UK Parliament POST

POSTNOTE

Number 681 October 2022

Automation in Military Operations

Automation allows systems to perform tasks that normally require human input. The UK Government expects automation to be crucial to maintaining military advantage. This POSTnote discusses current and future global applications of automation, and its impact on military organisations and conflict. Technical, legal and ethical challenges are also examined.

Overview heading

- Deploying automated technologies in military operations can increase effectiveness and reduce risk to personnel.
- Automation is being used in intelligence gathering, data analysis, and weapons systems, both in the UK and internationally.
- The UK Government is developing automated systems; technical challenges include data management, cyber security, and systems testing and evaluation.
- The legal and ethical implications of military automation are highly debated, especially in the case of weapons systems and targeting.

Background

Many military systems feature automation, including robotic systems that carry out physical tasks, and entirely software-based systems used for tasks such as data analysis.[1,2] Automation can increase the efficiency and effectiveness of certain existing military tasks,[3–5] and can relieve personnel of 'dull, dirty, and dangerous' activities.[6,7] Many experts view automation and autonomy on a spectrum relating to the level of human supervision a system has, although where to place some systems is debated,[8–10] and there can be disagreement as to whether systems should be described as 'automated' or 'autonomous'. The MoD has outlined 5 broad levels of autonomy in its 'autonomy spectrum framework' ranging from 'human operated' to 'highly autonomous'.[3] A single system may feature different operational modes for different circumstances, requiring differing levels of human input, and only certain functions may be automated.[11,12] Box 1 outlines the definitions used in this POSTnote.

The UK Government has recognised the military advantages of autonomous systems and artificial intelligence (AI, Box 1) and the integral role they are likely to play in the future of defence. In its 2021 Integrated Review and 2020 Integrated Operating Concept, it stated its commitment to embracing new and emerging technologies, including autonomous systems and AI.[13] In June 2022, the Ministry of Defence (MoD) published its Defence AI Strategy, which sets out its plans to adopt and exploit AI: automation will be a key application.[3] Globally, the UK,[14] US,[15] China[16] and Israel[17] have some of the most advanced autonomous and AI-based military capabilities. An overview of UK and global activities is given in Box 2.

Applications

Autonomous systems can be designed with multiple capabilities, and may be used for a range of applications.[18,19] This section gives an overview of the systems in use or development for military applications including intelligence, surveillance and reconnaissance, data analysis, and weapons systems.

Intelligence, surveillance, and reconnaissance

Automation is increasingly being applied to intelligence, surveillance, and reconnaissance (ISR), often using uncrewed vehicles (Box 1).[20,21] Uncrewed land,[22] air,[23] and sea vehicles[24,25] fitted with sensors can obtain data such as audio, video, thermal images, and radar signals, and feed it back to human operators.[26] Some systems can navigate autonomously,[27] or autonomously identify and track targets for potential attack.[28,29] The UK has several ISR drones in service, with others being trialled. These range from very small 'mini' drones that are similar in weight to a smartphone, up to large fixed-wing systems that can fly thousands of miles.[30–32] One system being trialled in the UK is a mini helicopter called the 'Ghost' drone, which can fly autonomously and identify and track targets using algorithms for image analysis.[33,34] Uncrewed underwater vehicles are used for applications including mine and submarine detection,[35] using on board sonar to navigate autonomously.[36] These vehicles may also be equipped with a technology that allows them to disarm mines.[13,37]

Data analysis

Many military systems collect large amounts of data, which require analysis to support operations and decision making. AI can be used in the analysis of very large datasets and

The Parliamentary Office of Science and Technology, Westminster, London SW1A 0AA
02072192840 **post@parliament.uk** **parliament.uk/post** **@POST_UK**

Box 1: Glossary

Terminology in this area is inconsistent, with key terms sometimes used interchangeably.

- **Automated system:** An automated system is one that has been instructed to automatically perform a set of specific tasks or series of tasks within human-set parameters.[38] This may include basic or repetitive tasks.
- **Autonomous system:** The Defence Science and Technology Laboratory (Dstl) defines an autonomous system as one that can exhibit autonomy. There is no agreed definition of autonomy,[8,39] but Dstl defines it as 'the characteristic of a system using AI to determine its own course of action by making its own decisions'.[40] Autonomous systems can respond to situations that were not pre-programmed.[40]
- **Uncrewed vehicles:** The move towards greater levels of autonomy has allowed 'uncrewed' vehicles to be developed that do not have a pilot or driver on board.[41–44] Some are operated *via* remote control, and others include varying levels of autonomy.[45,46] The most established type of uncrewed military systems are uncrewed aerial vehicles, or 'drones', which have versatile uses.[30,47,48]
- **Artificial intelligence:** There is no universally agreed definition of AI, but it usually refers to a broad set of computational techniques that can perform tasks normally requiring human intelligence (POSTnote 637).[3,49] AI is an enabling technology for higher levels of autonomy.
- **Machine learning:** (ML, POSTnote 633) is a branch of AI that has underpinned the most recent advances in technologies with autonomous capabilities.

discern patterns that might not be observed by a human analyst. This is likely to be applied increasingly in the field to inform tactical decisions, for example by providing information about the surroundings, identifying targets, or predicting enemy actions. The British army deployed AI for situational awareness during Exercise Spring Storm in Estonia in 2021.[50] US Project Maven aims to improve analysis of images and video footage using AI,[51–53] and the UK has a similar project using AI to support satellite image analysis.[3]

Weapons systems

Weapons systems featuring automation have been developed for defensive and offensive applications. These include systems ranging from those that respond automatically to external inputs to more sophisticated AI-based systems:

- **Defensive systems**: Automatic air defence systems can identify and respond to incoming airborne threats with faster reaction times than a human operator. Such systems have been in use for over 20 years;[54] one report estimated that they are in use by 89 countries.[55] Systems currently in use can launch munitions from the sea or land and are used in response to incoming missiles or aircraft. The UK operates the Phalanx CIWS air defence system. Although not widely adopted globally, fixed uncrewed gun systems are used for border defence by Israel[56] and have been trialled in South Korea.[57] These systems are capable of automatically aiming and firing at approaching humans or vehicles.
- **Guided missiles**: Offensive missiles are in use that can alter their path in-flight to reach a target without human input.[58–62] The British Dual Mode Brimstone (DMB) missile,[63] first used in combat in Afghanistan in 2009,[64] can be pre-programmed to search a specific area to identify, track, and strike vehicles using sensor data.[65]

Box 2: UK and global activity

UK

The UK Government has stated its ambition to invest in, develop and deploy autonomous and AI-capable systems for military applications across the land, air, sea, and cyber domains. Recent investment programmes include project NELSON, which aims to integrate data science into naval operations; and the Future Combat Air System, which will deliver a mix of crewed, uncrewed and autonomous systems for the RAF.[6,66–68] Following the publication of the 2021 Integrated Review,[13] the Government established a Defence AI Centre (DAIC) to coordinate the UK's development of AI-enabled technologies for defence.[69] This includes facilitating collaborations with academia and industry, with research hubs established at the Universities of Newcastle and Exeter, and the Alan Turing Institute.[70–72]

Global context

There is a global trend of increasing investment in autonomous military technology: 25 NATO countries already use some AI-enabled and autonomous systems in their militaries.[54] Limited publicly available information creates difficulties in evaluating militaries' autonomous capabilities, but countries known to have advanced systems include:

- **US:** The US Department of Defense 2021 budget allocated $1.7bn for autonomy research and development,[73] as well as $2bn in an AI programme.[74]
- **Israel:** State-owned Israel Aerospace Industries produces advanced autonomous systems, including uncrewed air and land vehicles[75,76] and air defence systems.[77]
- **China:** It is estimated that China's spending on defence AI is similar to that of the US. [78,79] Analysts suggest that this includes investment in AI for intelligence analysis and autonomous vehicles.[80]

Russia and South Korea are also investing heavily in these technologies.[81,82] In Russia, robotics is a key focus of the recently established Advanced Research Foundation, which had a budget of $63m in 2021.[83,84]

- **Uncrewed vehicles for weapons delivery**: Uncrewed air, sea,[85,86] and land-based[87,88] vehicles designed for weapons delivery can operate with a high level of autonomy. Such systems can autonomously search for, identify, and track targets. Most developments have been in the aerial domain. The only armed drone capable of autonomous flight that the UK operates is the MQ-9 Reaper,[89] but several are under development.[30,90] The MoD is also developing 'swarming' drones (Box 3). Although the technical capability exists, uncrewed offensive weapons are not used to make firing decisions without human authorisation; reported exceptions are rare and contested.[91–96] The role of autonomous systems in identifying targets and taking firing decisions is the subject of extensive ethical debate (see later).

Impacts

Proliferation of automated technologies and AI will have various implications for the UK military, including those relating to costs and the roles and skills required of military personnel. There may also be implications for global peace and stability.

Financial impacts

Some experts have said that military automated systems and AI are likely to reduce costs in the long term through improved efficiencies and reduced demand for personnel.[9,97,98] However, estimating cost implications is challenging. Development costs

Box 3: Drone swarming
Drone swarming refers to the deployment of multiple drones capable of communicating and coordinating with each other and personnel to achieve an objective. In a military setting, a swarm might be used to monitor an area, relay information, or attack a target.[99] In 2020, the RAF trialled a swarm of 20 drones controlled by one operator as part of Dstl's Many Drones Make Light Work project.[100–102] Swarm technology is not yet widely deployed.[103] It has been reported that the first use of a drone swarm in combat was in 2021 by the Israel Defence Forces.[104]

can be high, and returns are uncertain. Boosting expertise in automation and AI may involve recruitment from industries that offer higher pay. Militaries may have to raise salaries to compete,[105] which the MoD refers to as an 'AI pay premium'.[3]

Role and skills of military personnel

Automation is likely to reduce the number of military staff undertaking dangerous or repetitive tasks. However, some military tasks or processes, such as high-level strategy development, are less amenable to automation.[106,107] In many areas, autonomous systems are expected to play a support function to humans, or work with them in 'human-machine teams'.[4] Experts have highlighted that personnel must be able to trust the systems they work with.[108–111] The nature of some roles are also likely to be affected by automation, as are the skills required. For example, there may be an increased demand for developers and operators of autonomous systems with relevant technical knowledge. The MoD has highlighted the need to improve understanding of AI across the military,[112] and has committed to developing an 'AI Skills Framework' to identify future skills requirements for defence.[3] Some stakeholders have expressed concern about the impact of automation on military personnel's wellbeing, as it may limit their personal autonomy[113,114] or undermine their sense of identity and culture.[115,116]

Attitudes of personnel towards automation

Research into attitudes of military personnel towards automation is limited. A 2019 study of 197 MoD personnel found that 34% had generally positive views on the armed forces using robots that can use ML to make their own decisions, and 37% had a generally negative attitude.[117] There have been reports of a lack of trust in certain autonomous weapons systems, including in a 2020 survey of Australian military personnel.[118,119] In this study, 30% of respondents said they would be unwilling to deploy alongside 'potentially lethal robots' which decide how to use force in a predefined area without direct human oversight. Safety and accuracy of target identification were perceived as the two greatest risks. There is evidence that trust levels depend on culture and familiarity.[117]

Escalation and proliferation

Some experts have raised concerns that increasing use of autonomy in weapons systems risks escalating conflict by removing humans from the battlefield and reducing hesitancy to use force.[120,121] A recent wargame report by RAND (which played out a conflict scenario involving the US, China, Japan, South Korea, and North Korea) found that widespread AI and autonomous systems could lead to inadvertent escalation and crisis instability. This was in part due to the increased speed of AI-supported decision making.[122] Escalation might also be caused by unintended behaviour of automated systems.[123]

There are also concerns about automated and AI-based technology becoming more accessible to non-state actors due to it becoming cheaper and more abundant.[124–126] Such groups might also obtain inexpensive commercial drones, and adapt them using open source AI to create 'home-made' weapons systems.[127–129] Reports of non-state actors employing autonomous systems are limited and disputed.[130,131] However, non-state groups do use armed drones,[132] and there are concerns that AI could make such systems more effective.[124]

Technical challenges

Ongoing research into technologies including robotics and AI, which is primarily commercially driven, is expected to increase the range of applications and extent of adoption of automated systems. Some key technical challenges in this area are outlined below.[133] A more general challenge is the slow pace of military technology development relative to rapid advances in digital technologies, with the risk that components become obsolete before or shortly after deployment.[134–137]

Data transfer

Uncrewed vehicles and robotics often need to transfer data to or receive data from personnel. This can allow humans to oversee and direct their functioning or receive the data they collect. Systems may also need to communicate with one another in some situations such as in drone swarming (Box 3).[138] Militaries generally use radio waves to transmit data on land, which may have limited bandwidth (availability of frequencies).[139,140] This can be problematic when transferring large volumes of data, such as high-resolution images. 5G technology (POSTbrief 32) is likely to facilitate more efficient wireless communication in the field.[141,142] Radio communication between systems can be detected, alerting adversaries to covert operations. Adversaries may also seek to block or disrupt a system's communications data transfer.[143,144] There is ongoing research into minimising the data transfer required and optimising the method of data transfer.[145–148] More 'on-board' or 'edge' processing (POSTnote 631) can reduce the need to transmit data.[149] However, reduced communications require a system to behave as expected without monitoring.

Data processing

More sophisticated systems with higher levels of autonomy generally carry out more data processing and analysis on board, while in operation. This requires the system to have sufficient computing power. Generally, there is a limit to how much embedded data processing a system can do as the hardware takes up space and requires additional power to run.[150] This can limit the agility and range of systems that require battery power to operate.[151] However, advances in AI may also allow systems to run more efficiently, reducing the computational requirements. The processing power of computers is also expected to increase due to future advances in software, algorithms, and computer chip technologies.[152]

Training data

The creation and curation of large datasets relevant to military applications is important in producing reliable AI-enabled

autonomous systems.[133,153] Machine learning (ML, Box 1) relies on large datasets to train its underlying algorithms, which can be gathered from the real world or, in some cases, generated using simulations.[154] In general, the more representative, accurate and complete the data used to train a ML system, the more likely it is to function as required. Preparing training data (categorising it and ensuring its format is consistent) often needs to be done manually, and is resource intensive.[155,156]

Data privacy

Some AI systems might be trained on civilian data.[157] It is widely agreed that if data relating to individuals is used, their privacy must be protected. This may be done by anonymising personal data or only sharing the trained AI system.[3,158,159]

Cyber security

Increasing the number of systems underpinned by computer software increases the opportunity for cyber-attacks.[160] Cyber attackers may seek to take control of a system, disrupt its operations,[161,162] or gather confidential information.[163–166] AI-based systems can also be undermined by tampering with the data used to develop them.[167] The MoD established the Cyber Security Operations Centre in 2016 to focus on cyber defence.[168] In the UK, the Defence Artificial Intelligence Centre, established in 2021, helps to facilitate access to highly confidential data by industry partners or other collaborators.[3]

Testing and evaluation

It is important that military systems function reliably, safely, and in accordance with laws and regulations. AI and automation create different testing and assurance challenges to traditional software systems.[169] Further challenges arise from forms of ML where it may not be possible to fully understand how outputs have been produced (POSTnote 633).[170] AI software may also require ongoing monitoring and maintenance.[171–173] Stakeholders have highlighted a lack of fit-for-purpose tools and processes for testing, and are developing new tools and guidelines.[3,169,174,175] The UK Government's Defence AI Strategy committed to establishing innovative approaches to testing, assurance, certification, and regulation.[69]

Ethics, policy, and legislation

Current guidelines and legislation

There is currently no legislation specific to the use of automation or AI for military applications. While their use in warfare is governed by existing International Humanitarian Law,[176,177] how this relates to new technologies is debated.[178–180] There are many guidelines on more general use of AI at national and international levels, which can be applied to automated systems.[181–184] However, the 2021 Centre for Data Ethics and Innovation (CDEI) AI Barometer study found that it is difficult for industry to adapt general regulations to specific contexts.[185] In 2022, the MoD published ethical principles for the use of AI in defence in partnership with the CDEI.[186]

Accountability

Some stakeholders have highlighted the lack of clarity over responsibility for the actions of an autonomous system if it behaves unlawfully or not as intended.[187,188] This could lead to a 'responsibility gap' between a system and its decisions and the humans who have designed or operate it,[189] complicating legal and moral accountability.[190] The MoD's principles say there should be clear responsibility throughout the design and implementation of an AI system.[186] The Defence AI Strategy sets similar expectations for suppliers.[3]

Debate around autonomous weapons systems

Much of the legal and ethical debate in this area focuses on weapons systems. However, certain unarmed systems (for example, software-based decision support tools) may play a key role in identifying targets, and hence raise many of the same ethical issues as those that also deploy a weapon.[8,191,192]

There is specific international debate around the use of 'lethal autonomous weapons systems' (LAWS).[193] This term has no universally agreed definition, and is used to refer to a wide range of weapons with different autonomous capabilities.[8] Reports of the use of LAWS are highly contested, for example due to uncertainty around the modes in which systems were used.[91–96] The UN Convention on Certain Conventional Weapons (CCW) has discussed possible legislation of LAWS since 2014. It published guiding principles in 2019,[194] but these are non-binding, and no further consensus has been reached. While most nations represented at the CCW support new regulation of LAWS, others, including the UK, US, and Russia have argued that existing International Humanitarian Law is adequate.[195–197] According to campaign group Stop Killer Robots (SKR), 83 states support a legally binding instrument on autonomous weapons systems and 12 states do not.[198]

Many stakeholders believe that some form of human control of weapons and targeting systems must be maintained to be legally and ethically acceptable.[195,199,200] Certain organisations, such as SKR, have called for a prohibition on autonomous weapons systems that cannot be operated with 'meaningful human control', and on all systems that target humans. They have also called for regulations to ensure sufficient human control is maintained in practice.[192,201–204] In its 2022 Defence AI Strategy, the UK Government stated that weapons which identify, select and attack targets must have 'context-appropriate human involvement'. In response, some NGOs calling for regulation have said that more clarity is needed on how 'context-appropriate human involvement' should be assessed or understood.[205] Potential measures that stakeholders, including the UK Government, suggest to maintain human control include limiting the period and geographical range of deployment.[206,207] Factors believed to undermine human control include limited timeframes for humans to take decisions and 'automation bias', where individuals can become over-reliant on an automated system and less likely to consider other information.[208–210]

Public attitudes towards the technology

Most public opinion surveys of military automation focus on autonomous weapons systems. SKR commissioned a public opinion survey of 19,000 people across 28 countries. 62% of respondents were opposed to the use of LAWS; this figure was 56% in the UK.[211] Studies on public attitudes to AI, data, and automation more broadly have found that key public concerns include data security, privacy, and job losses.[53,212] However, public views can vary significantly depending on the function of a system and the context it is used in.[213,214]

POST is an office of both Houses of Parliament, charged with providing independent and balanced analysis of policy issues that have a basis in science and technology. POST is grateful to Dr Katherine Macfarlane, for researching this briefing, to the Royal Society of Chemistry for funding her parliamentary fellowship, and to all contributors and reviewers. For further information on this subject, please contact the co-author, Dr Lorna Christie. Image credit: BAE Systems.

References

1. Emma, H. (2020). Managing the military's big data challenge. *Military Embedded Systems*.
2. Rossiter, A. (2020). The impact of robotics and autonomous systems (RAS) across the conflict spectrum. *Small Wars & Insurgencies*, Vol 31, 691–700. Routledge.
3. Defence Artificial Intelligence Strategy. *GOV.UK*.
4. (2018). Joint Concept Note 1/18 Human-Machine Teaming. Ministry of Defence Development, Concepts and Doctrine Centre.
5. (2016). AI fighter pilot wins in combat simulation. *BBC News*.
6. Great Britain *et al.* (2021). *Defence in a competitive age*.
7. (2021). Robotics and autonomous systems: defence science and technology capability. Defence Science and Technology Laboratory.
8. Taddeo, M. *et al.* (2021). A Comparative Analysis of the Definitions of Autonomous Weapons.
9. Bode, I. *et al.* (2022). *Autonomous Weapons Systems and International Norms*. McGill-Queen's University Press.
10. Huang, H.-M. *et al.* (2005). A Framework For Autonomy Levels For Unmanned Systems. in *Proceedings of the AUVSI's Unmanned Systems North America*.
11. Khan, S. Z. *et al.* (2021). On GPS spoofing of aerial platforms: a review of threats, challenges, methodologies, and future research directions. *PeerJ Comput Sci*, Vol 7, e507.
12. Tutunji, T. A. *et al.* (2020). Unmanned Ground Vehicle Control using IoT. in *2020 21st International Conference on Research and Education in Mechatronics (REM)*. 1–5. IEEE.
13. Mills, C. (2021). Integrated Review 2021: emerging defence technologies. House of Commons Library, UK Parliament.
14. Stuart Maccrimmon (2019). UK Defence's Artificial Intelligence (AI) Landscape: is More Effort Required? *Defence In Depth*.
15. Missy Ryan (2021). The U.S. system created the world's most advanced military. Can it maintain an edge? *Washington Post*.
16. Cui, W. (2018). An Overview of Submersible Research and Development in China. *J. Marine. Sci. Appl.*, Vol 17, 459–470.
17. (2021). UK-Israel 2021 | How Israel military tech (and doctrine) will make the UK better at fighting the hybrid warfare of the future. *Fathom*.
18. Mark Schauer (2020). Versatile autonomous transport vehicle tested at U.S. Army Yuma Proving Ground. *US Army*.
19. Sánchez-García, J. *et al.* (2018). A survey on unmanned aerial and aquatic vehicle multi-hop networks: Wireless communications, evaluation tools and applications. *Computer Communications*, Vol 119, 43–65.
20. Reis, J. *et al.* (2021). High-Tech Defense Industries: Developing Autonomous Intelligent Systems. *Applied Sciences*, Vol 11, 4920. Multidisciplinary Digital Publishing Institute.
21. Frank Wolfe (2020). Autonomous ISR Assets Likely A Big Defense Growth Area. *Aviation Today*.
22. Grinter, P. (2022). Milrem Robotics Launches Autonomous ISR UGV. *Unmanned Systems Technology*.
23. (2013). UK Air and Space Power (JDP 0-30). Ministry of Defence.
24. Sparrow, R. *et al.* (2017). Naval robots and rescue. *International Review of the Red Cross*, Vol 99, 1139–1159. Cambridge University Press.
25. Knight, R. (2021). Militaries Are Taking Unmanned Underwater. *Inside Unmanned Systems*.
26. Balestrieri, E. *et al.* (2021). Sensors and Measurements for Unmanned Systems: An Overview. *Sensors*, Vol 21, 1518. Multidisciplinary Digital Publishing Institute.
27. Simpson, S. (2022). Autonomous Navigation & Positioning for Drones, UAV, UGV, USV & AUV. *Unmanned Systems Technology*.
28. Reddie, A. *et al.* (2019). Unmanned Underwater Vehicle (UUV) Systems for Submarine Detection. *On the Radar*.
29. Kumar, M. *et al.* (2021). Recent developments on target tracking problems: A review. *Ocean Engineering*, Vol 236, 109558.
30. (2022). An overview of Britain's drones and drone development projects. *Drone Wars UK*.
31. MOD signs £65-million contract for Protector aircraft. *GOV.UK*.
32. Mark Watson (2021). The future has landed – SkyGuardian arrives in the UK. *NATS Blog*.
33. (2021). Drone swarms support Commando Forces trials in a first for the UK's armed forces. *Royal Navy*.
34. Shanahan, J. G. *et al.* (2020). Introduction to Computer Vision and Real Time Deep Learning-based Object Detection. in *Proceedings of the 26th ACM SIGKDD International Conference on Knowledge Discovery & Data Mining*. 3523–3524. Association for Computing Machinery.
35. Kelsey D. Atherton (2022). These little robots could help find old explosives at sea. *Popular Science*.
36. Map the Gap: autonomous gap crossing survey Phase 2 Competition Document. *GOV.UK*.
37. Mine Countermeasures. *Thales Group*.
38. (2022). British Army Approach to Robotics and Autonomous Systems. British Army.
39. House of Lords, S. C. on A. I. (2017). *AI in the UK: ready, willing and able?*
40. (2021). Assurance of Artificial Intelligence and Autonomous Systems: a Dstl biscuit book. Defence Science and Technology Laboratory.
41. Konert, A. *et al.* (2021). Military autonomous drones (UAVs) - from fantasy to reality. Legal and Ethical implications. *Transportation Research Procedia*, Vol 59, 292–299.
42. (2021). Unmanned Underwater Vehicles: Defence and Technology Trends. *Naval Technology*.
43. Group, S. M. (2020). The Role of Autonomous Unmanned Ground Vehicle Technologies in Defense Applications. *SAE International Mobility Engineering*.
44. Norbert Neumann (2021). Robot wars: The battle for automated ground capability. *Army Technology*.
45. Scott N Romaniuk *et al.* (2021). Kill Empowerment: The Proliferation of Remotely Piloted Vehicles. *E-International Relations*.
46. (2014). Unmanned Vehicles – No pilot/driver on board. *Electronics Maker*.
47. Vyas, K. (2020). A Brief History of Drones: The Remote Controlled Unmanned Aerial Vehicles (UAVs). *Interesting Engineering*.
48. Elmeseiry, N. *et al.* (2021). A Detailed Survey and Future Directions of Unmanned Aerial Vehicles (UAVs) with Potential Applications. *Aerospace*, Vol 8, 363. Multidisciplinary Digital Publishing Institute.
49. (2021). National AI Strategy. Office for Artificial Intelligence, Department for Digital, Culture, Media & Sport, and Department for Business, Energy & Industrial Strategy.
50. (2021). Artificial Intelligence used on British Army operation for the first time. *The British Army*.
51. Brewster, T. (2021). Project Maven: Startups Backed By Google, Peter Thiel, Eric Schmidt And James Murdoch Are Building AI And Facial Recognition Surveillance Tools For The Pentagon. *Forbes*.

52. (2017). Project Maven to Deploy Computer Algorithms to War Zone by Year's End. *U.S. Department of Defense*.
53. (2017). Special Eurobarometer 460: Attitudes towards the impact of digitisation and automation on daily life. European Commission, Directorate-General for Communications Networks, Content and Technology and co-ordinated by the Directorate-General for Communication.
54. Gray, M. *et al.* (2021). Artificial Intelligence and Autonomy in the Military: An Overview of NATO Member States' Strategies and Deployment. 34. NATO Cooperative Cyber Defence Centre of Excellence.
55. Watts, T. *et al.* (2021). Meaning-less human control: Lessons from air defence systems for lethal autonomous weapons. Drone Wars UK, Centre for War Studies, and University of Southern Denmark.
56. Noah Shachtmane (2008). Israeli 'Auto Kill Zone' Towers Locked and Loaded | WIRED. *Wired*.
57. Parkin, S. (2015). Killer robots: The soldiers that never sleep.
58. (2019). From Sea Wolf to Sea Ceptor – the Royal Navy's defensive shield. *Navy Lookout*.
59. Exocet AM39 | Maritime Superiority, Exocet Solution. *MBDA*.
60. Jonathan Beale (2018). Syria air strikes: RAF used 'fire and forget' missiles to minimise risk. *BBC News*.
61. Storm Shadow / SCALP | Air Dominance. *MBDA*.
62. (2018). Lockheed awarded almost $632 million for Hellfire missiles for the Netherlands and Japan. *The Defense Post*.
63. Brimstone | Air Dominance. *MBDA*.
64. (2011). Dual Mode Brimstone. *MBDA*.
65. (2021). Brimstone. *Missile Threat*.
66. (2018). Royal Navy: NELSON Data Platform Product Development - Digital Marketplace. Programme NELSON, Information Warfare, Royal Navy, Ministry of Defence.
67. (2019). NELSON Data Platform Beta - Live Development - Digital Marketplace. Royal Navy, Ministry of Defence.
68. (2019). Cutting-edge technology on show in Royal Navy exercise | Royal Navy. *Royal Navy*.
69. Defence Artificial Intelligence Centre. *GOV.UK*.
70. (2022). New Dstl site opened in Newcastle. *Business and Partnerships - Newcastle University*.
71. (2022). Dstl launches Defence Data Research Centre. *Defence Science and Technology Laboratory*.
72. (2022). Launching the Defence Centre for AI Research. *Defence Science and Technology Laboratory*.
73. (2020). DOD Releases Fiscal Year 2021 Budget Proposal. *U.S. Department of Defense*.
74. AI Next. *Defence Advanced Research Project Agency*.
75. Twin boom UAV assisting military & law enforcement operations globally. *IAI*.
76. Autonomous Ground Systems. *IAI*.
77. Air Defense Systems: IAI's robust, advanced technologies. *IAI*.
78. Jon Harper (2022). China Matching Pentagon Spending on AI. *National Defense*.
79. Fedasiuk, R. (2021). Opinion | We Spent a Year Investigating What the Chinese Army Is Buying. Here's What We Learned. *POLITICO*.
80. Akashdeep Arul (2022). How China is using AI for warfare. *Analytics India Magazine*.
81. Peter Apps (2019). Commentary: Are China, Russia winning the AI arms race? *Reuters*.
82. Haner, J. *et al.* (2019). The Artificial Intelligence Arms Race: Trends and World Leaders in Autonomous Weapons Development. *Global Policy*, Vol 10, 331–337.
83. Nadibaidze, A. (2022). *Russian Perceptions of Military AI, Automation, and Autonomy*. 36. Foreign Policy Research Institute.
84. (2013). Work plan for Advanced Research Foundation approved for next 3 yrs. *TASS*.
85. Crumley, B. (2021). China develops a fully autonomous underwater attack drone. *DroneDJ*.
86. Osborn, K. (2021). Navy Pursues Large Undersea Attack Drones. *The National Interest*. The Center for the National Interest.
87. (2022). Land Industrial Strategy. Ministry of Defence.
88. Simpson, S. (2022). Autonomous Ground Vehicles (AGV) & Robotics. *Unmanned Systems Technology*.
89. MQ-9A 'Reaper'. *General Atomics Aeronautical Systems Inc.*
90. RAF Protector: What Is The Aircraft And What Can It Do? *Forces Network*.
91. Tingley, B. (2021). Marines Train With Handheld Swarming Drones That Can Also Be Fired From 40mm Grenade Launchers. *The Drive*.
92. Will Meddings [@WillJMeddings] (2021). Ulrike, just to be clear, although the system is in use, the version we are using is hand launched and does not include any munitions - it is purely used for surveillance and reconnaissance. *Twitter*.
93. Letter dated 8 March 2021 from the Panel of Experts on Libya established pursuant to resolution 1973 (2011) addressed to the President of the Security Council. United Nations Security Council.
94. Beyza Arslan An Evaluation of Lethal Autonomous Weapon Systems Under the Law of Armed Conflict and the Question of Kargu-2. *Hukukçular Derneği*.
95. Vincent, J. (2021). Have autonomous robots started killing in war? The reality is messier than it appears. *The Verge*.
96. Zachary Kallenborn (2021). Was a flying killer robot used in Libya? Quite possibly. *Bulletin of the Atomic Scientists*.
97. (2021). Digital Strategy for Defence. Ministry of Defence.
98. Laird, B. (2020). The Risks of Autonomous Weapons Systems for Crisis Stability and Conflict Escalation in Future U.S.-Russia Confrontations. *The RAND Blog*.
99. Hambling, D. (2021). What Are Drone Swarms And Why Does Every Military Suddenly Want One? *Forbes*.
100. (2021). Swarming drones concept flies closer to reality. Defence Science and Technology Laboratory and Defence and Security Accelerator.
101. Gareth Jennings (2021). UK concludes 'Many Drones Make Light Work' with large scale demonstration. *Janes*.
102. Allison, G. (2020). Royal Air Force swarming drone project 'exceeding expectations'.
103. Cheraghi, A. R. *et al.* (2022). Past, Present, and Future of Swarm Robotics. in *Intelligent Systems and Applications*. (ed. Arai, K.) 190–233. Springer International Publishing.
104. Hambling, D. (2021). Israel used world's first AI-guided combat drone swarm in Gaza attacks. *New Scientist*.
105. Allie Nawrat (2021). How the UK military is using recruitment technology to attract talent. *Unleash*.
106. Emma Salisbury (2021). Warbots: Tactically Brilliant, Strategically Naive. *War on the Rocks*.
107. Jim Perkins (2019). More than Killer Robots: Artificial Intelligence Will Displace More Soldiers than It Kills. *Modern War Institute*.
108. Warren, A. *et al.* (2020). Friend or frenemy? The role of trust in human-machine teaming and lethal autonomous weapons systems. *Small Wars & Insurgencies*, Vol 31, 822–850. Routledge.

109. Chahal, M. K. and H. (2021). Building trust in human-machine teams. *Brookings*.
110. (2022). The role of trust in teaming humans and machines. *QinetiQ*.
111. Krause, J. (2021). Trusted autonomous systems in defence: A policy landscape review. UKRI TAS Hub.
112. (2020). Integrated Operating Concept. Ministry of Defence.
113. Galliott, J. (2018). The soldier's tolerance for autonomous systems. *Paladyn, Journal of Behavioral Robotics*, Vol 9, 124–136. De Gruyter Open Access.
114. Rosario M. Simonetti (2020). Automation and the Future of Command and Control: The End of Auftragstaktik? *Journal of Advanced Military Studies*, Vol 11, 127–146.
115. Kepe, M. (2020). Considering Military Culture and Values When Adopting AI.
116. Gustavo Velho Diogo 'That Others May Die': Autonomous Military Technology and the Changing Ethos on the Battlefield. *Institute of Network Cultures*.
117. Butcher, F. D. (2022). Psycho-social factors influencing trust in artificial intelligence advice systems. University of Leicester.
118. Scharre, P. (2016). Autonomous Weapons and Operational Risk. *Center for a New American Security*.
119. Watts, B. D. (2007). *Six Decades of Guided Munitions and Battle Networks: Progress and Prospects*. 337. Center for Strategic and Budgetary Assessments.
120. Blanchard, A. *et al.* (2022). Autonomous weapon systems and jus ad bellum. *AI & Soc*,
121. Merel Ekelhof *et al.* (2020). Swarm Robotics. United Nations Institute for Disarmament Research.
122. Wong, Y. H. *et al.* (2020). Deterrence in the Age of Thinking Machines. RAND Corporation.
123. (2021). National Security Commission on Artificial Intelligence Final Report. National Security Commission on Artificial Intelligence.
124. Stuart Russell (2022). Why we need to regulate non-state use of arms. in *World Economic Forum Annual Meeting*.
125. T. X. Hammes (2019). Technology Converges; Non-State Actors Benefit. *Hoover Institution*.
126. Itamar Lifshitz *et al.* (2020). The Paradox of Precision: Nonstate Actors and Precision-Guided Weapons. *War on the Rocks*.
127. (2017). Photos show 'weaponised commercial drones' in Iraq. *BBC News*.
128. Alyssa Sims (2018). How do we thwart the latest terrorist threat: swarms of weaponised drones? *The Guardian*.
129. Dominic Selwood (2022). The Ukrainian drone unit that is changing warfare forever. *The New Statesman*.
130. Gross, J. A. (2021). IDF says it thwarted underwater drone attack by Hamas from northern Gaza. *The Times of Israel*.
131. Kreps, S. (2021). *Democratizing harm: Artificial intelligence in the hands of nonstate actors*. 19. Brookings.
132. Haugstvedt, H. *et al.* (2020). Taking Fourth-Generation Warfare to the Skies? An Empirical Exploration of Non-State Actors' Use of Weaponized Unmanned Aerial Vehicles (UAVs—'Drones'). *Perspectives on Terrorism*, Vol 14, 26–40. Terrorism Research Initiative.
133. Bloch, E. *et al.* (2020). Ethical and technical challenges in the development, use, and governance of autonomous weapons systems. 25. Institute of Electrical and Electronics Engineers Standards Association.
134. S. Rajagopal *et al.* (2014). Software Obsolescence in Defence. *Procedia CIRP*, Vol 22, 76–80. Elsevier.
135. Sally, C. (2016). Managing COTS obsolescence for military systems. *Military Embedded Systems*.
136. Duncan Young Lifecycle management and the impact of obsolescence on military systems. *VITA Technologies*.
137. (2017). Oral evidence - F-35 Procurement. House of Commons Defence Committee.
138. Campion, M. *et al.* (2019). UAV swarm communication and control architectures: a review. *J. Unmanned Veh. Sys.*, Vol 7, 93–106. NRC Research Press.
139. Kenneth Reginald Sturley Radio Technology | History, Principles, Types, & Facts. *Britannica*.
140. (2021). Why High Frequency Radio Remains Crucial for Military Communications. *Army Technology*.
141. (2019). 5G, a real game-changer for defence critical systems. *Thales Group*.
142. (2022). 5G in Defense Market worth $2,487 million by 2027 - Exclusive Report by MarketsandMarketsTM. *MarketsandMarkets*.
143. Xiao, P. *et al.* (2015). An Experimental Study of Jamming Attacks in Underwater Acoustic Communication. in *Proceedings of the 10th International Conference on Underwater Networks & Systems*. Vol 21, 1–5. Association for Computing Machinery.
144. (2022). Electronic Warfare and Jamming Systems (Land EW). *Army Technology*.
145. Wang, J. J. H. (2020). Stealth Communication Via Smart Ultra-Wide-Band Signal in 5G, Radar, Electronic Warfare, etc. in *2020 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting*. 1825–1826.
146. Liu, B. *et al.* (2021). Covert Underwater Acoustic Communication without Repeating Patterns. in *The 15th International Conference on Underwater Networks & Systems*. Vol 31, 1–5. Association for Computing Machinery.
147. Ryabinin, M. *et al.* (2021). SWARM Parallelism: Training Large Models Can Be Surprisingly Communication-Efficient. Under review as a conference paper at ICLR 2022.
148. Zhou, H. *et al.* (2021). Real-time Video Streaming and Control of Cellular-Connected UAV System: Prototype and Performance Evaluation. *IEEE Wireless Communications Letters*, Vol 10, 1657–1661.
149. Eversden, A. (2022). Army robotics official: More autonomy could ease battlefield bandwidth worries. *Breaking Defense*.
150. Jamie Whitney (2019). SWaP considerations for today's rugged computers. *Military Aerospace*.
151. (2018). Size, Weight & Power. *Abaco Systems*.
152. Leiserson, C. E. *et al.* (2020). There's plenty of room at the Top: What will drive computer performance after Moore's law? *Science*, Vol 368, eaam9744. American Association for the Advancement of Science.
153. (2020). Defence Data Management Strategy. 22. Ministry of Defence.
154. George Anadiotis (2021). Taking the world by simulation: The rise of synthetic data in AI. *VentureBeat*.
155. Cedric Cocaud (2020). Manual Data Labeling for Vision-Based Machine Learning and AI. *Airbus*.
156. (2021). Unsupervised Machine Learning in the Military Domain. *NATO STONewsArchive*.
157. Jackson Barnett (2021). The Army has built the largest facial recognition database of thermal images. *FedScoop*.
158. Balaban, M. (2019). Privacy Concerns with Big Data Analytics: US DoD/Army Landscape. in *Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC)*.

159. Nguyen, D. C. *et al.* (2021). Federated Learning for Internet of Things: A Comprehensive Survey. *IEEE Communications Surveys & Tutorials*, Vol 23, 1622–1658.
160. Angin, P. (2020). Blockchain-Based Data Security in Military Autonomous Systems. *Avrupa Bilim ve Teknoloji Dergisi*, 362–368.
161. Greenberg, A. (2020). Split-Second 'Phantom' Images Can Fool Tesla's Autopilot. *Wired*.
162. Su, F. *et al.* (2020). Artificial Intelligence, Strategic Stability and Nuclear Risk. SIPRI.
163. Ivanova, K. Automated and Autonomous Systems for Combat Service Support: Scoping Study and Technology Prioritisation. 100.
164. (2021). Algorithms and Terrorism: the malicious use of artificial intelligence for terrorist purposes. United Nations Office of Counter-Terrorism, UN Counter Terrorism Centre.
165. Hartmann, K. *et al.* (2016). UAV exploitation: A new domain for cyber power. in *2016 8th International Conference on Cyber Conflict (CyCon)*. 205–221. IEEE.
166. (2021). National Cyber Strategy 2022. UK Cabinet Office.
167. Andrew Lohn (2021). Poison in the Well. *Center for Security and Emerging Technology*.
168. The Rt Hon Sir Michael Fallon (2016). Defence Secretary announces £40m Cyber Security Operations Centre. Ministry of Defence.
169. Heather M. Wojton *et al.* (2020). Test & Evaluation of AI-enabled and Autonomous Systems: A Literature Review. Institute for Defence Analysis.
170. Došilović, F. K. *et al.* (2018). Explainable artificial intelligence: A survey. in *2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*. 0210–0215.
171. Disha Dasgupta (2018). Beware Steep Decline: Understanding Model Degradation In Machine Learning Models. *Elastic Blog*.
172. (2021). AI Model Maintenance: A Guide to Managing a Model Post-Production. *Appen*.
173. Shendre, S. (2020). Model Drift in Machine Learning models. *Towards Data Science*.
174. Pomerleau, M. (2022). Pentagon's AI center awards contracts to 79 companies in new test and evaluation agreement. *Military Times*.
175. Jon Harper (2022). DOD faces workforce challenges for AI test and evaluation. *FedScoop*.
176. (2014). War & Law. *International Committee of the Red Cross*.
177. (2022). Autonomous weapons: The ICRC calls on states to take steps towards treaty negotiations. International Committee of the Red Cross.
178. (2017). New Technologies in Warfare and International Humanitarian Law - World. Institute for Defence Studies and Aanlyses and International Committee of the Red Cross.
179. (2021). Killer Robots: Negotiate New Law to Protect Humanity. *Human Rights Watch*.
180. (2014). New technologies and IHL. *International Committee of the Red Cross*.
181. IEEE SA - IEEE 7001-2021. *IEEE Standards Association*.
182. Jobin, A. *et al.* (2019). The global landscape of AI ethics guidelines. *Nat Mach Intell*, Vol 1, 389–399. Nature Publishing Group.
183. (2021). The EU Artificial Intelligence Act. *The Artificial Intelligence Act*.
184. (1807). Establishing a pro-innovation approach to regulating AI. Department for Digital, Culture, Media & Sport, Department for Business, Energy & Industrial Strategy, and Office for Artificial Intelligence.
185. (2021). AI Barometer 2021. Centre for Data Ethics and Innovation.
186. Ben Kelly (2022). Enabling the responsible use of AI in defence. Centre for Data Ethics and Innovation.
187. Davison, N. (2017). A legal perspective: Autonomous weapon systems under international humanitarian law. Arms Unit, Legal Division, International Committee of the Red Cross.
188. Taddeo, M. *et al.* (2022). Accepting Moral Responsibility for the Actions of Autonomous Weapons Systems—a Moral Gambit. *Philos. Technol.*, Vol 35, 78.
189. Santoni de Sio, F. *et al.* (2021). Four Responsibility Gaps with Artificial Intelligence: Why they Matter and How to Address them. *Philos. Technol.*, Vol 34, 1057–1084.
190. (2015). Mind the Gap: The Lack of Accountability for Killer Robots. Human Rights Watch.
191. (2018). Ethics and autonomous weapon systems: An ethical basis for human control? International Committee of the Red Cross.
192. (2019). Targeting People. Article 36.
193. Klare, M. T. (2020). The Pentagon's Next Project: Automated War. *The Nation*.
194. (2019). Meeting of the High Contracting Parties to the Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons Which May Be Deemed to Be Excessively Injurious or to Have Indiscriminate Effects. The United Nations Convention on Certain Conventional Weapons.
195. (2020). Stopping Killer Robots: Country Positions on Banning Fully Autonomous Weapons and Retaining Human Control. Human Rights Watch.
196. (2013). The next generation: the UN considers the potential of lethal autonomous robots – All Party Parliamentary Group on Drones and Modern Conflict. All-Party Parliamentary Group on Drones and Modern Conflict.
197. Hoffberger-Pippan, E. *et al.* (2022). Autonomous Weapons Systems: UN Expert Talks Facing Failure. 7. German Institute for International and Security Affairs.
198. Automated Decision Research (2022). State positions monitor. *Automated Decision Research*.
199. Our policy position. *Stop Killer Robots*.
200. Heather M. Roff (2016). Meaningful Human Control, Artificial Intelligence and Autonomous Weapons. Article 36.
201. Problems with autonomous weapons. *Stop Killer Robots*.
202. (2021). Lethal Autonomous Weapons Exist; They Must Be Banned. *IEEE Spectrum*.
203. (2021). Advisory Note on Autonomous Weapon Systems that Target Humans. Campaign to Stop Killer Robots.
204. (2021). ICRC position on autonomous weapon systems. International Committee of the Red Cross.
205. Stop Killer Robots (2022). New UK Government position on "autonomous weapons" – recognises that lines need to be drawn, but lacks detail, or signs of real leadership. *Article 36*.
206. Stopping Killer Robots (2021). Stopping Killer Robots: A Guide for Policy Makers. Stop Killer Robots.
207. Ousman Noor (2022). Discussions at UN on Autonomous Weapon Systems Blocked by Russia, but States Indicate Way Forward. *Stop Killer Robots*.
208. Goddard, K. *et al.* (2012). Automation bias: a systematic review of frequency, effect mediators, and mitigators. *Journal of the American Medical Informatics Association*, Vol 19, 121–127.

209. Skitka, L. J. *et al.* (2000). Accountability and automation bias. *International Journal of Human-Computer Studies*, Vol 52, 701–717.
210. Lyell, D. *et al.* (2017). Automation bias and verification complexity: a systematic review. *Journal of the American Medical Informatics Association*, Vol 24, 423–431.
211. (2021). Killer Robots: Survey Shows Opposition Remains Strong. *Human Rights Watch*.
212. (2022). Public attitudes to data and AI: Tracker survey. Centre for Data Ethics and Innovation.
213. Smith, A. (2018). Public Attitudes Toward Computer Algorithms. *Pew Research Center: Internet, Science & Tech*.
214. What doctor? Why AI and robotics will define New Health - Explore the data. *PwC*.