat manufacturer approached us to discuss how we could work together. In less than a year, we have installed our BAE Systems' intelligent autonomous control system on to their already popular P38 fast interceptor craft.

Mike, Head of Strategy & Campaigns for Autonomous Systems, sets out why our system could be used so easily: "We built our intelligent autonomy solution using an open architecture, so that our customers and partners could apply it to various types and sizes of vessel, while avoiding being locked in to a single vendor for future feature enhancements. We anticipate customers wanting to incorporate new technologies and payloads from a variety of sources, so we developed the higher-level mission and payload autonomy software as modular plug-in components. This also has the benefit of simplifying product assurance and regulatory compliance, and enabling mission capabilities that have higher security restrictions to be logically segregated from the core product."

The P38 itself is a 14m fast interceptor craft, capable of speeds up to 55 knots and with a range of 400 nautical miles. The BAE Systems autonomous control system, once integrated into the vessel, allows it to operate either alone or as part of a human-machine teamed squad. For example, in a harbour security scenario, a human operator can designate a threat vessel using a Command and Control system, and task the P38 to pursue and launch a 'vessel arrest' entanglement device to forcibly prevent the target from entering a restricted area.



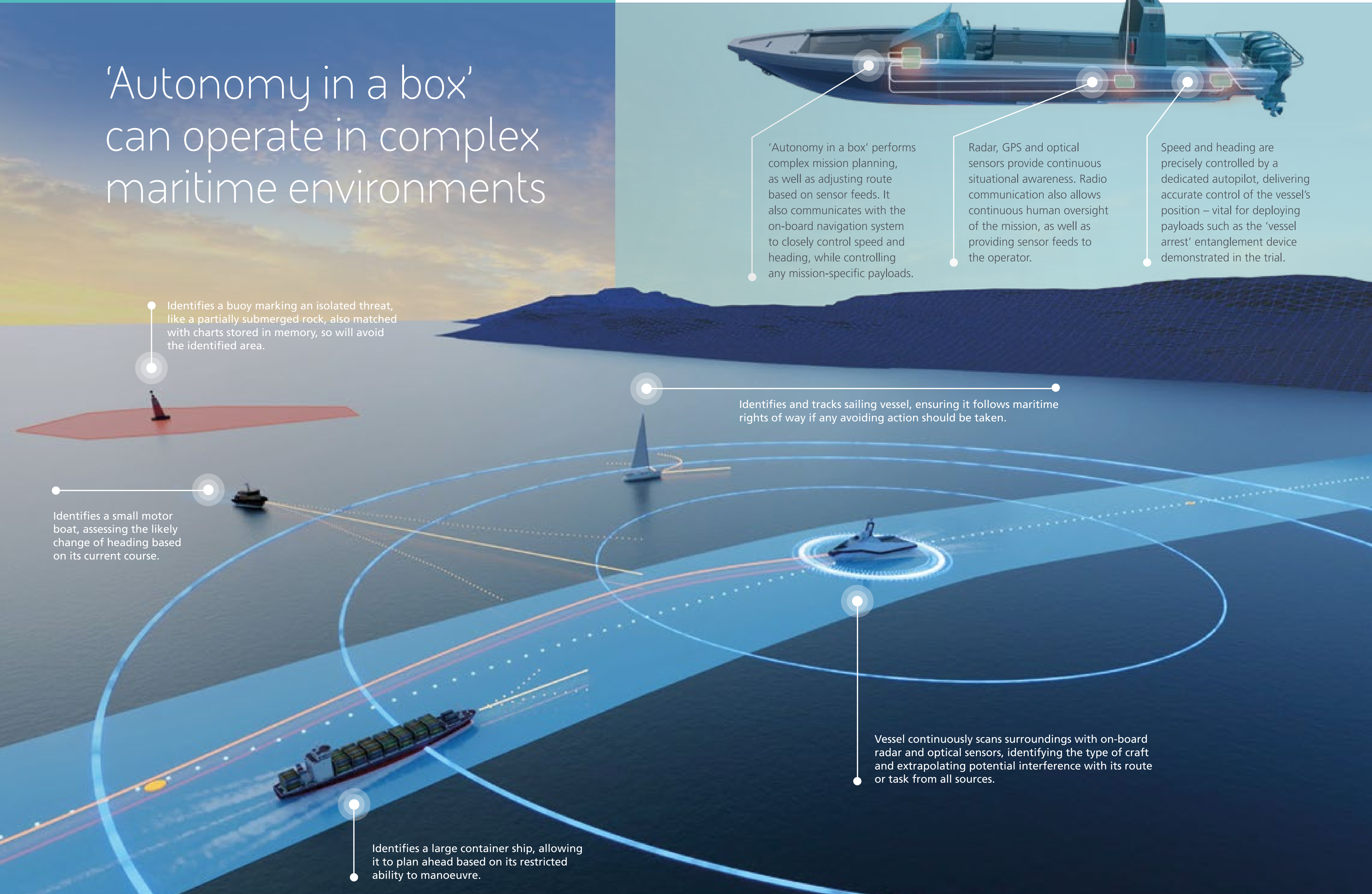


Having successfully used this autonomy solution in surface craft, we now also plan to demonstrate it in a HERNE® XLAUV (eXtra Large Autonomous Underwater Vehicle), where the higher level mission autonomy capability is more challenging.

Mike, on the right in this picture, when our AP24 autonomous boat received the Lloyds Register Unmanned Marine Systems Certification. It is the first ever uncrewed military vessel to do so.

Return to Contents page

'Autonomy in a box' can operate in complex maritime environments



Return to Contents page

Designing the next uncrewed submarine

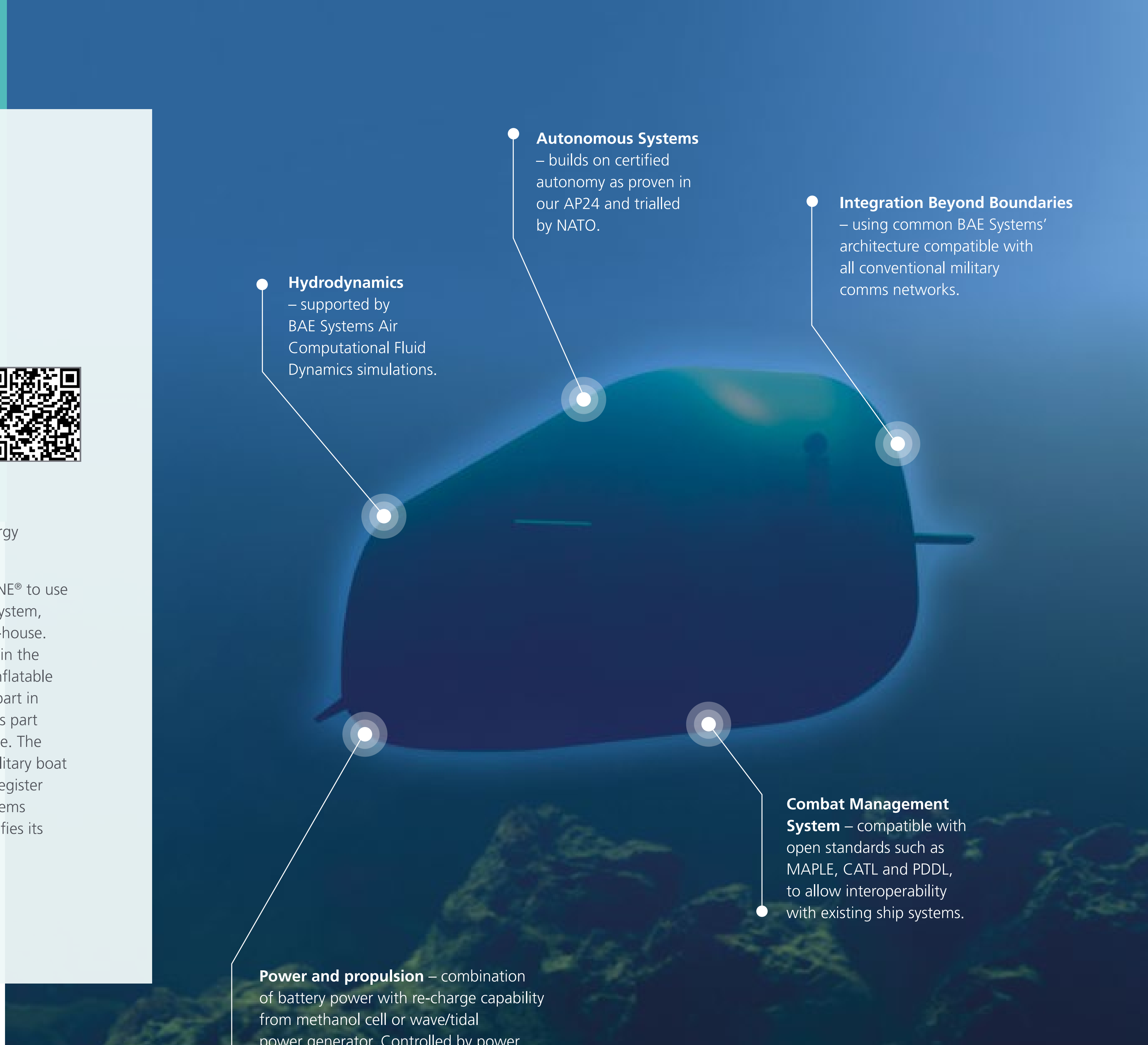
The defence market has seen a proliferation of uncrewed air and ground vehicles recently, most of which are remotely piloted. When it comes to uncrewed vehicles below the waves however, remote piloting is just not possible at all times.

Wireless underwater communications – particularly if you need to remain undetected – are more challenging, so these assets need to be capable of a greater level of autonomy, including mission purpose and feedback that informs future behaviour.

We have drawn on BAE Systems-wide experience as well as third-parties to design the HERNE® XLAUV (eXtra Large Autonomous Underwater Vehicle). While this is currently a digital design, it has been thoroughly tested in a digital environment and draws technologies tested in the real world.

The HERNE® design is around 12m long with a large payload bay. Murray, Chief Technologist for Underwater Weapons explained why: "We want HERNE® to be like an underwater transit van, able to carry a range of payloads stealthily on long endurance missions. The Extra Large size classification means it's got greater range – while batteries would provide high demand sprint capability, it will also have on-board power generation and a hybrid power architecture to enable long duration missions. We've also looked at more sustainable ways to re-charge, such as a methanol fuel cell or anchoring to the sea bed and using tidal or wave energy capture devices.

We have designed HERNE® to use our proven autonomy system, which we developed in-house. It is currently operating in the AP24, our 7.8m Rigid Inflatable Boat, which has taken part in successful NATO trials as part of an interoperable force. The AP24 is also the first military boat to be awarded Lloyds Register Unmanned Marine Systems Certification, which verifies its safety case.



Murray, Chief Technologist for Underwater Weapons

Return to Contents page

STRIX Uncrewed Aerial System introduces a new chapter in VTOL flight

Designing an aircraft capable of vertical take-off and landing (VTOL) traditionally requires trade-offs, such as losing maximum range and reducing payload. Yet the Red Ochre Autonomy team at BAE Systems Australia has designed an Uncrewed Aerial System (UAS) that doesn't require any such compromise.

Indeed, the innovative approach taken with the STRIX UAS – launched earlier this year at the Avalon Air Show near Melbourne – has also seen the team take a novel approach when it comes to bringing the platform to market, encouraged by the Australian customer's calls for 'speed to capability'.

Project Manager Carly has led the STRIX project from the outset and explains the technology that underpins the UAS:

"We've created a fixed-wing aircraft with four traditional front-facing rotors, but we've given it a unique way to take off. Combining the capabilities of vertical take-off, and landing by using the thrust from the front rotors we have virtualised a tilt-body aircraft, before STRIX then transitions to conventional flight."

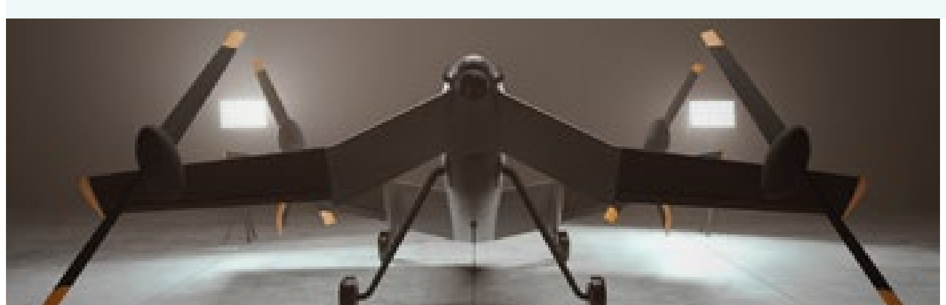
This unique VTOL capability sets it apart from other competitors on the market. STRIX will carry a 160kg+ payload over more than 800km without requiring an airfield. The platform will even take off from the helicopter pad on a small vessel, bringing long-range air power to ships without a runway. STRIX is also portable and the whole aircraft can fit into a standard 20ft ISO container, so is very easy to transport.

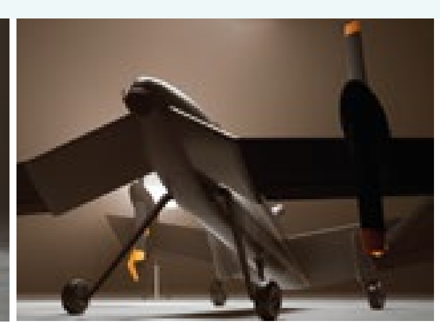
The autonomous capability underpinning the STRIX UAS is the tried and tested BAE Systems' Vehicle Management System using the same autonomy architecture that drives the MQ-28 Ghost Bat UAS developed for the Royal Australian Air Force.

The STRIX team – a small, agile and empowered group of employees – also took a rapid prototyping and minimum viable product approach to bring the capability into the hands of future customers faster. The intention is to complete development and testing rapidly, with the first STRIX scheduled to be available in 2026.

BAE Systems Australia took the deliberate choice to self-fund the research and development of STRIX, combined with focusing on a set of core requirements that could be tailored or prioritised later. It's a risk, but the successful launch at the Avalon Air Show and the interest it has generated globally, may mean it is a risk worth taking.

The fixed-wing VTOL aircraft, STRIX, is designed to carry payloads including the new RAZER guided munition, also announced by BAE Systems this year. Its innovative launch mechanism allows it to combine the advantages of fixed-wing endurance with VTOL flexibility, carrying a 160kg payload for up to 800km.





Carly, Project Manager – STRIX

Return to Contents page

STRIX – UAS combining vertical take-off with fixed-wing flight

1 Fits into a standard 20ft ISO container

2 At rest on runway

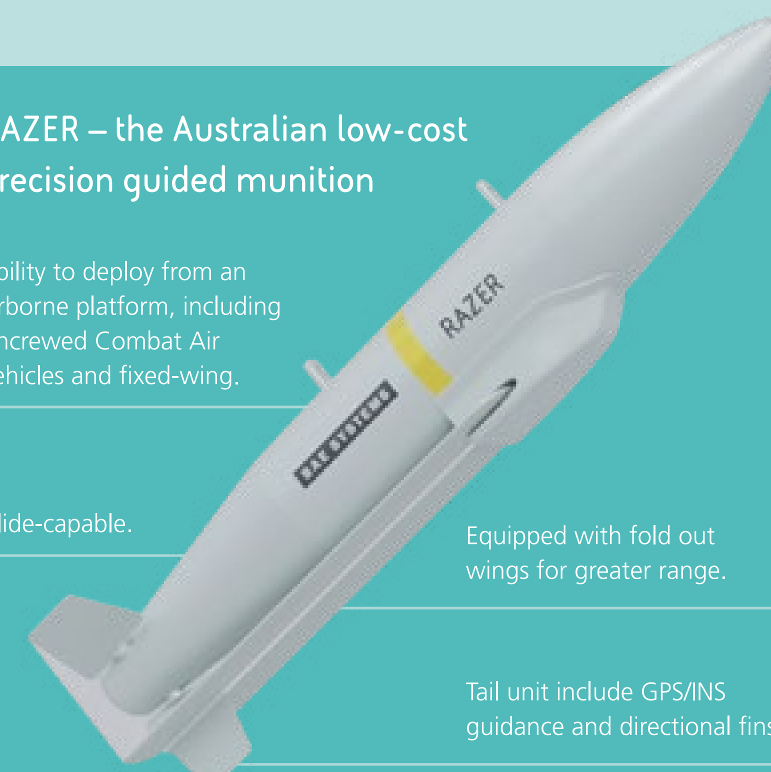
3 Pivots on back wheels to take off vertically

4 Leans forward to fly as a fixed-wing aircraft with long endurance

STRIX Specifications

Mode of Operation	VTOL and Fixed-Wing
Max Take-Off Weight (MTOW)	900kg
Typical Payload	160kg (max ~ 200kg)
Range with 160kg	800km
Range with 200kg	500km
Cruise Speed	140 knots (max >200 knots)
Flight Endurance at MTOW	~ 5 hours
Hover Endurance at MTOW	~ 2 hours
Collapsed Footprint	2.6m x 2.2m x 4.5m
Stored Footprint	ISO container 20ft
Weapon Options	Enforcer Air, Brimstone, Hellfire, JAGM-MR, laser-guided rockets, RAZER

RAZER – the Australian low-cost precision guided munition



Ability to deploy from an airborne platform, including Uncrewed Combat Air Vehicles and fixed-wing.

Glide-capable.

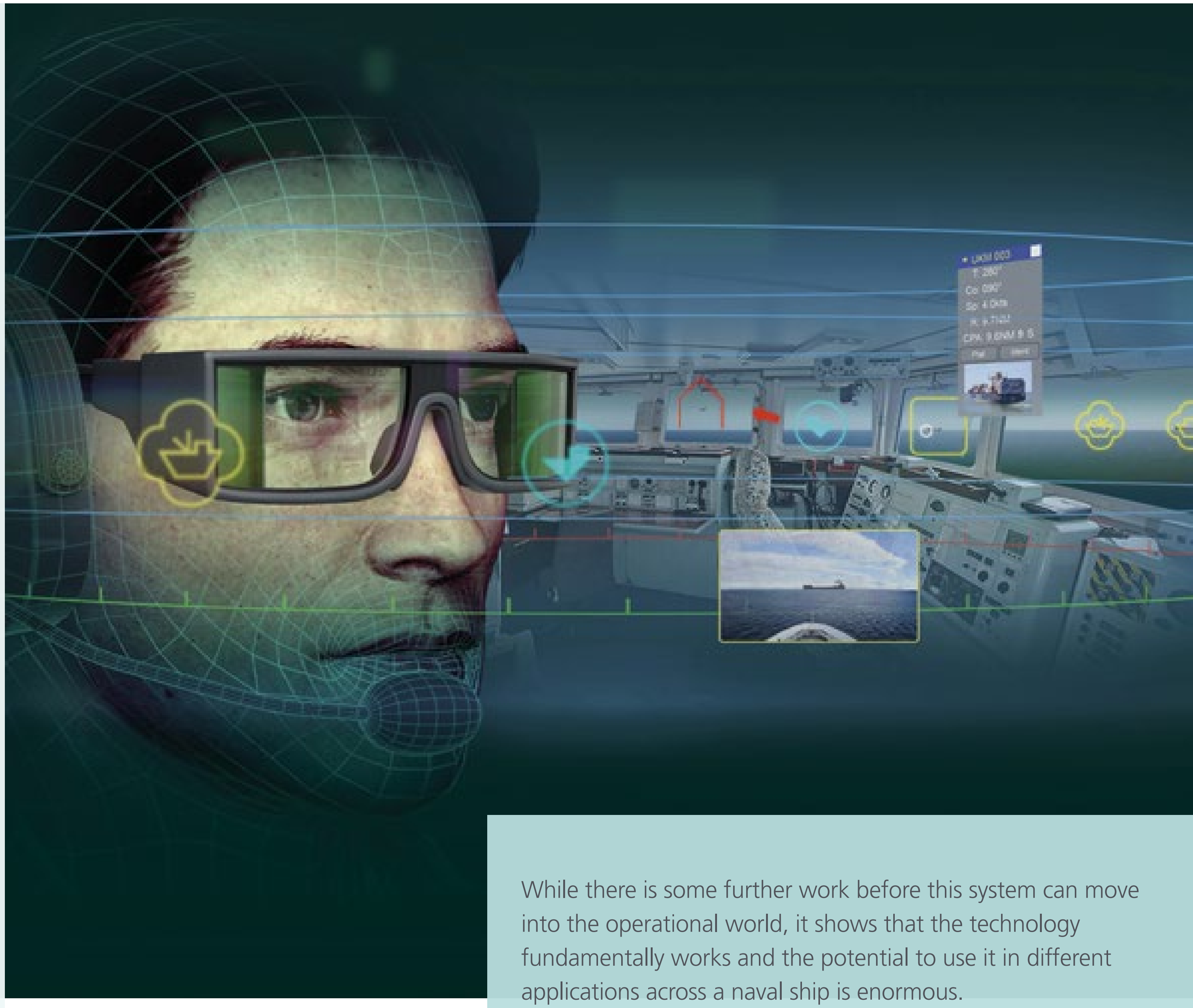
Equipped with fold out wings for greater range.

Tail unit include GPS/INS guidance and directional fins.

Return to Contents page

Augmented Reality on the bridge

A watch officer on the bridge bears an enormous responsibility. They're entrusted with the ship's safety and navigating its safe passage in all circumstances and conditions. But their role can be a challenging one, requiring timely and accurate decision making. This decision making is often hindered by poor weather and restricted visibility and they're heavily reliant on information from their operations team located elsewhere on the ship.



Augmented Reality (AR) has tremendous potential for helping military personnel to absorb complex information, but it's hard to make something flexible enough to work well in the environments they operate in. We have now tested a new AR system on a ship's bridge, which overcomes many of the most difficult challenges.

Dan, Technologist in Naval Ships, explains how: "To show you the correct information, AR glasses need to know where you're facing, as well as your movement in relation to your surroundings. On a ship you're also moving through the water, turning to port or starboard, as well as pitching and rolling with the movement of the sea, so you've got an extra set of axes to consider. AR headsets are typically used in static environments, but we've now successfully tested a system that addresses these complex challenges."

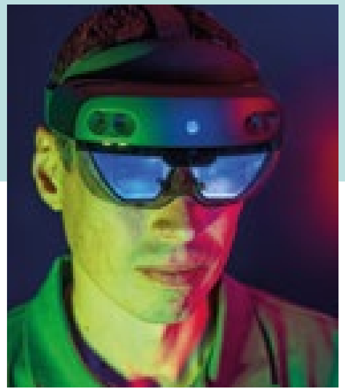
This means that when an officer looks out of the window at a real-world object, they can see crucial information about it through the AR headset, which is getting that data from the Combat Management System in real-time. It means the officer can spend more time maintaining a 'heads-up' visual lookout without having to refer to a fixed console or rely on clarifications from the operations team. Crucially, it means they have better situational awareness to help them deal with difficult and rapidly changing situations more effectively.

The trial was carried out with Southampton University, one of our strategic partners, on their research vessel 'Callista' using the Microsoft HoloLens 2 headset running our control and visualisation software, integrated with data from the on-board navigation and sensors. Dan continued: "Proving this on a vessel moving on the water is a real step forward. We were able to overlay tactical picture information on the view through the headset and show that it tracked objects while both the user and the vessel were moving."

While there is some further work before this system can move into the operational world, it shows that the technology fundamentally works and the potential to use it in different applications across a naval ship is enormous.

Our Codeathon team rapidly developed new opportunities for next generation Combat Mission Systems, including an AR display that fused a tactical picture with enhanced situational awareness.

Dan,
Technologist in Naval Ships



Return to Contents page

This trainer can read your mind

During military training, how can you be sure your students are confident enough to repeat their success in the real-world where there are countless variables and stresses that can't always be trained for?

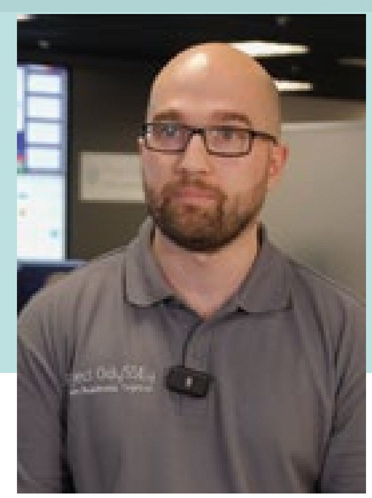
We're now measuring the cognitive, visual and cardiovascular performance of students using monitoring technologies in a highly realistic synthetic training environment, using artificial intelligence to provide unpredictable scenarios which can simulate what they may find in the real-world.

By assessing the reactions of students alongside the actions they took, we're able to objectively measure their heart rate, body temperature and eye movements to understand what was most stressful and when, and at what point, they approach cognitive overload. Not only does this allow us to prioritise the wellbeing of those in training, we can also monitor where students were looking for information enabling us to improve the design of our [cockpit/helmet/heads up] displays so they are seeing what they need to see, where they want to see it and information that is not necessarily obvious.

Engineering Manager Nick, explains: "As well as hearing from the students about their own experience, we're able to assess their performance and identify the challenges they had and then adapt the training accordingly. By tailoring the training we're able to make it much more individual and ensure the pilots have what they need to make decisive decisions with confidence, whether that be calling in casualty evacuations or an air strike.

This monitoring technology is now at the core of a single synthetic environment being developed to enable collective military training. Through this work on Project OdySSEy we have created the core systems which will enable air, land, sea, space and cyber forces to plug in and train together. From here our customers can train collectively using real software and real tactics away from prying eyes, preparing for scenarios which simply could not be undertaken in live training.

Nick also explains how students could be kept motivated: "By gathering data throughout the scenarios, not just on physiology but also on outcome and performance, we've been able to 'gamify' the training. This is really important, as those taking part can continually try to improve on their performance. We are working alongside a digitally native generation now where technologies like augmented reality and artificial intelligence are part of their everyday lives, so we need to change our training approach to better reflect students' everyday experiences of technology."



Nick,
Engineering Manager

Through this work on Project OdySSEy we have created the core systems which will enable air, land, sea, space and cyber forces to plug in and train together.

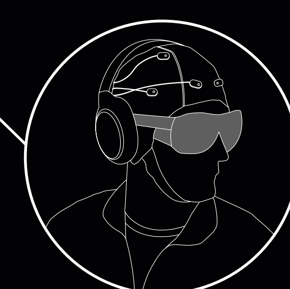
Return to Contents page

Project OdySSEy uses advanced psychophysiological measurements to enhance training

We use a range of physiological measuring equipment in order to get a more accurate picture of a trainee's mental state throughout training. It also helps us pinpoint the most stressful and difficult decisions for a trainee, so that we can better advise on future training. We use artificial intelligence to help us analyse the full suite of data, finding correlations between the three main types of monitoring:

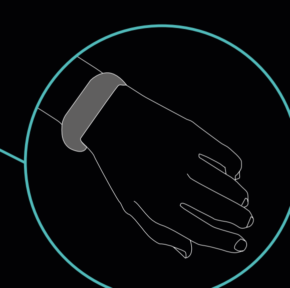
Brain scanning

EEG, or Electro Encephalogram scanners, look like swimming caps with a number of sensors placed around the outside. They are worn by students to monitor electrical activity in the brain, which we can link to a variety of brain states, from high stress through to the ideal 'flow' state, indicating high functioning and performance.



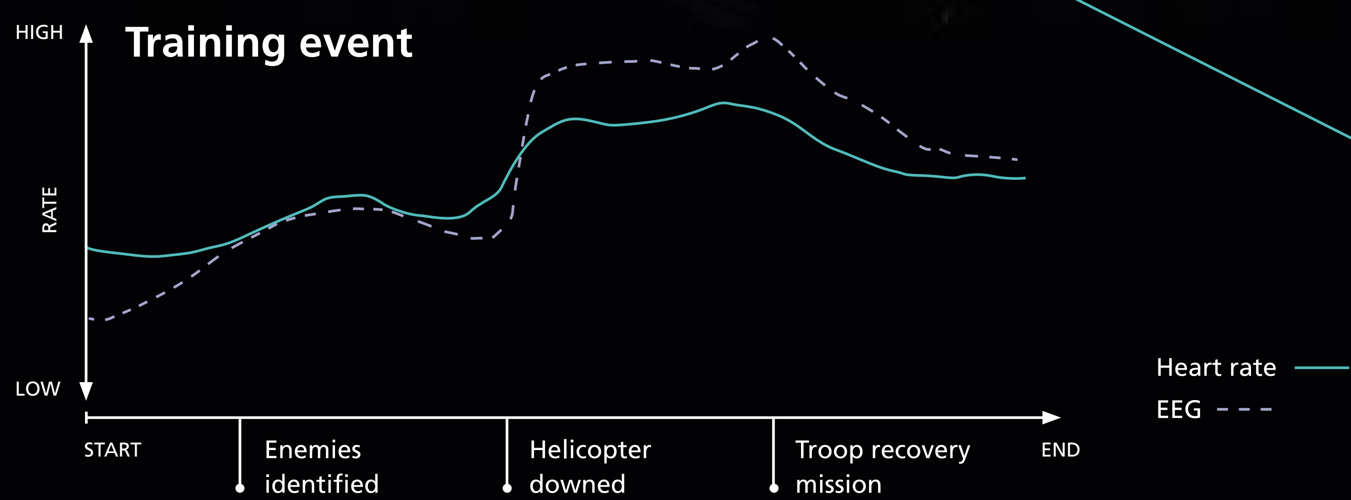
Eye-tracking

This serves two purposes. Firstly, pupils tend to dilate when a person is concentrating, which indicates difficulty making a decision. Secondly, eye tracking allows us to see exactly where someone is looking – if we can tell they're commonly struggling to find particular information, we can explore ways to improve the interface and make things easier.



Cardiovascular monitoring

Heart rate doesn't always get faster as stress increases, particularly for individuals with high cardiovascular fitness. A better indicator is Heart Rate Variance (HRV), which measures how the variance in time between your heartbeats fluctuates. A higher HRV is a good thing, because it's a sign that your body can adapt to change more easily. If a trainee's HRV drops suddenly during a scenario, it's a sign that they're highly stressed.



Return to Contents page

When mission planning and management meets wargaming

Mission planning software is often used to help move assets from A to B to carry out objectives. For the highly complex and dynamic battlespaces of the future we looked at how to select the best team for the mission, along with planning the roles of those team members and how to re-allocate tasks when the unexpected happens.

This was one of the challenges we tackled with our strategic university partner, Cranfield, and Prof. Gokhan Inalhan, as part of our AI and Autonomy Accelerator.

We have created an AI-powered mission planner with a graphical interface, which uses 'intelligence' about enemy forces (such as numbers, locations and capabilities) to work out the ideal mix of platforms and resources to carry out missions.

Nick, Principal Technologist in AI, Autonomy and Disruptors for Air runs the accelerator: "There will be so many more options for mission planners in the next few years, as numbers of uncrewed vehicles rapidly multiply in every domain; both among our allies and our potential adversaries. It's going to be very difficult to plan simple things such as what assets you need, in what formation, over which domains and with what payloads to complete a mission. As a result of technological advances, the speed at which warfare occurs and the complexity will present new challenges that require rapid and calculated responses. Plans also rarely survive contact with the enemy, so what if we could use this mission planning tool in real-time, autonomously, and all within boundary conditions and other constraints set by the operator.

An advantage of using AI in mission systems planning is the ability to think several moves ahead of your enemy, which could even include steps that seem counter-intuitive when carried out, but go on to make sense over time. As Nick explains: "One of the most famous examples is in 'Move 37' by the AlphaGo AI in a Google DeepMind Challenge match, during a game of Go – a complex board game that requires intuition and creative thinking to win."

A move made by AI in the challenge match made no sense to its human opponent at the time and many thought the AI had made a huge mistake. However, Move 37 proved to be the decisive step when the AI won, 174 moves later."

Nick,
Principal Technologist in AI, Autonomy, and Disruptors for Air

This is just one example of work carried out by our AI and Autonomy accelerator with Cranfield University. Other work underway includes an AI image classifier that is designed to provide machines with an ability to perceive the world in a similar way to humans; task allocation for large swarms and how to develop trust in human-machine teams.

Return to Contents page

Manufacturing

Nothing is more exciting for me than seeing one of the iconic platforms we produce in the hands of our customers, whether that's a submarine, a fast jet or a combat vehicle. While the way we design and build is becoming ever more digital, ultimately we still need to provide a physical asset that performs in every environment it encounters.

It's easy to forget the manufacturing journey behind those products, but I hope you'll be as fascinated as I am in how we're continually improving the way we do things to be better, faster and safer at every stage.

In Australia we're creating an entirely new shipyard for the Hunter class frigate, but instead of just copying an existing design, we're creating a 'factory simulation' using AI tools that can digitally simulate millions of different layouts to help find the most efficient build path. Not only that, but the system will also continue working in real-time during the build, helping us handle any changes or even re-order the plan in case a machine is down for maintenance.

We've been at the forefront of digitising manufacturing capabilities, working with our university partners to develop new approaches to sharing data across our factories and suppliers. One of the biggest challenges has been ensuring cybersecurity at every level. Like sharing military information on the battlefield, we can only share the right level of data classification required for each operation. We now have a robust system that we have been able to re-apply in different manufacturing environments.

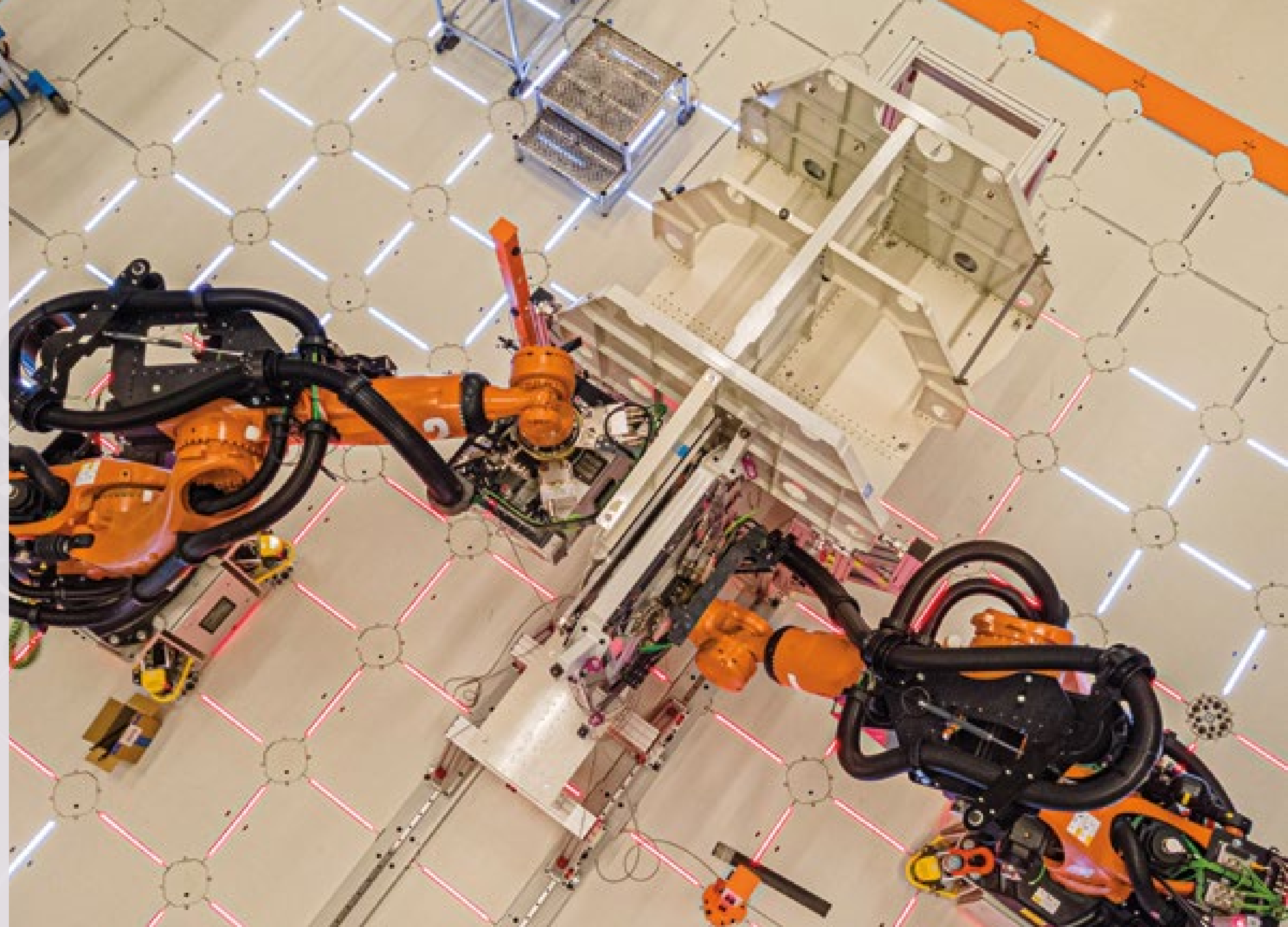
In our Factory of the Future in Lancashire, we're trialling cobots to augment our human operators and AI to assist with design. As you'll read on p.44, we have a design system that can extrapolate the impact of a single design change across the entire engineering lifecycle, as well as automatically redrawing designs based on changes, which human engineers can then review. This will save thousands of hours of manual CAD interventions and is just one more way we're saving time and cost in creating the Future Combat Air System.

Some people might still think of manufacturing as repetitive production lines and oily rags, but anyone visiting our factory today will see a vision of the future; creative teams working together with robotic assistants to deliver truly next generation products, in a setting that wouldn't look out of place in 'Star Trek: Next Generation'. If you'd like to visit, please let us know – we would be proud to show you what we do.

Jon Evans,
Manufacturing and Engineering Director

Digitalising the shop floor

We committed to delivering Tempest, the UK's next generation combat air system, in half the time of previous fighter jets, from more than 20 years down to just ten years. To do this, we've had to embrace new ways of working, new partnerships and collaborations and transform our approach to design, engineering and manufacture, demonstrated in our Factory of the Future.



Our Factory of the Future Manager, Steve explains how this is making a difference: "Through our Factory of the Future, we are developing new Engineering Toolsets and manufacturing processes that provide flexibility in our production systems, while bringing people and technology safely together to improve efficiency. To demonstrate the progress we're making on maturing these technologies, we have already used them to produce an example front fuselage, which tested new Model Based Engineering approaches and technologies such as Robotic Assisted Assembly – where people work in unison with robots to build combat airframes.

Our compressed development schedule on Tempest means we need to look at taking a completely different approach to engineering. The new engineering methods and toolsets we're developing means we are now combining our design, manufacturing and support engineering processes to happen simultaneously, rather than one after another, which saves a considerable amount of cost and time.

Ultimately, we're aiming to digitally link our engineering data so that our engineers can work together and collaborate much more easily. For example, if a Design Engineer makes a change to the design of the product, the impact of that change across the engineering lifecycle can be immediately understood, rather than having to wait for other specialist engineers to translate the updated information before the changes can be fully assessed. This significantly reduces our end-to-end engineering timescale, as we can do a number of activities concurrently.

This also provides an opportunity to save time on discrete engineering tasks. For example, if the design or specification of a standard fixing bolt is changed, which is used in hundreds of places, an engineer would traditionally have to make a change at every location that bolt is used. The new toolset enables this to be done automatically using set libraries contained in the system and enables the technical data associated with that bolt, to be used further down the workstream in manufacturing. If you scale this up to the hundreds of design changes you'd expect during the course of engineering a new aircraft, the savings in time and money and improvement in the quality of engineering and manufacturing, become significant.

The development of the toolsets, digitally-driven technologies and capabilities and connectivity across the factory, will contribute to a very powerful and transformational production system as we further expand the factory.

Digitalisation also extends to logistics, as we have delivery robots connected to the network that can autonomously collect specific parts then navigate through the factory to deliver these direct to operators. Steve explains how these differ to more commonly seen factory robots: "Most robotic vehicles used in factories in other industries are given very specific instructions – travel south for 20 metres, then west for 5m and so on – to get to their destinations, so anything unexpected can stop them. Our robots have a complete map of the facility and can detect unexpected obstacles, such as pallets or equipment, then select a new route based on their knowledge of their environment. If they encounter any people, they also stop to let them pass."

We are currently testing mobile autonomous robots with drill heads attached, so that they can travel to where they're needed in the factory then drill the required parts – helping the operator with more awkward and repetitive tasks. Like our more static production robots, they have highly accurate sensors and controls, to ensure they are working to the finest tolerances.

Aircraft manufacture is highly safety critical, so alongside adopting these new approaches we are also working with the relevant authorities, to certify the safety and precision of this approach. Steve continues: "As well as components and systems, the process of designing, building and flying an aircraft is understandably closely regulated. At the same time as pioneering these new approaches, we are working closely with regulators to ensure we maintain confidence and trust in the processes and we meet or exceed current safety standards."

Steve concludes:

"We're seeing tangible results from our digitalised, cobotic Factory of the Future, which is giving us the confidence that we will deliver Tempest within the timescales and affordability targets, and a next-generation capability required by the Royal Air Force, by 2035."

Return to Contents page

17 million ways to build a ship

Modern shipyards are a complex maze of activities, so when your job is to build the maximum number of ships in the shortest possible time, it's natural to look for help.

Yegor, our Simulation Lead in BAE Systems Australia, explains how his team created a digital simulation tool to provide assistance:

"There are more than 17 million ways to build a ship in our yard, and it takes a team two weeks to fully assess just one scenario. We didn't have a spare 600,000 years, so we created a Digital Twin that uses Artificial Intelligence to do the work for us. It took a lot of time up front to model everything correctly, but we're already seeing the benefit – we recently used it to validate how we could save eight months on an individual ship build, which is a big chunk of the nine year programme. That's nearly six years of build time across the nine vessels. Without the Digital Twin, we wouldn't have known to do this."

There was no existing shipbuilding simulation product we could use, so we adapted an off-the-shelf tool designed for manufacturing industries that produce thousands of products a day. It can now plan the production of complex, multi-year ship builds and model activity down to individual workstations.

Yegor outlines how we were able to demonstrate the eight month saving per build: "Each Hunter class ship is made up of 22 'blocks'. Once a block is built, it moves into a specialised paint chamber to get its anti-corrosion coating. Before we had the planning tool, it was really difficult to justify the expense of building a second painting chamber, as we couldn't prove conclusively that we needed it. Now that we've been able to run through all of the scenarios, we've been able to show that the second paint chamber will save time and money overall.

The tool is also being used dynamically, as efficiencies continue to be found in the build. If we find a 10% improvement in one part of the facility, this means we can model the impact and make sure we can take advantage of it throughout the build, rather than it causing bottlenecks elsewhere. Even if there's a delay caused by a delayed supplier or employee absence on one of the production lines, we can quickly model the impact and find the most efficient way to manage it."

The next step was to feed live data from across the shipyard back into the tool, so that it can be used proactively to spot new efficiencies or problems, as well as improve modelling still further with the latest data. Before we were able to do this, the Hunter cyber team had to prove it had a cyber-secure solution for transmitting data on the site.

BAE Systems' UK munitions business has experienced similar data challenges as Hunter, when trying to extract live data from production equipment, as Yegor explains:

"Our small arms ammunition facility in the UK was a real trailblazer in creating a smart connected factory, so they experienced many of these issues first time around. We've now taken a similar approach to prove our IT security solution, so now we're starting to get live data into our model."

Yegor, left, leads the team developing the advanced Digital Twin of the Australian shipyard.

The Digital Twin is fed live data from the shop floor, allowing it to dynamically spot efficiencies or any issues.

Return to Contents page

Shipyard safety 4.0

Industry 4.0 usually means new digital manufacturing techniques, but in Australia we're bringing the same approach to automating our processes, as well as improving safety, productivity and quality.

As well as a new lighting system that doubles as a network of sensors to monitor and control environmental conditions, we're also testing wearable devices that monitor if operatives are in awkward positions for extended periods of time and give proximity warnings to help avoid collisions.

These new technologies have come from three innovative SMEs, who are all members of the Industry Capability Network in Australia. As a member, at BAE Systems we can raise our requirements and problem statements as an 'Innovation Challenge' on the digital portal, which is then highlighted to more than 1,700 suppliers on the network.

The smart lighting solution from MyModular monitors and controls environmental conditions, displaying updates on a live dashboard interface. The built-in sensors detect the presence of our operatives, which supports evacuation during emergencies. It also carries a data connection over its electricity powerline to provide a wireless network throughout the base. It does all this on a low power 48v direct current system, which is more sustainable as well as lower risk than a conventional high-voltage 240v AC system. Given its success, we want to use this system in our UK shipyards, so have applied for a Kitemark from the British Standards Institute to enable this.

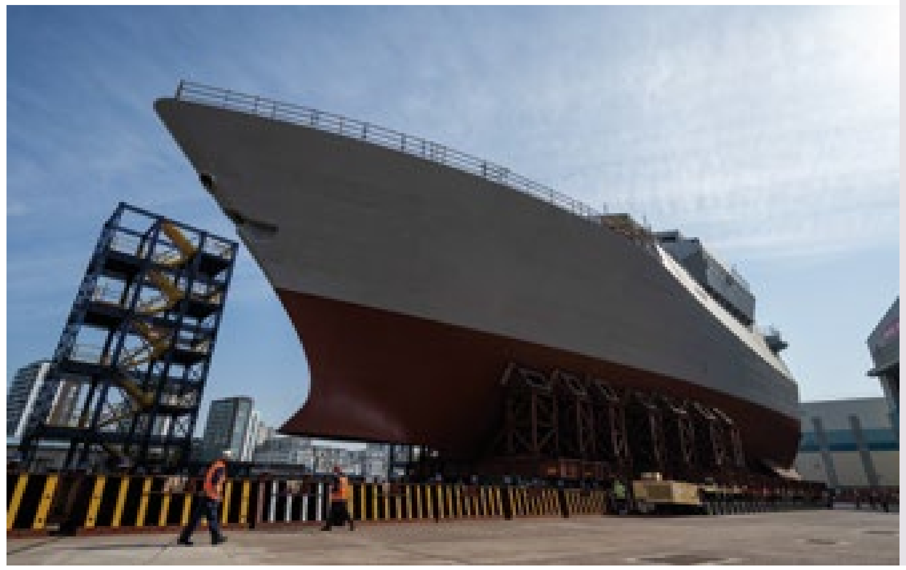
By its very nature, building a ship means people have to work in confined areas, sometimes in positions that could cause discomfort or even muscular strains if maintained for too long. We already have robust processes in place to prevent this, but to provide another layer of safety we've now trialled Electrocad's lightweight wearable body sensors that alert users to manual risks including handling loads, poor body positioning or repetition of activities. We're currently working with Flinders University Biomechanical faculty in Adelaide to make the sensors even smaller and self-powered by the user's body heat and movement.

Forklift trucks and mobile cranes are another well-known hazard in manufacturing facilities. While again there are established safety protocols, we wanted to take extra precautions, given we were making big changes to the layout of the shipyard and employing lots of new workers. Cohda Wireless has fitted devices to heavy moving machinery that constantly broadcast a location signal, which is detected by sensors worn by people on the shop floor, triggering an alert when they are approaching one another. The trial has been successful and we will be looking to mature the solution for further uses in the near future.

André and the team developing the safety improvements in the shipyard, following the installation of the new smart lighting solution.

André, Project Manager for the Hunter Class Frigate Research and Technology Programme sums up the achievements:

"Safety is always the top priority for BAE Systems, both for our employees and our customers. In creating a shipyard to build the Hunter class frigates, we wanted to use the latest technology to protect those working on it, to improve our workforce safety and increase productivity and quality outputs. It's just the right thing to do."



Return to Contents page

In a spin – simulating complex munition flight

Wind tunnels are perfect for testing aircraft designs, even at hypersonic speeds, but what about the flight of munitions that are simultaneously spinning and wobbling, as well as travelling at over Mach 5?

Thomas, Computational Fluid Dynamics (CFD) Analyst sets out the problem: "When you test an aircraft wing you look at the drag and lift caused by airflow over the wing, so you're mainly looking at two 'degrees of freedom'. An artillery shell spins as well as pitching on its axis as it moves, giving us six degrees of freedom. In a wind tunnel it would be impossible to tell which of those specific factors was affecting the observed flow of air across the shell, but our simulator can model all of these movements of the shell and airflows around it, telling us exactly what's going on."

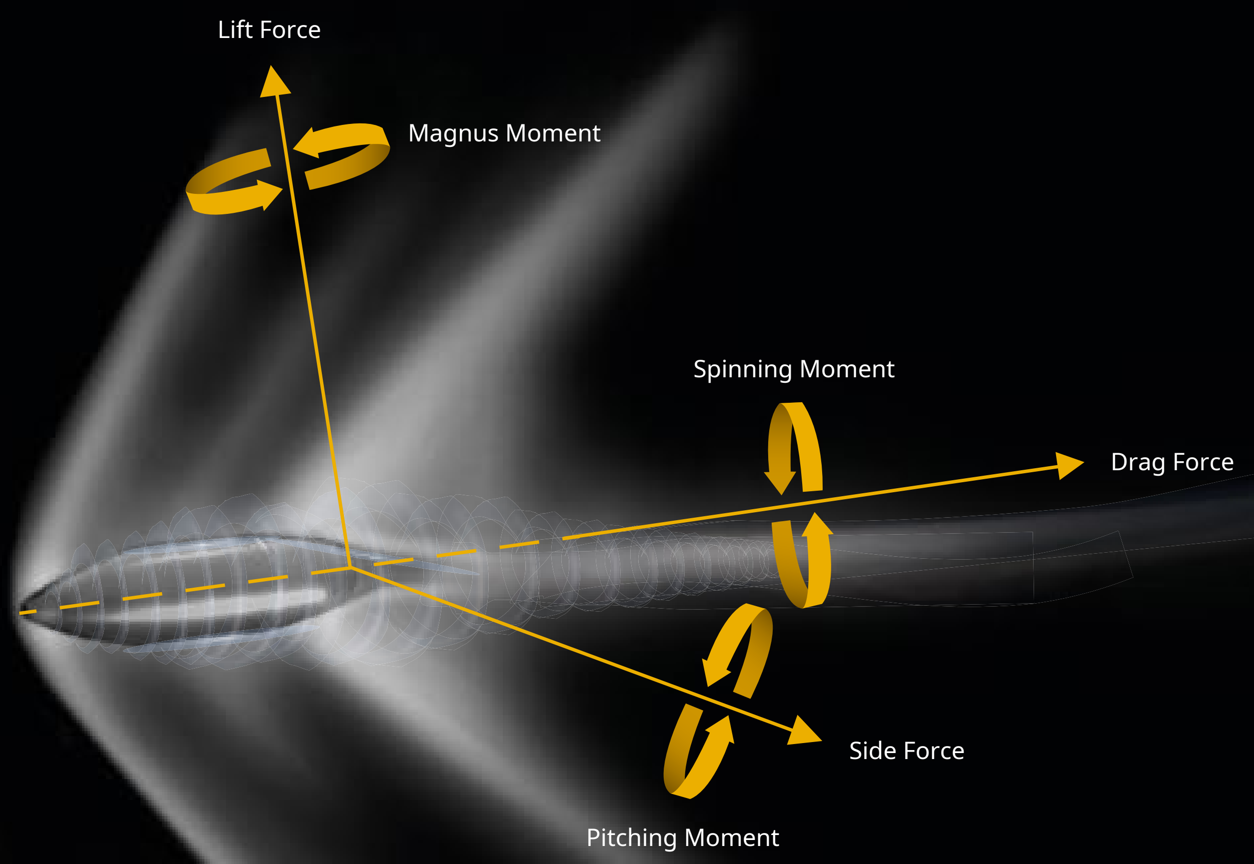
Shells still need to be physically tested as part of their safety case, but using our high-fidelity CFD models, we can reduce this to a few dozen rather than several thousand, which significantly reduces costs. Unlike the traditional semi-empirical shell models, our CFD simulations are also not limited to conventional shapes, so we can achieve similar savings for physically testing unusually shaped projectiles.

One example where the CFD approach has been vital to fixing an issue was with a munition that had a non-standard shape and weight distribution, and was falling short of its expected range. Given the different shape, the traditional empirical model wasn't able to explain the underlying flight mechanics. However, once we modelled the shell using our CFD process, we were able to identify the cause and help design a solution.

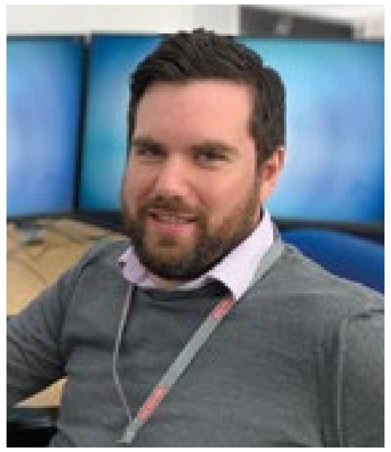
Lucy, CFD analyst on the project says:

"We've also automated our CFD process to test all the use cases we know we need, modelling all the altitudes, humidity levels and air temperatures that shells could be fired in, from equatorial desert to arctic conditions. All we need is the CAD data for a projectile, then we can leave the computer to perform all the tests we need without manual intervention."

The model simulates all the forces and moments in order to calculate the coefficients required to define its motion in a 6 degree of freedom trajectory model.



"We can also test for a number of other variables, testing different spin rates and even the surface roughness of the shell material. As is the case for golf balls, we've shown that some rougher surfaces can actually be more aerodynamic than a smooth finish."



Lucy,
Computational Fluid Dynamics (CFD) Analyst

Thomas,
Computational Fluid Dynamics (CFD) Analyst

Return to Contents page

Sustainability

With the Russian invasion of Ukraine, it can be easy to forget about the commitment we and our customers have made to sustainability. However, when so much new green technology can enhance performance as well as reducing environmental footprint – and even cost – it makes even more sense to continue our focus here.

For the first time this year, we've set our strategic university partners a grand sustainability challenge to really move the dial on defence. The University of Strathclyde and The University of Birmingham are working together on how to improve the energy efficiency of warships, accelerate the pull-through of new technology and model the through-life costs of carbon, so that we can help customers make more informed decisions about future upgrades. The teams will also look at sustainable fuels, more efficient engines and AI-controlled support systems. While this is our first sustainability grand challenge, we plan to run more in the coming years for other areas of defence.

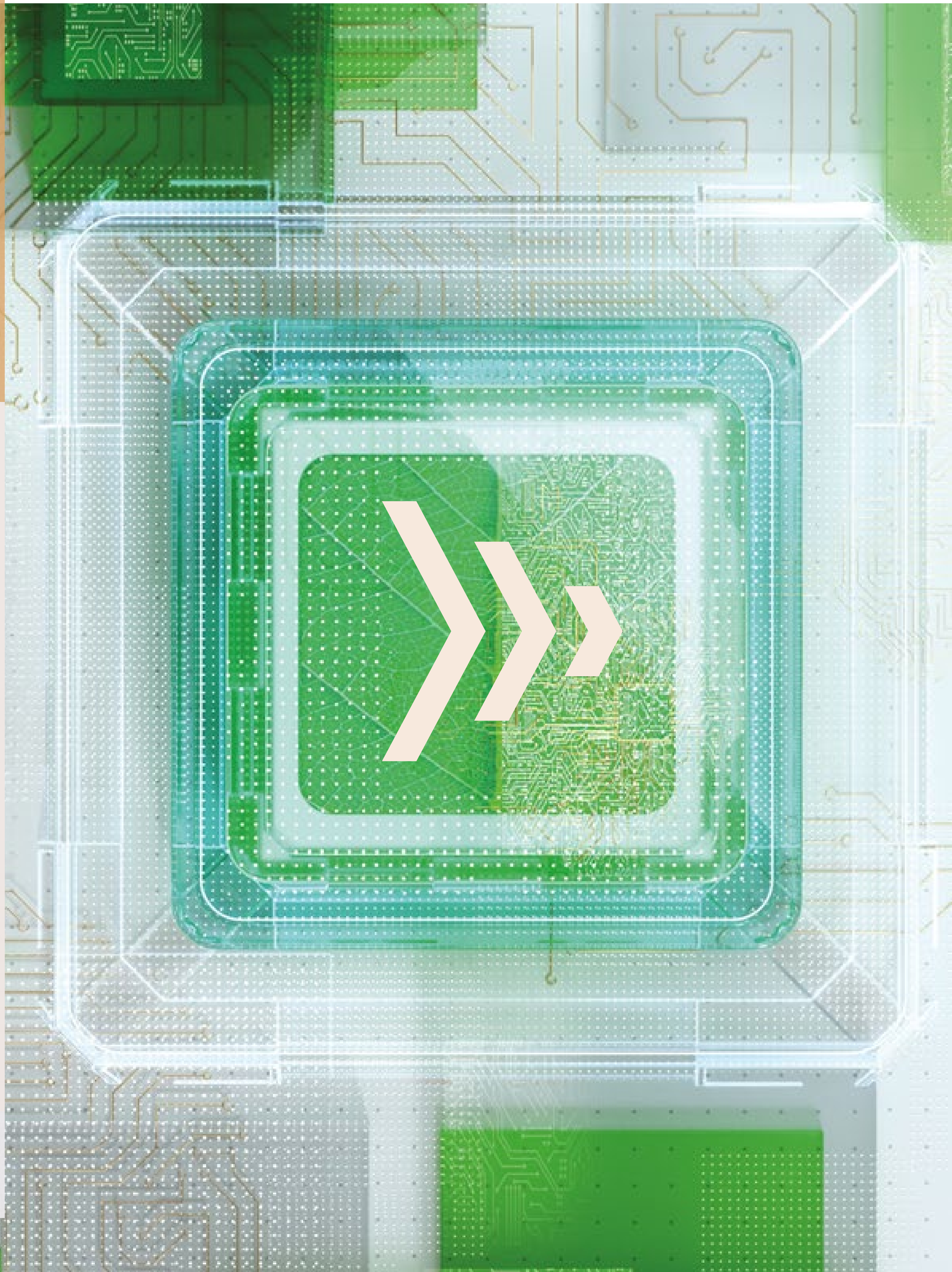
As a company, we are also looking at battery safety in aircraft, given a battery fire in the air is potentially much more catastrophic than when on the ground. We're exploring novel ways to monitor batteries and predict failures in advance, allowing us to do planned preventative maintenance rather than reactive repair (p.68). We're also testing new types of battery technology that weigh less, allowing an aircraft to go further.

Commodore Mike Knott CBE RN (p.26) talks about our new highly immersive synthetic training in terms of reducing cost and concealing our capability from our ever watchful enemies, but clearly this can also be more sustainable. In 2022, we supported the RAF's Typhoon Force to fly 6,336 synthetic missions, which would have burned 34,380 tonnes of fuel, releasing 107,600 tonnes of CO_2, had the missions been flown live.

Sustainability doesn't only apply during operations and training, either. We've brought in a more sustainable approach to support, including battery operated ground power units to keep Typhoons charged and ready to fly before missions (p.66). These are much quieter, have a lower carbon footprint and are expected to bring £13m of savings over the next decade, given the reduced operating costs and need for maintenance.

Our next generation of engineers want to work for a company that cares about sustainability and our customers tell us their new recruits feel the same way. We still need to win the fight, but we believe that working more sustainably will actually help us deliver the required performance, as well as maintaining our moral conviction to fight climate change.

Cathy Davis, Technology & Innovation Sustainability Director



Return to Contents page

PHASA-35® first successful stratospheric flight

British engineers have successfully completed a stratospheric flight trial of BAE Systems' High Altitude Pseudo Satellite (HAPS) Uncrewed Aerial System (UAS) – PHASA-35.

Over a 24-hour period, PHASA-35 soared to more than 66,000 feet, reaching the stratosphere, before landing successfully. The trial, completed in June 2023 in New Mexico, USA, allowed engineers to assess the performance of the experimental solar-electric drone within the outer-reaches of the planet's atmosphere.

The flight marks a significant milestone in PHASA-35's development which began in 2018. Designed by BAE Systems' subsidiary Prismatic Ltd to operate above the weather and conventional air traffic, it has the potential to provide a persistent and stable platform for various uses including ultra-long endurance intelligence, surveillance and reconnaissance, as well as security.

It also has the potential to be used in the delivery of communications networks including 4G and 5G and could be used in a wide range of applications, such as disaster relief and border protection, as an alternative to traditional airborne and satellite systems.

The PHASA-35 programme sits within FalconWorks™, a new centre for advanced and agile research and development within BAE Systems' Air sector, designed to deliver a range of cutting-edge combat air capabilities to the UK and its allies.

PHASA-35, which has a 35-metre wingspan and carries a 15kg payload, uses a range of world-leading technologies including advanced composites, energy management, solar-electric cells and photo-voltaic arrays to provide energy during the day which is stored in rechargeable cells to maintain flight overnight.

The successful trial assessed the performance of the experimental system across a range of areas. It is the first in a series of trials planned to confirm system performance, support development activities and validate test points to enable PHASA-35 to be made available in defence and commercial markets internationally.

The latest trials took place from Spaceport America in New Mexico, flying in the White Sands Missile Range, and are sponsored by the US Army Space and Missile Defense Command Technical Center. This test flight was coordinated and directly supported by personnel attached to Naval Surface Warfare Center, Port Hueneme Division, Detachment White Sands.

"PHASA-35 is breaking new ground – opening up the stratosphere to new possibilities. The team, which brings together BAE Systems' know-how from across the globe with innovative solar and power management technologies, demonstrated tremendous commitment and ambition as they tackled the challenges associated with novel technologies and approaches. This partnership approach is key to our ability to enhance our defence expertise with new thinking and technologies."

Cliff, Group Managing Director for BAE Systems' Air Sector

"This is a fantastic achievement for everyone involved and shows the commitment of BAE Systems to invest in new technologies and markets. PHASA-35's first stratospheric flight demonstrates that this vehicle is on track to become the go-to system for long endurance, high altitude and communications applications in the future. The successful trials are a testament to the hard work of the fantastic team that we have built over the last couple of years within Prismatic and across our partner companies including Piran, Amprius, Microlink, Honeywell, PMW Dynamics and the Met Office. I look forward to the next steps as we develop this unique system."

Dave Corfield,
CEO of Prismatic Ltd

Return to Contents page

What we learnt from working with the NHS

Back in 2021 we worked with a Lancaster-based SME to make a new rebreather hood for the NHS, which transformed their ability to protect themselves while still taking care of patients during the pandemic. More recently, we helped clear the hood for general use, rather than just for Covid patients. What we learnt has helped improve the way we operate, as Michael, Chief Engineer for Submarines explains:

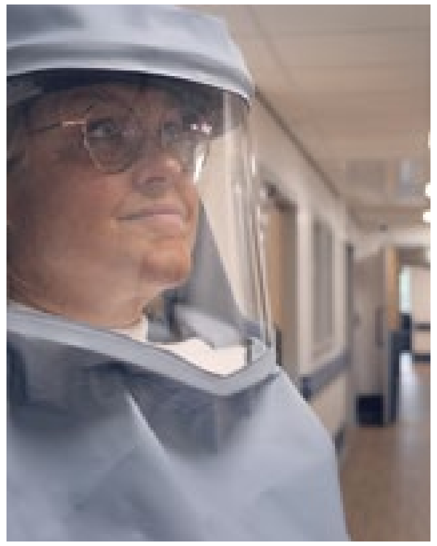
"The NHS is – quite understandably – focused on patient outcomes. If they have a need, they'll find something off-the-shelf at the right cost that achieves it. In BAE Systems, we often take a different approach – we work out the requirements and then engineer a solution that fits, again to the right cost. Both approaches are valid, but we've each taken away some valuable lessons from working together. If I'm now in a design review even for a small component of a much larger system, I'll always ask, is this helping us meet the overall outcome?"

For Alan, Engineering Delivery manager in BAE Systems, it's also changed his perspective on the comfort and wellbeing aspects of design: "While we've always thought about end-users during design, those aspects are always balanced against cost, compliance and other 'hard' engineering considerations. I've now seen the tremendous difference that our more comfortable hood has had on NHS staff, allowing them to do long shifts without getting fatigued, reducing stress and improving their ability to communicate with each other and patients. It's opened my eyes to the difference this can make to human performance, and made me increase the weighting on comfort during design."

It's not just BAE Systems that has benefited from the collaboration. Stuart Hosking-Durn, Head of Resilience & Patient Flow at University Hospitals of Morecambe Bay NHS Foundation Trust, says: "We don't have our own engineering team in the NHS, so historically we've been limited to what was already available. Working with BAE Systems has opened our eyes to the benefits of designing something to specifically meet our needs."

"When our nurses and doctors first got their hands on a BAE Systems' hood, many of them had tears of gratitude for a product that met their needs so completely. We want to keep working with BAE Systems and will now consider engineering teams rather than reaching for something off-the-shelf."

Main image: Left, **Stuart,** Head of Resilience UHMBT
Middle, Team Leader **Michael,** Head of Engineering, Specialist Engineering and Technology Group
Right, **Neville,** Managing Director, Lancastle



The new hood has also had a positive effect on a local small business, Lancastle, who were involved in the design and is now the licensed manufacturer. Lancastle is looking to market the hood for international customers, which has been made possible by the hood's recent certification. As well as wider use in clinical environments, it's expected to be used in industrial settings where there's a risk of poor air quality.

Return to Contents page

Sustainable ground power rolled out to UK Typhoons

Royal Air Force Typhoons are being powered up by new electric battery ground power units following a trial conducted by the Royal Air Force and BAE Systems on a Typhoon Squadron. The units will replace diesel powered systems and reduce harmful emissions by more than 90% while cutting running costs by 80%.

The battery powered units will deliver sustainable ground power to the Typhoon fleet across RAF Lossiemouth and RAF Coningsby, saving more than a thousand tonnes of CO_2 per year. The units have a 90% reduction in CO_2 emissions and will reduce over 40% of emissions from across Typhoon ground operations.

The battery units are also much cheaper to operate at around £3 per hour which will save the RAF £13m over the next decade. To power up a Typhoon aircraft for a whole week, each unit only needs an eight hour charge.

The new battery powered units are also quieter, producing less than 60 decibels of noise, which is equivalent to the sound of a dishwasher or electric shower. This will significantly reduce hazards and improve conditions for ground crew and pilots.

Vicky, Change Manager for BAE Systems' Air sector, says: "Improving environmental performance where we can in fast jet support is a key goal for both BAE Systems and the RAF. Not only will the new ground power units reduce the environmental impact of operations, they will also help to reduce the cost of running the UK Typhoon fleet."

Flight Lieutenant Adam Hayler, DE&S Typhoon Development Team:

"In addition to the battery powered unit's green credentials, the maintenance costs with each unit are a lot less compared to the diesel units, meaning that overall operating costs are also lower. This is a clear benefit in light of current energy prices."

The Prince of Wales visited RAF Coningsby to see some of the improvements made to the base.

Future support – getting ready for Tempest

When Tempest enters service in 2035, it's going to need a digitally enabled, AI-based maintenance and support system. To make sure we're ready, we're working closely with the RAF now to bring these technologies into service, evolving support progressively by bringing forward Tempest technologies to benefit Typhoon today.

We're currently looking at several improvements that could be brought in over the next 1-2 years:

- Electric hydraulic rig: replacing the diesel powered unit currently used to articulate heavy aircraft parts such as wing flaps during maintenance.
- Mobile hydrogen-powered substations: these could replace diesel generators during deployments, providing clean ground power to the aircraft. Studies are complete and we plan to move into initial tests.
- Keeping people warm rather than buildings: we're currently trialling battery heated suits, which could significantly reduce the heating required for operating in large hangars.
- Exoskeletons: we have delivered trials at RAF Coningsby with exoskeletons in the maintenance space to see the potential benefits using this technology can deliver from a health and safety and efficiency perspective.
- Electric autonomous vehicles: we are already using manually operated electric vehicles, but the next step is to trial autonomous vehicles, as used at our Factory of the Future in Warton.
- Tool-tracking: trials are currently underway to test the next generation of smart tools, which can track exactly how, where and at what time they've been used, even allowing you to record the exact torque applied to bolts during maintenance.

Return to Contents page

Safe battery management for aircraft use

We've all seen the stories – thankfully much rarer today – of electric car batteries overheating and even catching fire, but the prospect of this happening on an aircraft is much worse. As more electric aircraft take to the skies, battery management is becoming even more of a safety critical issue.

To meet this need, we've used our seedcorn technology fund to create a new battery testing unit on our site in Rochester, dedicated to trialling new technologies that can monitor battery health, give advance warnings of failures and automatically close down a battery cell that's overheating – all without losing performance. The results have been very promising.

Over the last year, Chris and his team have developed an entirely new capability at their site: "We've always been involved in safety critical avionics, so it was a natural step to bring these skills to batteries. In an aircraft, weight makes a huge difference to your performance and efficiency, so we've focused on special lightweight 'pouch cell' batteries, which have minimal supporting structures unlike more traditional batteries.

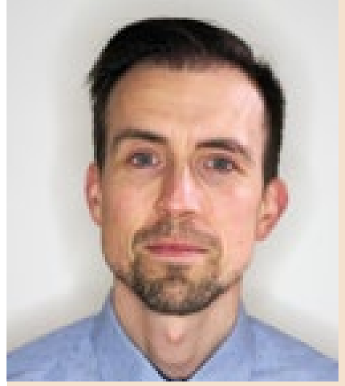
The key things you need to monitor in a battery are temperature, current and voltage. The lightweight pouch cells we've been using also expand and contract, creating an additional monitoring requirement, but they also have a thin cell membrane meaning that traditional monitoring methods – which use metal sensors – can damage that membrane. Instead, we've used a 'conductive ink' sprayed on the outside of the cell. This allows us to monitor the movement of the cell and its temperature, which we can cross-reference with the voltage and current to detect if anything is abnormal."

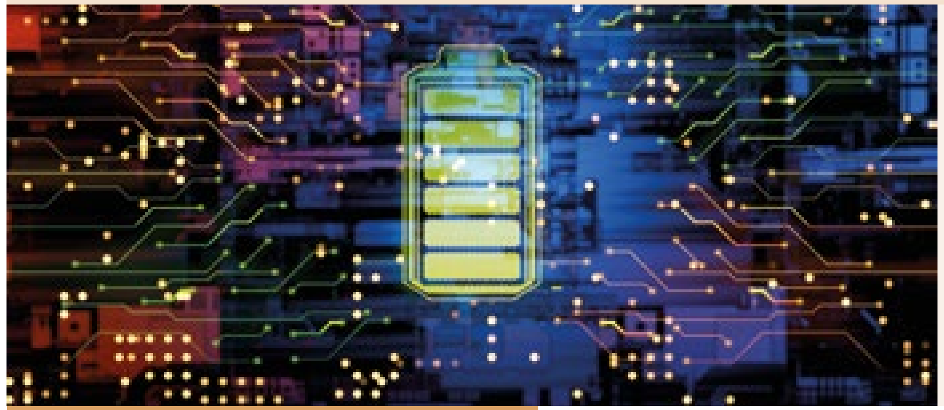
As well as providing real-time monitoring of the battery cells, the team has been running the batteries for hundreds of hours in temperature-controlled environments, under a variety of loading scenarios to simulate them being used in an aircraft. This gives us 'pattern of life' data about the batteries so we can better understand their performance. Also, by analysing the data on current, temperature and voltage against the external temperature and the loading on the batteries, we can work out the most efficient way to run the cells, to maximise life and performance. In addition to the standard monitoring metrics, Chris also found another indicator that can give an early indication of battery failure: "The most important thing with an aircraft battery is to avoid thermal runaway, which can lead to a fire – not something you want on an aircraft. We knew there was an 'out gas' released by batteries when this was happening, but it's too late at that stage to do anything about it. Instead we found a way to detect that runaway before it happened, so that could be another way to add safety features."

The next steps are to work on certifying the overall system for aircraft use. Since battery powered aircraft are still in relative infancy, the development of certification is happening in parallel with the development of new aircraft – much like in the early days of flight. Chris adds: "At the moment, because it hasn't been proven conclusively that thermal runaways can be controlled, certification authorities are insisting on a way of 'containing' cell fires so they don't propagate to adjacent cells. This requires dedicated structures in the battery that add weight, so we're trying to prove that you can actually detect the potential of thermal events in individual cells early and then prevent it through active battery management instead. In addition to the hardware we've been testing, we are also creating software to provide this control."

Chris,
Innovation & Growth Leader

"Our aim is to make the lightest weight, highest performance and safest battery system possible for use in aircraft."





The team in Rochester created new outdoor battery labs using shipping containers. These were easy to temperature control, as well as meeting health and safety regulations around battery testing by providing a sealed environment.

Return to Contents page

Training: the next generation

Training a fast jet pilot takes years, and live flying training absolutely has to be part of the syllabus. This involves lots of aircraft and pilots in the air, along with instructors. It's a very time intensive – and expensive – process.

While synthetic training in simulators on the ground is nothing new, we're now working with Red 6 to incorporate its augmented reality technology in to our helmet-mounted displays for pilots to wear while they're in the air in our Hawk advanced jet trainer aircraft. This technology can simulate enemies, as well as wingmen – either driven by AI or controlled by pilots in VR simulators back at the base.

Using the Red 6 technology, pilots can experience flying alongside adversaries or allies without the need to put another aircraft in the sky with them. This not only saves time and money, it is better for the environment and enables us to create more complex scenarios to challenge test pilots' skills.

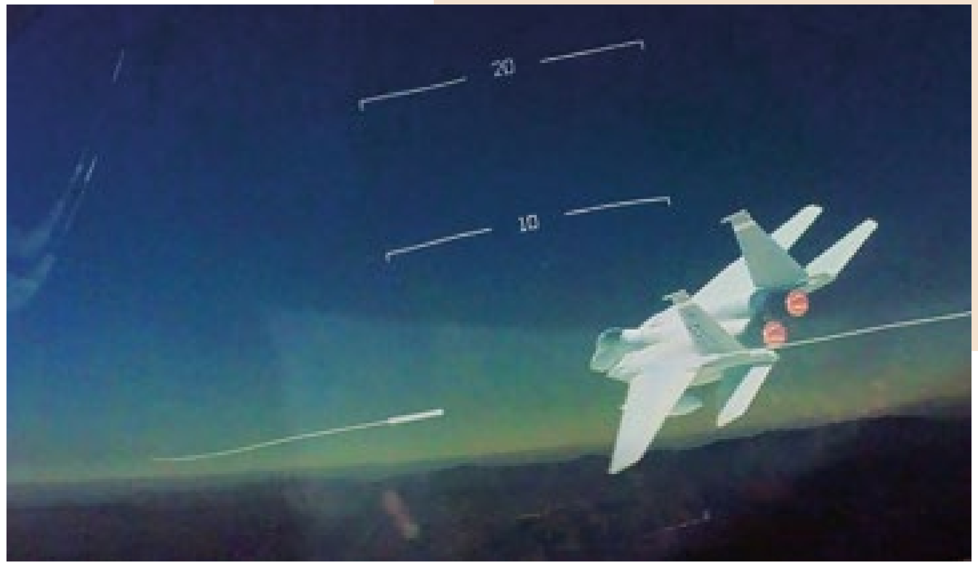
There are other benefits, as Lucy, our Head of Training, explains: "The potential of this training system is clear. As well as the significant cost savings, it trains pilots more quickly and safely and we should also be able to gain much more out of an individual training session.

Pilot training is a bit like a session at the gym, where you do 'reps and sets' – repetitions of a set of exercises. To restart each rep today, pilots and their wingmen need to fly back to a starting location, which could be a 60 nautical mile trip each time. With the Red 6 capability integrated on Hawk, the scenario can simply be reset in the pilot's existing location."

Given the pressure on qualified flying instructors across the world to train more pilots quickly, we estimate this system could save an air force the time to train another 10 pilots a year using the same resources that are available now.

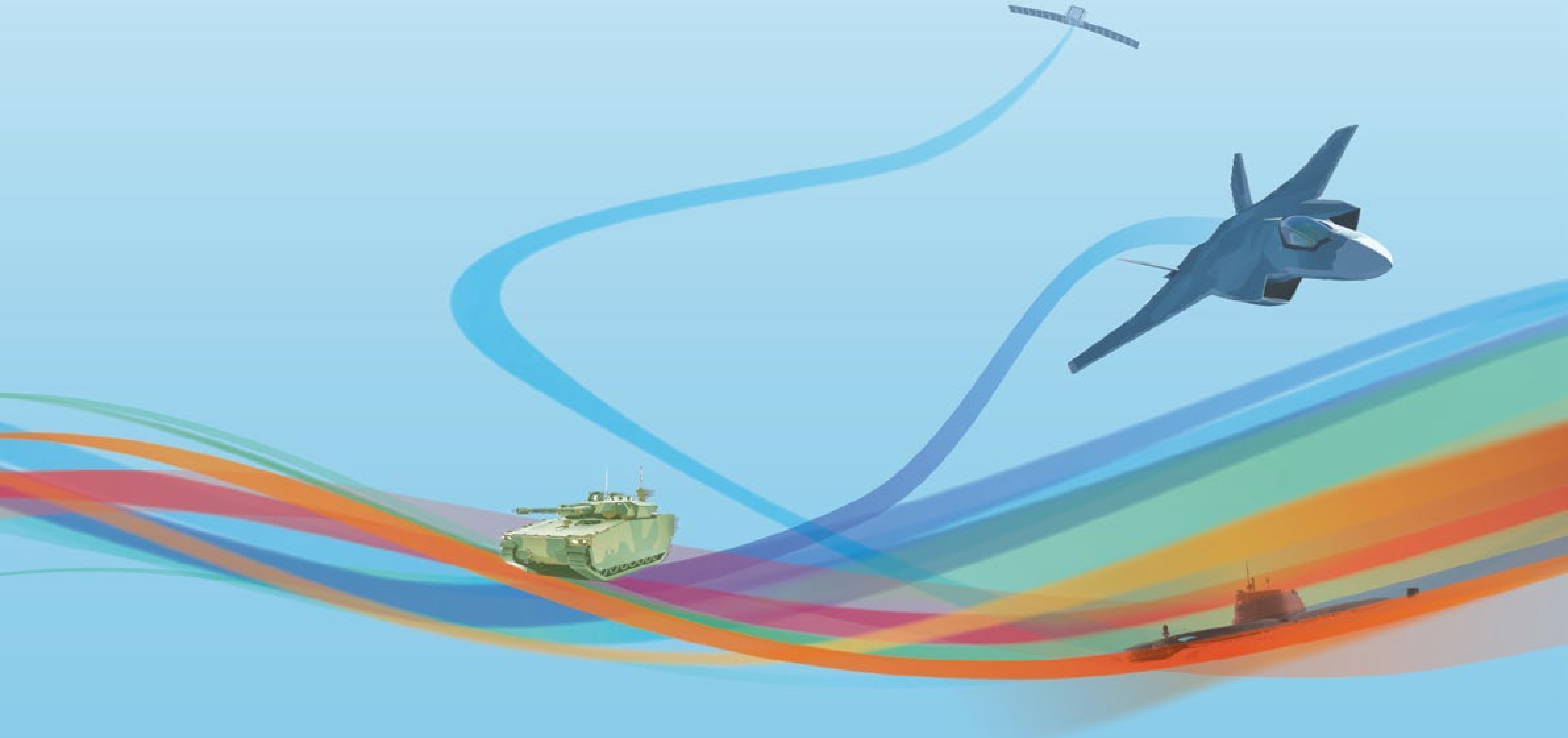
Lucy sets out what we're doing next: "We've got an agreement in place with Red 6 to develop this system for the Hawk training aircraft and expect to have a trial system in place in 2024. We work every day with the world's leading air forces, so we understand their requirements and how this technology can help."

"Red 6 are working towards a field of view of 160 degrees in their headset, whereas typical aircraft Heads Up Displays give only around a 50 degree field of view. For comparison, a human with unobstructed sight can see a 180 degree field of view."



Lucy,
Head of Training, Air Sector

Return to Contents page



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