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Military mimicry: the art of concealment, deception, and imitation

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ABSTRACT
Three dominant thematics emerge from the biological mimicry and camouflage literature, namely, concealment, deception, and imitation. These phenomena are interesting in their own right, but conceptually have similar analogs in the military context that have attracted only minimal intellectual curiosity. Accordingly, the purpose of this paper is to apply biological mimicry and camouflage concepts to the military environment. Concealment in the form of camouflage is traced from its nineteenth century origins to the military's imminent twenty-first century perfection of an "invisibility cloak". Military deception is the art of duping enemies with fakes and dummies. Finally, imitation is examined from three perspectives: firstly, replacement of military personnel with animals; secondly, exploration of bioengineering, including exploitation of avian aerodynamics, insect biophysical structures, and mammal sonar attributes; and, thirdly, Artificial Intelligence that is driving military mimicry along an evolutionary path towards robots, swarms, and avatars in an emerging and novel military technology revolution.

KEYWORDS
Bioengineering; swarms; artificial Intelligence; camouflage; drones; robotics; genomics

Introduction

The focus of this paper is on mimicry. It is a concept that has attracted substantial academic enquiry in the biological world, leading to a wealth of scholarship. Examination of the fascinating biomimicry processes provides the taxonomy for this study on the applied subject of military mimicry. There are, we posit, three elements to military mimicry: firstly, concealment – normally reflected through camouflage to conceal military assets; secondly, deception – reflecting the evolution of "dummy" military assets, often to encourage the enemy to attack, reveal their positions, and quickly be destroyed as a consequence; and, thirdly, imitation. The final element in this taxonomy is the most complex, as it can be decomposed into three further subfields of analysis. To begin, there is animal imitation of military tasks, such as WWI pigeons replacing the role of military runners. In reverse, there is also military emulation of animal performance through

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bioengineering, including the adaption of cockroaches and ants for military purposes. Finally, as armed forces become immersed in Artificial Intelligence (AI) and robotics, there is the unfolding phenomenon of these technologies, including swarms, avatars, neuroscience, and genomics, mimicking military forces and assets in the pursuit of twenty-first Century warfare. These three imitative pathways are illustrated in Figure 1, below.

Structurally, the paper begins with the identification, explanation, and analysis of the role of mimicry and camouflage in the natural world. The remainder of the paper concentrates on a critical discourse of military mimicry as per concealment, deception, and the three imitative pathways depicted in Figure 1. The third pathway of military mimicry is novel, reflecting the world's rapid transition to a higher technological stage in what is often termed the Revolution in Military Affairs (RMA). The principal change driver is AI. Thus, whilst the use of animals in military settings will not disappear, their involvement will diminish, to be replaced by robotics and software-intensive systems that will herald dramatic transformational change in the nature of war. The paper closes by offering conclusions on mimicry's contribution to the conduct of war. The imperative here is to achieve the elusive trifecta of strategic benefits, namely optimisation of cost-effective military capability, reduction in systems complexity and minimisation of manned-asset attrition and military casualties.

Mimicry's roots in the natural world

Biological mimicry

The term mimicry derives from the Greek word "mimesis",[1] defined by Aristotle as the perfection and imitation of nature.[2] This paper treats mimesis and mimicry as synonymous, and henceforth only the latter term will be employed. Mimicry has a long history in the field of biology.[3] Biological mimicry can broadly be defined as the evolved resemblance between an organism and a given object. More specifically, it involves one or more species undertaking three different roles: the model, the mimic itself, and the receiver/dupe (the species that is deceived by the mimic's signals).[4] The model on which the mimic bases itself can be a living organism (e.g. a poisonous species with a clear warning colouration) or, according to some definitions, an inorganic object (e.g. stones), although other authors consider the latter to represent a distinct concept.[5] The same species can be the model, mimic, and receiver (and any

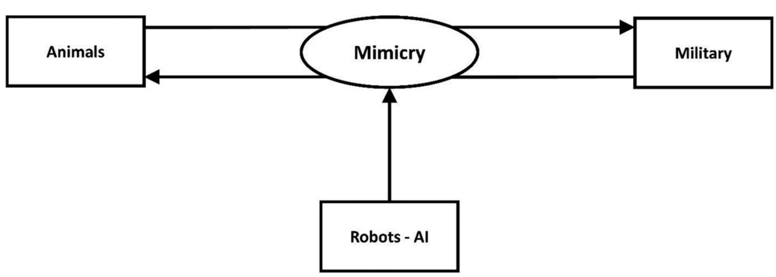

Figure 1. The three imitative pathways of military mimicry.

combination), and mimicry evolves if the receiver perceives the resemblance between model and mimic and changes its behaviour accordingly, thus providing a selective advantage to the mimic.

Whilst some authors contend that biological mimicry must involve some sort of deception (hence the use of the term dupe), others have argued that the receiver need not suffer a cost of failing to distinguish between the mimic and the model, and indeed can even benefit from the process (i.e. mutualistic mimicry).[6] It is also worth noting that the mimic is not necessarily mimicking the model itself, but rather the receiver's perception of the model, and because of this, in addition to other reasons, imperfect mimicry is a common occurrence in nature. The perception of the receiver is in fact central to the presence of biological mimicry, as if a receiver does not perceive the similarity between mimic and model in relation to a particular signal (e.g. a chemical cue), the signal is not said to be mimetic.

Mimicry has evolved across a broad range of taxonomic groups, including vertebrates, invertebrates, fungi, and plants;[7] and can involve a number of different signals, individually or in combination, including visual, acoustic, tactile, chemical, and possibly even electrical signals.[8] Based on these different signals, and on the different contexts in which mimicry occurs – including for protective purposes (e.g. where the mimic is potential prey), reproduction, competition, or aggression (e.g. where the mimic is a predator) – there are many different types of biological mimicry. These types include: Batesian mimicry – where members of a potential prey species gain protection from predation by mimicking the defensive and warning (i.e. aposematic) signalling of an unpalatable or defended species (a "sheep in wolf's clothing"); Emsleyan mimicry – whereby a lethal mimic resembles a less deadly (but lesson-teaching) model; Dodsonian mimicry – whereby a given flower species mimics the signals of other flower species to attract pollinators; and Kirbyan mimicry – where a parasite mimics its own host (e.g. brood parasitism).[9]

Spectacular examples of these different types of biological mimicry abound. For example, the African swallowtail butterfly (*Papilio dardanus*) mimics different model species (e.g. species of unpalatable butterflies) in different parts of its range.[10] There is additionally the case of the green, star-shaped flowers of an obscure South African plant *Ceropegia gerrardii* producing a fluid and scent that mimic the smell of honeybee blood, spilt after being killed by spiders and praying mantises. The purpose of this subterfuge being to entice Jackal flies, which feed on the blood of the bees, to pollinate the *C. gerrardii* flowers.[11]

Camouflage

While camouflage is often discussed in the context of natural mimicry, certain authors consider it to be a distinct phenomenon; that is, mimicry involves replication of certain signals of other organisms and incorporates both a behavioural change from the receiver and a demographic/evolutionary change in the model, whilst camouflage simply relates to a blending-in with the background environment. Either way, camouflage offers the means for concealment through environmental adaption. Indeed, while Charles Darwin did not use the term directly, he viewed camouflage in the animal kingdom as representing evidence of evolutionary adaptation. In his 1859 seminal work, *On the Origin of Species,* Darwin noted: "When we see leaf-eating insects green, and bark-feeders mottled-grey; the alpine ptarmigan white in winter, the red-grouse the colour of heather, and the black-grouse that of peaty earth, we must believe that these tints are of service to these birds and insects in preserving them from danger."[12] Thus, in a zoological context, camouflage can be defined as the suite of adaptations, including body colour, patterning and a range of other morphological adaptations that reduce the probability a given animal is detected or recognised by another.[13] This typically occurs by increasing the resemblance between the organism and the background environment (protection through concealment) or, at least according to certain authors, inanimate objects (i.e. masquerade; that is, protection through misidentification).[14]

As with mimicry, there are many striking examples of camouflage in the natural world. For example, some species of chameleon, fish and octopus are capable of changing their skin colours and patterns according to the surrounding environment for purposes of concealment, or to signal, or to attract partners.[15] Indeed, Peter Forbes describes octopuses – rather than the chameleon – as the archetypal camouflaged animal, representing a "living, breathing, swimming compendium of every camouflage and mimicry technique known."[16] Moreover, even plants engage in camouflage to avoid being eaten by herbivores, including humans.[17] For example, a recent study found that a species of alpine plant (*Fritillaria delavayi*), commonly harvested by humans for use in traditional Chinese medicine, has evolved to match the colouration of its leaf with the background environment; the degree of background matching being related to the amount of harvest pressure.[18]

Military mimicry

Three dominant thematics emerge from the above review of the biological mimicry and camouflage literature, namely, concealment, deception, and imitation. These phenomena are interesting in their own right, but conceptually have similar analogs in the military context; which, as yet, have attracted only minimal intellectual curiosity. The derived analytical framework employed in this paper was first adopted in 2003 by Christopher Flaherty, who argued that mimicry in the natural world "may represent an increasingly cost-effective way of achieving a desired [military] operational effect … to exploit concealment, deception and imitation techniques."[19] Military mimicry is hence relevant to endeavours aimed at hiding, misrepresenting, copying, and improving military capability. While animals[20] have played a pivotal historical role; either in replacing military personnel and/or offering opportunities for copying nature's enhanced performance characteristics, other technological dynamics are now evolving.

Concealment through camouflage

Following the explanatory framework for biological mimicry and camouflage outlined above, the first form of military mimicry to be considered is concealment. It has a long and illustrious history of innovation, with its origins rooted in the transformation of nineteenth century uniforms in European land battles. Counter-intuitively, the Prussian troops at the 1815 Battle of Waterloo were dressed in brightly coloured uniforms. Yet, there was a logic to the gaudy colours. In an age of close combat, ready identification of "friend and foe" was the paramount military objective, and easily identifiable uniforms represented the basis for recognition and coherence during the fog of battle. The advent of longer-range infantry rifles dramatically changed battle tactics. As a consequence, effective concealment principally through camouflage became a priority. Repeating rifles required soldiers to become less obvious targets, and British Regiments, mimicking their animal counterparts, adopted rifle green to become less conspicuous against the natural habitat backdrop.[21] Similarly, in 1848, the British Corps of Guides in India adopted so-called "drab" uniforms – invisible in a land of dust – by using a local dye to transform the natural dark colour into Khaki (Urdu for dusty, soil-colored).[22]

Although camouflage was used in the nineteenth century, the term did not formally enter the military lexicon until WWI, when the French used it to describe the application of colours and materials to uniforms to conceal military personnel from enemy observation.[23] Avoidance of detection not only applied to uniforms but also to military assets, specifically to make platforms, such as vehicles, warships and aircraft, "disappear". Long-range observation, often by spotter aircraft, facilitated accurate artillery assault, and this inevitably led to the wide-scale adoption of camouflage. In fact, the French military recruited artists as camouflage officers, who were influenced by the concept of counter-shading; that is, the art of merging objects into background environmental contexts.[24] The industrial scale of camouflage activities during the war can be illustrated by France's 1915 establishment of a *section de Camouflage* at Amiens,[25] and just three years later, there was a command of camouflage workshops employing in excess of 9,000 workers, not counting the *camoufleurs* working at the front.[26] The British military also had a camouflage capability, which, by the war's end, had reportedly painted more than 2,300 vessels.[27] Art and nature had seemingly come together in the service of warfare.

The arrival of WWII confirmed the importance of camouflage, with the conflict spurring sophisticated forms of scale invariance, typically digital patterns comprising pixels, designed to disrupt platform invariance and silhouettes at a distance. "Olfactory" camouflage also emerged through, for example, sniper garments made from strips of Hessian cloth treated with mud or even manure to hide a sniper's human odour.[28] The use of camouflage in WWII was not confined to the European theatre, but also played an important role in the North African campaign. Of significance here is Hugh Cott's celebrated 1940 work on animal-related camouflage, *Adaptive Coloration in Animals,*[29] which has been described as "the only compendious zoology tract ever to be packed in a soldier's kitbag".[30] Cott later led the camoufleurs working for the British Eighth Army in Egypt, where concealment via camouflage was used to great effect.[31]

The twenty-first century witnessed further camouflage developments, albeit that effective design in different operational contexts remained elusive. For example, for nearly a decade, U.S. military engagement in Afghanistan suffered from a case of the "emperor's new clothes": from the initial invasion in 2001 until about 2009, many U.S. Army soldiers were deployed wearing a protective camouflage pattern so ineffective that it actually seemed to attract enemy fire.[32] Since then, dramatic changes have been introduced to improve camouflage effectiveness. The principal focus of these innovations has been to develop active or adaptive technologies that will adapt rapidly to the surrounding environment, seeking concealment from visual detection. "Active" camouflage is derived from land-based animals, including many reptiles, but more importantly from cephalopod molluscs, such as cuttlefish, octopuses, and squids; these being able, from chromatophore organs, or tiny pigment sacks inside their skin, to change texture, pattern, and colour in milliseconds in response to new backdrops.[33] U.S. researchers are working with the military to isolate pigment granules from these organs, better to understand their role in colour change, especially when incorporated into the military camouflage textiles. Whilst the science behind this innovation – biomimetics, nanotechnology, and genetic modification – is futuristic, the expectation is that it will become operational in 5–10 years.[34]

The *National Geographic* publication states that no man-made technology comes close to matching the transforming talents of the cephalopods, which have proved the inspiration for U.S. university researchers to develop military vehicle optoelectronic camouflage sheets capable of reading the environment and mimicking their surroundings.[35] The technology can be enhanced to operate in full colour spectrum, having a flexible skin, composed of extremely thin layers of semi-conductor actuators, switching components and light sensors, with inorganic reflectors and organic colour-changing materials that combine to allow the sheet to autonomously colour-match its background.[36] Similarly, South Korean researchers have created a robot capable of changing its colour; just like a chameleon, by using heated nanowires and thermocromic materials.[37] Active military camouflage has also been tested using organic light-emitting diodes (OLEDs), allowing images to be projected onto irregularly shaped surfaces.[38] There has also been military-related research on computational holography, but perhaps the most sophisticated technology is the focus on developing Quantum Stealth Light Bending Material, possessing more than a passing semblance to Harry Potter's "Invisibility Cloak"; it not only hides a military target in the visible spectrum, but also "bends" in the ultraviolet, infrared, and shortwave infrared, thus blocking the thermal spectrum, and translating into a true broadband Invisibility Cloak.[39] Indeed, fiction will shortly become fact, given early 2024 reports that Putin's forces will soon be equipped with a new invisibility cloak that will hide them from heat-detecting lens.[40] Military efforts designed to hide assets have similarly been applied to aerial systems, whereby the introduction of heat-seeking missiles has led to innovations designed to conceal the emission of hot exhaust gases from aircraft engines.[41]

To deceive, "as old as War itself"

The second principal form of military mimicry is deception, defined as "actions executed to mislead opponent decision makers into taking specific actions or lack of action that contributes to the success of one's own efforts."[42] Deception in military conflict invariably translates into the deployment of fakes and dummies.[43] In WWII, Operation Bertram played a decisive part in the British victory over Germany's Field-Marshal Rommel in the battle of El Alamein, North Africa, where, in addition to camouflage, deceptive mimicry was employed through the creation of large-scale decoys, including a dummy railhead.[44] The fake assets consisted of large numbers of realistic dummy tanks and artillery made from local calico and palm frond hurdles, and supported by electromagnetic deceptions that laid a trail of false radio traffic, convincing Rommel that the British had an additional armoured division in reserve.[45]

In the Vietnam War, the U.S. Air Force pursued a novel form of deception in response to North Vietnamese fighter successes in shooting down heavily laden and slow-moving U.S. F-105 bombers.[46] U.S. Air Force pilot, Robin Olds, devised a deceptive mimicry mission called Operation Bolo. The plan was to deceive the North Vietnamese by locating F-105 Electronic Counter-measure pods on F-4 Phantom fighters, so that they would display the F-105 signature on the enemy's radar systems, with the deception reinforced by using the same call signs, flight paths and timings as the F-105 bombers.[47] In the resulting dogfight, Old's "wolf-pack" was credited with seven confirmed Mig-21 kills, and a further two probable kills, representing the destruction of more than half North Vietnam's combat aircraft inventory, against zero U.S. losses.[48]

In the twenty-first Century, high technology has continued to play an important role in military deception. The proliferation of radar and sonar systems, for example, has reduced dependence on the human eye for detection of military assets, auguring the use of stealth technology. Combat aircraft and warships are now configured to deflect radar impulses, with radar-absorbing materials applied to reduce radar signatures. For instance, the U.S. Miniature Air-Launched Decoy, or MALD system, is a low-cost, expendable, air-launched craft that acts to deceive the most advanced enemy integrated air defence systems.[49] It does this by copying the combat flight profiles and signatures of U.S. and allied aircraft, while keeping pilots and aircraft out of harm's way.[50] The MALD employs a *Signature Augmentation Subsystem* (SAS) that leverages active radar enhancers across a range of frequencies to fool defensive radar systems into mistaking the missile-shaped MALD for jets, ranging from stealthy F-117 Nighthawks to massive B-52 payload-ferrying bombers.[51] Among the first American assets to enter enemy airspace, these MALD jamming decoys will be deployed into a contested area alongside cruise missiles and aircraft, forcing enemy air defence systems to differentiate between real and fictional radar returns; the difficulties being compounded by the stream of static delivered by MALD's jamming capabilities.[52] Launching interceptors at a swarm of real and simulated radar returns would leave enemy systems vulnerable to attack from anti-radiation missiles, such as the AGM-88/AARGM-ER on the F-35s, while simultaneously depleting the enemy's surface-to-air missile stores.[53]

While the present Russia-Ukraine war does not reflect this degree of technical sophistication, deception nevertheless features in land operations. Ukraine's use of dummy assets probably accounts for the discrepancy between Russian and Ukrainian estimates regarding the destruction of the latter's HIMAR Rocket Launcher units, with one U.S. diplomat arguing that Moscow has "claimed to have hit more HIMARS than we have … [supplied]".[54] The Ukrainians are reportedly even replacing traditional heavy wooden dummies of tanks and artillery pieces with inflatable versions, which are cheaper and faster to deploy.[55] Moreover, to make the inflatable military equipment more realistic, Ukrainian forces are simulating tank tracks and comms traffic, and using valid radar signals and reflectors to simulate the heat emitted from gunfire to fool thermal imaging cameras on drones, and invite Russian attacks that lead to inevitable Ukrainian responses.[56]

Military imitation

The third form of military mimicry is imitation, representing the act of copying and effecting the resemblance of another object.[57] As such, imitation represents the principal focus of the remainder of this paper, with attention directed, as illustrated in Figure 1, towards three forms of imitation: firstly, deployment of animals in military roles; secondly, military mimicry of animals; and thirdly, AI mimicry of the military.

Animals deployed to mimic the military

Here, the focus is on the use of animals to mimic military roles. For instance, during WWI, pigeons were used instead of runners to facilitate communications, even receiving battlefield honours for their bravery.[58] In WWII, dogs were used to reinforce the security of military camps and coastlines, with the U.S. providing an interesting case study on the use of dogs in war. After the Japanese attack on Pearl Harbour in December 1941, "Dogs for Defense" was formed to train dogs to patrol U.S. borders, beaches, and industrial facilities, as well as to perform sentry duty, in order to prevent sabotage; reportedly, by war-end, the Quartermasters Corps had assigned 3,174 dogs to the U.S. Coast Guard alone.[59] War dogs were also trained to "sniff-out" Japanese and German soldiers in the respective Asia-Pacific and European campaigns, proving effective at ranges up to 1,000 yards, and saving many lives from possible ambush.[60]

From the 1950s, the U.S. military switched its focus to exploiting the strategic capabilities of mammals, to complement, if not supplant, the role of naval personnel. The Naval Marine Mammal Program (NMMP) has studied a variety of animals, such as seals, killer whales (*Orcinus orcann*), dolphins, sea lions, and beluga whales (*Delphinapterus leucas*).[61] After testing the military suitability of 19 species of marine mammals, including sharks, the navy selected sea lions for operational duty due to their impeccable underwater vision; and in 2003, they were deployed to Bahrain to support Operation Enduring Freedom following the September 11 attacks.[62] Dolphins also attracted attention, but more for their highly-evolved bio-sonar capability, making them especially suited for detecting underwater mines.[63] Dolphins continue to serve, and replace navy divers. Prior to mission-deployment they must undergo a rigorous training process, lasting several years for assigned military functions; the latter comprising several Marine Mammal Systems that include detecting and/or marking the locations of sea mines attached to, or buried in, the ocean floor, identifying safe areas in shallow waters, detecting and marking the location of swimmers, or divers, that might be a threat to ships at anchor or piers, and allowing safe paths for troops and equipment to pass.[64] To track a dolphin underwater, a "pinger" device is attached to its pectoral fin, and if it detects an enemy asset, it will either attack or surface, to alert handlers who are monitoring events in small boats.[65]

The U.S. Navy has deployed dolphins in war zones, including five dolphins to protect sailors in Cam Ranh Bay during the Vietnam War, six to escort Kuwaiti oil tankers through the Persian Gulf in the late 1980s, and nine to clear Iraq's Umm Qasr harbour in March 2003.[66] Reportedly, in the first month after arriving in Iraq, the dolphin teams achieved an impressive number of operational successes, including unofficial clearance of 913 nautical miles of water, investigation of 237 objects, and recovery and/or destruction of over 100 mines in the Umm Qasr port and the Khawr Abdullah waterway linking the port to the Gulf.[67] Dolphins possess numerous military benefits, including flexibility and versatility. This is reflected in their capability to deep dive without fear of debilitating decompression sickness, the possession of biological echolocation sonar to detect and mark underwater mines, a readiness level of deployment via C-17 cargo aircraft to anywhere in the world within 72 hours, and their ability to presently guard one quarter of U.S. nuclear submarines bases.[68]

Not wanting to be left behind in what had become an animal (mimicry) Cold War arms race, the Soviet Navy in 1965 created a research facility at Kazachya Bukta, near Sevastopol, to explore the military uses of marine mammals.[69] The facility experienced a checkered history: inherited by the Ukrainian Navy after the Soviet Union imploded, it then suffered a period of neglect, symbolised by the transfer of all its dolphins to Iran in 2000, with the facility reinvigorated by Ukraine in 2012, only to return to Russian control in March 2014 after Moscow annexed Ukraine's Crimea region.[70] Russia seemingly still views dolphins as part of its military capability, with reports indicating it spent US$18,000 in 2016 acquiring five bottlenose dolphins, which were then subsequently trained to plant explosives on enemy vessels and to detect abandoned torpedoes and sunken ships in the Black sea.[71] In 2017, Russia's military mammal conscripts also reportedly included beluga whales; indeed, one of them was captured by the Norwegian navy in 2019, wearing a harness (stamped "Equipment of St. Petersburg") that was capable of housing a camera.[72] In May 2023, the same Russian beluga "spy" whale was spotted off Sweden's coastline, apparently in search of a mate.[73] The Swedes have an historical nervousness over Russian incursions into their waters, which began with the grounding of a Russian submarine in 1981, not far from the Swedish coastline.[74] In 1995, at the height of the Cold War, underwater sounds were detected, but according to the then Swedish Prime Minister Ingvar Carlsson, they were soon discovered to be emitted by minks (semi-aquatic mammals).[75] Then in 1996, what were initially thought to be bubbles generated by Russian submarine propellers were eventually identified as herring flatulence.[76]

Nevertheless, the actuality of underwater noises has led the U.S. military to investigate whether fish and other sea-life are effective in detecting enemy activity in the oceans through the monitoring of audible or visible reactions to sound, optical, electromagnetic, and chemical shifts in water by schools of sea bass, or microbes, when responding to magnetic signatures emitted by submarines.[77] The military has experience of experimenting with military mammal-messaging, as was illustrated in 1974 when coded signals disguised as pilot whale sounds were sent between the submarine USS Dolphin and a surface ship.[78] Recent advances in computing suggest that concealing or hiding covert messages in marine mammal sounds has reached a higher level of competence. The 2018 U.S. Persistent Aquatic Living Sensors (PALS) programme received US $45mn to fund research aimed at exploring the innate and ubiquitous marine animal sensing capabilities in the oceans for identifying and tracking adversary assets.[79] Additionally, the U.S. Defense Advanced Research Projects Agency (DARPA)reported in 2024 that it had developed an unmanned monster manta ray spy drone capable of long-endurance lingering on the seabed for intelligence gathering.[80] DARPA is also investigating whether sea-life, such as bioluminescent plankton and goliath groupers (*Epinephelus itajara*) can serve as components of underwater surveillance systems, capable of detecting enemy oceangoing drones, large nuclear submarines and other underwater vehicles.[81] The programme comprises five research teams focused on different sound medium, including "booms" emitted by the 8 foot, 800 lb, territorial goliath groupers in the face of potential underwater drones, or submarines.[82] Research is also directed towards the natural sonar from the 200-decibel sonar "pops" of snapping shrimps, striking even the quietest enemy platforms and bouncing back to sensors to alert their presence.[83] Geopolitical rivalry ensures that Washington is not alone in researching the benefits of marine animal sounds to both disguise military communications and create covert sonar systems. Chinese efforts, for instance, have gone beyond using recordings of whale and dolphin songs as secret code, unnoticed by enemy eavesdroppers, to using artificial signal synthesis to create whale and dolphin sounds.[84] The 1972 Marine Mammal Protection Act seeks to regulate noises that humans can generate in the oceans, and NATO also has standards for underwater sounds, but as with other environmental legislation, China benefits from non-compliance.[85]

Bioengineering: military mimicry of animals

In parallel with animals being used in military roles, a phenomenon has emerged of the military mimicking animals. This approach accords with the concept of "biomimicry", discussed in the opening pages of this paper, but in the context of military mimicry it is often referred to as biologically inspired engineering.[86] The origins of bioengineering can be traced back to the 1480s, when Leonardo da Vinci developed the "Ornithopter" by mimicking the flight of birds.[87] Avian biomimicry has continued into the modern era. Since 2013, the U.S. military has demonstrated a keen interest in the potential of mimicking avian flight in the development of unmanned vehicles. A US$2mn budget was allocated to investigate locomotive strategies for drones, especially "flapping-wing" technology, which is more efficient and wind-tolerant than inert wings, flies with greater agility, and can stop mid-flight to hover, observe or monitor; combined, these features enable drones to better navigate rugged and unpredictable environments.[88] Specialist biomechanical research has also been conducted on how the dragonfly, with four powerful wings flapping independently, can maintain effective control of its wingbeat, enabling it to hover and strike with lightning speed, fly vast distances carrying small cargoes, such as medicine, and remain stable in high winds.[89] Separately, Japanese researchers have sought to develop an ornithopter; that is, a full scale bird-like flapping-wing micro aerial vehicle (MAV), shaped and patterned after a typical pigeon and capable of avian maneuvers, such as rapid takeoff, hover, and gliding.[90]

There are broader biomimicry opportunities, with the military recognising that animals display superior performance attributes, including traction, maneuverability, and tactical adroitness, that readily lend themselves to improvements in military capability. WWI first generation tanks, for instance, emulated the motions of caterpillars and the introduction of modern radar mimics the sonar mechanisms of bats and dolphins.[91] More recently, in a bid to create lightweight body armour, Californian scientists have researched local tiny and lethal spiders to identify the genes and DNA sequences of dragline silk proteins.[92] These proteins exhibit the qualities of strength and extensibility, enabling absorption of enormous amounts of energy and raising the possibility of human engineering of "bio" armour.[93] Similarly, the unique combination of fibre and exoskeleton in certain animal groups, such as in the snail-shell and mantis shrimp claw, represent a composite of hard ceramic and elastic organic materials; the multiple layering of which also carry the potential for body armour.[94] Mimicry research extends to the development of military helmets, based on the woodpecker's unique biophysical skull design, which is able to withstand a shock of 60,000 g of force without damage to the brain.[95] The keratinous hair-like bristles attached to the feet of geckos are also the target of military investigation, enabling military personnel to climb buildings in hard-to-clear urban operations.[96] Other biotechnology innovations include military "cyborg" cockroaches. These are currently under development by University of Connecticut engineers using Madagascar hissing cockroaches (*Gromphadorhina portento*) as mules to transport tiny backpacks containing microcircuits to enable reliable and precise control of insect motion.[97] The backpacks incorporate a 9-axis inertial measurement unit, allowing detection of the roach's six degrees of free motion, its linear and rotational acceleration and its compass heading, making such cyborg cockroaches potentially suitable for National Defence.[98] China, too, is experimenting with insects, creating flying robotic machines that mimic the ways lightning bugs move, communicate, and fly.[99] South Korea's Defense Acquisition Program Administration (DAPA) is also developing biometric robots, "bio-bots", that are believed to be a game-changer in the way they mimic birds, snakes, marine species, and insects.[100]

The scope of military-related bioengineering even extends to the auto-sensing capabilities of butterflies and plants. For example, the U.S.' DARPA has invested US $6.3mn in a programme to identify chemical and biological threats; this includes a project seeking to transform the nano-structures of *Morpho* butterfly wing scales into sensors, which, through colour changes can warn of chemical or biological threats to humans.[101] Related research is being conducted by DARPA in its Advanced Plant Technologies programme, whereby plants will become the next generation of intelligence gatherers, possessing the ability to harness their natural mechanisms for sensing and responding to environmental stimuli for military application in the detection of certain chemicals, pathogens, radiation, and even electromagnetic signals.[102] DARPA through its Insect Allies Program also seeks to encourage insects to transfer positive viruses from plant-to-plant, providing a defensive boost to protecting the food supply from pathogens, drought, and dangers introduced by state or possibly non-state actors.[103]

In the emerging field of bioengineering directed towards mammals, the U.S. Army has been funding Harvard and Duke university researchers to build a tiny 1.5-gram shrimp-scale robot which mimics a mantis shrimp.[104] The violent mantis has two military-related capabilities: first, its raptorial appendages can be used as "spearers", stabbing soft prey through the heart, and as "smashers", whose punches can be delivered at such speed and heat (up to 8,500 degrees Fahrenheit) that they can crush shells and break fingers; secondly, the crustacean's sight uniquely possesses circular polarising light, which the military believes can be used for undersea navigation, without GPS.[105] Selected mammal characteristics have also influenced the design of robots, such as the U.S. Navy's Rapid Innovation Cell called the GhostSwimmer, whose purpose is to gather data on tides and weather conditions to support future tasks.[106] The GhostSwimmer mimics the swimming style of a shark or tuna-sized fish, having the attributes of being quieter than propeller-driven craft, the ability to oscillate its tail fin back and forth, and the possession of unmanned systems engineering, unique propulsion and control capabilities.[107] Biomimicry of this fish-shaped drone allows it to undertake a variety of tasks, including moving easily through the water, fitting into tight spaces, avoiding detection, and performing inspections, surveillance, and reconnaissance in low visibility environments too dangerous for divers.[108] Similar results were obtained in 2021, when Florida Atlantic University scientists successfully built robotic jellyfish (jellybots), powered by hydraulic silicon tentacles, with the ability to swim through openings narrower than their bodies.[109]

AI-enhanced mimicry of the military

The twenty-first century defence environment has now gone full circle; albeit that it is not animals now mimicking military capability, but electro, mechanical, and AI-intensive systems undertaking the mimicking. This forms part of the evolution of 4iR (4th industrial Revolution) defence-related technologies, comprising robots, swarms, and avatars, all aimed at replacing and enhancing traditional military capability. The world is witnessing a new arms race spawned by AI and reflected by robotic armies with the potential to think and fight for themselves.[110] Autonomous weapons systems can be defined as lethal devices that are empowered by human creators to survey their surroundings, identify potential enemy targets, and independently choose to attack those targets on the basis of sophisticated algorithms.[111] No fully autonomous weapon has yet been developed, but some 400 partially independent weapons and robotic systems are under development in 12 countries.[112] These include Israel, which has already successfully developed "Harpy" – a kamikaze drone, whose purpose is to seek out and destroy radar systems on its own, without human permission, loitering in the sky until a target appears.[113] The UN has sought to regulate such weapons, but the "genie is out of the bottle". Global spending on military robotics has grown considerably from US$2.4bn in 2000 to what is estimated to be US$16.5bn in 2025.[114] In broader-based, defence-related R&D, the Biden Administration proposed a dramatic increase of US$112bn in the Pentagon's fiscal year 2022 budget; the biggest such increase on record, with US$874mn allocated to AI.[115]

Although the contemporary push is for AI-enhancement of drone capability, there continues to be a fascination with imitating the dynamic performance of animals. As far back as the 1950s, the Pentagon began developing bird-drones, designed for surveillance during the Cold War. Later research included biomimicry of the great horned owl (*Bubo virginianus*), focused especially on its capability for silent flight and applying it to the development of autonomous drones.[116] Then, in 2008, the Micro Autonomous Systems and Technology (MAST) programme was launched with the aim of developing pocket-sized battlefield scouts and spy drones that could be held in the palm of a soldier's hand.[117] Indeed, mini-cyclocopters were developed, tipping the scale at less than 30 grams, with their aerodynamics mimicking species of flying insects, whose lift is generated by stirring air into vortices rather than airflow over aero-foils.[118] Drone mimicry of birds of prey has now proliferated rapidly across the world: the U.S. is the global leader, having developed a bird-drone attached to a quadcopter capable of landing and stabilising anywhere, including the use of talons for landing on trees; the EU has its Griffin project, also aimed at producing bird-drones; the French have developed a bionic bird, and are working on an insect-like drone called metafly; and the Chinese are developing a hi-tech spy drone code-named "dove" that mimics 90 percent of real dove movements, and is apparently hard to detect since actual birds are attracted to fly alongside it.[119]

The inevitable next step in drone development is for them to be deployed in swarms, replicating the natural phenomenon exhibited by insects, flocks of birds, and shoals of fish. Swarming is defined as a large number of entities (e.g. animals) massed together, and usually in motion, providing a method for combining situational awareness, elusiveness, mass, speed, mobility, and surprise.[120] The army ant, for example, has mastered the art of swarming to conduct massive predatory raids against other insects; they are able to move over twenty yards per hour at a width of 20 metres and a length of up to 100 metres, attacking from air, land, and underground (omni-directional warfare), often catching prey by surprise.[121] In the fifteenth century, Beijing employed an early version of swarming, using live birds with ember pouches strapped around their necks (so-called "firebirds").[122] These firebirds were released in swarms, and as the embers burnt through the pouches and fell onto enemy encampments, a firestorm of destruction would ensue; but this came with the danger that the returning avian drones, with their payload intact, would wreak similar devastation on friendly encampments.[123]

Today, the technological and doctrinal approach of drone swarms has undergone a huge transformation and can rightly be ascribed as a formidable and growing element of the RMA.[124] Yet drones suffer from a major flaw; in that unlike swarms of, say, tens of thousands of common starlings (*Sturnus vulgaris*) flying in "murmuration" and responding rapidly to changes in the flight behaviour of their neighbours,[125] drones are dependent on ground-based sensors and a central controller to stop them colliding. In a bid to resolve this problem, the U.S. military is presently ramping up research into the management of military swarms; often referred to as "loyal wingmen", when used in combination with high-value manned platforms, such as F-22 Raptor and F-35 fighters, and even NG B-21 bombers.[126] Loyal wingmen add combat mass to conventional fleets, creating a challenge for the enemy in distinguishing between manned aircraft and expendable decoys. Expendability is premised on the fact that while loyal wingmen systems are force multipliers, they are also low-cost, due to simpler airframes, construction, and reduced development cycles. A further economic benefit was demonstrated in 2021 when a small UAV, the X-61 Gremlin, was deployed and later recovered in mid-air by a C-130, with the future intention of recovering swarms of sensor-equipped UAVs using cargo aircraft.[127]

The U.S. DoD has committed US$3bn on human machine combat teaming and swarming operations by unmanned drones,[128] driven by the imperative of acquiring autonomous drone swarm capability to counter Anti-Access/Area Denial (A2/AD) systems. The aim is to develop a command swarm with the ability to control other swarms of thousands of unmanned aerial, surface, underwater, and ground drones to overwhelm enemy military installations.[129] This will form part of DARPA's Autonomous Multi-Domain Adaptive "Swarms-of-Swarms" (AMASS) research programme, aimed at countering China's DF-16 and DF-21D short-range ballistic missiles and carrier-killer anti-ship missiles that can hit U.S. naval flotillas and second island chains.[130]

DARPA is seeking AMASS alternatives to manned aerial and surface platforms entering hostile A2/AD environments. These systems will possess AI-driven features of autonomy, common language co-ordination, and the expansion of communication protocols to allow liaison with other swarms.[131] This, in turn, will enable a division of labour through independent specialist operations, including intelligence, surveillance, reconnaissance, search and rescue, logistics, mine-sweeping, destruction of improvised explosive devices, armed patrol, and targeted killing.[132] Swarms may also have adaptive properties, such as "self-healing", where the swarm modifies itself to accommodate the loss of some members, or self-destruction, to complete one-way missions.[133] Moreover, individual drones within the swarm can be configured to peel off to perform just one mission, and then rejoin the entire formation to carry out multiple tasks simultaneously.[134]

Responding to AMASS, China is attempting to build a counter drone-swarm capability, leveraging on its status as the world's leader in drone technology and possessing the widest range of attack, surveillance, and logistics drones. In fact, in late 2022, evidence emerged of a low volume 10 drone swarm in fully autonomous mode navigating through a thick bamboo forest, albeit that the Chinese admit the technology needs to mature, and thus the search continues to find the elusive intelligent algorithm.[135] Aside from the requirement for drones to be autonomous, parallel research is examining the appropriate delivery vehicle for launching drone swarms. One possible option is China's infamous high-altitude balloon. Indeed, in 2017 it was reported that at least two un-crewed bat-sized drones were launched from a stratospheric balloon over Inner Mongolia.[136] An inherent benefit of high-altitude balloons is that they offer the possibility of low-cost, long-endurance, maneuverable military missions. A further key attribute of balloons is that they are navigable and once in range of a target, can loiter and release fully networked swarms. Significantly, the Pentagon has recently disclosed that the Chinese spy balloon shot down near the coast of South Carolina in February 2023 had the ability to maneuver via four sets of propellers.[137]

Swarming has emerged as a hotly contested dimension of Sino-U.S. rivalry, driven by what is considered to be a swarm's enhanced military effectiveness.[138] This was attested by a 2018 U.S. Army study, which argued that swarming would make attack drones at least 50 percent more lethal whilst decreasing the losses taken from defensive fire by 50 percent.[139] Volume deployment of drones has been used on a number of occasions, including the 2018 attack on the Russian airbase at Khmeimim, Syria, the 2019 attack on Saudi Arabia's Abqaiq oil processing facility, the 2020 Azerbaijan-Armenian conflict, the 2021 Israeli attack against Hamas in Gaza, and the almost daily 2023 attacks by Moscow on Ukrainian cities,[140] but drone swarms, and especially super swarms, have not yet been used. The notion of autonomous swarms takes drone warfare to a completely different level. Once this capability is realised, as for example, via DARPA's vision of "Mosaic" warfare – where everything is decentralised and attacks are carried out by a kill web rather than manned aircraft or tanks – it will likely to lead to the supranational classification of drone swarms as Weapons of Mass Destruction (WMD).[141] Clearly, no human could plausibly have meaningful control of such "thinking" drone swarms, especially when scaled up into super-swarms of 1,000 or even up to a million drones.[142] Paradoxically, however, this eventuality alarms Pentagon policy-makers, because "Heterogeneous Group Control" of large robotic flocks able to co-ordinate without outside intervention raises the spectre of freebooting killer robots.[143]

A separate, but interrelated AI-mimicry development is the recruitment of avatars as co-pilots in Future Combat Air Systems, such as in the 6th-Generation Tempest aircraft. This UK-led fighter programme was launched in 2018, with full development planned for 2025 and operational capacity reached in 2035.[144] It is an international collaborative programme, comprising the UK, Italy and Japan, with Sweden on the margins, and Saudi Arabia in August 2023 demonstrating an interest to join.[145] The Tempest will have a human pilot, but through AI will be assisted by a virtual co-pilot.[146] This "avatar" would determine when the human pilot becomes overloaded, and in the event it happens, will take over responsibility for some of the workload, enabling the pilot to concentrate on core tasks.[147] The avatar concept has the benefit of reducing the aircraft's weight, cost and effectiveness, and would be programmed to react to a range of different scenarios, including functional responsibility for electronic jamming, weapons control, and even pilot loss, at which point it would take over control and landing of the aircraft.[148] To reduce cost and eliminate delays, Tempest has been designed from the inside-out, focusing on software in a bid to exploit AI and plug-in technologies, rather than the traditional model of outside-in, where sensors and weapons would be added via the slow and expensive construction of hardware.[149] The aircraft's systems are expected to possess the capacity equivalent to the "internet traffic of a large city, such as Edinburgh, every second,"[150] with the ability to process 10,000 times the military theatre data of its predecessor aircraft, Eurofighter Typhoon.[151]

While Tempest is expected to be a manned combat aircraft, DARPA has made dramatic strides in developing an unmanned aerial platform through its Air Combat Evolution (ACE) programme.[152] In less than three years, AI algorithms have enabled the transition from simulated F-16 aerial dogfights on computer screens to controlling an actual dogfight in flight. Through close multi-partner collaboration amongst DARPA, the U.S. Air Force Pilot Test School, the Air Force Research Laboratory, and AI-development contractors, ACE has achieved several objectives, including demonstrating that AI agents can control a full-scale fighter in flight.[153] It has also facilitated associated research into the trust that pilots exhibit in the AI agent during within-visual-range air combat, while the human pilot focuses on larger battle management tasks.[154] The potential for an AI-programmed autonomous fighter aircraft appears immense, as demonstrated early in the ACE programme, when AI agents flying simulated F-16s in a virtual dogfight competition defeated an experienced F-16 fighter pilot flying in a simulator.[155]

AI is the core dynamic driving the emerging twenty-first century Military-Technology Revolution, with China the leading force in weaponising AI and biotechnology. In particular, the Chinese seek hybridisation of human and machine intelligence, leveraged from brain-computer interfaces to create intelligent autonomy. According to PLA scientists, the future human brain will become the new combat space.[156] Cutting-edge technologies will be developed from across the biotechnology spectrum, from bio-sensing to biomaterials, to accelerate human enhancement for achieving military mental/cognizance dominance. Operational advantage will be determined by algorithmic competitive advantage via "intelligentised" military systems, which, for the Chinese, are mooted to include transcranial magnetic stimulation to maximise integration between humans and weapons on future complex battlefields.[157] Research aimed at brain mimicry and brain control has already commenced, with the intention of facilitating transition to completely autonomous robotic weapons systems. Future weapon systems will also derive from biologically broadening the battlefield canvas to not only include bioengineering of living organisms but also to capture genomics – the next disruptive technology frontier.[158] This raises the spectre of the PLA embarking on highly lethal ethnic-specific genetic warfare, including gene-editing of animals and human embryos. In fact, one Chinese research team has already successfully inserted a gene from a microscopic tardigrade (water bear) into human embryonic stem cells, leading to increased resistance to radiation and the prospect of super-PLA troops surviving nuclear fall-out.[159]

Conclusions

Military mimicry is a unique field of intellectual endeavour that to date has received only piecemeal intellectual attention. Accordingly, the purpose of this paper is to make a modest contribution to the literature by offering a coherent and composite treatment of the subject. Structurally, the paper begins by highlighting that mimicry's intellectual origins are rooted in nature, offering a rich typological tapestry of different types of animal mimicry behaviour across the three dominant themes of concealment, deception, and imitation. This affords comparative analysis of the role that mimicry has played in the historical development of military capability up to, and including, the contemporary period. Concealment through camouflage represents the first element of military mimicry. Many animals, including chameleons and octopuses, are masters of concealment, with the ability to change colour, physical appearance, texture, and odour, aimed at hiding from both predators and prey. Animals (and plants) offer a palate of capabilities, especially through the design and application of camouflage. In the nineteenth Century, following the radical shift from hand-to-hand combat to longer range engagement, the military embraced tawdry coloured uniforms to mimic the natural background environment. During WWI, an entire industry emerged that sought to exploit the synergies between "art and war". The use and expansion of camouflage continued into the twenty-first century, and is increasingly applied to land systems, warships, and other platforms in the search for the elusive quality of invisibility.

Deception is the second principal form of military mimicry, and the use of dummies and decoys on the battlefield has become an important and enduring element of military campaigns. The primary aim is to deceive the enemy as to the true size and capability of military assets, but a secondary benefit is that enemy attacks on dummy or disguised systems reveal their positions and attract return fire. The military's use of deceptive mimicry extends beyond stationary dummies to novel tactics designed to mask aircraft capability as was demonstrated by the U.S. Air Force's successful deception in the Vietnam war of deploying F-4 Phantom fighters with identical radar signatures as lumbering F-104 bombers, leading to dire consequences for the attacking Vietnamese Mig-21 fighters. The use of deceptive mimicry continues to this day, as exemplified by the Ukrainian Army's use of fake inflatable equipment, including missile systems, in its war against Russia. Decoys continue to offer an important military capability in modern high-tech warfare. This is demonstrated by the development of modern unmanned aerial systems, such as the U.S. MALD, which is able to modify its radar contours to resemble the signatures of highly expensive manned combat and heavy-lift aircraft. Similarly, the strategic use of robotic swarms carries the potential of deceiving enemy radars to the existence of manned systems within the swarm, with the Chinese deliberately intermingling real birds with bird-drones to disguise the latter's presence.

The final element of military mimicry is imitation, which has been assessed via three levels of analysis. The first has regard to the use of animals to mimic selected military roles. Here animals have been directly employed by armed forces to replace human personnel. For example, pigeons and dogs have been successfully used in both world wars. Then, from the 1960s, the great powers of the U.S., Russia and China all began experimenting with mammals, especially dolphins and beluga whales, for military activities such as mine detection, surveillance, and military coded communications. The second form of imitative behaviour reflects the reverse process in which the military seeks to mimic the physiological and performance attributes of animals. This is captured by the evolving importance of bioengineering, seeking to exploit an array of superior animal performance characteristics, ranging from spider DNA to bio-armour, from woodpecker skull design to strengthened military helmets, and from six-legged cockroaches to their future enlistment as cyborg "Blattodea"[160] military battalions. The third form of imitation has regard to AI-driven mimicry of the military, representing the latest and potentially most radical dynamic of the omnipresent 4iR epoch. Huge levels of investment are now targeting military-related AI, directed towards the development of autonomous robots, drones, and swarms. AI has the potential to change the nature of warfare. Fuelled by Sino-U.S. rivalry, the world is now entering a dangerous era, where military-related human-intelligence and machine-learning interfaces, biotechnology, and genome sciences are moving mankind beyond defence, as conventionally understood.

Notes

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