ARTIFICIAL INTELLIGENCE IN MILITARY AVIATION

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INTRODUCTION

Persistent depiction of Artificial Intelligence (AI) in military and strategic journals as an "arms race" is as hackneyed as it is inaccurate (some call it an experimentation race[1]). AI is a technology which, along with its subset technologies (Machine Learning (ML), etc.), is certainly not classifiable as "arms"; Elon Musk's famous remark[2] that, "I think the danger of AI is much bigger than the danger of nuclear warheads by a lot" may subtext AI's weapon connotation, but not adequately to qualify it as "arms". However, the "race" part is certainly true and is manifest in feverish pursuit of AI by all major global powers in every facet of national security (in addition to other fields). Thus, national security strategies (inclusive of defence strategies), having identified weapons with applied exploitation of AI as critical to future warfare, are embracing military AI with enthusiasm.

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1. Peter Layton, "The Artificial Intelligence Battlespace", RUSI Commentary, p. 1, at https://rusi.org/commentary/artificial-intelligence-battlespace. Accessed on March 9, 2021.
2. Melia Robinson, "Elon Musk Thinks Artificial Intelligence is Ultimately More Dangerous Than Nuclear Weapons", *Business Insider*, March 12, 2018, p. 1, at https://www.businessinsider.in/elon-musk-thinks-artificial-intelligence-is-ultimately-more-dangerous-than-nuclear-weapons/articleshow/63273433.cms. Accessed on March 14, 2021.

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Currently, the US is at the head of the pack. As far back as November 15, 2014, at the annual keynote address[3] at Reagan National Defense Forum in California, US Secretary of Defense Chuck Hagel declared that, "Today I'm announcing a new Defense Innovation Initiative—an initiative that we expect to develop into a game-changing third 'offset' strategy." He elaborated that the initiative was an effort to sustain and advance US military dominance for the 21st century and outlined some actions. Two years later the government released a National Artificial Intelligence Research and Development Strategic Plan[4] which, without belabouring military aspects much, set the scene for the establishment of Joint Artificial Intelligence Centre (JAIC) in 2018 by US Department of Defense (DoD) to exploit AI technology for the benefit of national security. In February 2019, President Trump signed an executive order with a plan for US leadership in AI development;[5] DoD promptly followed up with an unclassified document entitled "Summary of the 2018 Department of Defense Artificial Intelligence Strategy". The National Security Commission on Artificial Intelligence (NSCAI) was tasked around then to make recommendations to the President and Congress to "advance the development of artificial intelligence, machine learning, and associated technologies to comprehensively address the national security and defense needs of the United States."[6] Its report,[7] submitted on March 1, 2021 accentuates US apprehension of Chinese ambitions to be the global AI leader by

3. Keynote speech by US Secretary of Defense, Chuck Hagel, at the Reagan National Defense Forum, November 15, 2014, para 26, at https://www.defense.gov/Newsroom/Speeches/Speech/Article/606635/. Accessed on March 10, 2021.
4. *The National Artificial Intelligence Research and Development Plan* (Washington, D.C.: White House Office of Science and Technology Policy, 2016), at https://www.nitrd.gov/PUBS/national_ai_rd_strategic_plan.pdf. Accessed on March 1, 2021.
5. Executive Order 13859 of February 11, 2019, *Maintaining American Leadership in Artificial Intelligence* (Washington, D.C.: White House, 2019), at https://www.govinfo.gov/content/pkg/FR-2019-02-14/pdf/2019-02544.pdf. Accessed on March 3, 2021.
6. *Final Report National Security Commission on Artificial Intelligence* (Arlington: National Security Commission on Artificial Intelligence, 2021), Introductory Chapter, p. 15, at https://www.nscai.gov/wp-content/uploads/2021/03/Full-Report-Digital-1.pdf. Accessed on March 4, 2021.
7. Ibid., p. 25.

2030 and belabours possible loss of US military-technical superiority to China in the coming years.

This misgiving is premised on an official Chinese document[8] entitled "New Generation Artificial Intelligence Development Plan released on 20 July 2017" which stipulates three objectives, the last one (to be achieved by 2030) as "…China's AI theories, technologies, and applications should achieve world leading levels, making China the world's primary AI innovation centre, achieving visible results in intelligent economy and intelligent society applications, and laying an important foundation for becoming a leading innovation-style nation and an economic power."

In Europe too, AI is being revered in military terms and an example is the Future Combat Air System (FCAS) joint project between France, Germany and Spain. Other notable nations pursuing AI are the UK, Sweden, Turkey, Israel and India, with Saudi Arabia and UAE the latest entrants.

Russian President Putin, in a 2017 meeting, warned in the context of AI that "the one who becomes the leader in this sphere will be the ruler of the world", offering to cooperate with other nations to eliminate a monopolistic situation. In Europe too, AI is being revered in military terms and an example is the Future Combat Air System (FCAS) joint project between France, Germany and Spain. Other notable nations pursuing AI are the UK, Sweden, Turkey, Israel and India, with Saudi Arabia and UAE the latest entrants. This paper reconnoitres the demands of military aviation from AI and the munificence of AI in meeting them.

AI AS A FRAME OF REFERENCE FOR MILITARY AVIATION

AI is a term used loosely and hence perceptions about it vary widely. According to US DoD,[9] "AI refers to the ability of machines to perform

8. *China's New Generation Artificial Intelligence Development Plan 2017* (full translation), chapter entitled, "II. The Overall Requirements", Section entitled, "Strategic Objectives", at https://www.newamerica.org/cybersecurity-initiative/digichina/blog/full-translation-chinas-new-generation-artificial-intelligence-development-plan-2017/. Accessed on March 2, 2021. Original Chinese document ostensibly at http://www.gov.cn/zhengce/content/2017-07/20/content_5211996.htm according to translators.
9. *Summary of the 2018 Department of Defense Artificial Intelligence Strategy* (Washington, D.C., 2019), p. 5, at https://media.defense.gov/2019/Feb/12/2002088963/-1/-1/1/SUMMARY-OF-DOD-AI-STRATEGY.PDF. Accessed on March 12, 2021.

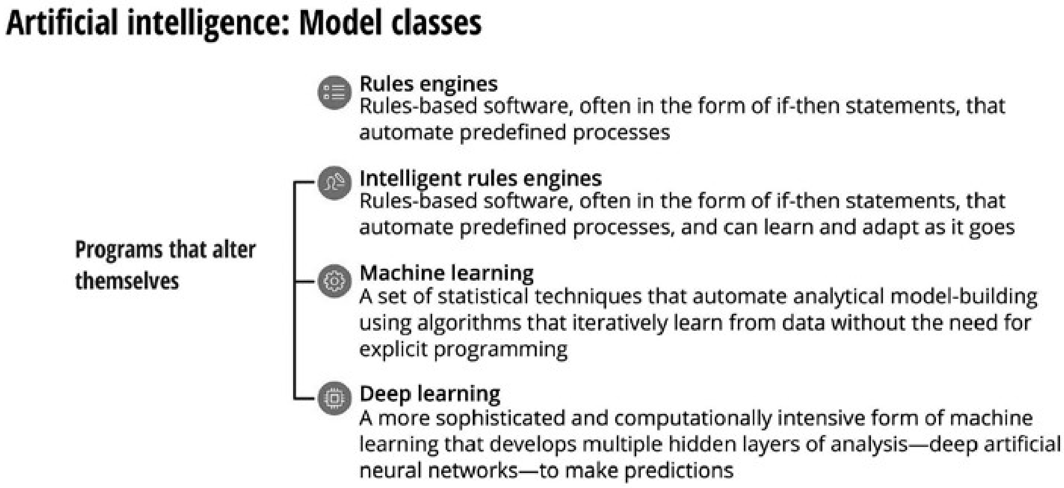
tasks that normally require human intelligence—for example, recognizing patterns, learning from experience, drawing conclusions, making predictions, or taking action—whether digitally or as the smart software behind autonomous physical systems." In essence, AI is being demonstrated by any machine imitating human brain functions; the problem lies in understanding how the human brain functions. For decades computers have been executing tasks that the human brain can; they have attained much higher speeds than the human brain but those tasks could be generally clubbed under Common Artificial Intelligence (CAI). The term General Artificial Intelligence (GAI) pertains to cognition functions, i.e., thinking faculty of the brain. Current research endeavours aim at understanding how the brain functions and then mimicking the processes in AI machines.[10] The laudable, and apparently technologically achievable, aim is to make GAI machines think like human brains although such machines may be functional many years ahead in future.

Starting with second-generation fighter aircraft, some human functions were getting delegated to on board avionics; fly-by-wire (FBW) was an extension of that rationale—by accelerating the process of computing and predicting flight conditions, safe control of the aircraft could be assured. Speed mattered critically but FBW still functioned within the envelope defined beforehand and every deed by FBW was a response to 'If… Then….' preset parameters; in other words, no intelligence was displayed by the machine. GAI aims at reacting to situations as they develop with a capability to learn from each situation or interaction; some examples are speech recognition, mastery of games like chess and Go, autonomous systems, flight and combat simulations, etc. The challenge lies in moving up from, say, carrying out guided missile attacks on designated targets to making decisions on which target should be attacked. While AI, replete with super-fast computers, can almost instantly access and analyse huge amounts of data to provide inputs for command and control decisions, subjective problem solving is still not possible by AI (and

10. Paul Yaworsky, *A Model for General Intelligence* (New York: Information Directorate, Air Force Research Laboratory, 2018), p. 2, at https://arxiv.org/ftp/arxiv/papers/1811/1811.02546.pdf. Accessed on February 27, 2021.

GAI is the objective that will do so). According to a Deloitte Insights paper[11] a hierarchy of AI based on how it works is depicted in Figure 1.

Figure 1



Source: Deloitte analysis.

Military aviation, constantly in need of very fast decision making, is locatable in this frame of reference; as AI moves towards Deep Learning, military aviation moves towards applied GAI. Let us look at current and emerging AI applications in military aviation.

AI IN THE COCKPIT

In August 2019, US Defense Advanced Research Projects Agency (DARPA) proclaimed that, "No AI currently exists, however, that can outduel a human strapped into a fighter jet in a high-speed, high-G dogfight."[12] A year later, under DARPA's famous AlphaDogFight trials, a simulated F-16 fighter with AI in the cockpit defeated a top gun from US Air Force (USAF) in five bouts of mock air combat. Deeper analysis would show that the simulation trial conditions were biased in favour of AI; the human pilot was not in an actual

11. Frank Strickland, Joe Mariani and Isaac Jenkins, "Military readiness through AI", in *Deloitte Insights*, April 24, 2019, pp. 1-2, at https://www2.deloitte.com/us/en/insights/industry/public-sector/ai-military-readiness.html. Accessed on February 24, 2021.
12. DARPA Outreach, "Training AI to Win a Dogfight", August 5, 2019, p. 1, at https://www.darpa.mil/news-events/2019-05-08. Accessed on February 24, 2021.

aircraft which he was trained to fly, and had only a Virtual Reality (VR) headset to give him situational awareness. However, the demonstration was historic inasmuch as it validated the very concept of AI replacing a pilot in the cockpit for something as fast moving as a dogfight.

This was a step forward from civil aviation precedents of AI in the cockpit like the Autonomi system from Garmin which enables, in case of pilot incapacitation, for on-board systems to take over either automatically or on activation by the pilot or a passenger, stabilise the aircraft and then autoland it, if required. Interestingly, this system, now certified by US Federal Aviation Administration (FAA), is not projected as an AI system but as automation. The patent application for Emergency Autoland System[13] does not use the term 'artificial' or 'intelligence' anywhere. Xwing, a US-based company, claims its software integrates sensors and maps with on-board flight control systems to allow regional aircraft to navigate, take off and land; indeed it has secured FAA certification for unmanned cargo operations on a converted Cessna 208B Grand Caravan. Xwing is already flying with a single pilot on board and autonomous operations are expected to start in 2022.

While civil aviation has its own problems accepting AI in the cockpit (including the expected iron wall of resistance to passengers boarding a pilot-less aircraft), military aviation grapples with the problem differently. On December 15, 2020, USAF flew a single-seat U-2 on a simulated missile strike mission[14] with an AI algorithm called ARTUμ as a working crew member; a human pilot flew the aircraft and coordinated with ARTUμ which was responsible for sensor employment and tactical navigation. The system is designed to be transferable to another type of aircraft with ease and has the potential to be a cockpit occupant in modern fighters as well as future ones. The implication is that pilot workload of flying and fighting can be reduced by AI in the cockpit taking over complex tasks of managing data

13. United States Patent Application Publication No. US 2017/0249852 AI dated August 31, 2017, at https://patentimages.storage.googleapis.com/04/81/09/55bcc0207e50fd/US20170249852A1.pdf. Accessed on February 20, 2021.
14. Secretary of the Air Force Public Affairs, "AI Copilot: Air Force achieves first military flight with Artificial Intelligence", Official US Air Force website, December 16, 2020, p. 1, at https://www.af.mil/News/Article-Display/Article/2448376/ai-copilot-air-force-achieves-first-military-flight-with-artificial-intelligence/. Accessed on February 22, 2021.

from multiple sources and sensors. An ARTUμ (or similar system) could also manage autonomous systems teamed with the fighter it is located in (manned-unmanned teams are discussed later in detail). There have been reports of Japan developing an unmanned fighter to be operational by 2035,[15] and AI in the cockpit appears to have caught the attention of military aviation grippingly.

Current technological prowess encourages optimism about military aviation accommodating incremental AI participation in cockpit workloads. The AlphaDogFight series of demonstrations is part of DARPA's Air Combat Evolution (ACE) programme which aims to progressively automate aerial combat and foster confidence in unmanned cockpits. Evolving fighter designs, prevalently clubbed into sixth-generation fighters, stand to benefit immensely from the inexorable tiptoe of AI into modern cockpits. A promising example is DARPA's Aircrew Labor In-Cockpit Automation System (ALIAS) which is aimed at developing a flexible, drop in, removable kit that would permit appending high levels of AI driven automation into an existing aircraft; the ultimate aim is to execute an entire mission from take-off to landing.[16]

AI AND EVOLVING COMBAT AIRCRAFT

There is no universally accepted classification of combat aircraft into "generations" but the first-generation is generally considered to be the earliest jet fighters entering service during the fag end of World War II; and the second, those that operated during the Korean War period, many with swept wings. Technology in the late 1950s and 1960s ushered in the third-generation with supersonic speeds and sophisticated engines. The fourth-generation brought in impressive degrees of avionics and automation in the 1970s (fly-by-wire (FBW), Full Authority Digital Engine Controls (FADEC), etc.) while the fifth-generation is characterised by, among others,

15. Smriti Chaudhary, "Japan to Deploy Unmanned Fighter Jets By 2035 With Aim to Counter Rising Chinese Military Might", January 1, 2021, p. 1, at https://eurasiantimes.com/japan-to-deploy-unmanned-fighter-jets-by-2035-with-aim-to-counter-rising-chinese-military-might/. Accessed on March 7, 2021.
16. Dr. Stuart H. Young, "Aircrew Labor In-Cockpit Automation System", DARPA official site, undated paper, p. 1, at https://www.darpa.mil/program/aircrew-labor-in-cockpit-automation-system. Accessed on March 12, 2021.

It is the sixth-generation which is still evolving that promises to incorporate hypersonic speeds, adaptive shapes, dual mode engines along with many emerging and astonishing technologies, but, most importantly, very potent levels of AI.

high stealth, Active Electronically Scanned Array (AESA) radars and plug and play electronics with automation permitting the aircraft limited autonomy in some areas. It is the sixth-generation which is still evolving that promises to incorporate hypersonic speeds, adaptive shapes, dual mode engines along with many emerging and astonishing technologies, but, most importantly, very potent levels of AI.

The US is leading in the race to produce 6th-generation, AI-endowed fighters; US Air Force Research Laboratory (AFRL) released news of F/X, also known as Next Generation Air Dominance (NGAD) or Penetrating Counter Air (PCA), with a projected date of induction of 2030 into USAF. Another programme called F/A-XX, which the US Navy also calls NGAD, relates to a sixth-generation replacement for US Navy's F/A-18E/F.[17] Not much is known about this programme yet but some analysts aver that the NGAD will most likely have an AI co-pilot.[18]

In Europe, France, Germany and Spain are collaborating on a Future Combat Air System (FCAS) which is aimed at producing the Next Generation Fighter (NGF) connected to a variety of Unmanned Aerial Vehicles (UAVs) with offensive and surveillance roles through cloud connectivity driven by AI; the objective is to turn the NGF into a battlefield management platform commanding one or more UAVs for multifarious roles. The FCAS was initially slated to go operational by 2040[19] but that seems doubtful at the time of writing this.

17. Valerie Insinna, "Congress has questions about the Air Force's and Navy's next-generation fighter programs", *Defense News*, June 23, 2020, p. 1, at https://www.defensenews.com/air/2020/06/23/congress-has-questions-about-the-air-force-and-navys-next-generation-fighter-programs/. Accessed on March 9, 2021.
18. Theresa Hitchens, "NGAD Likely to Carry AI Copilot: Next Step Certifying Them Flight Ready: Roper", *Breaking Defense*, December 18, 2020, p. 1, at https://breakingdefense.com/2020/12/ngad-likely-to-carry-ai-copilot-next-step-certifying-them-flight-ready-roper/. Accessed on March 10, 2021.
19. Justin Bronk, "FCAS: Is the Franco-German-Spanish Combat Air Programme Really in Trouble?", RUSI Commentary, March 1, 2021, p. 1, at https://rusi.org/commentary/fcas-franco-german-spanish-combat-air-programme-really-trouble. Accessed on March 9, 2021.

Russia is working on MiG-41, a long-range sixth-generation interceptor, with a projected entry into service after 2030; informed conjecture has it that an unmanned variant may also emerge from the programme. This is in addition to the Su-57 programme which is a fifth-generation aircraft, born out of Russian Air Force PAK FA programme. It first flew in 2010; India was a development partner but pulled out in 2018 due to slow progress and less than satisfactory technological progress. According to a RAND Corporation commentary,[20] the Su-57 is somewhere between a fourth and a fifth-generation design and the Izdeliye 30 engine intended for it is not yet ready. Reportedly, 76 aircraft will enter service with the Russian Air Force in the late 2020s. However, the fact that the Su-57 falls short of fifth-generation criteria is a portent of similar dearth of delight from the MiG-41 sixth-generation aircraft as also of almost certain delays in the programme's fruition.

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The UK is working on the Tempest sixth-generation combat air system in collaboration with Italy and Sweden to produce an aircraft that will enter service with RAF and others in 2035. It would be able to work in cooperation with UAVs for coordinated offensive or defensive operations. China's AI-loaded sixth-generation project, expected to come to fruition by 2035, is also looking at UAV control (including swarm control) and to be an improvement over its existing leading-edge fighters—the J-20 and the J-31. Japan is also planning to develop at Mitsubishi, in collaboration with a foreign partner (possibly the US or UK) a new design called the F-X or the F-3 to replace

20. Ryan Bauer and Peter A. Wilson, "Russia's Su-57 Heavy Fighter Bomber: Is It Really a Fifth-Generation Aircraft?", RAND Blog, August 17, 2020, p. 1, at https://www.rand.org/blog/2020/08/russias-su-57-heavy-fighter-bomber-is-it-really-a-5th.html. Accessed on March 12, 2021.

its F-2 aircraft. The F-3 is expected to be a sixth-generation aircraft although its design is yet to be finalised and so it could well turn out to be a fifth-generation one. A Nasdaq report[21] said that Japan had picked Mitsubishi Heavy Industries (MHI) to lead the development of the new fighter jet but the MHI site (mhi.com) refrains from mentioning this development. It is safe to presume that, given Japan's diligence over the F-3 design (and rejection of three US and UK OEM proposals for collaboration), the final aircraft will incorporate leading-edge AI features.

As the fighter aircraft progressed through successive generations, increasing complexity of technology rendered their development arduous and their costs astronomical. US F-22 and F-35 sport exorbitant price tags and sales have been muted, despite their unquestionable credentials as fifth-generation leading-edge machines. Indeed, the US is the only aerospace power to have fifth-generation aircraft, all the other nations/nation groups with sixth-generation programmes having leapfrogged the fifth! Not surprisingly, there is a current rethink over fifth and sixth-generation aircraft in favour of rejuvenating fourth-generation ones—with some additional features of later generations, obviously those that can be retro-fitted without major design changes. This thought process points towards the emergence of a 4.5th generation which achieves a compromise between cost (far less than a fifth/sixth-generation aircraft) and capability (decidedly better than fourth generation). There is no doubt that the capability enhancement will embrace AI to the extent that refurbishment will permit.

Indeed, retrofit of AI is already being undertaken on some older battle-proven aircraft; according to one report,[22] "The Air Force has over 600 projects incorporating a facet of artificial intelligence to address various mission sets." The B-2 bomber, dating back to the 1980s, has been given new flight management control processors and fibre optic cables are replacing the old wiring. The on

21. Reuters, "Japan picks Mitsubishi Heavy to lead development of new stealth jet fighter", *Nasdaq,* October 20, 2020, p. 1, at https://www.nasdaq.com/articles/japan-picks-mitsubishi-heavy-to-lead-development-of-new-stealth-jet-fighter-2020-10-29. Accessed on March 3, 2021.
22. Kris Osborn, "Air Force Has Plans to Turn the B-2, F-35 and F-15 Into Even More Deadlier Killers. Here's How", July 31, 2018, p. 1, at https://nationalinterest.org/blog/buzz/air-force-has-plans-turn-b-2-f-35-and-f-15-even-more-deadlier-killers-here%E2%80%99s-how-27327. Accessed on March 5, 2021.

board memory and its networking speeds are being enhanced manifold so as to enable AI perform essential procedural functions (database access, information organising, scanning, viewing, organising, targeting, radar warning, images and video) and fusing sensor information autonomously thus lowering pilot workload related to flying and navigation, and leaving his cognitive faculties free for mission related tasks. The F-15 is also being re-engineered with Advanced Display Core Processor (ADCPII), one of the fastest processors in the world, so as to permit faster and more reliable processing capability on board; there is also a plan to apply cognitive AI and ML algorithms to enhance the capabilities of its EW systems[23] under the cognitive EW concept. The EA-18G Growler is also getting AI injected into its systems to give it enhanced Electronic Warfare (EW) capabilities: an illustration is a system called Reactive Electronic Attack Measures (REAM).[24] Northrop Grumman was awarded a contract for the development of this capability of transitioning Machine Learning Algorithms (MLAs) to the EA-18G's airborne electronic attack suite to achieve capabilities against agile, adaptive, and unknown hostile radars or radar modes. REAM technology is expected to join active Navy fleet squadrons around 2025.[25] Many of the AI applications mentioned above are already available in varying degrees of sophistication and could be grafted on to existing or evolving aircraft types with ease.

As in-cockpit AI permits aircraft to perform more and more vital combat functions at speeds far exceeding those human pilots are capable of, combat aircraft could move from AI sharing cockpits with human pilots (as the U-2 illustration mentioned above) to manning them independently. Thus, an "optionally manned cockpit" design is a key attribute of the sixth-generation fighter. As is also evident from the discussion on sixth-generation fighters above,

23. John Keller, "Air Force asks industry for artificial intelligence (AI) cognitive electronic warfare (EW) for F-15 jets", *Military & Aerospace Electronics*, March 15, 2021, p. 1, at https://www.militaryaerospace.com/computers/article/14199230/electronic-warfare-ew-cognitive-artificial-intelligence-ai. Accessed on March 17, 2021.
24. US Department of Defense, "Contracts for April 25, 2018", April 25, 2018, sixth item under NAVY, at https://www.defense.gov/Newsroom/Contracts/Contract/Article/1503297/. Accessed on March 2, 2021.
25. John Keller, "Vadum to support electronic-warfare project to counter waveform-agile enemy radar with machine learning", *Military & Aerospace Electronics*, February 20, 2019, p. 1, at https://www.militaryaerospace.com/sensors/article/16722184/vadum-to-support-electronicwarfare-project-to-counter-waveformagile-enemy-radar-with-machine-learning. Accessed on March 3, 2021.

a quintessential element of ongoing sixth-generation fighter programmes is the AI-driven capability to team with UAVs for the performance of sundry offensive and defensive roles; this teaming is discussed next.

AI AND MANNED-UNMANNED TEAMING

Manned-Unmanned Teaming (MUM-T) has been around as a concept even before it was juxtaposed on to combat aircraft, and more specifically, to sixth-generation fighters. Interestingly, it was the US Army which pioneered the concept in 1997 with four concept evaluation programmes which blossomed into two current systems involving the Apache AH-64D and the Apache AH-64E linking with UAVs.[26] Perhaps the most eye-catching accomplishment of that MUM-T has been a demonstration (in October 2020) involving a live missile fire through cooperative engagement between an Apache AH-64E helicopter, a Shadow RQ-7BV2 Block 3 tactical unmanned aircraft system (TUAS) and an MQ-1C Gray Eagle Extended Range (GE-ER) UAS.[27]

Fixed wing MUM-T involving fighters has not been far behind but, in the context of fighters and high-speed UAVs, cooperative engagements demand more immersive AI for successful operations. US AFRL has been working on the 'Loyal Wingman' concept entailing a manned command aircraft with an unmanned aircraft serving as an adjunct flying platform, scouting for threats and taking them on, if required (hence the term loyal wingman). Live demonstrations with one manned and one unmanned F-16 were impressive[28] and promising enough for all sixth-generation aspirations to envision such an option as part of the design requirements. According to a paper from NATO's conglomerate of

26. Lt Col Steven G. Van Riper, "Apache Manned-Unmanned Teaming Capability", Association of the United States Army site, p. 2, at https://www.ausa.org/sites/default/files/apache-manned-unmanned-teaming.pdf. Accessed on February 23, 2021.
27. Becky Bryant, "Aerial MUM_T reaches new heights at DPG", US Army site, October 27, 2020, p. 1, at https://www.army.mil/article/240283/aerial_mum_t_reaches_new_heights_at_dpg. Accessed on March 1, 2021.
28. Joseph Trevithick, "This Is What the US Air Force Wants You to Think Air Combat Will Look Like in 2030", *The Drive*, March 26, 2018, see section entitled "Loyal Wingmen", at https://www.thedrive.com/the-war-zone/19636/this-is-what-the-us-air-force-wants-you-to-think-air-combat-will-look-like-in-2030. Accessed on February 4, 2021.

analysts (called Joint Air Power Competence Centre[29]), while the F-16 tests were conducted in a semi-autonomous mode based on predetermined parameters, future plans include "flocking" wherein more than one unmanned wingman would operate under the manned command aircraft which would give more abstract commands than exercise direct control over them, and "swarming" which would obviate the possibility of the command aircraft having situational awareness over each of a huge swarm of UAVs but permit it to exercise command over the swarm as an aggregate. A demonstration related to this concept was made in October 2016 with three F/A-18 Super Hornets releasing a swarm of 103 autonomous micro-drones which then proceeded to exhibit "collective decision-making, adaptive formation flying, and self-healing."[30] The swarming UAVs are especially alluring as they represent myriad possibilities: some UAVs could have offensive roles, some could be sheer decoys, some could carry out Intelligence, Surveillance and Reconnaissance (ISR) tasks, some could carry EW payloads, some others could aid in target recognition and tracking, and yet others could be loitering munitions with possibly air-to-air capability so that they can sacrifice themselves in defence of their command aircraft; the possibilities are boundless.

As the foregoing suggests, UAVs present a compelling alternative to exposing progressively expensive (witness the almost unaffordable F-35!), scarce, manned aircraft to high threat environments. Not only can they be used again and again like manned aircraft, but are comparatively so economical that greater risks can be taken with them, with no danger of losing a valuable human pilot. They are variously referred to as Low Cost Attritable Aircraft (LCAA) and Attritable/Reusable (A/R) UAVs,[31] designed for short life spans (in comparison to manned fighters), recoverable (if not attrited during a

29. Andy J. Fawkes and Lieutenant Colonel Martin Menzel, "The Future Role of Artificial Intelligence", *Joint Air Power Competence Centre Journal*, 27th edn., Autumn/Winter 2018, p. 73, at https://www.japcc.org/wp-content/uploads/JAPCC_J27_screen.pdf. Accessed on March 2, 2021.
30. US Department of Defense, "Department of Defense Announces Successful Micro-Drone Demonstration", US DoD Release, January 9, 2017, p. 1, at https://www.defense.gov/Newsroom/Releases/Release/Article/1044811/department-of-defense-announces-successful-micro-drone-demonstration/. Accessed on March 3, 2021.
31. Col Mark Gunzinger and Lukas Autenreid, "The Promise of Skyborg", *Air Force Magazine*, November 1, 2020, p. 1, at https://www.airforcemag.com/article/the-promise-of-skyborg/. Accessed on March 4, 2021.

Skyborg was launched in 2018 by AFRL's Strategic Development Planning and Experimentation (SDPE) and AFRL calls it "an autonomy-focused capability that will enable the Air Force to operate and sustain low-cost, teamed aircraft that can thwart adversaries with quick, decisive actions in contested environments."

mission), low cost, and usable with multiple manned aircraft. The crucial AI technologies that are lodged in these UAVs enable them to be part of MUM-T programmes like the US Skyborg, one of three Vanguard programmes launched by AFRL.

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In May 2019, DARPA launched Air Combat Evolution (ACE) programme to adopt AI in individual and team aerial combat tactics and to develop Air Combat Manoeuvring (ACM) algorithms for visual 1-versus-1, 2-versus-1 and 2-versus-2 engagements with a broad spectrum of performance. The AlphaDogFight trials mentioned earlier were a part of ACE which embraces manned and unmanned aerial combat. While ACE is aimed at developing AI software capable of close combat by unmanned platforms autonomously, Skyborg has modern capabilities (Beyond Visual Range (BVR) missiles and long-range sensors) in mind for loyal wingmen. However, as both programmes look at unmanned wingmen, they may be merged at some

32. Air Force Research Laboratory, "What Is Skyborg?", p. 1, at https://afresearchlab.com/technology/vanguards/successstories/skyborg. Accessed on February 23, 2021.

future point in time as the programmes mature. That will remove the dividing line between close aerial combat and BVR engagements by AI-enabled UAVs toiling as wingmen.

Boeing, which has a stake in US Skyborg programme, is also designing and developing in collaboration with Royal Australian Air Force (RAAF) the Airpower Teaming System (ATS)—its first unmanned system in Australia. On March 1, 2021, Boeing announced[33] the first test flight of its loyal wingman, a UAV slightly smaller than an F-16 (its length is 11.6 metres) which can fly like a fighter (as loyal wingman) to say an F-18 or F-35 class of aircraft (up to six could fly with one manned aircraft), or fly on roles like EW and ISR along with P-8 Poseidon or E-7 Wedgetail aircraft.

Moving to Europe, the decision to develop FCAS was taken in 2017 by Germany and France but they signed an investment agreement only in Febraury 2020 with Spain joining up in December that year.

Moving to Europe, the decision to develop FCAS was taken in 2017 by Germany and France but they signed an investment agreement only in Febraury 2020 with Spain joining up in December that year. Within the programme, the Next Generation Weapon System (NGWS) aims at teaming sixth-generation manned fighters (possibly NGFs) with UAVs (called Remote Carriers (RCs) under the programme) which will be appendable in a scalable and flexible manner. RCs from 200 kg to several tons All-Up Weight (AUW) are envisaged under NGWS with EW, ISR, Target Acquisition, Air-to-Ground strike and Suppression of Enemy Air Defences (SEAD) as the possible roles. Airbus Defence and Space was working with US-based ANSYS, an engineering simulation company but, reportedly, there are some problems faced by the programme[34] and its future is uncertain.

33. Boeing Media Room, "Boeing Loyal Wingman Uncrewed Aircraft Completes First Flight", March 1, 2021, p. 1, at https://boeing.mediaroom.com/news-releases-statements?item=130834. Accessed on March 5, 2021.
34. Justin Bronk, "FCAS: Is the Franco-German-Spanish Combat Air Programme Really in Trouble?", RUSI Commentary, March 1, 2021, p. 1, at https://rusi.org/commentary/fcas-franco-german-spanish-combat-air-programme-really-trouble. Accessed on March 9, 2021.

Russia has also been working on developing new UAVs to function as autonomous loyal wingmen; reportedly 'Grom' (meaning thunder), developed by Kronstadt Group was presented at Army 2020 Arms Expo in Moscow. Grom is designed to operate in conjunction with Su-35/Su-57 fighters for reconnaissance and missile firing (500 kg payload) under their command.[35] It resembles the XQ-58 Valkyrie but is longer by half a length (13.8 metres to Valkyrie's 8.8 metres). According to TASS, Russia's state news agency, Kronstadt has stated that the Grom will be able to control a swarm of ten smaller drones called 'Molniya' (or lightning).[36] Another UAV, the S-70 Okhotnik-B (Hunter) designed by Sukhoi Design Bureau and Russian Aircraft Corporation MiG first flew in 2019 and is also designed to be a loyal wingman capable of carrying 2 tons of internal payload including missiles and bombs, or be installed with electro-optic targeting, communication and reconnaissance equipment. The actual AI capability and content of these two UAVs is not ascertainable as all information about them is from Russian state media (and hence susceptible to scepticism).

Sixth-generation programmes appear intent on MUM-T capabilities but not all of them will survive the onslaught of shrinking defence budgets; already there is a mild clamour on about revitalisation of fourth-generation aircraft with additional AI retro-fitted to give them capabilities transcending fourth generation. Without a doubt, there would be built into the MUM-T UAVs the modular capabilities to dovetail into partnerships with aircraft hierarchically lower than the sixth-generation designs they are being developed for originally. An interesting consequence of this happening could be the realisation that a UAV is as effective in MUM-T roles with sixth-generation aircraft as it is with less-than-sixth ones.

AI ON UAVS

Beginning with a spectacular flight in 1969 by Israel's Military Intelligence Directorate using toy drones mounted with 35 mm still cameras programmed

35. "Russia's top long-range attack drones", *Air Force Technology*, November 27, 2020, p. 1, at https://www.airforce-technology.com/features/russias-top-long-range-attack-drones/. Accessed on February 3, 2021.
36. "Russia's latest combat drone to control swarm of reconnaissance UAVs", TASS news site, March 15, 2021, p. 1, at https://tass.com/defense/1265961. Accessed on March 17, 2021.

to click pictures every ten seconds to harvest details of trenches, signals cables and deployments over Egyptian territory along the Suez, UAVs have grown impressively—in size and in capability. Incrementally additive AI has added value to UAVs by providing autonomy for myriad roles and tasks. UAVs are being used in combat during military conflicts for long; a US Predator first fired a missile in 2001.[37] More recently, Azerbaijan and Armenia saw wide (and decisive!) use of UAVs in the latter half of 2020. Autonomous UAVs can now execute accurate strikes against ground targets carrying out target selection and firing premised on AI (which is either on board or on a platform they are in data communication with). The MQ-9 Reaper has been used to test Agile Condor, an AI pod designed to detect, categorise and track potential objects of interest; this AI pod has the potential to identify targets and determine priorities for engagement. The loyal wingman UAV developed by Boeing for RAAF has similar target detection, prioritisation and engagement capabilities, as claimed by Boeing. This is applicable to loitering munitions as well, AI enabling them to carry out their suicidal missions without an operator in the loop but investing them with enough autonomy to recover safely if no worthwhile target is unearthed. An interesting European project is NeurONN, a demonstrator for the development, integration and validation of European technologies for next-generation combat aircraft and UAVs. Russian UAVs Okhotnik and Grom (both with AI capability for working with fighters) have been mentioned earlier; Altius, Sirius and Orion are three other Russian UAVs with autonomous/semi-autonomous capabilities.

AI has been quietly and surreptitiously making its way into UAV operations and each episode of success for UAVs strengthens the motivation to embed AI in diverse forms to enhance their capabilities. The US Navy X-47B has demonstrated not only deck launches, landings and go-arounds, but even an aerial refuelling, all carried out autonomously.[38] The QF-16,

37. Lee Ferran, "Early Predator Drone Pilot: I Had bin Laden in My Crosshairs", ABC News Network site, November 18, 2014, p. 1, at https://abcnews.go.com/blogs/headlines/2014/11/first-pilot-to-fire-missile-from-predator-drone-breaks-silence. Accessed on February 24, 2021.
38. Andy J. Fawkes and Lieutenant Colonel Martin Menzel, "The Future Role of Artificial Intelligence", *Joint Air Power Competence Centre Journal*, 27th edn., Autumn/Winter 2018, p. 72, at https://www.japcc.org/wp-content/uploads/JAPCC_J27_screen.pdf. Accessed on March 2, 2021.

an unmanned platform derived by converting old F-16s, has the capability to fly autonomously on predetermined routes for decoy roles or used as aerial targets for testing air-to-air missiles and guns. Looking ahead, it is easy to imagine UAVs that will be primed for fully autonomous missions with their designs hybrid to accommodate MUM-T errands when tasked to. Automatic target detection using optical, thermal and/or electromagnetic sensors would empower them for offensive roles while long-range sensors would render them invaluable for autonomous operations, including in hostile environments. A demonstration in 2020 showed a USAF MQ-9 Reaper engage a cruise missile using an AIM-9X air-to-air missile, thus revealing another aspect of AI-enabled UAVs' offensive potential.

Last year, US Army's Combat Capabilities Development Command (CCDC) released a Request for Information (RFI) for Air Launched Effects (ALE)[39] which would be a new family of UAVs air launched from scout and assault helicopters which would have multifarious capabilities including scout role, EW, attack, decoy, suicide munitions and swarm capabilities. The RFI stipulates that these UAVs need to be capable of semi-autonomous and fully autonomous operations and specifies that the camera systems on the UAVs would also be paired with AI-driven machine learning algorithms to automatically identify potential targets of interest. The steady rise of AI technologies is matched by the wants and needs of military aviation for a wide spectrum of AI capabilities.

Several spectacular demonstrations of UAVs operating in swarms have caught military attention in the recent past. Their small size and Radar Cross Section (RCS), low cost (permitting proliferate numbers to be used together), and AI to connect them together to seemingly think like one, makes UAV swarms objects of desire for military. Dramatic swarm attacks like the one on Saudi Aramco oil facilities at Abqaiq and Khurais in September 2019 have helped keep that interest live. DARPA's Offensive Swarm-Enabled Tactics

39. Joseph Trevithick, "The Army Has Unveiled Its Plan for Swarms of Electronic Warfare Enabled Air-Launched Drones", *The Drive*, August 20, 2020, p. 1, at https://www.thedrive.com/the-war-zone/35726/the-army-has-unveiled-its-plan-for-swarms-of-electronic-warfare-enabled-air-launched-drones. Accessed on March 3, 2021.

(OFFSET)[40] programme has contracted with nine companies to develop AI technology that will enable 250 small air and/or ground units to collaborate; aimed primarily at facilitating operations in dense urban environments, the programme showcases the promise of swarming UAVs. The interest in swarming UAVs is not restricted to US military only. China is making significant strides in that direction as also the European Union where several joint military programmes are on to produce AI-driven swarm technologies; the DRONEDGE-E project, for example, is aimed at designing an edge computing platform for the autonomous control of UAV swarms in real time with automatic generation of algorithms through AI. Details of some other swarm related projects can be found in a recent document called "Artificial Intelligence in European Defence: Autonomous Armament?"[41] authored by GUE/NGL, the left-wing group of the European Parliament. Roborder is another European project that is aimed at developing AI-piloted UAVs which would be tasked to patrol European borders autonomously; working in swarms, these UAVs will corroborate and coordinate information among air, ground and seaborne platforms.

Edge computing,[42] already being talked about as the next major revolution in information technology, is the emerging solution to the problem that, when it comes to high speed, highly manoeuvrable swarm UAVs collaborating with each other tactically in close proximity to each other and to hostile aerial platforms, cloud computing is too slow for their cooperative communication. Edge computing eliminates the time taken for devices/UAVs to communicate through cloud computing (which connects through centralised data centres or servers) and processes data on the spot at the "edge" of the network,

40. DARPA Outreach, "OFFSET Awards Contracts to Advance Swarm Tactics for Urban Missions, Enhance physical Testbeds", April 13, 2020, p. 1, at https://www.darpa.mil/news-events/2020-04-13#:~:text=DARPA%20has%20awarded%20contracts%20to,operate%20in%20dense%20urban%20environments. Accessed on February 14, 2021.
41. Christoph Marischka, *Artificial Intelligence in European Defence: Autonomous Armament?* (THE LEFT Group in the European Parliament: Brussels, 2020), pp. 28-30, at https://documentcloud.adobe.com/link/track?uri=urn%3Aaaid%3Ascds%3AUS%3A1884c966-f618-4110-a5f3-678899e4c8ee#pageNum=1. Accessed on March 5,2021.
42. Paul Miller, "What is edge computing?", *The Verge*, May 7, 2018, p. 1, at https://www.theverge.com/circuitbreaker/2018/5/7/17327584/edge-computing-cloud-google-microsoft-apple-amazon. Accessed on March 6, 2021.

Mosaic warfare visualises all military forces as plug and play tiles that conjointly form a mosaic which is constantly morphing with changing circumstances.

i.e., at or near the source of the significant data. This munificence of the information technology is quintessential to the progression of swarm UAVs; so is their employment of AI. Their copious use in future military kinetic action can be predicted with no risk of being proved specious.

AI IN MOSAIC WARFARE

With manned and unmanned aerial platforms being operated by more than one service under the Joint All-Domain Command and Control (JADC2) operations concept, DARPA has an admirable project in hand called Air Space Total Awareness for Rapid Tactical Execution (ASTARTE)[43] as a part of its mosaic warfare programme. As the name suggests, mosaic warfare visualises all military forces as plug and play tiles that conjointly form a mosaic which is constantly morphing with changing circumstances. The ASTARTE programme has three parts: first, algorithms that identify and predict airspace usage conflicts and determine restricted operating zones; second, sensors that in real time can detect and track manned and unmanned platforms; and third, a virtual lab testbed that enables modelling, simulation, and virtualisation of military airspace management systems. The idea is to leverage AI to handle diverse data sets to prevent fratricide between different services and to facilitate continuation of mosaic warfare even when some of its components get attrited or are withdrawn.

North Atlantic Treaty Organisation (NATO) has similar plans to use AI to help multinational coordinated air attacks[44] by using a new Alliance Ground Surveillance (AGS) technology to connect USAF RQ-4D Phoenix Global Hawks which gather, organise, analyse, process and transmit ISR

43. Theresa Hitchens, "DARPA Builds AI to Avoid Army, AF Fratricide", *Breaking Defense*, February 17, 2021, p. 1, at https://breakingdefense.com/2021/02/darpa-builds-ai-to-avoid-army-af-fratricide/. Accessed on March 6, 2021.
44. Kris Osborn, "Upgrade You: NATO's Global Hawk Drones Are About to Get Even Better", March 9, 2021, p. 1, at https://nationalinterest.org/blog/buzz/upgrade-you-nato%E2%80%99s-global-hawk-drones-are-about-get-even-better-179711. Accessed on March 10, 2021.

data among platforms from other member nations (of NATO). The objective is to enable uninterrupted operations. The two illustrations cited above are just a whiff of how AI is being yoked to reinforce operations; many other applications of AI exist, or are emerging. DARPA itself has approximately 30 programs focused on AI and another 90 that are leveraging AI technologies, according to Matthew Turek, programme manager in DARPA's Information Innovation Office.[45]

AI IN TRAINING AND SIMULATION

USAF has been exploiting AI for accelerating pilot training through its Pilot Training Next (PTN) programme since 2018 with some remarkable success in speeding up the training and in the assessed quality of programme graduates. When Virtual Reality (VR) was added on to AI, the training became even better and meaningful. As one instructor put it, "Students that get into the seat and start flying in the virtual environment are reacting like they would in the actual aircraft within minutes."[46] AI, in tandem with VR and high-volume data analytics, was instrumental in garnering and analysing the feedback from the trainees' actions thus empowering the instructors with individual training and correctional requirements for each trainee. Another development enabled by AI in pilot training is Live, Virtual and Constructive (LVC) training: Live refers to a pilot in an actual cockpit, Virtual relates to a pilot in an aircraft simulator, and Constructive is a purely software simulated training asset. According to CAE, global leader in the development and

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45. GCN Staff, "DARPA developing AI into a mission-critical partner", *GCN Digital Version*, March 12, 2021, p. 1, at https://gcn.com/articles/2021/03/12/darpa-ai-mission-partner.aspx. Accessed on March 16, 2021.
46. Geneva Giaimo, "Pilot instructor training 'embraces change' through virtual reality", Air Education and Training Command official site, October 22, 2018, p. 1, at https://www.aetc.af.mil/News/Article-Display/Article/1667413/pilot-instructor-training-embraces-change-through-virtual-reality/. Accessed on February 3, 2021.

delivery of integrated LVC training solutions for defence forces, "A truly integrated LVC training environment also provides infinite space to conduct training, variable threats needed for added realism, and the ability to test and exercise fifth generation platforms.[47]" This capability is critical to training for, say, the fifth-generation F-35, which does not have a dual seat version at all, all three versions being single-seat![48] Worthy of mention here is USAF's RPA Pilot Training Next (RPA: Remotely Piloted Aircraft) which has advanced AI infusion that helps faster and more efficient pilot training with provision to cater to their individual training needs as assessed by AI.[49]

The Chinese have also been planning to achieve similar arrangements using L-15 jet trainer aircraft; reportedly, the aircraft would be fitted with an AI-driven virtual tactical training system which could be linked to other aircraft or a ground simulator with the two being interconnected. According to *Global Times*, a Chinese English newspaper, Zhang Lang, L-15's Chief Designer, has reportedly stated that, "With the development of AI technologies in the future, we will be able to identify different habits each pilot has in flying…"[50]

Akin to AlphaDogFight (and indeed based on it), there are projects afoot to provide pilots in real aircraft but with Augmented Reality (AR) headsets to pit their combat skills against AI driven virtual fighters mimicking enemy aircraft. One remarkable experiment in this direction was the AR dogfight between a Berkut 540, a US-made piston engine, canard wing, pusher type, under one ton aircraft, and a simulated Chinese J-20 created by technology from EpiSci, a US-based AI company.[51] Clearly, AI, in tandem with VR

47. CAE, "Live-Virtual-Constructive (LVC) Training", CAE official site, undated, p. 1, at https://www.cae.com/defence-security/training-systems-integration/live-virtual-constructive-lvc-training-1/. Accessed on March 18, 2021.
48. "The Most Advanced Fighter Jet in the World", at Lockheed Martin official site, undated, p. 1, at https://www.lockheedmartin.com/en-us/products/f-35/f-35-about.html. Accessed on March 15, 2021.
49. "Air Force flight training experts eye artificial intelligence (AI) to help hone skills of unmanned pilots", July 2, 2020, p. 1, at https://www.militaryaerospace.com/unmanned/article/14178834/artificial-intelligence-ai-unmanned-flight-training. Accessed on February 6, 2021.
50. Liu Xuanzun, "China's future fighter trainer could feature AI to boost pilot's combat capability: top designer", *Global Times*, November 15, 2020, p. 1, at https://www.globaltimes.cn/content/1206906.shtml. Accessed on February 8, 2021.
51. Thomas Nedwick, "Pilot in a Real Aircraft Just Fought an AI-Driven Virtual Enemy Jet for the First Time", *The Drive*, November 16, 2020, p. 1, at https://www.thedrive.com/the-war-

and AR, is moving at an impressive pace towards providing speedier and superior training and simulation solutions for military aviation.

AI AND AIRCRAFT MAINTENANCE

Aircraft maintenance is hugely expensive and any reduction in maintenance repairs or replacements can save large amounts of money while maintenance lapses or material/component failures before prescribed schedules can have air safety implications, not to mention expensive hull losses and catastrophic pilot casualties. AI is proving to be a useful tool in predictive and preventive maintenance. Preventive maintenance is regular and routine maintenance so as to keep an aircraft flying and prevent any costly unplanned downtime from unexpected equipment failure. Predictive maintenance uses AI and data analytical tools to predict how long an aircraft component will last and can be seen as a subset of preventive maintenance. Early endeavours to automate preventive maintenance date back to Lockheed Martin's Autonomic Logistics Information System (ALIS) designed for the F-35 in 2015 but, since then, technologies (and especially AI/ML technologies) have come a long distance.

USAF has four Advanced Technology and Training Centres (ATTCs); the one in Pittsburgh, a city considered a hub in the industry of robotics, AI and machine learning, has been tasked to develop, among others, predictive maintenance algorithms that will identify potential maintenance issues on aircraft faster. According to Nathan Parker, USAF Rapid Sustainment Office (RSO), "Historically, 70 percent of weapon system lifecycle costs are in the operation and sustainment phase. The ATTCs are one tool to help reduce future costs…" The RSO is also working with C3.ai since 2017 and is now expanding that relationship for more predictive analytics while JAIC issued an RFI last year for a Holistic Aircraft Component Health Predictor (HAC-HP) programme for the H-60 helicopter. These are some of the programmes that showcase AI/ML in preventive/predictive maintenance.

Predictive maintenance is theoretically possible based on what has happened in the past; it is but the use of data and ML techniques to identify the probabilities

zone/37647/pilot-in-a-real-aircraft-just-fought-an-ai-driven-virtual-enemy-jet-for-the-first-time. Accessed on February 7, 2021.

of future outcomes based on historical data. The problem is that with complex technologies and exceptional data collection tools, the quantum of data that needs to be analysed has grown tremendously. The information overload makes manual analysis impossible and that is where AI-powered predictive analysis comes in for handling "big data", a term first used in 1997 to describe data sets that "are generally large, taxing the capabilities of main memory, local disk, and even remote disk." Today's context of cloud computing renders that definition mirthful but certainly the term big data can be visualised as data that cannot be handled by computers without machine learning to assist (and, of course, extensive server space on cloud). The use of AI/ML to handle big data by software designed for use on board UAVs under Project Maven is in trouble (discussed later), but use of AI/ML for preventive and predictive maintenance does not invite the same objections that Project Maven did.

USAF has two initiatives for predictive maintenance: Condition Based Maintenance Plus (CBM+) being used for B-1, C-5 and KC-135 aircraft, and Enhanced Reliability Centred Maintenance (ERCM) which has a large number of aircraft and weapon systems under it with more being added. These are but two of the predictive maintenance programmes using AI/ML for predictive maintenance while JAIC has other projects too in various stages of fruition.[52] Although maintenance activities are not as visible as the operations end, the deployment of AI into the maintenance domain is certainly a largesse that military aviation can benefit from, and be grateful for.

ETHICS IN MILITARY AI

Henry Kissinger, former US Secretary of State and National Security Advisor (NSA), writing in 2018 about AI, raised a profound and ponderable question, "…It may be impossible to temper those mistakes, as researchers in AI often suggest, by including in a program caveats

52. Frank Wolfe, "Air Force to Add 12 Weapons Systems for AI/ML-Informed Predictive Maintenance This Year", July 9, 2020, p. 1, at https://www.defensedaily.com/air-force-add-12-weapons-systems-ai-ml-informed-predictive-maintenance-year/army/. Accessed on March 12, 2021.
Full recording of Mitchell Institute for Aerospace Studies virtual discussion with Lt Gen Warren Berry can be viewed at https://www.youtube.com/watch?v=Zaezgq9xjN0&ab_channel=TheMitchellInstituteforAerospaceStudies. Accessed on February 15, 2021.

requiring 'ethical' or 'reasonable' outcomes. Entire academic disciplines have arisen out of humanity's inability to agree upon how to define these terms. Should AI therefore become their arbiter?[53]" Many individuals and groups before that have articulated misgivings about the increasing role of AI in military spheres. Since October 2012, a "Campaign to Stop Killer Robots", a coalition of Non-Governmental Organisations (NGOs), has been opposing fully autonomous weapons on the grounds that they, as machines, "would lack the inherently human characteristics such as compassion that are necessary to make complex ethical choices",[54] and canvassing for a complete ban on their development, production and use. Another notable initiative is a "pledge"[55] introduced by the Future of Life Institute, a Boston-based charity organisation, which avers that AI developments can contribute to future danger. Elon Musk and Google's DeepMind co-founders Demis Hassabis, Shane Legg and Mustafa Suleyman are among the (more than 3,000) individual signatories; a large number of organisations have also signed up.

Within the US, which is currently the leading global military AI power, there is noteworthy opposition to military use of AI; one DoD programme that has brought this to the fore is Project Maven. Also called Algorithmic Warfare Cross-Function Team, or AWCFT, it was launched in April 2017 and is aimed at developing and deploying AI-based algorithms to integrate and manage big data—largely video collected in support of counter-insurgency and counterterrorism operations—into actionable intelligence; a major thrust was analysis of videos amassed by UAV missions. In 2018, around 3,000 Google employees, fearing that the project would eventually be used for military purposes, signed an open letter affirming their belief that Google should not be in the business of war to Sunder Pichai, CEO, who then

53. Henry A. Kissinger, "How the Enlightenment Ends", *The Atlantic*, June 2018, p. 1, at https://www.theatlantic.com/magazine/archive/2018/06/henry-kissinger-ai-could-mean-the-end-of-human-history/559124/. Accessed on March 3, 2021.
54. Campaign to Stop Killer Robots official site, "The Problem", p. 1, at https://www.stopkillerrobots.org/learn/. Accessed on February 4, 2021.
55. Future of Life Institute, "Lethal Autonomous Weapons Pledge", Future of Life Institute official site, p. 1, at https://futureoflife.org/lethal-autonomous-weapons-pledge/. Accessed on February 7, 2021.

The outcry over Project Maven and the trepidation over possible civilian casualties led DARPA to launch a programme called Urban Reconnaissance through Supervised Autonomy (URSA); its most innovative feature is the inclusion of ethics from the very start and to develop technology to enable autonomous systems that US ground forces supervise and operate to detect hostile forces and establish positive identification before any US troops or UAVs assault them.

published on his blog seven "Objectives for AI Applications"[56] and also a list of what AI applications Google would not pursue. Eventually Google bowed out of the Project but not before posting a sticky note on public attention about ethics in military use of AI. In February 2020, DoD was forced to adopt ethical principles for AI and designate JAIC as the nodal implementation agency.[57] At least one analyst has identified an "ethics gap"[58]—the higher ethical hurdle that the US faces as compared to its adversaries (mainly China) to developing and deploying military AI.

In 2012, US DoD had issued a directive on AI that specified that, "Autonomous and semi-autonomous weapon systems shall be designed to allow commanders and operators to exercise appropriate levels of human judgment over the use of force."[59] The outcry over Project Maven and the trepidation over possible civilian casualties led DARPA to launch a programme called Urban Reconnaissance through Supervised

56. Sunder Pichai, "AI at Google: our principles", blog.google, June 7, 2018, p. 1, at https://blog.google/technology/ai/ai-principles/. Accessed on February 3, 2021.
57. US Department of Defense, "DOD Adopts Ethical Principles for Artificial Intelligence", US DoD official site, February 24, 2020, p. 1, at https://www.defense.gov/Newsroom/Releases/Release/Article/2091996/dod-adopts-ethical-principles-for-artificial-intelligence/. Accessed on March 5, 2021.
58. Benjamin Boudreaux, "Does the US Face an AI Ethics Gap?", RAND blog, January 11, 2019, p. 1, at https://www.rand.org/blog/2019/01/does-the-us-face-an-ai-ethics-gap.html. Accessed on February 7, 2021.
59. US Department of Defense, "Directive No. 3000.09", US DoD official site, November 21, 2012, amended on May 8, 2017, p. 1, sub-para 4.a.(1), at https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodd/300009p.pdf. Accessed on March 9, 2021.

Autonomy (URSA);[60] its most innovative feature is the inclusion of ethics from the very start and to develop technology to enable autonomous systems that US ground forces supervise and operate to detect hostile forces and establish positive identification before any US troops or UAVs assault them. DoD stresses that humans will continue to make the final decision on whether to escalate or reduce response to a perceived threat with URSA, providing additional intelligence for that decision making.

Military AI is inevitable and the US, although shackled by public opinion in this regard, would have to accept that and continue to try and get ahead of China even in the face of public opprobrium. Alternatively, it could lose out to China.

Military AI opponents' perceived inescapability of a human brain in weapon use is based on distrust in AI-driven autonomous weapons which, they argue, could be less ethical than human operators in the context of International Humanitarian Law (IHL) premised on the principles of humanity and of military necessity. Arguments have been offered to the contrary[61] suggesting that AI systems can be programmed to comply with IHL and would be more likely to follow them than humans who can forget them or disregard them due to a whole range of human emotions, cognitive biases and beliefs in the fog of war. DoD's official adoption of a series of ethical principles for AI was a bid to assuage public apprehensions about ethics of using AI so that the US could continue working towards maintaining the lead in AI (which is threatened by a speedily gaining China). Military AI is inevitable and the US, although shackled by public opinion in this regard, would have to accept that and continue to try and get ahead of China even in the face of public opprobrium. Alternatively, it could lose out to China.

60. Bartlett Russell, "Urban Reconnaissance through Supervised Autonomy (URSA)", DARPA official site, undated, p. 1, at https://www.darpa.mil/program/urban-reconnaissance-through-supervised-autonomy. Accessed on March 7, 2021.
61. Adriel Hampton, "What if autonomous weapons are more ethical than humans?", in *Extra News Feed*, December 9, 2020, p. 1, at https://extranewsfeed.com/what-if-autonomous-weapons-are-more-ethical-than-humans-5369890659cf. Accessed on March 11, 2021.

The UN Convention on Certain Conventional Weapons (UNCCCW), also known as the Inhumane Weapons Convention, has the stated purpose to ban or restrict the use of specific types of weapons that are considered to cause unnecessary or unjustifiable suffering to combatants or to affect civilians indiscriminately. Since 2014, it has included in its gambit "emerging technologies in the area of Lethal Autonomous Weapon Systems (LAWS)."[62] US DoD defines an autonomous weapon system as "a weapon system that, once activated, can select and engage targets without further intervention by a human operator. This includes human-supervised autonomous weapon systems that are designed to allow human operators to override operation of the weapon system, but can select and engage targets without further human input after activation."[63] In 2019, UNCCCW adopted 11 guiding principles on LAWS; the first one reiterates that IHL continues to apply to development and use of LAWS. However, only 97 nations have openly revealed their thinking on banning of LAWS; indeed, some—like Australia—have official, documented policies on ethical use of military AI.[64] Significantly, in UNCCCW, Australia, France, Germany, Israel, New Zealand, Russia, South Korea, Spain, Turkey, the UK and the US have consistently opposed any ban,[65] while China has supported a ban on the use, but not on development, of LAWS. Thus, banning of LAWS (with repercussions on military use of AI) appears to be a distant dream.

Despite strong criticism of AI controlled weapon systems, global consensus on military AI appears to be a distant dream but a G-7 backed

62. UN official site, "Background on LAWS in the CCW", p. 1, at https://www.un.org/disarmament/the-convention-on-certain-conventional-weapons/background-on-laws-in-the-ccw/. Accessed on March 4, 2021.
63. US Department of Defense, "Directive No 3000.09", US DoD official site, November 21, 2012, amended on May 8, 2017, p. 1, at https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodd/300009p.pdf. Accessed on March 9, 2021.
64. Kate Devitt, Michael Gan, Jason Scholz and Robert Bolia, "A Method for Ethical AI in Defence" (Canberra: Aerospace Division, Defence Science and Technology Group, Australian Government Department of Defence, accessed on February, 2020), at https://www.dst.defence.gov.au/sites/default/files/publications/documents/A%20Method%20for%20Ethical%20AI%20in%20Defence.pdf. Accessed on March 9, 2021.
65. Kelley M. Sayler and Michael Moodle, "International Discussions Concerning Lethal Autonomous Weapon Systems", Congressional Research Service, US Congress, p. 1, at https://fas.org/sgp/crs/weapons/IF11294.pdf. Accessed on March 6, 2021.

initiative called Global Partnership for Artificial Intelligence (GPAI) aims to bridge the gap between theory and practice on AI by supporting cutting-edge research and applied activities on AI-related priorities. India is a founding member while China is conspicuous by its absence; clearly its government is blinkered with respect to its objective of leading the world in AI by 2030. Ethics do not seem to be a serious consideration for China and the result could be that other players too may be compelled to disregard ethical and legal issues in pursuit of AI supremacy.

CONCLUDING REMARKS

The penetration of AI into military aviation is inexorable and unlikely to be thwarted by protestations at national, public or organisational levels. Given UN's record at securing consensus on international treaties, ongoing (and rather inordinately slow-moving) proceedings of UNCCCW are unlikely to stop (or even slow down) the rapid advances being tendered by AI to military aviation. The projects and programmes outlined above are constantly being incrementally rendered more and more ambitious by the expanding potential of AI to enrich and enhance them. The single most significant AI munificence promises to be AI in the cockpit with the competence to autonomously fly an aircraft in its full spectrum of roles. That is not within reach of current day technology despite the sensational AlphaDogFight demonstration, but it is not hard to visualise it happening over the next few years. Besides cockpit AI, connectivity between manned and unmanned elements of the envisioned teams is going to be a problem with edge computing still not ready to deliver at speeds needed for aerial combat in teams. When that becomes possible, ethical demurral is unlikely to be able to stop solo flights by AI in military aircraft because of the immense advantages intrinsic to that option. Meanwhile apprehensions about AI's ethical credentials for occupying a cockpit are being assuaged by projecting the near future as a manned and unmanned teamwork with a human in command of a mission and all its elements (in contrast to an autonomous decision-making AI in any cockpit).

Size, Weight and Power Consumption (SWaP) is critical to embedded AI in avionics, and technology is obsessed with reducing this set of parameters to make AI more usable and deployable. Another innovation is neuromorphic computing which endeavours to mimic the human brain's neural structure so as to reinforce what Intel calls the "third generation of AI"[66] dealing with human cognition, interpretation and autonomous adaptation. As these advances provoke AI to imitate human brain functions with increasing fidelity and reducing proneness to failure, the prospect of an AI-manned cockpit executing an autonomous mission becomes brighter and closer.

While the military world awaits that significant leap, the other benefits of AI in military aviation are worth exulting over. On the downside, with US and China grappling for the lead in AI and with AI gaining more and more leverage in military spheres, a Cold War kind of situation, replete with implacable distrust, deadly subterfuge and unyielding rivalry is already upon us. With an impressive number of AI companies, a very fecund start-up ecosystem, a highly productive scientific academia, and the world's fourth largest Air Force, India is at a rallying point of all the ingredients for inducting AI into its labouring aerospace industry. On January 15, 2021, the Indian Army staged an impressive demonstration with 75 UAVs in offensive roles; notwithstanding that demonstration, the ingress of AI into Indian military aviation is not consistent with the potential described above. Reports at the time of writing this prognosticate government's approval for development of India's Advanced Medium Combat Aircraft (AMCA); when that happens, it would be time to harness our best AI academic, technological and industry assets so as to endow the AMCA with the best in AI. Whether that campaign is spearheaded by an internally inefficient public sector, or an eager but deprived private sector, would decide the level of exploitation that India derives from AI in military aviation.

66. "Neuromorphic Computing", Intel official site, p. 1, at https://www.intel.in/content/www/in/en/research/neuromorphic-computing.html. Accessed on March 14, 2021.