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Mitigating the Risks of AI-Driven OODA Loops in Military Decision-Making

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1. Introduction: Intellectual History of OODA Loop

Since its conceptual emergence in the 1970s, the OODA loop - Observe, Orient, Decide, Act - has become one of the most widely cited (and also debated) constructs in modern military thought, particularly in airpower studies.[1] Developed by U.S. Air Force Colonel John Boyd, the OODA loop was initially rooted in tactical air combat and derived from his pioneering 'Energy - Manoeuvrability' theory, which revolutionised the study of fighter-jet dogfighting.[2] Boyd's early insight - based on his experience as a fighter pilot - was tactical in nature: in fast-moving, high-stakes environments, the ability to observe, orient, decide, and act faster than an adversary could yield decisive decision advantage.

Over the two decades following his initial theoretical conceptions, Boyd continued to refine his ideas into a series of influential lectures and briefings - from *Destruction and Creation* (1976) to *Patterns of Conflict* (1986), *The Conceptual Spiral* (1992), and *The Essence of Winning and Losing* (1995) - in which he expanded the OODA loop into strategic and operational art levels - as a dynamic interface for complex, adaptive decision-making in competitive environments.[3] At the heart of this evolving thought was the *orientation* aspect - not merely as a stage in a cycle, but as a multilayered and multidimensional approach, shaped by culture, experience, analysis, synthesis, and learning. Boyd argued that true advantage lay not in speed alone, but in the ability to shape and disrupt an adversary's orientation - ultimately creating a cascading spiral of 'uncertainty, doubt, mistrust, confusion, disorder, fear, panic, and chaos'.[4]

Boyd's ideas arguably influenced conceptual shifts within the U.S. Department of Defence in the late 1970s, i.e. the Military Reform Movement, underpinning the U.S. Army's *AirLand Battle Doctrine*, introduced in the 1982 edition of *Field Manual (FM) 100-5*, and further developed in the 1986 revision, as well as the U.S. Marine Corps' *Warfighting*

[1] David S. Fadok, *John Boyd and John Warden: Air Power's Quest for Strategic Paralysis* (Air University, 1995).

[2] Defense Technical Information Center, *DTIC AD1001631: Col John Boyds Innovative DNA*, 2015, http://archive.org/details/DTIC_AD1001631.

[3] Frans P. B. Osinga, 'The Enemy as a Complex Adaptive System: John Boyd and Airpower in the Postmodern Era', in *Airpower Reborn: The Strategic Concepts of John Warden and John Boyd* (Naval Institute Press, 2015), 48–92; J. Boyd, 'Destruction and Creation', 1976, https://www.semanticscholar.org/paper/Destruction-and-Creation-Boyd/483359fa9420efcddde5a17da597f462c2a788c2; John Boyd, 'Patterns of Conflict', 1986, https://static1.squarespace.com/static/58a3add7e3df28d9fbff4501/t/58a4a2675016e127587d7e20/1487184492053/Patterns+of+Conflict_Dec+1986.pdf; John Boyd, 'Conceptual Spiritual', 1992, https://static1.squarespace.com/static/58a3add7e3df28d9fbff4501/t/58a4a5b0a5790ad178d5e09b/1487185329595/Conceptual+Spiral_Jul-Aug+1992.pdf; John Boyd, 'The Essence of Winning and Losing', 1996, https://slightlyeastofnew.com/wp-content/uploads/2010/03/essence_of_winning_losing.pdf.

[4] Brian R. Price, 'Colonel John Boyd's Thoughts on Disruption: A Useful Effects Spiral from Uncertainty to Chaos', *Journal of Advanced Military Studies* 14, no. 1 (30 June 2023): 98–117, https://doi.org/10.21140/mcuj.20231401004.

manual, first published in 1989.[5] Its underlaying conceptual ideas continued to evolve further, shaping the development of Network-Centric Warfare concepts in the U.S./NATO countries from the mid-1990s, converging information superiority, shared situational awareness, and precision strike capabilities to accelerate decision cycles and in doing so, outmanoeuvre adversaries across any military domain.[6]

Boyd's final articulation of the OODA loop, presented in his 1995 briefing 'The Essence of Winning and Losing,' depicted the concept as an 'evolving, open-ended, far from-equilibrium process of self-organisation, emergence, and natural selection.' As he concluded, 'without OODA loops...and without the ability to get inside other OODA loops (or other environments), we will find it impossible to comprehend, shape, adapt to and in turn be shaped by an unfolding, evolving reality that is uncertain, ever-changing, and unpredictable.'[7]

Today, as artificial intelligence (AI)-enabled technologies are increasingly integrated into military intelligence, surveillance, and reconnaissance (ISR), command-and-control (C2) and battle-management systems (BMS), Boyd's theories and concepts arguably regain critical relevance again - but in a new dimension.

As this policy note argues, the OODA loop can now be understood not only as a decision-making heuristic but as an adaptive interface between human cognition, machine augmentation, and autonomous systems. Historically, this man-machine interface could be seen in the evolving relationship between the pilot and the fighter jet - a symbiosis of human instinct and technological capability. Over time, it extended to commanders and ISR networks, analysts and algorithmic architectures, and now increasingly, autonomous systems operating alongside or in the place of human agents.

In the emerging paradigm, the AI-driven OODA loop arguably transforms into a novel architecture, where AI *systems* amplify the *Observe and Orient* phases through real-time data fusion and pattern recognition, while automated or semi-autonomous *processes* direct the *Decide and Act* phases. Consequently, what emerges could be termed by this author as 'AI-driven' or amplified OODA decision-making cycle - where artificial intelligence and autonomous systems rapidly observe, orient, decide, and act at machine speed, often outpacing human cognition and responses. The implementation of 'AI-driven' OODA promises profound strategic and operational advantages, but inherently also amplifies risks of displacing the very human capacities - judgment, adaptability, and empathy - that are most critical in contending, ambiguous, or escalatory situations.

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[5] Todd Larsen, 'John Boyd and the AirLand Battle Doctrine', 2012, https://apps.dtic.mil/sti/tr/pdf/ADA566716.pdf; Ian T. Brown, *A New Conception of War: John Boyd, the U.S. Marines, and Maneuver Warfare* (Marine Corps University Press, 2018).

[6] Arthur K. Cebrowski and John J. Garstka, 'Network-Centric Warfare: Its Origin and Future', 1998, https://www.semanticscholar.org/paper/Network-Centric-Warfare%3A-Its-Origin-and-Future-Cebrowski-Garstka/f131f411b06c907214ecffa974db5303588e6887.

[7] John Boyd, 'The Essence of Winning and Losing', 1996, https://slightlyeastofnew.com/wp-content/uploads/2010/03/essence_of_winning_losing.pdf.

In this context, as James Johnson and others have noted, automating the loop risks marginalising its most vital function: *orientation*.[8] Similarly, John Boyd viewed orientation not as a mechanical input-output stage, but as the cognitive space where 'meaning is generated, novelty is created, and strategic coherence is formed'.[9] Outsourcing this process to opaque machine-learning algorithms trained on historical datasets may increase speed of 'sense-making', but it may also produce what can be termed as the 'digital fog of war' - a new layer of uncertainty and confusion, in which nearly every event is constructed and reinterpreted through multiple AI systems, with varying levels of reliability, blurring our understanding of the real situation at any given time.[10]

In this context, this GC REAIM policy note addresses three interrelated questions:

- How is the integration of AI technologies reshaping each phase of the OODA loop?
- What are the risks and challenges of delegating key cognitive and decision-making functions to machines in the AI-driven OODA concepts?
- How can government, intelligence, and military organisations design platforms, technologies, and systems that preserve human oversight, adaptability, and control within increasingly automated decision architectures?

For GC REAIM, understanding the evolving advances and challenges of 'AI-driven' OODA loops may therefore provide a critical lens for assessing the changes in the direction and character of warfare as well as challenges of next-generation AI systems and decision-making in future conflicts.

[8] James Johnson, 'Automating the OODA Loop in the Age of Intelligent Machines: Reaffirming the Role of Humans in Command-and-Control Decision-Making in the Digital Age', *Defence Studies* 23, no. 1 (2 January 2023): 43–67, https://doi.org/10.1080/14702436.2022.2102486.

[9] *Ibid.* "Note how orientation shapes observation, shapes decision, shapes action, and in turn is shaped by the feedback and other phenomena coming into our sensing or observing window."

[10] Michael Raska, 'Israel-Hamas Conflict Risks Getting Lost in the Digital Fog of War', *The Straits Times*, 2 November 2023, https://www.straitstimes.com/opinion/israel-hamas-conflict-risks-getting-lost-in-the-digital-fog-of-war.

2. Transformation of OODA Loops

Phase	Past: Human-Driven	Present: Technology-Augmented	Future: AI-Driven OODA
Observe	Manual, visually based inputs; limited to pilot/operator perception and basic sensors	Real-time, multi-domain inputs from satellites, drones, radar, and EW systems	AI-driven predictive sensing; integration of cyber, space, and physical domains via edge computing
Orient	Dependent on individual situational awareness, training, and experience	AI-assisted data fusion and pattern recognition; multi-source intelligence integration	Adaptive machine learning continuously updating situational models and adversary behaviour profiles
Decide	Human decisions based on intuition, doctrine, and rules of engagement	AI-supported decision aids and simulations; partial automation in time-sensitive scenarios	Autonomous decision-making; decentralized and dynamic responses with limited human oversight
Act	Manual execution of actions; limited by human reaction time and command chains	High-speed, semi-automated systems (e.g. ECM, missile defence) with networked C2	Machine-to-machine execution at machine speed; governed by pre-defined rules of engagement

Table 1: Overview of the Conceptual Evolution of OODA Loops.[11]

2.1 *The Past*: Human-Driven OODA Loops

Historically, the OODA loop reflected a human-centric processes grounded in direct sensory input, individual expertise, and hierarchical organisational military structures. During the Korean and Vietnam Wars, for example, pilots depended primarily on visual observation, early warning radar systems, and limited radio communications to process real-time information.[12]

These technological and organisational constraints meant that pilots' ability to adapt in combat relied heavily on their personal situational awareness, quality of training, and capacity to synthesise observations into actionable mental models. In this context, Boyd, drawing on his experience as an F-86 pilot in Korea, observed that pilots who could cycle

[11] Adapted from: Michael Raska, 'Reshaping Air Power Doctrines: Creating AI-Enabled "Super-OODA Loops"', Shift Paradigm., 2024, https://theairpowerjournal.com/reshaping-air-power-doctrines-creating-ai-enabled-super-ooda-loops/.

[12] Robert G. Angevine, 'Adapting to Disruption: Aerial Combat over North Vietnam', National Defense University Press, 2020, https://ndupress.ndu.edu/Portals/68/Documents/jfq/jfq-96/JFQ-96_74-83_Angevine.pdf?ver=2020-02-07-150502-850..

through the OODA phases faster than adversaries gained a decisive edge - a principle later formalised in his 'Patterns of Conflict' briefings. The orientation phase, which Boyd termed the 'genetic code' of decision-making, was not merely a procedural step but the cognitive core of the loop, shaped by institutional norms, prior experience, and the ability to reframe problems under stress. [13]

However, these early OODA loops were constrained by the limitations of the 'analogue' era. Military command structures introduced latency, human cognition bore the full burden of data processing, and physiological thresholds such as reaction times capped operational agility. For example, Vietnam-era pilots faced significant challenges despite technological advances: disjointed radar coverage, unreliable missile systems (i.e. the AIM-7 Sparrow achieving less than a 12 percent success rate), and rigid tactical protocols often delayed responses and reduced effectiveness.[14]

To offset these constraints, military services shifted toward intensive training and pilot initiative as key pillars of decision superiority. The U.S. Navy's rapid implementation of the *Top Gun* program in 1969, for example, provided realistic air combat training that dramatically improved performance.[15] The U.S. Air Force, recognising the value of such training only after the war, established *Red Flag* exercises in 1975 to simulate high-stress combat environments and hone split-second decision-making under conditions mimicking information overload and sensory deprivation.[16] These initiatives acknowledged that while human-driven OODA loops were effective, they were inherently bounded by the limitations of available technologies at that time, and the physiological limits of human operators.

Yet even in this era, the OODA loop arguably functioned as a proto-human-machine interface. The symbiotic relationship between pilot and aircraft illustrated how human cognition and machine capabilities co-evolved under combat pressures. This interplay foreshadowed modern-era human-machine teaming, with the conceptual alignment of human intuition (*orientation/decision*) and technological speed (*observe/act*) - a division of labour that transcended into the IT-driven Revolution in Military Affairs (RMA) in the 1990s and early 2000s.[17]

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[13] Frans P. B. Osinga, 'The Enemy as a Complex Adaptive System: John Boyd and Airpower in the Postmodern Era', in *Airpower Reborn: The Strategic Concepts of John Warden and John Boyd* (Naval Institute Press, 2015), 48–92.

[14] Robert G. Angevine, 'Adapting to Disruption: Aerial Combat over North Vietnam', National Defense University Press, 2020, https://ndupress.ndu.edu/Portals/68/Documents/jfq/jfq-96/JFQ-96_74-83_Angevine.pdf?ver=2020-02-07-150502-850, p. 76.

[15] Christopher Papaioanu, 'TOPGUN's Impact', U.S. Naval Institute, 1 September 2019, https://www.usni.org/magazines/proceedings/2019/september/topguns-impact.

[16] Jimmy Cummings, 'Red Flag's 50th Anniversary', Air Combat Command, 11 April 2025, https://www.acc.af.mil/News/Article-Display/Article/4152997/red-flags-50th-anniversary/https%3A%2F%2Fwww.acc.af.mil%2FNews%2FArticle-Display%2FArticle%2F4152997%2Fred-flags-50th-anniversary%2F.

[17] Michael Raska, 'The Sixth RMA Wave: Disruption in Military Affairs?', *Journal of Strategic Studies* 44, no. 4 (7 June 2021): 456–79, https://doi.org/10.1080/01402390.2020.1848818.

2.2 *The Present*: Technology-Augmented OODA Loops

The next wave of OODA loop conceptual evolution began to crystallise in the 2010s, shaped by three interrelated developments that have fundamentally altered global defence and military innovation trajectories: (1) *Geostrategic Competition* - the intensifying rivalry between the United States, China, and Russia that triggered a race for military-technological superiority, particularly in the development and deployment of AI-driven capabilities; (2) *Convergence of Advanced Technologies* - the fusion of artificial intelligence with emerging fields such as synthetic biology, quantum sensing, and neurocognitive science - exemplified by innovations such as neural interface systems; and (3) *Dual-Use Technology Proliferation* - the rapid diffusion and widespread availability of commercial AI technologies that empowered smaller states and non-state actors to challenge the traditional dominance of established military-industrial primes. Collectively, these trends have arguably shaped an AI-enabled Revolution in Military Affairs (AI-RMA), characterised by the convergence of multiple technological revolutions: enhanced digital connectivity, autonomous systems, AI-assisted decision-making, and the expansion of conflict into new physical and cognitive domains.[18]

As a result, advanced militaries have been able to experiment and selectively implement *technology-augmented OODA loops*, characterised by AI-enabled decision-making architectures that are no longer linear or centrally controlled, but increasingly distributed, adaptive, and autonomous. Decision cycles in military operations have become faster, more decentralized, and more responsive to real-time data streams. This is evident, for example, in the war in Ukraine, where the Ukraine's forces demonstrated how AI-enhanced commercial drones, modified by local tech firms such as *Infozahyst*, conduct low-cost, high-frequency tactical ISR missions - autonomously identifying and geolocating enemy positions in real time, even in GPS-denied environments.[19]

The ongoing transformation can be projected in the range of emerging military technologies such as next-generation ISR systems, C2 and battle management systems, and ultimately, the rapidly evolving capabilities of autonomous weapons systems across all military domains that redefined the OODA dynamic. In particular, the diffusion of AI-enabled sensors and platforms across all domains is fundamentally transforming how militaries acquire, process, and act on data.[20] First, militaries seek to leverage AI systems to enhance the autonomy and persistence of *data acquisition* across interconnected ISR systems and platforms.[21] ISR platforms equipped with machine learning can operate in

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[18] Michael Raska and Richard A. Bitzinger, *The AI Wave in Defence Innovation: Assessing Military Artificial Intelligence Strategies, Capabilities, and Trajectories* (Taylor & Francis, 2023).

[19] Kateryna Bondar, 'Ukraine's Future Vision and Current Capabilities for Waging AI-Enabled Autonomous Warfare', 3 June 2025, https://www.csis.org/analysis/ukraines-future-vision-and-current-capabilities-waging-ai-enabled-autonomous-warfare.

[20] Brendan Cook, 'The Future of Artificial Intelligence in ISR Operations', 2021, https://www.airuniversity.af.edu/Portals/10/ASPJ/journals/Volume-35_Special_Issue/F-Cook.pdf.

[21] John Keller, 'Wanted: Artificial Intelligence (AI) and Machine Autonomy Algorithms for Military Command and Control', Military Aerospace, 7 June 2022, https://www.militaryaerospace.com/computers/article/14277721/artificial-intelligence-ai-machine-autonomy-command-and-control.

remote or contested environments with minimal human oversight, providing near-continuous surveillance across vast and complex terrains.

In the maritime situational awareness domain, Australia's *Ghost Shark* AUV programme is another example. Developed by Anduril Australia, Ghost Shark uses AI for undersea data acquisition ISR capabilities. The AUV system is designed for long-endurance surveillance, capable of detecting and classifying undersea threats autonomously.[22] In the air domain, one can point to the Medium Altitude Long Endurance Remotely Piloted Aerial System (MALE RPAS), commonly known as the *Eurodrone* - a collaborative programme between Germany, France, Italy, and Spain - designed to conduct AI-enabled ISR missions, including autonomous target detection and persistent monitoring.[23]

Second, militaries seek AI to revolutionise *data analysis* (orientation) phase of the OODA cycle - arguably its most transformative impact - by automating the analysis of massive and diverse data streams - i.e. terabytes per second range x multiple sensors per platform. AI tools such as computer vision, natural language processing (NLP), and deep learning models can now process, fuse, and interpret vast, heterogeneous data streams with unprecedented speed and precision and provide potential outcomes and scenarios in real time.

In the space domain, for example, AI-enhanced Earth observation capabilities from satellite constellations like *Pléiades Neo* use AI to detect changes in critical infrastructure and track areas for the French military - automating tasks once requiring hours of human analysis.[24] Commercial satellite constellations such as Planet Labs' Flock (optical) and Capella Space (SAR) provide near-real-time global surveillance, while Starlink's dual-use communications network supports secure military data communications.[25] In the cyber domain, Singapore's Cyber Security Agency, Ministry of Defence, and the Digital and Intelligence Service (DIS), for example, employ AI-driven analytics to scan cyber and information grids for disinformation, malware, and hostile influence operations to safeguard Singapore's critical information infrastructure, military networks, and public trust.[26]

Third, the use of AI systems is changing *decision-support functions* in the OODA loop dynamic by enabling predictive analytics, scenario-based planning, and threat prioritisation in command-and-control systems.[27] In this context, for example, the

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[22] Gordon Arthur, 'Australia and Anduril Jointly Invest to Promote Ghost Shark Production', *Naval News* (blog), 9 August 2024, https://www.navalnews.com/naval-news/2024/08/australia-and-anduril-jointly-invest-to-promote-ghost-shark-production/.
[23] Shephard Media, 'Eurodrone', 2025, https://plus.shephardmedia.com/detail/eurodrone/.
[24] Aiport Technology, 'Pléiades Neo 3 Earth Observation Satellite', *Airport Technology* (blog), 7 May 2021, https://www.airport-technology.com/projects/pleiades-neo-3-earth-observation-satellite/.
[25] Sandra Erwin, 'Starlink's Rise in the Defense Market Forces Industry to Adapt', SpaceNews, 8 April 2025, https://spacenews.com/starlink-pushes-rivals-to-rethink-military-comms/.
[26] Michael Raska, 'Reimagining Defense Innovation: Defense AI in Singapore', in *The Very Long Game: 25 Case Studies on the Global State of Defense AI*, ed. Heiko Borchert, Torben Schütz, and Joseph Verbovszky (Cham: Springer Nature Switzerland, 2024), 555–80, https://doi.org/10.1007/978-3-031-58649-1_25.
[27] Brendan Cook, 'The Future of Artificial Intelligence in ISR Operations', 2021, https://www.airuniversity.af.edu/Portals/10/ASPJ/journals/Volume-35_Special_Issue/F-Cook.pdf.

Singapore Armed Forces (SAF) - in collaboration with the Defence Science and Technology Agency (DSTA) - are testing and gradually deploying advanced Command and Control Information System (CCIS). Augmented by a Decision Support System (DSS), the CCIS leverages AI-enabled tools such as data analytics and weapon-to-target matching algorithms to generate real-time operational insights and propose optimised strike options.[28]

Taken together, these examples show an ongoing shift in the design of AI-enabled OODA decision cycles - from reactive intelligence gathering to proactive, AI-driven foresight, planning and decision-making in the use of force.

Yet critical tensions arise. Despite enhanced sensing and computational capabilities, tech-augmented OODA loops are constrained by technological, operational, legal, and increasingly cognitive challenges, particularly in navigating contested and saturated information environments. As one expert shared, 'we task our systems based on what we have already analysed, and we analyse information based on what we believe we need to know.[29] This creates an inherent limitation, where decision-making is shaped not by the full scope of available data, but by prior assumptions and existing mental models. In a rapidly evolving battlespace, such constraints risk narrowing situational awareness and delaying adaptive responses.

As a result, we begin to witness the emergence of a new operational phenomenon: the 'digital fog of war.' Unlike Clausewitz's classical friction, this fog is not the result of uncertainty in the physical environment, but of informational opacity generated by the overwhelming scale, velocity, and automation of data-driven decision systems. In high-tempo, machine-speed engagements, human operators may be unable to validate the sources, logic, or implications of machine-generated decisions in real time.[30] In short, the tech-augmented OODA architectures offer new operational possibilities, but also expose novel vulnerabilities.

2.3 *The Future*: 'AI-Driven OODA Loops'

Looking ahead over the next two decades, the trajectory of future warfare will be increasingly shaped by the convergence of next-generation AI systems that will amplify real-time sensing, edge computing, and autonomous weapons technologies. The diffusion of these capabilities, combined with the development of novel operational concepts and organizational structures, will likely accelerate the transformation of traditional tech-augmented or AI-enabled OODA loops into what may be termed AI-Driven 'Super-OODA' Loops. These loops can be broadly defined as the fusion of AI-enabled sensing and reasoning - where AI systems reshape the *Observe and Orient*

[28] Ministry of Defence Singapore, 'Fact Sheet: SAF Harnesses Artificial Intelligence and Data Analytics to Sharpen Sense and Strike Capabilities with Command and Control Information System', MINDEF, 23 September 2021, https://www.mindef.gov.sg/news-and-events/latest-releases/23sep21_fs2.

[29] Interview with anonymous AI-defence expert, Singapore, 22 November 2023.

[30] Michael Raska, 'Israeli Forces Display Power of AI, but It's a Double-Edged Sword', *The Straits Times*, 17 April 2024, https://www.straitstimes.com/opinion/israeli-forces-display-power-of-ai-but-it-s-a-double-edged-sword.

phases through real-time data fusion, pattern recognition, and adaptive learning - with semi-autonomous or autonomous strike mechanisms that increasingly direct the *Decide and Act* phases.

Importantly, the prefix 'super' is not intended to imply superiority or positive normative judgment. Rather, it denotes a fundamental transformation in the architecture of military decision-making cycles - marked by the integration of AI and autonomy at machine speed, expanding the scale, tempo, and reach of operational decision-making beyond traditional human cognitive limits. While early iterations of these architectures are already visible in select ISR networks, C2 nodes, and decision-support systems across military domains, their full strategic and operational implications - particularly for escalation control, alliance interoperability, and ethical governance - are only beginning to emerge.[31]

Notwithstanding ongoing debates, the concept of amplified 'AI-driven OODA Loops' will arguably represent a shift from IT-enabled to AI-driven Revolution in Military Affairs in the direction and character of warfare - AI systems will not merely compress the Observe-Orient-Decide-Act cycle; they will fundamentally reconceptualise its logic. Human-in-the-loop models may increasingly give a way to autonomous, machine-to-machine communication chains, reshaping the ways and means of military command and control. In doing so, 'AI-driven Super OODA Loops' - will minimise human control in environments requiring split-second decisions. For example, future air power doctrines will incorporate squadrons of uncrewed combat autonomous vehicles (UCAVs) and other AI-amplified, self-directing platforms that can operate remotely across distributed battle networks, make collaborative decisions with human and machine partners, and ideally manoeuvre faster than opposing sides can detect, orient, or counter.[32]

In this 'AI-amplified-OODA' dynamic, one could argue that 'observation' will further transition from passive ISR collection to predictive sensing. AI-enhanced 'edge computing' will process multispectral data from satellites, airborne radar, and cyber-intelligence feeds in real-time.[33] 'Orientation' feedback loops will continuously synthesize historical patterns, real-time threat data, and environmental conditions to generate 'context-aware' orientations. Orientation will no longer merely cognitive but computational - performed by self-learning systems embedded in ISR and C2 platforms.

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[31] James Johnson, 'Artificial Intelligence & Future Warfare: Implications for International Security', *Defense & Security Analysis*, 3 April 2019, https://www.tandfonline.com/doi/abs/10.1080/14751798.2019.1600800; Kenneth Payne, *I, Warbot: The Dawn of Artificially Intelligent Conflict* (Hurst Publishers, 2021); Paul Scharre, 'Autonomous Weapons and Operational Risk', CNAS, 2016, https://www.cnas.org/publications/reports/autonomous-weapons-and-operational-risk; Michael C. Horowitz, 'Artificial Intelligence, International Competition, and the Balance of Power', Texas National Security Review, 15 May 2018, https://tnsr.org/2018/05/artificial-intelligence-international-competition-and-the-balance-of-power/; Michael Raska and Richard A. Bitzinger, *The AI Wave in Defence Innovation: Assessing Military Artificial Intelligence Strategies, Capabilities, and Trajectories* (Taylor & Francis, 2023).

[32] Peter Layton, 'Algorithmic Warfare: AI-Enabled Combat Aircraft in Future Air Operations', *Air & Space Power Journal* 37, no. 2 (2023): 4–20.; John Robert Pellegrin, 'Boyd in the Age of Loyal Wingmen', U.S. Naval Institute, 1 June 2024, https://www.usni.org/magazines/proceedings/2024/june/boyd-age-loyal-wingmen.

[33] Jamie Whitney, 'Artificial Intelligence (AI) Takes Its Place in Sensor, Signal, and Image Processing', Military Aerospace, 16 April 2025, https://www.militaryaerospace.com/computers/article/55273984/artificial-intelligence-ai-and-machine-learning-in-sensor-signal-and-image-processing.

Finally, the boundaries between decision and action phases will be increasingly blurred. AI-driven fire control systems, drone swarms, and predictive logistics platforms will execute decisions in milliseconds. As a result, these systems will arguably reduce human involvement to mission parameter definition or strategic oversight.

At this stage, the concept of amplified 'AI-driven Super OODA Loops' remains largely academic and theoretical, but its underlying logic reflects ongoing search for novel decision-making constructs and conceptual military innovation relevant to changes in the direction and character of warfare. For example, one such emerging model is the '4D framework' - *Discovery, Design, Decide, Disseminate/Monitor* - recently published in the U.S. *Marine Corps Gazette*.[34] Its authors attempt to further advance and converge strategic and operational elasticity of the OODA loop with additional elements relevant for conflicts in an era of geostrategic competition and grey zone challenges - including potential AI applications - *See Figure 2.*

Stage	Core Function	Strategic Purpose	Potential AI Applications
Discovery	Active effort to understand the environment, adversary, and self	Build strategic empathy; identify constraints, biases, and 'known unknowns'	AI-driven data fusion, ISR analysis, pattern recognition, anomaly detection, and predictive analytics
Design	Continuous problem framing and option development	Create and refine strategic approaches in complex, uncertain contexts	Scenario simulation, AI-enabled wargaming, red-teaming, decision-tree modelling, and cognitive mapping
Decide	Strategic choice based on hypothesized cause-effect relationships	Link actions to desired ends through rigorous, risk-informed decisions	Decision support systems, risk modelling, outcome forecasting, adversary behaviour prediction
Disseminate / Monitor	Communicate decisions and assess implementation	Ensure execution aligns with strategic intent; adapt based on feedback	Autonomous monitoring tools, performance analytics, sentiment tracking, operational feedback integration

Table 2: Overview of the "4 D" Model (Discovery, Design, Decide, Disseminate/Monitor)[35]

[34] Thomas C. Greenwood and Frank G. Hoffman, 'Evolving the OODA Loop for Strategy - Marine Corps Association', 1 March 2025, https://www.mca-marines.org/gazette/ooda-loop-for-strategy/; Brian R. Price, 'Decision Advantage and Initiative: Completing Joint All-Domain Command and Control', 2024, https://www.airuniversity.af.edu/Portals/10/ASOR/Journals/Volume-3_Number-1/Price.pdf.

[35] Adapted from: Thomas C. Greenwood and Frank G. Hoffman, 'Evolving the OODA Loop for Strategy – Marine Corps Association', 1 March 2025, https://www.mca-marines.org/gazette/ooda-loop-for-strategy/.

3. Strategic and Policy Ramifications

The transformation toward amplified 'AI-driven OODA Loops' inherently also amplifies its strategic, operational, policy, and ethical challenges. As AI systems increasingly displace human deliberation, the traditional spaces for reflection, proportionality, and escalation control are compressed.[36] The outsourcing of orientation - Boyd's vital domain of creativity, learning, and adaptability - to opaque algorithmic processes risks generating brittle, overly optimised systems. These may function effectively in controlled environments but are prone to systemic failure under conditions of strategic surprise, deception, or data manipulation. Moreover, the delegation of lethal authority to AI-enabled systems - even under tightly coded rules of engagement - raises serious questions of accountability, ethical judgment, and compliance with international humanitarian law – as shown in the GC REAIM policy reports series.

Most importantly, however, the diffusion and implementation of 'AI-driven OODA Loops' expands the scope of *digital fog of war* - in the opacity of assumptions, data sources, or logic embedded in AI-amplified outputs. Algorithms may process and execute actions without clear human understanding of why or how certain decisions were made. In effect, the sheer velocity of decision-making may outpace human comprehension, introducing new forms of cognitive and operational spiral of confusion - in reverse.

This opacity becomes particularly challenging when adversaries use adversarial AI, spoofing techniques, or cyber deception to manipulate input data. By targeting the orientation phase - feeding AI systems with false or misleading information - hostile actors can induce miscalculations in targeting, trigger unintended escalation, or sow confusion in distributed machine-machine command chains. In these conditions, more data does not necessarily mean more clarity. Instead, clarity will depend on a military's ability to interrogate, audit, and override algorithmic logic - a capacity that is increasingly at risk in systems designed for speed and scale, rather than interpretability and resilience.

In short, these converging technological trends will further amplify critical governance challenges – particularly as nations invest in increasingly autonomous decision-making architectures. For GC REAIM, it is no longer sufficient to focus regulatory attention solely on kinetic autonomous weapons systems or human-in-the-loop thresholds. The policy implications of the 'digital fog of war' extends to the entire cognitive architecture of military decision-making - how orientation is constructed, how decisions are justified, and how escalation is constrained.

As such, strategic policy recommendations for the GC REAIM and AI governance stakeholders should include:

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[36] James Johnson, 'Artificial Intelligence & Future Warfare: Implications for International Security', *Defense & Security Analysis*, 3 April 2019, https://www.tandfonline.com/doi/abs/10.1080/14751798.2019.1600800

- **Strengthen Professional Military Education for AI-Centric Decision Environments**
  Prioritize the integration of AI literacy, algorithmic risk assessment, and human-machine teaming concepts into Professional Military Education. Future commanders must be equipped not only to leverage AI-enabled decision tools, but to critically interrogate algorithmic outputs, manage escalation dynamics, and exercise strategic judgment under conditions of cognitive compression.
- **Define Accountability Across AI-Driven OODA Loops**
  Define clear, enforceable lines of responsibility for all outputs of AI-enabled decision systems, ensuring human accountability remains intact across sensing, orientation, decision, and action phases. Mechanisms must ensure commanders can interrogate and override AI recommendations, preserving human judgment in their decisions.
- **Safeguard AI Systems Integrity Against Adversarial Disruptions or Manipulations**
  Protect AI-driven OODA against adversarial manipulation, data spoofing, and cognitive attacks. Future governance frameworks must mandate resilient system design, including adversarial testing, data validation, and cognitive security protocols.
- **Advance International Norms for AI-Enabled Decision-Making Systems**
  Extend regulatory frameworks beyond autonomous weapon platforms to encompass AI-driven C4ISR architectures. Future norms must address algorithmic transparency, escalation management, and verification to mitigate deceptive, escalatory, and systemic risks inherent in AI-driven decision-making environments.

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