Ministry of Defence

Defence Technology Framework

Defence Science and Technology

September 2019

Foreword

We live in an era of extraordinary and accelerating technological change. This brings a host of opportunities while also raising increasingly complex and destabilising threats.

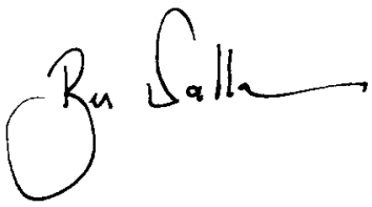
Alongside this, our Armed Forces face significant challenges with a strategic environment that is increasingly threatening, and our adversaries are investing heavily to erode our military advantage.

As the world changes, so must we. Our Armed Forces need – and deserve – the best modern capabilities to deter and, where necessary, confront our enemies around the world. We need to harness the power of technology and innovation to stay ahead of our adversaries, secure our future military edge and safeguard our security and prosperity.

The UK has a long and proud history of adapting and innovating, working with our Allies to develop cutting-edge capabilities and continuously transforming the way we think and fight. Through our 'mobilise, modernise and transform' agenda, we are gearing ourselves to confront the demands of today and tackle the threats of tomorrow.

The Defence Technology Framework – along with the Defence Innovation Priorities, which we are publishing simultaneously – is central to our approach. It sets out our strategic assessment of the technologies we consider essential to drive modernisation, and the areas where there is greatest potential to transform military capabilities to achieve battle-winning impacts. It supports our new 'Technology-led Modernisation' approach, driving the adoption of cutting-edge technologies (such as Artificial Intelligence, quantum technologies and advanced electronics) into front-line service.

Defence can't do this alone. We must collaborate with industry, academia and international partners. And we must exploit the best that the defence and civil sectors have to offer. We are therefore providing a clear signal for these essential partners: driving deeper engagement around areas of focus, making it easier to do business with us, and ensuring that we maximise the benefits of our investments. Working together we can address future challenges, build national industrial resilience and drive prosperity.



The Rt Hon Ben Wallace MP

Secretary of State for Defence

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Introduction

Strategic context

Rapid and profound technological change is one of the most potent factors shaping the modern world. It creates significant opportunities, but drives increasingly complex, ambiguous and destabilising global threats, and catalyses profound societal, economic and political shifts.

Technology is a strategic force; the nations that are best able to anticipate and exploit technological opportunities may have a decisive edge in future conflicts. UK Defence needs to:

- **Understand** the issues, implications, threats and choices that arise from technological developments.
- **Develop** the technology policies and strategies needed to respond appropriately and realise our strategic ambitions.
- **Optimise** our approach to the exploitation of technologies across the Defence Enterprise.
- **Prioritise** investment in those Science and Technology (S&T) capabilities[1] and activities that offer greatest potential impact, both now and for the future.

This Defence Technology Framework (DTF) is central to Defence's **understanding and approach**. In a resource constrained environment and given the breadth and relentless pace of technological change, some focusing of effort is essential. Defence needs to identify the source of the greatest technological challenges and opportunities. It needs access to the right capability base (people, knowledge, facilities, industrial capacity etc.) to understand and develop technologies that offer the most promising cross-cutting applications. And it needs to exploit those technologies at a speed of relevance for transformative real-world impact. This DTF has been developed to provide the necessary focus.

[1] S&T Capability includes access to people, knowledge, infrastructure and licences to practice, whether held in house (by Dstl) or held by government partners, external suppliers and International Allies.

We assess that the fundamental technologies identified here will be critical to the development of capabilities that achieve decisive and affordable military effect in future conflict. This Framework will therefore inform and shape Defence policy, strategy and investment planning. It also provides a demand signal to help the Defence enterprise, including its internal delivery agents, to anticipate – and plan to support – future capability requirements.

However, we know that fundamental technology developments will largely take place outside the government sector, and that effective Defence modernisation must be a partnership with industry, academia and international partners. This Framework clearly signals our direction of travel to these external partners and acts as an important reference point to help them understand how Defence intends to engage with them in pursuit of better and quicker capability outcomes.

Technology-led Modernisation

This DTF builds on and complements wider initiatives across Defence to modernise approaches, enhance important international partnerships, build industrial resilience and support prosperity. It is part of a policy of Technology-led Modernisation that aims to drive more rapid and ambitious capability outcomes by ensuring that strategy, investment and plans across Defence are all guided by a shared strategic understanding of how technology is developing, how it can be applied, and where it can be used to address Defence's current and future challenges.

The priorities and policy direction for Defence were set out in the Strategic Defence and Security Review (2015) and refined through the Modernising Defence Programme (2018), defining Defence's objectives to 'mobilise, modernise and transform'. In addition, the Future Force Concept (2017) provides authoritative high-level guidance about how UK Defence must prepare to fight and win over the longer term; while strategic initiatives such as Information Advantage, Modern Deterrence, Digital Transformation, and the cross-government Fusion Doctrine all highlight how Defence must think and act differently, including through novel approaches, technology solutions and operating concepts.

Defence has already taken significant strides in pursuit of these policy objectives: optimising our S&T research portfolio (building on the 2017 Defence S&T Strategy); bringing greater strategic coherence to Front-Line Command experimentation and exploitation activities; and harnessing private sector ingenuity through the Defence Innovation Initiative. We are also investing in novel 'Spearhead' and Transformation Fund programmes that will pilot streamlined approaches to accelerate the pull-through of new and emerging technologies into Front-Line military capability.

Defence's ability to bring these activities together, harness the UK's world-class S&T, academic and industrial base, and exploit these important technologies at pace will be critical to securing our military edge and to realising the objectives of the 'mobilise, modernise and transform' agenda.

The Framework

The Framework identifies seven ‘families’ of technologies, grouped together based on shared characteristics, applications or where exploitation requires common underpinning S&T capabilities. These families are **foundational areas of technology** that we believe will be critical to drive innovation and radical transformation across a range of Defence activities, from optimising the performance of military equipment, to reducing its cost, to enabling new or enhanced military effects.

The first part of this Framework provides an overview of each technology family describing the technologies it comprises, their potential impact in a Defence context, and our overall approach to development and acquisition.

The seven technology families are:

- Advanced materials.
- Artificial Intelligence, Machine Learning, and Data Science (i.e. software).
- Autonomous systems and Robotics.
- Power, energy storage, conversion, and transmission.
- Sensors.
- Advanced electronics and computing (i.e. hardware).
- Effector technologies.

Technology families were identified based on Defence S&T expert judgement, drawing on an understanding of: developments in industry and academia; policy direction and strategic capability requirements; and relationships with important International Allies.

We identified the **technology families** that were assessed to offer the greatest opportunities to transform important **application areas** by being used – individually or in combination – to develop capabilities that achieve battle-winning **impact**.

Application areas

This Framework also sets out application areas where there is the most potential for technology to support transformational capability change. For each area, we explain how and why Defence applies the technologies and identify illustrative examples of new military applications that could be developed in future. This is intended to help external partners understand our requirements and how we want to engage with them. These application areas are not MOD priorities for technology investment, but rather our assessment of where the DTF technologies offer greatest potential to mobilise, modernise and transform. In simple terms:

- **DTF technologies,** such as Advanced electronics or Artificial Intelligence), may be used in combination to develop enhanced or novel…
- **Technology applications**, optimised to specific platforms, such as a directed energy weapon onto a frigate, to achieve a critical…
- **Impact**, such as enhanced lethality and mass effect.

Where example applications are included, they are intended to illustrate the power of technology in delivering decisive military effect. Innovation is focused on applications that will help to mobilise and modernise Defence to meet the threats and technologies of today and tomorrow. Modernisation is also likely to require fundamental longer-term technology invention that is driven through the Defence S&T programme. Both S&T and Innovation support the aim to transform Defence to be more flexible, adaptable and empowered.

The application areas are:

- Space.
- Platforms.
- Comprehensive Intelligence, Surveillance and Reconnaissance (ISR).
- Modernised logistics and support.
- Enhanced cyber and electronic warfare.
- Next-generation weapon systems.
- Resilient communications.
- Human enhancement.
- Next-generation command and control (C2).

Impacts

Enhanced capability in these areas will help achieve the following impacts:

- **Enhanced lethality and mass effects** – projecting hard power to overpower adversaries across multiple domains.
- **Improved protection** – capability that is suitably agile, robust, manoeuvrable, and capable of delivering effect with persistence.
- **Decision-making superiority** – collect, analyse and understand data more efficiently and at increasing speeds to rapidly identify threats, opportunities and choices.
- **Operational tempo** – process and share information more effectively to act quickly, jointly, and at a pace that adversaries cannot match and in ways that are complex and unpredictable.
- **Resilient enablers** – enhanced support to the Future Force through better logistics, medical treatment, intelligence and information.
- **Sub-threshold activities –** increased availability of legal and ethical opportunities to respond, detect and retaliate to adversarial action below the threshold of conventional warfare.

Using the Defence Technology Framework

Defence will use this Framework to manage technology in a more coherent way. This includes ensuring we have the right balance of in-house S&T capabilities to understand and develop applications using these cross-cutting technologies. However, we recognise that commercial research and development budgets exceed government spending in many areas and that we need to work closely with partners in industry and academia, and internationally, to fully exploit these opportunities.

The Framework will therefore be used, in conjunction with the Defence Innovation Priorities, to drive a range of new approaches and activities within Defence as well as helping to shape engagement with external partners, suppliers and Allies.

Within Defence, the Framework will be used to:

- **Inform policy, strategy and plans:** shaping how the Department understands and responds to the opportunities and threats associated with technological change.
- **Influence Core Research investment:** ensuring access to the right S&T capabilities to underpin DTF technologies (noting that MOD S&T also provides critical support for military operations and maintains important national resilience and emergency response capabilities).
- **Cohere experimentation:** encouraging a common focus on the most promising technological opportunities to mobilise and modernise Defence capabilities.

- **Optimise delivery approaches:** in conjunction with innovation, helping Defence to understand future demand, ensuring that structures and processes are ready to support new ways of working, and more rapid pull through of technology developments into real world capability solutions.

Outside Defence, the Framework should be used by:

- **Major industry suppliers:** to understand Defence thinking about future capability development, our research priorities, and our acquisition philosophy towards important technologies i.e. whether we expect to develop in-house, shape the market, seek external innovation or procure Commercial Off the Shelf (COTS) solutions.
- **Small and Medium Enterprises, entrepreneurs and academia:** to understand the rationale underpinning Defence research and experimentation priorities, and to help identify potential military applications and users for the technologies that they are developing.
- **Public sector partners:** to understand the underpinning science and technology capability that Defence is investing in – and the outcomes it is seeking – to help identify potential opportunities for partnership, burden sharing and economies of scale.
- **International Allies:** to understand the technology areas that UK Defence will be prioritising for international research collaboration and where there may be opportunities for co-development or to bolster existing bilateral and multilateral partnerships.

Technology Families

Advanced materials

Technology definition

Advanced materials are those whose structure and function has been designed to support specific applications. It also includes the innovative use of conventional materials to improve the performance of a product or technology.

A broad discipline, advanced materials includes, but is not limited to, nanotechnology, advanced manufacturing (including 3D printing and digital manufacturing), some applications of synthetic biology, and the development of materials with novel molecular structures resulting in useful properties (graphene, ultrathin materials, etc.).

Illustrative Defence applications

- Development of new materials with militarily-useful properties including low and high temperature performance for extreme environments, lowered weight for more manoeuvrable and sustainable vehicles and personnel, and improving protection and stealth characteristics to enhance survivability.
- Rapid manufacturing of essential, bespoke, military components and possibly more complex systems, at the point of use and on demand.
- Totally new approaches to traditional physical challenges – such as the use of metamaterials to improve both sensing and camouflage in the congested electromagnetic environment, or through adding functionality or reconfigurability into existing structures.
- Cost reduction through improved damage and wear resistance; and more intelligent approaches to design, inspection and maintenance; whilst reducing environmental impact.

Challenges and opportunities

While advanced materials technologies vary greatly, including in their maturity, if we exploit developments in this field, we can expect to benefit from smaller logistics footprints, quicker and more efficient maintenance and resupply of important capabilities, and better protected personnel. Platforms exploiting advanced materials may offer an edge through more sophisticated protection, stealth, endurance, sensing and data transfer.

Defence will need to: harness materials developments in other sectors which are driven by global challenges and societal need, develop the right partnerships to meet Defence-specific materials requirements, maintain awareness of ongoing developments to avoid technological surprise, inform acquisition and ownership, and respond to urgent requirements.

Advanced materials could allow adaptive camouflage

Artificial Intelligence, Machine Learning, and Data Science

Technology definition

Artificial Intelligence (AI) is the ability of machines to perform tasks normally requiring human intelligence. Machine Learning (ML) is the ability of computer systems to learn without being explicitly programmed. Data Science is the extraction of useful insights from data.

These three distinct but related technologies exploit computer processing, algorithm development, data gathering and storage, and electronic connectivity, and are expected to enable radical transformation across almost every area of Defence activity. They can be used to make assessments and provide recommendations to support human decision making and activity, or integrated into physical or virtual systems that independently perform actions under meaningful human oversight. They are therefore critical enabling technologies for autonomous systems and build confidence and understanding at all levels that AI systems may change responses as they learn.

Illustrative Defence applications

- Automated computer-network defence – real time anomaly detection and patching of vulnerabilities.
- Logistics – improved and automated stock management and resupply.
- Performance optimisation – real-time monitoring of data about both people and equipment to predict problems and target appropriate interventions such as repairs, rest, or training.
- Intelligence analysis – new kinds of advanced analytics to identify patterns and anomalies in large, diverse datasets, freeing up human analytical capacity and supporting more complex assessments.
- Autonomous platforms – systems that sense and understand their environment, decide how to respond, and then perform tasks to achieve goals, overseen by humans.
- Streamlining administrative back office functions such as HR and finance.

- Supporting decision making – such as the use of algorithmic approaches to modernise wargaming.

Challenges and opportunities

It is widely recognised that countries that successfully exploit AI, ML and Data Science will gain significant economic and strategic advantages including the ability to exert international influence. Through these technologies we stand to gain more military effect per person; quicker, better decisions; and more effective allocation of resources to achieve our objectives. They will also open up new ways of delivering military effects, which are not possible with human-centric systems.

The commercial sector is investing heavily in these technologies, and Defence can exploit systems and technologies developed in other sectors for military applications. AI also benefits from a burgeoning and global open-source software community. Defence investment is likely to focus on application of these techniques to military challenges, agile development of solutions to support military capability, development of niche algorithms unlikely to be matured by civil investment, and addressing cross-cutting issues that may challenge integration and scaling of AI & autonomous systems in military capability. At the same time, Defence will need to ensure developments are safe, ethical and interoperable with other nations so that we build consent for, and confidence in, their use.

Machine Learning techniques can help commanders estimate the likelihood of enemy courses of action

Autonomous systems and Robotics

Technology definition

Autonomous systems exploit sensors and other data sources to gather information on their environment, use advanced algorithms and Artificial Intelligence to process and understand it, and make decisions about how to respond, and perform tasks – whether physical or virtual – to achieve assigned goals.

Robotic systems are automated machines that carry out complicated actions independently of, or in conjunction with, humans.

Illustrative Defence applications

- Replacing human operators with machines in high-risk environments, such as logistics resupply or explosive ordinance disposal.
- Maximising the effectiveness of our human capability by allowing our personnel to focus on complex mission tasks while the simple and low-value tasks are delegated to machines.
- Exceeding the performance of a human operator by taking actions autonomously, such as in response to cyber threats.
- Generating physical mass in the battlespace through resilient swarms of low-cost systems.
- Completely new ways of operating, including through integrated human-machine teams which use the respective strengths of both humans and autonomous systems.
- Supporting an active military presence in areas where it would not traditionally be possible.

Challenges and opportunities

Autonomous systems have the potential to affect every aspect of Defence, at all levels and across all operational domains as well as our business processes. If we exploit autonomous systems and robotics successfully, we will be able to be present in more locations (including using robots in place of humans in the most hazardous operational situations), gather more information and exert greater influence. We will be able to use our human capability where it adds most value and to 'force multiply' each serviceperson, extending their impact by supporting them with numerous, potentially low-cost, autonomous or semi-autonomous systems. New and improved platform designs and configurations will be realised as the need for in-situ human operators (pilot, crew, driver) can be removed. We can re-shape the future human-machine relationship, with machines working alongside people as part of an intelligent team.

Many of these technologies and systems will be developed in the commercial sector. To fully exploit this potential, we will need to overcome the technical challenges of integrating these capabilities into our proprietary Defence systems, ensure we have the appropriate interfaces to provide confidence to users and allies, and widen understanding at all levels that autonomous systems may make decisions that we do not expect. Almost every sector of the global economy is investing in autonomous systems, from finance and law to manufacturing and transport, so we must capitalise on that external investment while also determining what applications the market will not provide, to guide our investment. In doing so, we must recognise the challenges associated with the use of autonomous systems in military applications, not least ethical concerns, and important decisions about when human control needs to be maintained.

Autonomous Systems can provide last mile resupply to forces on the ground, removing human operators from this high-risk part of the battlespace

Power, energy storage, conversion, and transmission

Technology definition

Energy storage and conversion technologies offer ways of harnessing energy from one source and in one form, and preserving it for later use or altering it into another form. This can involve established technologies to harness power from the environment like fossil fuels, nuclear power, and renewables; or energy storage, usually via batteries. We are also starting to see novel ways of gathering and storing energy, including next-generation batteries and fuel cells.

Illustrative Defence applications

- Self-sustaining autonomous platforms able to operate at range, without support, for long periods, including in challenging and remote environments.
- Ultra-low-power electronics that operate with minimal energy demands, allowing new capabilities including at the small scale.
- Platforms and devices supported by new advanced battery technologies with greater power output, endurance, lifespan and tolerance range. This is particularly critical for unmanned vehicles.
- Support the exploitation of information by powering storage, processing and transmission of data.
- Powering directed energy weapons that require high power density sources.
- Intelligent energy management, potentially exploiting AI, to maximise the efficiency of energy used, both in individual platforms and across the whole of the Defence estate.

Challenges and opportunities

Taking advantage of novel approaches to energy generation and storage will mean we are able to operate more efficiently with lower cost, at greater ranges and for longer, and with more self-sufficiency. Possibly supported by low-power electronics, new technologies in this area will support long-endurance autonomous systems which can improve Intelligence, Surveillance and Reconnaissance and also avoid the need for humans to deploy to hostile and remote regions.

Future developments are expected to help scale down technologies and enable capabilities currently only deployable on large platforms to be developed and deployed on smaller assets like armoured and unmanned vehicles, and infantry. For the dismounted soldier, the growing suite of future capabilities (increased electronic warfare, anti-drone technologies, situational awareness and multispectral sensors), will increase local power demand, driving a requirement for high-output, efficient and low-weight sources.

Commercial sector is investing heavily in energy storage and conversion, especially batteries and renewables, and, while Defence will benefit from this, some commercial solutions will need modification to meet our needs. This is especially true for primary batteries, and power sources needing resilience to extremes of temperature, shock and vibration. Innovation is therefore likely to come from a partnering between Defence and industry.

Fuel cells such as SFC Energy's 'Emily' can offer long-endurance silent auxiliary power

Sensors

Technology definition

A sensor detects a physical phenomenon such as an electrical field, vibration or particle, and generates a response, such as the transmission of digital information or a change in colour to represent a detected chemical. Data from sensors, appropriately stored and analysed, builds our understanding of the operating environment, identifies items within it, and combines to provide situational awareness. Sensing therefore informs Defence's decisions at all levels.

Sensing technologies are diverse and include: electromagnetic sensing (e.g. electro-optic, infra-red, radar and electronic surveillance); gravity sensing; acoustic sensing; position navigation and timing (PTN); chemical, biological, radiological and nuclear (CBRN); explosive sensing; quantum sensing; and sensor fusion. Sensors are deployed on a range of platforms operating in a variety of environments – and need to overcome congestion and clutter, detect difficult (including fast or stealthy) targets, continue to function despite adversary jamming attempts and counter-surveillance techniques, and conform to stringent size and weight requirements.

Illustrative Defence applications

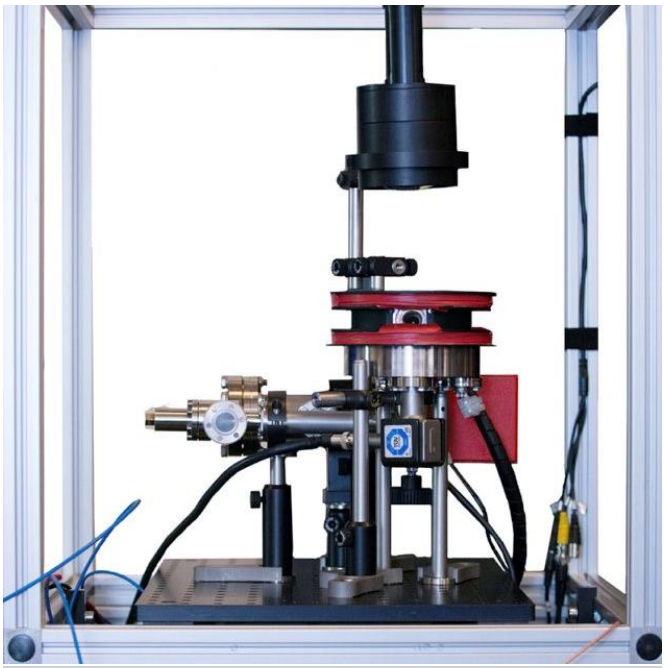
- Situational understanding to allow informed timely decision making.
- Identification and accurate location of targets of interest.
- Confirmation of effect (battle damage assessment).
- Contributing to big datasets from the Internet of Things, to improve our understanding of a situation and the use of our assets to respond to it.

Challenges and opportunities

Exploiting developments in sensing technology will mean we can detect signals with increasing sensitivity, at lower cost and reduced weight. It will enable us to detect across multiple physical signal types to improve discrimination and provide resilience and redundancy against compromise in our sensor suites. We will be able to harness new types of data about human and platform performance and, with Data Science and Machine Learning, integrate these into our understanding.

Novel developments are likely to give rise to reliable quantum gravity sensing, new materials allowing ultra-small, thin and efficient sensors, self-healing and adaptable sensors, and 3D printable sensors on demand. Advances in associated computing and energy technology will make on-sensor processing more viable, potentially opening the possibility of 'cognisant' sensor systems, and reducing the need for large capacity datalinks.

While much will be driven commercially, Defence-specific activity will need to focus on hardening and integration, and the use of modular designs and open standards to enable sensors to be swapped in and out which will allow us to exploit new technologies as they become available. Some niche sensor systems will continue to be shaped by Defence research (e.g. CBRN). The significant commercial activity means that much of novel sensor technology will be available to both us and our adversaries, meaning that our ability to quickly integrate and intelligently exploit new technologies as they become available will be important to us to deriving advantage.



Gravity sensing can reveal buried objects and underground structures

Advanced electronics and computing

Technology definition

Advanced electronics and computing[2] are concerned with information processing, systems that are programmable, and the technologies that support them.

It includes silicon-based digital information processing technologies like traditional microprocessors; specialist chips such as Graphical Processing Units (GPUs); Field Programmable Gate Arrays (FPGAs); Application-Specific Integrated Circuits (ASICs); and system-on-chip computing boards. It includes supporting elements like memory and associated software development environments. It also includes emerging information technologies like neuromorphic processors, and non-silicon-based quantum and DNA computing.

Illustrative Defence applications

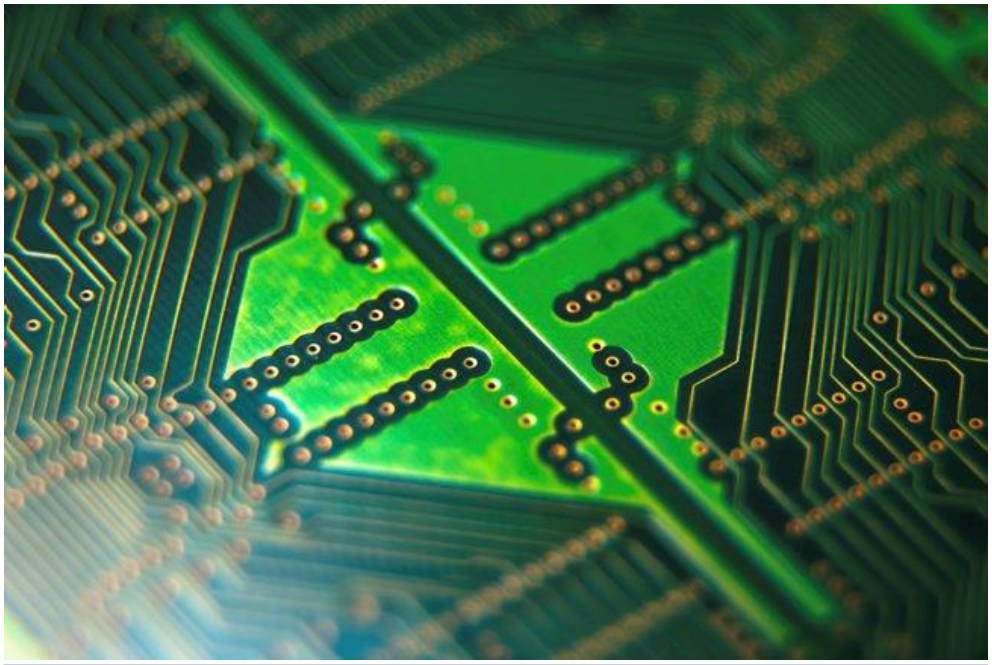
Rather than supporting a range of specific Defence applications, advanced electronics and computing are of critical importance to Defence as a foundational technology supporting other systems. Almost all platforms, systems and services contain a programmable element, and in many cases, this is critical to delivering the capability. Examples include the targeting systems for weapons, the processing of sensor data, and the flight control systems for aircraft. In addition, since programming is comparatively easy to change, this technology family contributes towards the agility necessary to counter today's rapidly-changing threats.

[2] Including cloud computing

Challenges and opportunities

Maintaining our edge in this technology area will ensure we can store, process and act on more information, more quickly, resulting in more agile and potent platforms and quicker, better decisions.

Developments in this area include neuromorphic processors and Tensor Processing Units (TPUs) developed specifically for Machine Learning applications, the future use of quantum computing for complex problems and parallel processing not suitable for traditional computing, and the future use of DNA-based computing for high-density information storage. In addition, the programmable nature of these technologies means that, even when developed for one application they can be applied to others. To exploit these technologies fully, MOD needs a sound, in-house understanding of the associated principles, so that computations can be verified and validated, and that programmable elements can be assured. This needs to allow new types of programmable element, and the associated computations, to be fielded at pace.



Advanced electronics and computing are of critical importance to Defence as a foundational technology supporting other systems

Effector technologies

Technology definition

Effectors are defined here as those technologies that aim to change the properties of a target and, when integrated with other technologies (such as sensors, advanced computing etc.), form weapons systems. These include current conventional or novel/next-generation explosives & warheads, cyber and electronic warfare (jamming and spoofing) through to Directed Energy Weapons (DEW) including laser and high-power Radio-Frequency. The ability of these technologies to overmatch our adversaries provides deterrent effect in addition to being an important enabler for modern offensive and defensive capabilities.

UK Defence requires the capability to deliver a spectrum of lethal and non-lethal effects of its choosing against a variety of growing threats. It needs to do this across the full range of current and future operating environments. Consequently, the UK will investigate ways of maintaining and improving lethal effects technology but will also investigate alternative methods beyond conducting lethal operations to achieve the desired result. These alternative approaches enable options that are complementary to traditional weapons systems as they may provide utility against a wide range of targets and offer a graduated level of effect; from temporary disruption through to destruction.

Illustrative Defence applications

Defence needs to provide a range of affordable, scalable effects against numerous threats and in a range of environments. Example applications may include targets such as:

- Sophisticated military networks and their command and control.
- High speed air and missile defence systems.
- Sophisticated unmanned systems (UxV).
- Swarm attacks against high value assets.
- Platforms with advanced defensive capabilities.

Challenges and opportunities

Advances in chemical formulation and synthesis, manufacturing processes, and new modelling tools provide opportunity for novel explosives and warhead technologies (such as reactive fragments), options to deliver increased damage and target degradation within size, mass and safety constraints of conventional weapons, and the ability to overmatch adversary armour and defensive aides.

Novel manufacturing processes such as additive manufacture may also provide new approaches to warhead design allowing the inclusion of more sophisticated and complex shapes which deliver improved effects.

The emergence of compact-pulsed power generation and fast switches provide technology opportunities for RF-directed energy weapons. Furthermore, improved compact laser amplifiers, beam combining and control technologies, and sensors will support the development of High Energy Lasers across a range of land, sea and air platforms.

Wider growth in cyber security tools and techniques will also provide opportunities for future offensive cyber capabilities. In many of these cases, Defence will need to invest to ensure that technologies are developed appropriately for our use. In addition plasma formation, requiring high input energies and intense lasers potentially offer a number of opportunities to Defence.

Novel effectors can bring enhanced capabilities in addition to legacy weapons systems

Application Areas

Space

Context

We want to develop resilient, affordable space capabilities – exploiting new technology to support operations, provide situational awareness, inform decisions and protect critical national services.

Space-based capabilities enable all aspects of modern military operations, from reliable worldwide communications to imaging, positioning and targeting. The space domain – once the preserve of national governments with large budgets – is becoming increasingly accessible, with commercial companies and smaller nation-states deploying ever more assets as manufacturing and launch costs fall and satellites decrease in size. At the same time, adversaries are developing and testing new capabilities that could threaten the critical space services underpinning modern economies.

Defence uses of space

- Communications satellites: supporting our forces worldwide with data and voice services.
- Intelligence, Surveillance and Reconnaissance: monitoring of all warfighting domains to provide situational awareness, gather intelligence, and inform decisions.
- Position, navigation and timing (PNT): supply of information enabling military users to determine their precise location and time, which is critical to communications and weapons targeting.
- Space situational awareness: current and predictive knowledge of space, including characterising space objects, tracking their motion to avoid collisions and understand which satellites are visible from a given location, and predicting the effect of space weather on capabilities.
- Hardening and resilience to ensure our assets are protected and our services maintained, even if challenged by adversary action or environmental attrition.

Technology opportunities

The recent decrease in the cost of manufacturing small satellites and launching them in a range of orbits has reduced the barrier to entry for space. This democratisation has driven the emergence of new business models and the evolution of old ones, offering the UK new ways to independently and affordably exploit space in future. The number of satellites in orbit is projected to continue to increase dramatically, and satellites in ‘mega-constellations’ will increasingly provide more persistent and resilient surveillance and communications covering the entire surface of the planet. In the near future, we expect to see developments in optical communications technology, further improvements in information extracted from space-based sensors, the emergence of on-orbit servicing and assembly, and the continued growth and proliferation of space and counter-space capabilities by our adversaries, which we will need to address.

Underpinning technology families

This area is underpinned by all seven technology families.

CubeSats offer a low-cost route to space capability (NASA)

Platforms

Context

We need to optimise military platforms, both manned and unmanned, for technology insertion and upgrade, to enable us to integrate new capabilities and developments as soon as they become available and provide greater flexibility and agility and maintaining the battle-winning edge even as platforms age.

Defence uses of platforms

The UK has committed significant investment to new platforms and systems in support of Joint Force 2025, including two new aircraft carriers and their complement of F-35 next-generation fast jets, plus modern weapons, fighting vehicles and many others. The rapid pace of current technological change means that these systems must be able to evolve in response to new threats and innovations, minimising the cost and time overheads that can result from modifying complex integrated systems. Technology proliferation means that platforms will need the ability to adapt rapidly to both traditional and asymmetric threats.

Technology opportunities

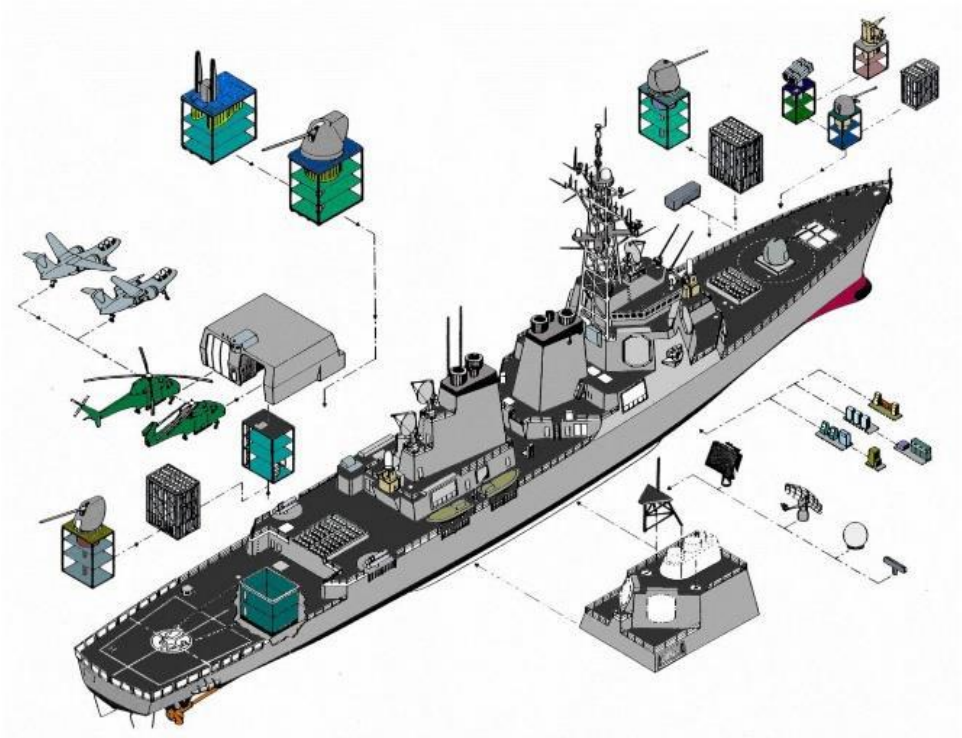
Modern software developments emerging in civil markets offer the opportunity for flexible and portable applications that can be modified and reused across a range of settings. The challenge for Defence is to use these advances in a way that is secure and robust enough for a military context. Promotion of open systems architectures will stimulate increased competition in the supplier base, with cost and capability benefits. Improved system modularity will enable more rapid technology insertion and the potential for more affordable through-life support. These enhancements will allow more straightforward integration of new equipment and weapons as and when they become available.

Maximising these opportunities will be dependent on updates to MOD acquisition and regulatory regimes. Procurement strategies will need to allow for agile, small enhancements rather than traditional approaches such

as large, mid-life updates. Novel business models will help greater re-use of technology across multiple projects and will provide greater access to niche expertise. New approaches to safety certification and security accreditation, such as modular certification, will also be required to ensure benefits are realised.

Underpinning technology families

- This area is underpinned by all seven technology families.



Improved system modularity will enable more rapid technology insertion and the potential for more affordable through-life support

Comprehensive Intelligence, Surveillance and Reconnaissance

Context

In an increasingly complex and contested world, we must maintain our ability to sense the world around us, understand the data gathered and transfer that intelligence to those who need it. Intelligence, Surveillance and Reconnaissance (ISR) is the co-ordinated tasking of collection capabilities and the processing and dissemination of information in support of operations and decisions.

Defence uses of ISR

The situational understanding provided by ISR underpins all military operations, allowing informed decisions to be made, targets to be effectively prosecuted and effects to be understood, and is a critical contributor to our strategic and operational advantage. It includes sensor systems and their tasking, processing of data and information, and automated tools to minimise user burden and provide timely insight and understanding.

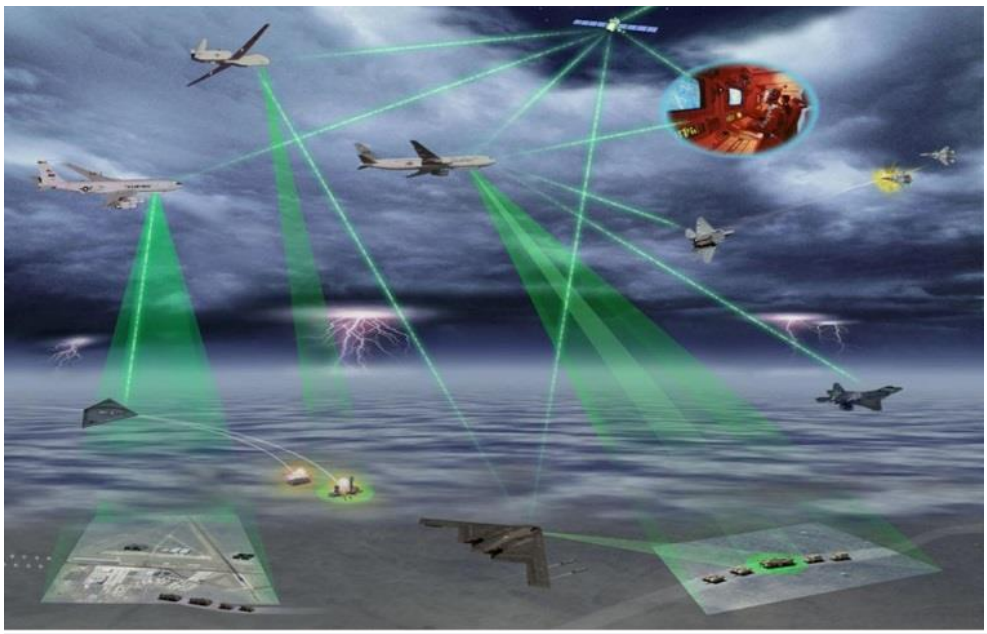
Technology opportunities

Civilian technology in all aspects of ISR is moving forward at pace, with cheap, lower power, miniaturised, fused sensing technology becoming available for a greater number of tasks. This presents opportunities for body-borne sensing, autonomous sensor platforms, and unattended or disposable sensor systems, and offers novel solutions to traditional defence challenges. The trends in data analytics, Artificial Intelligence, automated tools, visualisation tools and interfaces will offer increasingly agile ISR solutions which will provide us with both opportunity and challenge. But commercial drivers will not address Defence-specific requirements for military targeting and security, such as in contested environments or challenging physical conditions, nor will they address need for UK resilience. Finally, as we take advantage of cheaper and smaller commercial sensors, the amount of data collected and transferred will

drastically increase and we will need to choose the correct mix of collection capabilities, intelligently fuse this data into information, and securely distribute it.

Underpinning technology families

- Advanced Materials.
- Artificial Intelligence, Machine Learning, and Data Science.
- Autonomous Systems and Robotics.
- Power, Energy Storage, Conversion and Transmission.
- Sensors.
- Advanced Electronics and Computing.



Using multiple assets to maintain our ability to sense and understand the world around us

Modernised logistics and support

Context

The Defence support network (DSN) of the future will need to respond to global incidents at short notice, with resources accurately matched to meet operational needs, and enabled by digital information to provide an enhanced decision-making capability.

Defence uses of logistics and support

Logistics and support are fundamental to generate, prepare, project, sustain and redeploy all the military capabilities required to meet policy requirements. In the military context, logistics is end-to-end – from industry through to the frontline in an operational theatre or to a deployed force element, such as a warship. Logistics and support includes:

- Design and development, acquisition, storage, movement, distribution, maintenance, recovery and disposal of material.
- Transport of personnel.
- Acquisition or construction, maintenance, operation and disposition of facilities.
- Acquisition or furnishing of services.
- Medical and health service support.

These are provided by a network of integrated services including UK-based warehouses, strategic lift and tactical distribution platforms, information services and maintenance activities. This network accounts for one third of the annual Defence budget and generates a substantial deployed footprint.

Technology opportunities

The DSN will need to modernise to achieve the levels of responsiveness and agility required to affordably support future operational needs. There are opportunities to automate processes and decision-making and to embed predictive capabilities to reduce cognitive burden, increase

productivity and improve accuracy. Autonomous and data-driven systems will provide a more agile, responsive and resilient network. Advanced manufacturing has the potential to disrupt current supply chains, replacing inventory with information in the form of digital files, with items manufactured closer to the point of need with locally sourced or recycled materials. Emerging technologies could help assure the supply chain, including the tracking and monitoring of items through life. Advances in energy generation and distribution provide greater opportunity for self-sufficiency with a significant reduction in the reliance of fossil fuels and a subsequent reduction in the deployed footprint. The future DSN will be underpinned by digital information, connecting, informing and supplying all of its nodes, including industry and international partners.

Underpinning technology families

- Advanced materials.
- Artificial Intelligence, Machine Learning, and Data Science.
- Autonomous systems and Robotics.
- Power, energy storage, conversion, and transmission.
- Sensors.
- Advanced electronics and computing.

Deployed additive manufacturing hubs could produce spare parts locally

Enhanced cyber and electronic warfare

Context

Cyber and electronic warfare (EW) has become a feature of modern military operations. It can be used for both defensive and offensive purposes, with defensive use providing intelligence and protection for our people and platforms and data, while offensive use can deny adversaries capabilities, shape their understanding and act as a deterrent. Both are required to exploit information for strategic and operational advantage and both are inherently socio-technical in nature.

Defence uses of cyber and electronic warfare

MOD's cyber estate is significant and comprises commercial Information and Communications Technology (ICT) alongside bespoke weapon and platform systems operating far from the UK, and this single information environment blurs traditional wired/wireless system boundaries. Commercial cyber-security solutions do not cover the breadth of the architecture and expected use cases. Defence's need to operate remotely through the Electromagnetic Environment (EME) means that cyber and EW capabilities are converging into a common information operating environment, in turn leading to a convergence in the technologies used: cyber-space is increasingly reliant on the EME, and EW is about understanding, denying or shaping the data and information used by human or machine decision makers. Specifically:

- Cyberspace is the foundation that supports all of MOD's planning, logistics and operational capabilities by providing the data storage, processing and communications required to operate. Its defence is critical to successful military operations.
- EW can provide valuable intelligence and be used to defend our people and platforms from threats that rely on electro-magnetic sensors or datalinks for their operation.
- Cyber and EW can both be used offensively to deceive or deny our adversaries ability to sense, understand, communicate or attack our EM

capabilities. They can also deny, degrade or destroy other networked military capabilities.

Technology opportunities

Our future advantage in this area will be shaped by developments in technologies that support or enable efficient transmission of high power, high-fidelity waveforms whilst simultaneously receiving weak signals. It will exploit rapid and accurate analysis of large datasets to detect vulnerabilities in software and systems and find threat signals in EME data. It will depend on secure and resilient system design and implementation. The most impactful technologies will be those that address the scale of data and data flows, the diversity of technologies and targets, and the pace of development and operations. EW also faces challenges as target systems take advantage of improvements in commercial radio technologies, signal processing and algorithms.

Underpinning technology families

- Advanced materials.
- Artificial Intelligence, Machine Learning, and Data Science.
- Autonomous systems and Robotics.
- Sensors.
- Advanced electronics and computing.
- Effector technologies.

The potential reach of cyber extends to the whole of modern societal infrastructure

Next-generation weapon systems

Context

To meet the challenge presented by emerging threats and increasingly complex and congested environments, we need to improve existing weapons, further enhancing precision in addition to new capabilities which deliver non-conventional effects. This will increase the range of choice available to politicians and military commanders, offering a broader range of alternative courses of action than those traditionally available.

Defence uses of weapons

Conventional weapons such as bombs and missiles are designed to cause kinetic damage to a target – physically destroying it or degrading it. As such, they are an appropriate response to some, but not all, modern threats and scenarios. The presence of civilians or civilian infrastructure may preclude the use of current conventional weapons. As such, Defence is interested in enhanced precision guidance and 'smart' munitions, the latter being able to distinguish its target from its surroundings and providing directional lethality. Other targets may not be suitable for conventional engagement due to their dispersed nature, imprecise or hidden location information, or resilience to conventional attack. In this situation, alternative weapons including offensive cyber and low-collateral effectors (often termed non-lethal weapons) provide additional options for the commander and may allow the target to be engaged. In addition, next-generation weapons can deliver scalable or temporary effects, in situations where military action is required but lethal force is not desirable. Hypersonic and high-speed weapons could provide a rapid response to emerging threats and time-sensitive targets.

There are a range of technology opportunities for weapons, including Radio Frequency and Laser Directed Energy Weapons (RF- & L-DEW), and offensive cyber, and these vary in their impact and potential. RF-DEW allows the engagement of targets containing electronics-rich systems or subsystems, potentially including mobile threats, targets within infrastructure, hostile sensors, and command and control. L-DEWs can counter a broad target set from improvised unmanned aeriel vehicles to

complex missiles with low cost per shot, reduced logistics burden or risk of collateral damage.

Offensive cyber can deny or even destroy adversaries' capabilities affecting their ability to understand the world. Even when not used, these effects can act as a deterrent supporting the UK's stated National Security objectives.

Technology opportunities

Developments in propulsion are required to develop hypersonic and very high-speed weapon capabilities, as are advancements in materials which are able to mitigate the effects of re-entering the atmosphere and sustaining combustion inside the missile while enduring extreme temperatures and speeds.

Next generation guidance and navigation systems utilising miniaturised multimodal sensors and advanced algorithms will enable precise delivery of effects onto a target in a GPS denied environment.

Exploiting technologies and manufacturing processes from the commercial sector enables a range of new opportunities for Defence. This is being demonstrated in DEW systems which are developed from RF and laser technologies first used in the civil market.

Wider growth in cyber security tools and techniques will provide opportunities for future offensive cyber capabilities.

In many of these cases, Defence will need to invest to ensure that technologies are developed appropriately for our use.

Underpinning technology families

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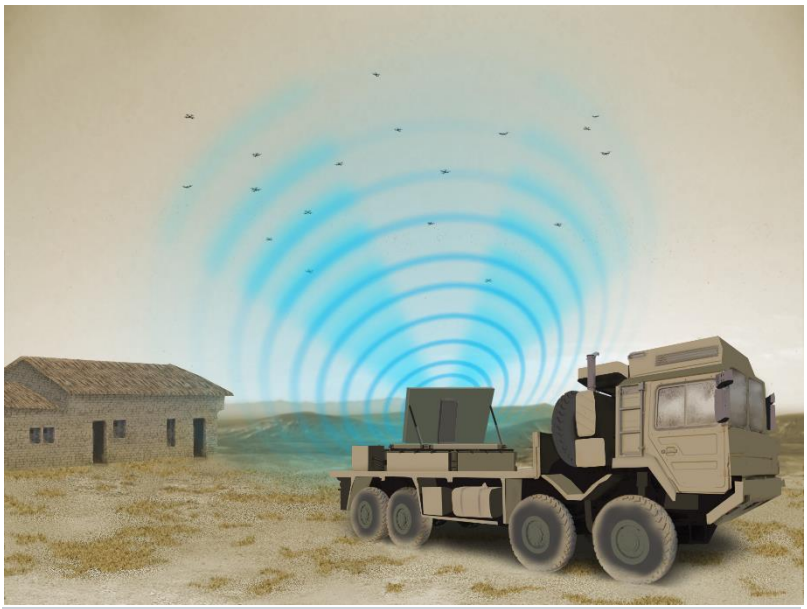

Concept of a novel RF Directed Energy Weapon System to counter swarming UAV attacks

Resilient communications

Context

Defence needs to field resilient, robust, secure and affordable communications capabilities for deployed, highly mobile forces to meet operational requirements. These need to address the communications demand in the contested, constrained and congested electro-magnetic spectrum. All communications are vulnerable to adversary disruption, introducing significant operational risk.

Defence uses of communications

Communications capabilities underpin all aspects of modern military operations and missions, enabling the multiple contributors to coordinate their contributions, maximising their combined effectiveness, while reducing risk in the face of determined adversaries. They enable command and control, logistics planning, the operation of unmanned systems, and the exchange of personnel and welfare information, among other activities.

The need for interoperable communication services is critical to modern coalition operations. This requires effort across Defence to cohere and address demand across space, land, air and sea (including underwater), and cyber, across different nations' Armed Forces, and to address various platform constraints.

Technology opportunities

The rate of change in communications technologies is rapid, and it is challenging for the military to maintain pace with commercial developments. Innovations such as secure messaging apps and civilian mobile systems based on open standards are also available to adversaries, and provide us with challenges as well as opportunities.

Providing communications to forces that are more dispersed and that operate at long ranges, often beyond line of sight, means that military and civilian satellite communications will continue to be required and developed.

In future, options such as troposcatter systems, airborne relays and optical communications may provide improvements to the throughput, resilience and robustness of our current capabilities. In addition, we will see further innovations like new and complex waveforms, novel antenna design, agile frequency-hopping radios, barrage flooding radio systems, and software-defined radios. The rise of the Internet of Things, and advanced communications traffic management techniques, will enhance capabilities further.

Defence must also ensure effective exploitation of the available electromagnetic spectrum, and explore techniques to minimise its communications signatures whilst providing a useful and robust level of operational capability. Some of the major benefits offered may only be realised if the appropriate business, procurement and support models for MOD and industry are developed and adopted, and the right research is carried out into options that may be developed by industry.

Underpinning technology families

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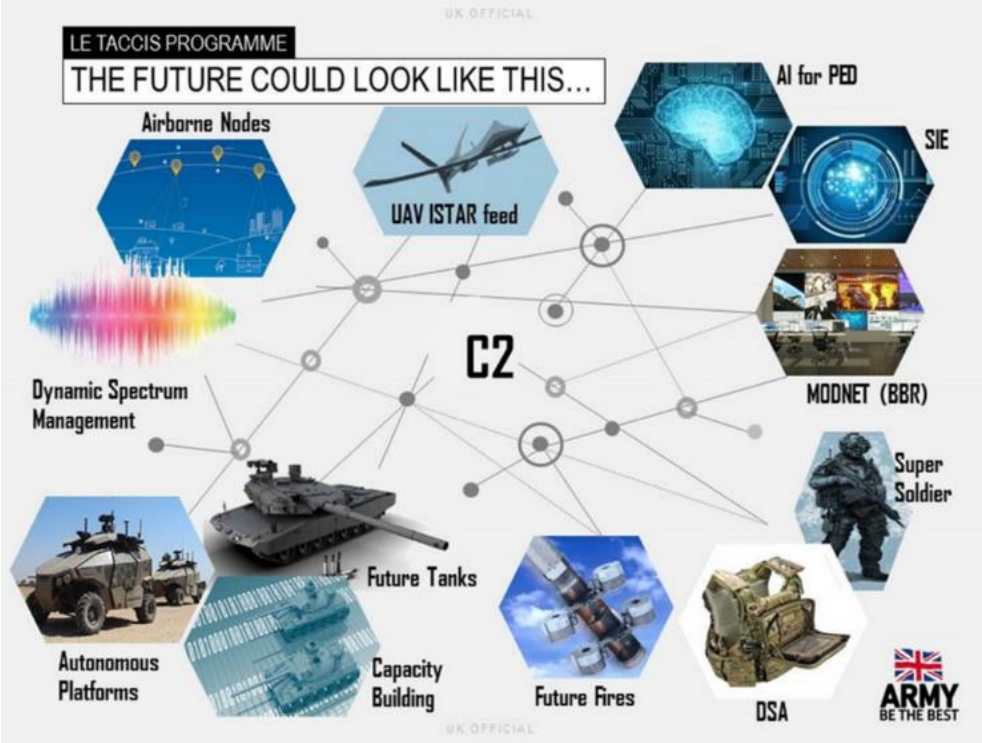


A concept for MOD's future land communications systems

Human enhancement

Context

Future conflict may expose UK Armed Forces to a technologically enhanced adversary where human enhancement is the norm. Armed Forces employing extensively enhanced human capability are likely to achieve a significant strategic and tactical advantage over those whose personnel are constrained to their innate abilities.

Human enhancement involves the application of technology, including biotechnology, to achieve transient or permanent enhancement that exceeds the scope of what is possible through training or education; or physical and/or cognitive performance beyond the innate, unaided functional range. Examples include: Mechanical aids such as wearable or implantable assistive-technology exoskeletons and robotic prostheses; synthetic biology (including gene editing); human-machine interfaces; transcranial stimulation; telexistence (i.e. remote reality); and others.

Defence uses of human enhancement

To date, application of human enhancement within the workforce has been mainly limited to safety aids for manual handling and tools for decision-support. Medical applications, and innovation in robotic prostheses (particularly for limb amputees), have advanced this area of science and demonstrated the benefits of human enhancement. Legal, moral and ethical considerations must be addressed before the full potential of this rapidly developing science can be fully exploited. However, developments continue to emerge in healthcare, sports science and neuroscience. Artificial Intelligence (AI) has accelerated research in human enhancement and has created further opportunity for human-systems to support Defence (enhancing operational readiness and combat effectiveness).

Technology opportunities

Currently, the science and technology underpinning human enhancement is diverse, and varies greatly in its maturity, complexity and ethical acceptability. External markets are driving innovation in this area at a pace

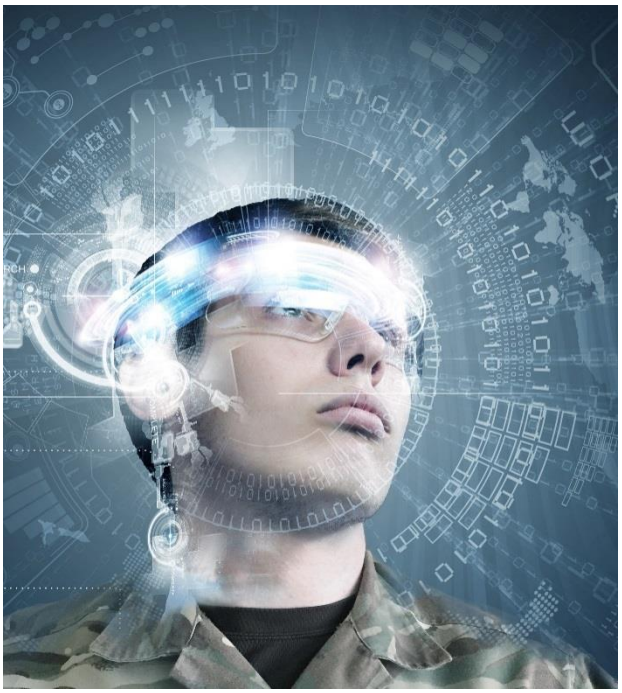
that seems likely to establish some types of enhancement as mainstream in the near future.

Methods currently being addressed include:

- Nutrition and nutrigenomics (i.e. genetically personalised meals and supplements) designed to optimise physical and cognitive performance.
- Pharmacological enhancement (e.g. nootropic substances, or smart drugs) to modify biochemistry and improve physical and cognitive performance.
- Assisted wearable technologies and exoskeletons which enable loads to be carried that exceed the unaided ability whilst reducing injury risk.
- Human-Machine Interfaces such as data visualisation tools to support understanding and decisions; adaptive automation to manage workload and performance under high-stress situations; human-autonomous teaming that combines the best capabilities of humans and AI to optimise outcomes; novel sensing capabilities (e.g. haptics) and visual display technologies such as augmented- and mixed-reality, to augment the user's perception of the world; medical implants which monitor the human body, and could also support cognition and spatial sensing.

In the longer term, it is likely that those technologies which are currently at an early stage will mature and become available to Defence. Examples include brain-machine interface technologies which link humans seamlessly with machines to better control multiple assets (potentially offering a force multiplying effect); transcranial electrical and magnetic stimulation (TEMS) to improve cognitive performance and learning; genome editing that can modify DNA to potentially introduce physical enhancements and protection from disease; 3D bioprinting which optimises the functional morphology of body parts to achieve physical, cognitive or sensory performance gains; telexistence to expand the delivery of innate human capabilities (such as expertise from trained technical knowledge and skills), to other locations without the need to be physically present.

Maintaining our understanding of such technologies will be essential to defend against an adversary that may choose to employ these enhancements.



Humans and technology should be part of the same team

Underpinning technology families

- Advanced Materials.
- Artificial Intelligence, Machine Learning, and Data Science.
- Autonomous systems and Robotics.
- Sensors.
- Advanced Electronics and Computing.

Next-generation command and control

Context

Effective Command and Control (C2) is a prerequisite for success in demanding military operations. Defence needs to develop effective, adaptable and resilient command and control capabilities – that exploit new and emerging technology – to support greater organisational agility and more effective ways of working. This includes enabling better design and execution of missions and more efficient co-ordination of activities and effects.

C2 enables all other military capabilities by directing and enabling their use, but it faces increasing challenges as the operating environment becomes ever more dynamic and complex, both in terms of the number of adversaries we face and the number of actors with whom we must collaborate. Electronic and cyber warfare means that threats and responses are no longer constrained to physical domains, so C2 systems need to be robust and resilient. And in the face of growing numbers of sensors and increasing volumes of data, C2 still needs to enable accurate situational understanding and to direct complicated, coordinated responses across a range of highly interconnected domains and environments.

Defence uses of command and control

C2 is a complex socio-technical system whose purpose is to direct and coordinate military intent and activity across services and multiple domains. It encompasses behaviours, tools and techniques, enabled by the interactions between people, structures, technology and processes, and it must be capable of adapting to meet the changing requirements of the mission. Common functions of C2 include: developing situational understanding and forecasting the likely outcomes of UK or others' action, using a range of information and intelligence; enabling intent, by developing a clear vision of the desired future in relation to a mission and an approximate route to achieve that; supporting decisions and plans that are necessary to organise activities and resources, through analysis and development of options despite situational complexity and uncertainty; directing the use of resources to convert plans into action and communicate

these effectively; monitoring and assessing a situation including through the analysis of data to develop understanding about what may be happening; enabling collaboration by facilitating the interaction with a wider range of actors working towards a joint outcome.

Technology opportunities

Opportunities for technology to improve the effectiveness of command and control are widespread. Data analytics tools, including those which exploit Artificial Intelligence, can support understanding and decision making in complex situations. Data fusion and visualisation technologies may assist with monitoring and assessment of a situation. Technologies to visually represent rationale and arguments may assist in developing and communicating intent. Advanced high-bandwidth, low probability-of-intercept (POI) wireless communication systems, supported by battlefield cloud-based data storage are likely to offer greater C2 agility and resilience and enable greater dispersion and mobility of C2 elements, assuming we can manage security and electromagnetic challenges. In addition, high-bandwidth, short-range communication technologies such as WiGig and Li-Fi, could offer many advantages for intra-HQ communications, enabling greater flexibility in the internal organisation of the HQ itself. Defence C2 will need to adopt new commercial technologies but also has unique requirements not shared by commercial users, meaning we will need to work in partnership with industry to develop the capabilities we need.

Underpinning technology families

- Artificial Intelligence, Machine Learning, Data Science.
- Autonomous Systems and Robotics.
- Power, energy storage, conversion, and transmission.
- Sensors.
- Advanced electronics and Computing.

Current and future C2 concept

How to engage with MOD

The DTF will support and inform current industry engagement with Defence on science and technology and innovation opportunities.

If you are developing a technology in any of the families and application areas detailed in the DTF, see an opportunity to develop novel technologies or use them in innovative ways, or would like to know about the kind of challenges Defence seeks to overcome through technology, we would like to hear from you. Pathways for industry to engage with Defence include:

Defence Suppliers Forum (DSF) Research, Technology and Innovation Group (RTIG):

The main conduit for MOD-industry relationships is through the Defence Suppliers Forum (DSF), chaired by the Secretary of State for Defence and including representatives from prime contractors, international companies and small and medium sized enterprises. It is supported by several sub-groups with similar wide-ranging membership, including the Research, Technology and Innovation Group that is the main forum for discussion of science, technology and Innovation issues.

Information about the DSF and its sub-groups is available at:
https://www.gov.uk/government/groups/defence-suppliers-forum

Defence Science and Technology Laboratory (Dstl):

Dstl is the principal channel for Defence to engage with suppliers (in industry and academia) to understand and procure research and development products and services in the technology areas set out in this Framework. Dstl manages a range of competitions and R&D procurement activities, including the Searchlight function which aims to attract non-traditional Defence suppliers and SMEs that are developing ideas or products with potential Defence and Security applications.

Further information about Dstl is available at:
https://www.gov.uk/guidance/how-to-sell-to-dstl-industry-academia-and-other-research-organisations

Defence and Security Accelerator (DASA):

DASA finds and funds exploitable innovation to support UK Defence and security quickly and effectively, and support UK prosperity.

DASA ‘Open Calls’ welcome ideas on any subject. DASA’s themed competitions exist to offer suppliers the opportunity to submit proposals around specific government areas of interest. Themed competitions may only run for a short time and have set closing dates. Some competitions may be jointly sponsored with international partners.

More information about DASA is available at:
https://www.gov.uk/government/organisations/defence-and-security-accelerator

Defence Equipment & Support (DE&S):

DE&S manage a vast range of complex projects to buy and support all the equipment and services that the Royal Navy, British Army and Royal Air Force need to operate effectively. DE&S works closely with industry, and is the primary interface with industry for the procurement and support of Defence equipment, including the exploitation of new and emerging technologies into safe, integrated, and sustainable military equipment systems. The DE&S Future Capability Group provides its corporate link to UK MOD's technology and innovation organisations, to enable DE&S to meet customer requirements, enabled by emerging technologies, with the necessary agility and pace.

Further information about DE&S is available at:
https://www.gov.uk/government/organisations/defence-equipment-and-support

The Defence Technology Framework is produced and managed by Defence Science and Technology

DST-Secretariat@mod.gov.uk

Notes

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