Cyber Challenges:

In which ways will technology transform military conflict over the next twenty years?

[DRAFT]

Joshua Alexander Joseph McManus

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2401049

BA (Hons) – Security, Intelligence and Cyber

The University of Buckingham (2024-2026)

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Introduction.

The nature of war is that it is ever changing[1], war adapts – it evolves to meet the technological and strategic capabilities of the time. Adaptation, by its very nature, "is the mechanism to build advantage"[2] within operational contexts. Developments within technology over the next two decades, especially the emerging fields of Artificial Intelligence and cyber warfare, will reshape and advance military strategies and tactics. Nations are heavily investing in unmanned systems, advanced electromagnetic technology and defensive capabilities - this can be seen through NATO's DIANA project, that emphasises "technological edge through innovation"[3]

As these technologies continue to evolve, military strategy will become more data-driven, autonomous, and interconnected, raising important questions about ethical implications, security risks, and the balance of power within geopolitics and global strategies. These technological advances have become more integrated and coordinated within "mission planning, rehearsal, and execution, providing immersive experiences that integrate multi-source data inputs."[4] Understanding these developments is crucial for anticipating the future of global security and the changing dynamics of military conflict in the 21st century.

[1] Captain Roncolato, G. (2022). *The Character of War Is Constantly Changing*. [online] U.S. Naval Institute. Available at: https://www.usni.org/magazines/proceedings/2022/may/character-war-constantly-changing.

[2] Ryan, M. (2024). Winning Modern Wars through Adaptation. *Futura Doctrina*. [online] Available at: https://mickryan.substack.com/p/winning-modern-wars-through-adaptation [Accessed 16 Mar. 2025].

[3] Mills, C. (2023). *Emerging and disruptive defence technologies*. [online] *House of Commons Library*, House of Commons, p.10. Available at: https://researchbriefings.files.parliament.uk/documents/CBP-9184/CBP-9184.pdf [Accessed 16 Mar. 2025].

[4] Universal Defence and Security Solutions (2024). *How will how key emerging technologies shape the future military operating environment?* [online] Universal-defence.com. Available at: https://www.universal-defence.com/blog/how-will-how-key-emerging-technologies-shape-the-future-military-operating-environment [Accessed 16 Mar. 2025].

Semi-Autonomous and Unmanned Systems

Semi-Autonomous and Unmanned systems, particularly UAVs (Unmanned Aerial Vehicles) and UUVs (Unmanned Underwater Vehicles), have rapidly evolved from reconnaissance to semi-autonomous combat platforms. As Artificial Intelligence has been introduced within military technology, the capabilities of technology have been "revolutionised"[5], allowing for "real-time decision making "[6] as well as swarm co-ordination (Hive mind logical processing) and operational capacity within inaccessible frontiers (such as deep-sea and high-altitude operations).

UAVs play an integral role in modern warfare[7], with drones like General Atomics MQ-9A (Reaper) used by many nations, such the RAF and the USAF. The MQ-9A's main roles includes ISTAR ("Intelligence, Surveillance, Target Acquisition and Reconnaissance")[8] as well as "precision strike"[9] missions. Similarly, UUVs such as the U.S. Navy's 'Manta

[5] Sharma, S. (2022). Global Developments in Sea-based Unmanned Crafts. *Journal of Defence Studies*, [online] 16(4), pp.21–50. Available at: https://www.idsa.in/system/files/jds/jds-16-4_Sanur-Sharma_04.pdf [Accessed 15 Mar. 2025].

[6] Bendett, S., Boulègue, M., Connolly, R., Konaev, M., Podvig, P. and Zysk, K. (2021). *Advanced military technology in Russia Capabilities and implications*. [online] *Chatham House*, p.50. Available at: https://www.chathamhouse.org/sites/default/files/2021-09/2021-09-23-advanced-military-technology-in-russia-bendett-et-al.pdf [Accessed 15 Mar. 2025].

[7] miriam (2024). *Drones in Modern Warfare: Enhancing Capabilities with Satellites*. [online] Ground Control. Available at: https://www.groundcontrol.com/blog/satellite-enabled-drones-in-modern-warfare/ [Accessed 15 Mar. 2025].

[8] Royal Air Force (RAF) (n.d.). *Reaper (MQ-9A)*. [online] Royal Air Force. Available at: https://www.raf.mod.uk/aircraft/reaper-mq9a/ [Accessed 15 Mar. 2025].

[9] U.S. Air Force (2015). *MQ-9 Reaper*. [online] U.S. Air Force. Available at: https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104470/mq-9-reaper/ [Accessed 15 Mar. 2025].

Ray'[10] and the Royal Navy's 'Project Cetus'[11] represent a shift towards AI-assisted stealth and reconnaissance operations in underwater warfare. As AI becomes more advanced, these platforms are moving towards autonomous mission execution, reducing the need for human oversight and significantly changing the nature of military engagements.

The development of AI-powered Unmanned platforms introduces both risks and great opportunities. AI integration allows unmanned systems to adapt dynamically to threats, reducing reliance on human operators, allowing for Enhanced operational efficiency. This technology can also allow for UAVs can operate in coordinated swarms, overwhelming enemy defences. This can be seen through China's AI-driven Fei Hong FH-97 "loyal wingman" UAVs, which are designed to accompany manned fighter jets, improving combat effectiveness[12]. AI integration enables real-time object recognition, autonomous target engagement, and collaborative mission execution, making these platforms highly effective in contested environments.

However, within the debate of UUVs and UAVs, ethical challenges persist. The ethical concerns surrounding AI-driven kill decisions remain unresolved, especially considering how AI systems in UAVs and UUVs are susceptible to hacking and electronic warfare countermeasures. Furthermore, the lack of human oversight could lead to unintended

[10] Defense Advanced Research Projects Agency (2024). *Manta Ray UUV Prototype Completes In-Water Testing*. [online] Darpa.mil. Available at: https://www.darpa.mil/news/2024/manta-ray-uuv-prototype [Accessed 15 Mar. 2025].

[11] Royal Navy (2022). *Royal Navy orders first crewless submarine to dominate underwater battleground*. [online] Royalnavy.mod.uk. Available at: https://www.royalnavy.mod.uk/news/2022/december/01/20221201-royal-navy-orders-first-crewless-submarine-to-dominate-underwater-battleground [Accessed 15 Mar. 2025].

[12] Saballa, J. (2024). *China Develops Own 'Loyal Wingman' to Rival US*. [online] The Defense Post. Available at: https://thedefensepost.com/2024/12/16/china-loyal-wingman-us/ [Accessed 15 Mar. 2025].

military conflicts, particularly with autonomous targeting systems. The potential for errors and lack of morality-based decision-making, questions the integrity of these unmanned systems.

The future battlefield will be increasingly shaped by AI-driven UAVs and UUVs, offering unprecedented capabilities in air and naval warfare. While the United States and China are leading innovation in AI-driven drone swarms, the expansion of autonomous underwater warfare raises concerns over strategic stability and escalation risks. While UAVs are already combat-proven, the deployment of UUVs is still in its early stages, yet their potential for stealth operations and autonomous attacks could redefine naval dominance. Ultimately, the ethical and strategic implications of AI-driven military systems will shape future conflicts, requiring new policies for autonomous warfare governance.

Hybrid warfare is revolutionising modern conflict by integrating conventional military tactics with cyber operations, disinformation, economic coercion, and the use of proxy forces. Advances in artificial intelligence, cyber warfare and equipment interface are enabling state and non-state actors to disrupt adversaries without engaging in open military confrontation. These strategies exploit vulnerabilities in critical infrastructure, political stability, and public perception, making it increasingly difficult to distinguish between war and peace. As future conflicts span both physical and digital domains, nations must develop adaptive defence strategies, strengthen cybersecurity resilience, and enhance international cooperation to effectively counter hybrid threats in an era where the battlefield is no longer confined to traditional warzones.

In the digital age, hybrid warfare increasingly relies on cyber threats, ranging from ransomware to DDoS attacks. These attacks have become a critical concern for intelligence and defence agencies, particularly in recent years—a notable example being Stuxnet. Widely believed to be the work of the Israeli[13] and U.S.[14] governments (with some speculation about Commonwealth actors via the Equation Group[15]), Stuxnet targeted Iran's Natanz uranium enrichment facility, aiming to disrupt physical infrastructure, specifically the centrifuges.

[13] Anderson, N. (2012). *Confirmed: US and Israel created Stuxnet, lost control of it*. [online] Ars Technica. Available at: https://arstechnica.com/tech-policy/2012/06/confirmed-us-israel-created-stuxnet-lost-control-of-it/ [Accessed 6 Mar. 2025].

[14] Sanger, D.E. (2012). Obama Order Sped Up Wave of Cyberattacks Against Iran. *The New York Times*. [online] 1 Jun. Available at: https://www.nytimes.com/2012/06/01/world/middleeast/obama-ordered-wave-of-cyberattacks-against-iran.html?pagewanted=2&_r=1&seid=auto&smid=tw-nytimespolitics&pagewanted=all [Accessed 6 Mar. 2025].

[15] Council on Foreign Relations (n.d.). *Connect the Dots on State-Sponsored Cyber Incidents - Equation Group*. [online] Council on Foreign Relations. Available at: https://www.cfr.org/cyber-operations/equation-group [Accessed 6 Mar. 2025].

While the precise method of deployment remains uncertain, the worm was designed to degrade mechanical components while simultaneously falsifying data in monitoring systems, ensuring the attack went undetected.[16]

Beyond individual attacks like Stuxnet, cyber warfare has evolved into a strategic tool used by nation-states to achieve military objectives without direct confrontation. Countries now integrate cyber operations into their broader defence strategies, leveraging digital attacks to weaken adversaries before or alongside physical military actions. From Russia's attacks on Ukraine's power grid to China's extensive cyber-espionage campaigns, these incidents demonstrate the growing importance of cybersecurity in national defence.

Unlike traditional warfare, cyber-attacks exist in a legal grey area. While some argue that large-scale cyber operations should be classified as acts of war, international law remains ambiguous, making it difficult to establish clear rules of engagement. This is evident in NATO's lack of a specific Article 5 provision addressing cyber warfare. However, in 2024, NATO heads of state came together to "reiterate that hybrid operations against allies could reach the level of an armed attack and could lead the North Atlantic Council to invoke Article 5 of the Washington Treaty."[17] The repeated use of 'Could' within this message

Critics[18] argue that this weakens NATO's deterrence posture, as adversaries can exploit cyber loopholes without triggering a collective defence response. However, others,

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[16] Fildes, J. (2011). Stuxnet virus targets and spread revealed. *BBC News*. [online] 15 Feb. Available at: https://www.bbc.co.uk/news/technology-12465688 [Accessed 10 Mar. 2025].

[17] NATO (2024). *The Washington Summit Declaration*. [online] Nato.int. Available at: https://www.nato.int/cps/en/natohq/227678.htm?selectedLocale=en [Accessed 15 Mar. 2025].

[18] Neilsen, R. and Pontbriand, K. (2025) '"Hands off the keyboard": NATO's cyber-defense of civilian critical infrastructure', *Defence Studies*, pp. 1–24. doi: 10.1080/14702436.2025.2454353.

including analysts from the Centre for Strategic and International Studies (CSIS), suggest that this ambiguity benefits NATO states—particularly the U.S.—allowing them to leverage cyber capabilities for offensive operations without formally declaring war.

Electro-magnetic Warfighting Capabilities.

The forefront of military technology development, within the modern global defence sector, consists of Electro-magnetic warfighting capabilities. These advanced weapon systems contain a wide range of both lethal and non-Lethal electronic interference (such as Electro-Magnetic Pulse – EMPs) and directed energy weapon systems (DEWs). Electro-magnetic warfare aims to disrupt, disable and or destroy enemy systems, providing significant strategic advantages.

Among the most promising advancements in this field are laser-directed energy weapons (LDEWs) and radio-frequency directed energy weapons (RFDEWs). These technologies offer cost-effective and scalable solutions for countering evolving threats, particularly UAVs. For example, the British DragonFire LDEW system can neutralise drones with a cost “typically less than £10 per shot.”[19] To place within perspective, the MIM-104 Patriot (PAC-3) Surface to Air Missile, commonly used in UAV defence globally, has a unit cost of “£2.5 million”[20] This drastic reduction in cost makes DEWs a financially and logistically viable alternative to other forms of UAV interception.

Another form of Electromagnetic warfighting capabilities would reside within the use of electronic interference weapon platforms such as EMPs and High-Power Microwave (HPM) systems. Examples of HPM include BAE Bofor HPM Blackout, which has

[19] Defence Science and Technology Laboratory and Ministry of Defence (2024). *Advanced future military laser achieves UK first*. [online] GOV.UK. Available at: https://www.gov.uk/government/news/advanced-future-military-laser-achieves-uk-first [Accessed 16 Mar. 2025].

[20] Baraniuk, C. (2017). Small drone ‘shot with Patriot missile’. *BBC News*. [online] 15 Mar. Available at: https://www.bbc.co.uk/news/technology-39277940 [Accessed 16 Mar. 2025].

"destructive effects been proven even at a considerable distance."[21] HPMs work by delivering a "high power, short bursts of radiofrequency at a given target set."[22] EMPs on the other hand are based on findings from the ionising affect from the use of nuclear bombs, however EMP producing non-nuclear devices (E-Bombs) use " high-temperature superconductors to create intense magnetic fields"[23]. EMPs can create high voltages that, for lack of better words, 'fry' electronic hardware. The effects of EMPs and HPMs has been said to not be dissimilar from "that experienced through exposure to close proximity lightning strikes"[24]. These weapons may cause targets to fully replace the equipment damaged, or at least substantial portions.

As these technologies continue to develop, the integration of EM warfare systems is expected to play a crucial role in shaping future military engagements. Enhanced power efficiency, improved targeting precision, and greater operational flexibility will enable forces to disrupt enemy assets while minimizing collateral damage. With future research and innovation into these weapons systems, cost per unit for the platforms will most likely decrease, allowing for full scale integration within operational fronts. However, adversaries are also likely to develop countermeasures, such as hardened electronics, adaptive shielding, and advanced electronic warfare tactics, leading to an ongoing technological arms race in EM warfare capabilities.

[21] Karlsson, M.U., Olsson, F., Åberg, D. and Jansson, M. (2009). Bofors HPM blackout - a versatile and mobile L-band high power microwave system. pp.499–501. doi:https://doi.org/10.1109/PPC.2009.5386327.

[22] Major McGonegal, J. (2020). *HIGH POWER MICROWAVE WEAPONS: DISRUPTIVE TECHNOLOGY FOR THE FUTURE*. [online] Air Command and Staff College, Maxwell Air Force Base, AL. Available at: https://apps.dtic.mil/sti/pdfs/AD1107488.pdf [Accessed 16 Mar. 2025].

[23] Washington State Department of Health (2003). *Electromagnetic Pulse (EMP) WHAT IS EMP AND HOW IS IT CREATED?* [online] Available at: https://doh.wa.gov/sites/default/files/legacy/Documents/Pubs/320-090_elecpuls_fs.pdf [Accessed 16 Mar. 2025].

[24] Kopp, C. (n.d.). *The Electromagnetic Bomb -a Weapon of Electrical Mass Destruction*. [online] Available at: https://www.airuniversity.af.edu/Portals/10/ASPJ/journals/Chronicles/apjemp.pdf [Accessed 16 Mar. 2025].

Guidance and Monitoring systems.

As technologies previously discussed begin to advance, we cannot neglect the evolution of sensor and guidance capabilities. Advancements within these sectors of the defence industry will push the future of missile targeting and counter-stealth capabilities. If an weapons system's control centre acts as the brain, the role of the eyes and ears of the platform fall on the targeting and sensor centres – providing valuable data to the control centre, especially when referring to semi and fully autonomous UAVs and UUVs. Furthermore, counter-stealth capabilities are evolving to match the advancements within airframe designing[25] and anechoic coating[26], which allows for a higher degree of security against stealth-based aircraft and submarines.

Modern missile systems employ a combination of radio, infrared (IR), optical and ultraviolet (UV) sensors[27] to improve targeting within a multitude of operational environments. Sensor fusion, the ability to combine data from different sources to gather intelligence on your environment[28], is a key tool for enhancing the situational awareness of any system. This enhancement can be seen through the different roles sensors can play. Optical and IR imaging play a crucial role in target discrimination, particularly in low-visibility conditions such as cloud cover or nighttime operations, while UV sensors can

[25] Allison, G. (2022). *How Do Stealth Aircraft work?* [online] UK Defence Journal. Available at: https://ukdefencejournal.org.uk/how-do-stealth-aircraft-work/ [Accessed 17 Mar. 2025].

[26] Qian, C. and Li, Y. (2017). *Review on Multi-scale Structural Design of Submarine Stealth Composite*. International Conference on Materials, Architecture and Engineering Technology (ICMAET 2017).

[27] Fontana, S. and Di Lauro, F. (2022). An Overview of Sensors for Long Range Missile Defense. *Sensors*, [online] 22(24), p.9871. doi:https://doi.org/10.3390/s22249871.

[28] Wilfried Elmenreich (2002). *An Introduction to Sensor Fusion*. [online] ResearchGate. Available at: https://www.researchgate.net/publication/267771481_An_Introduction_to_Sensor_Fusion [Accessed 17 Mar. 2025].

contribute to early-warning tracking by detecting missile exhaust plumes. These technologies are constantly[29] being researched and upgraded, with potential for integration within the future fleets of UAVs, allowing them to be not only cheaper but significantly more precise in their targeting systems (in comparison to current UAVs).

Outside of Aircraft and missile systems, stealth technology continues to evolve leading to new detection methods being developed to counteract low-observable threats. As the threat of hybrid warfare increases, chemical and biological sensors play a key role in identifying hazardous agents and supporting CBRN (Chemical, Biological, Radiological, and Nuclear) defence strategies. Additionally, LiDAR and sonar systems provide high-precision mapping and are instrumental in detecting stealth threats, particularly in underwater and urban environments. These systems, when used in union with Magnetic Anomaly Detection (MAD) become essential for locating submarines as well as subterranean structures.[30]

The exact future of sensor and counter-stealth technology remains to seen, however it is generally thought to be quite transformative. As future technological advancements are made within realms such as Quantum computing, the application within sensors and targeting systems have the potential to be revolutionary. Furthermore, Artificial intelligence may hold the capability to enhance sensor fusion, allowing for more dynamical decision making, especially within unmanned platforms. These tools, if researched and developed with haste, may hold the key to the future of advanced combat within the next twenty years.

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[29] Shepard News (2025). *Lockheed wins $270 million USAF contract for F-22 infrared sensor upgrade*. [online] Shephardmedia.com. Available at: https://www.shephardmedia.com/news/air-warfare/lockheed-wins-270-million-usaf-contract-for-f-22-infrared-sensor-upgrade/ [Accessed 17 Mar. 2025].

[30] Liu, H., Zhang, X., Dong, H., Liu, Z. and Hu, X. (2023). Theories, Applications, and Expectations for Magnetic Anomaly Detection Technology: A Review. *IEEE Sensors Journal*, [online] 23(16), pp.17868–17882. doi:https://doi.org/10.1109/jsen.2023.3294498.

Conclusion.

War shapes technological developments – and in turn, technology shapes war. From fireworks used to "ward off evil spirits"[31] to GPS and the internet[32], the defence industry is by far one of the influential sectors of human advancements and technological evolution. These aspects are highly interconnected, for example, sensor technology works in tandem with UAVs, cyberwarfare and electronic warfare. Understanding these technologies is half the process, while strategically planning their tactical applications and operation effectiveness is paramount.

Over the next two decades, the fusion of artificial intelligence, cyber warfare, and electromagnetic weapons will fundamentally alter the nature of military conflict by increasing automation, reducing human oversight, and blurring the boundaries between digital and physical warzones. It is said that "Intelligence is the main driver of innovation itself"[33] Thus technologies such as Artificial Intelligence bring unprecedented change, "exponentially"[34] advancing leaving us to wonder what 'game-changing' technologies are just beyond our reach at this moment but may be within our grasp within the decade. Fundamentally - Understanding these developments is crucial for anticipating the future of global security and the changing dynamics of military conflict in the 21st century.

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[31] American Pyrotechnics Association (2018). *History of Fireworks*. [online] Americanpyro.com. Available at: https://www.americanpyro.com/history-of-fireworks [Accessed 17 Mar. 2025].

[32] North Atlantic Treaty Organization (n.d.). *Military inventions that we use every day*. [online] NATO. Available at: https://www.nato.int/cps/fr/natohq/declassified_215371.htm?msg_pos=1 [Accessed 17 Mar. 2025].

[33] Roser, M. (2023). *Technology over the long run: zoom out to see how dramatically the world can change within a lifetime*. [online] Our World in Data. Available at: https://ourworldindata.org/technology-long-run [Accessed 17 Mar. 2025].

[34] McCarthy, D. (2021). *Tech is improving at an exponential rate. Here's what that means for society*. [online] Emerging Tech Brew. Available at: https://www.emergingtechbrew.com/stories/2021/11/24/tech-is-improving-at-an-exponential-rate-here-s-what-that-means-for-society [Accessed 17 Mar. 2025].

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3. Anderson, N. (2012). *Confirmed: US and Israel created Stuxnet, lost control of it*. [online] Ars Technica. Available at: https://arstechnica.com/tech-policy/2012/06/confirmed-us-israel-created-stuxnet-lost-control-of-it/ [Accessed 6 Mar. 2025].
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25. Royal Navy (2022). *Royal Navy orders first crewless submarine to dominate underwater battleground*. [online] Royalnavy.mod.uk. Available at: https://www.royalnavy.mod.uk/news/2022/december/01/20221201-royal-navy-orders-first-crewless-submarine-to-dominate-underwater-battleground [Accessed 15 Mar. 2025].
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