Killing Me Softly

Competition in Artificial Intelligence and Unmanned Aerial Vehicles

By Norine MacDonald and George Howell

The conduct of war is being fundamentally altered by the revolutionary impact of artificial intelligence (AI). The competition in AI and unmanned aerial vehicles (UAVs) marks the onset of the "7th Military Revolution" and the states that integrate these advances first will have a prodigious military advantage."[1] China has seized this moment, increasingly posing a risk to the historical technological advantage of the United States and destabilizing the foundations of modern warfare.

China has invested extensively in artificial intelligence and used significant aggressive covert and overt technological appropriation to rapidly revolutionize its military capabilities. China's innovation on the military front is mirrored by its national commitment to achieving superiority in the civilian and commercial applications of AI systems. The United States not only risks falling behind in the AI arms race but also is in danger of losing its commanding edge in commercial AI, where the Chinese government has committed vast amounts of capital to achieving dominance in AI applications across the economy. For example, China was the source of most cited high-impact research papers on AI in 2018 and has demonstrated an efficient strategy of technological capacity appropriation and civil-military fusion to build advanced defense capabilities.[2]

This is augmented by not only a specific alignment with Russia, but also a deepening of infrastructural and financial ties with Pakistan (the world's specialist in mini-nuclear weapons).[3] A consolidation of influence through infrastructural development in Central Asia and Africa, through the Belt and Road Initiative, as well as growing defense relationships in the Gulf region, with deepening ties with the United Arab Emirates and Saudi Arabia, are cases in point. Through such global efforts China is establishing strategic alliances together with a global technology infrastructure of satellites, undersea cables, and wireless networks that will support the capacity of its unmanned artificial intelligence–empowered system.[4]

The emergent battlefield will be a contested electromagnetic environment requiring adaptability across the battle network and intensive integration in order to exploit weaknesses in enemy networks and penetration points while protecting one's own. Systems designed for the historical asymmetric context will no longer be suitable and will have to be repurposed. There must be both multi-domain situational awareness and the ability to rapidly follow up with strike, swarming, and anti-swarming capabilities.

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This study of the current range of UAVs, and the ways in which AI can enhance them, offers a specific consideration of the metamorphosis of the battlespace—what one can expect competitors to field, and what sort of response will be required. We do not reference the creation of a general AI but the extensive, consolidated use of narrow AI to integrate, process, and sort the vast amounts of accumulated and incoming data at all levels of the military enterprise.[5] Unmanned systems must be empowered with AI capability to enable swarming, teaming, and sensor interpretation.

There must be both reimagining of the conduct of warfare and adding new methodologies for managing and developing these breakthroughs. Both an AI core and AI "nervous system" are needed, with an accompanying integration of systems and networking capacity. As former Commander, U.S. Special Operations Command General Raymond Thomas has noted,

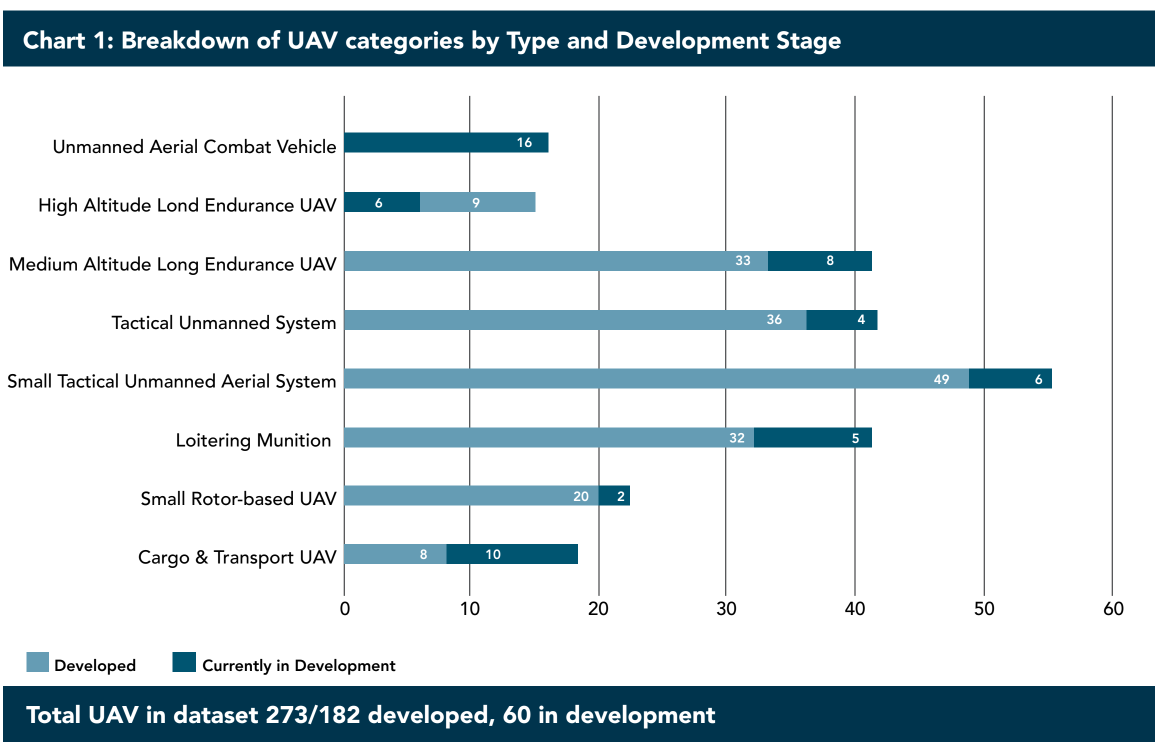
> *We have a conflation of opportunities in terms of unmanned that is extraordinary. Unmanned everything, ships, ground mobility vehicles, aircraft it's almost limitless. I visualize you can do almost all of that unmanned in the near future.*[6]

This UAV research serves as another alert call to the danger of becoming a technological laggard in the new battlespace in the face of an industrious, focused, innovative challenger.

UAV Classification System

This article is informed by open source research on prevalent unmanned systems available globally, conducted between February and August 2019, in

Figure 1. UAV Categories by Type and Development Stage



Source: UAV technical specifications complied by the authors between February and August 2019. Specifications for each UAV system gathered from manufacturer web sites and specialist UAV news web sites are listed in note 7.

an original taxonomy of more than 250 platforms, focusing on the integration of AI with such systems.[7] We offer a presentation of the characteristics of the different platforms of UAVs and an analysis of the pivotal impact of AI in such systems. The breakdown differs from the Department of Defense classification by weight, altitude, and speed in order to bring a more detailed description to the smaller platforms.[8]

The breakdown of UAV systems available is shown in Table 1. Small tactical systems are the most common, followed by rotor-based larger tactical systems and loitering munitions. Many medium-altitude long endurance (MALE) UAVs are available. There are currently very few high-altitude long endurance (HALE) UAVs, but more are on the way. All unmanned combat aerial vehicle (UCAV) projects are still in development. A brief description of each of the categories follows.

UCAVs in Development

The UCAV segment will be the largest of all military UAV segments in the 2018 to 2028 period, estimated at $57 billion and accounting for 39 percent of the $153 billion cumulative global market.[9] This demonstrates the strategic importance of the UCAV that is related to the potential ease that such platforms could be combined with nuclear payloads. The research dataset shows a total of 16 projects being developed around the world, with the United States having 37 percent of the global total and China following closely with 31 percent. India, Russia, the United Kingdom, and a European consortium have one project each.

Most UCAVs are Flying Wing stealth designed and generally look very similar to the RQ-170 Sentinel surveillance HALE-class UAV that landed in Iran in 2011.[10] The result was a technology leap by Iran and others. UCAVs aim to penetrate denied area spaces, which is indicative of the global push toward fielding

Table 1. Unmanned Combat Aerial Vehicles

Purpose
Intelligence, Surveillance, Reconnaissance (ISR): 7%
Weapons Systems: 75%
(Guided Missiles, Precision Bombs, potential nuclear payloads and small UAV swarms)

	Total (273)	Weaponized	Unarmed	ISR	ISTAR	EW	Relevant AI	Sector Specific Factors	Top Companies	Producer Countries (share of global total)	Operator
UCAV	16	12 (Bombers)	4	3	6	3	Auto-mission: 16 (100%) MUM-T: 8 (50%) ATOL AI Combat algorithms	Stealth: 11 (62%) Attainable: 2 (16%) Hypersonic: 2 (16%) Refueling: 1	Boeing, Lockheed Martin Northrop Grumman, BAE, AVIC, CASC, CASIC	USA (37%) China (31%)	Air Force Navy
In Dev	0	75%	25%	18%	6	18%					
	EW is Electronic Warfare, MUM-T is Manned/Unmanned Teaming, ATOL is Automatic Take-off and Landing AVIC is Aviation Company of China, CASC is China Aerospace Science and Technology Corporations, CASIC is China Aerospace Science and Industry Corporation, BAE is British Aerospace Engineering Total UAVs is dataset: 273/Total UCAVs: 16										

Source: UAV technical specifications complied by the authors between February and August 2019. Specifications for each UAV system gathered from manufacturer web sites and specialist UAV news web sites are listed in note 7.

UAVs for use in near-peer competition. The missions of such aircraft are predominantly strategic bombing and covert intelligence, surveillance, and reconnaissance (ISR) missions.

Three different talents define the UCAV segment: stealth (to gain access to enemy territory undetected), hypersonic speed and agility, and serving as an "attritable aerial asset," meaning a disposable apparatus that can be locally controlled by aircraft pilots. In this review, we found that 11 of 16 are designed for the stealth approach, only China and the United States are currently involved in hypersonic projects, and three attritable aerial assets are being developed—two in the United States and one in Australia.

HALE UAVs

HALE systems are characterized by satellite control links and a high operational ceiling, operating for long periods of time and having the capability of surveying very large areas. A well-known specimen is the Northrop Grumman Triton, which can scan 100,000 square meters a day and stay airborne for more than 30 hours at a time.[11] Such systems conduct long-range ISR and intelligence, surveillance, target acquisition, and reconnaissance (ISTAR) missions, as well as being used for battle network communication and increasingly for electronic warfare. This provides persistent near-real-time coverage using imagery intelligence, signals intelligence, and moving target indicator sensors.

In their current form, HALE systems deployed by the United States are suited for asymmetric warfare environments and global scanning rather than conflicts involving anti-access/area denial (A2/AD) capabilities. The Global Hawk has suffered in contested environments, as the downing of the vehicle in June 2019 by an Iranian surface-to-air

Table 2. High-Altitude Long Endurance UAVs

Purpose
Intelligence, Surveillance, Reconnaissance (ISR): 33%
Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR): 66%
Weapons Systems: 50% (Surface to Ground Missiles)

	Total (273)	Weaponized	Unarmed	ISR	ISTAR	EW	Relevant AI	Sector Specific Factors	Top Companies	Producer Countries (share of global total)	Operator
HALE Developed	6	3	3	2	4	2	Autonomous Flight Mode: (RQ170)	Stealth: 1 Hybrid VTOL: 1	Northrop Grumman Lockheed Martin General Atomics	USA 4 China 2	Air Force Navy
HALE In Dev	9	3	4	7	0	0		Solar: 3 (27%) Hydrogen Powered: 1	AVIC Boeing Lockheed Martin Northrop Grumman	USA: 5 (63%) China: 3 (45%)	Air Force Navy
	EW is Electronic Warfare AVIC is Aviation Company of China Total UAVs is dataset: 273/Total UCAVs: 16										

Source: UAV technical specifications complied by the authors between February and August 2019. Specifications for each UAV system gathered from manufacturer web sites and specialist UAV news web sites are listed in note 7.

missile demonstrated.[12] Following that incident, India backtracked on a deal to purchase the platform because of perceived ineffectiveness in a potential conflict with A2/AD-enabled Pakistan.[13] Northrop Grumman is adapting the Global Hawk with longer range sensors to allow it to operate in contested environments. However, the issue with the platform is that it was not designed for near-peer competition, illustrating an opening for a next stage product.[14]

China's Aviation Industry Corporation (AVIC) recently introduced two sensor laden HALEs with the capability of airborne warning and control systems (AWACS), specifically the detection of stealth aircraft. The Soar Dragon and Divine Eagle are also equipped with anti-ship missiles.[15] Chinese AWACS technology is advanced, and the possibility of detection by such aircraft undermines the viability of the F-35 as a radar-evading platform.[16] A Soar Dragon was used to track the movements of a U.S. cruiser in the Taiwan Strait in June 2019.[17]

MALE UAVs

The MALE segment of UAVs is the most well-known strike-capable UAV, made famous by the General Atomics Predator platform. Sixty percent of MALE platforms found had weapons capabilities, and 96 percent of those include precision and anti-armor strikes. Ninety-six percent of platforms had the purpose of situational awareness through ISR or ISTAR missions. Such systems include sensor equipment such as synthetic aperture radar, thermal and infrared sensors, and live video feed transmission capabilities.

China has a high number of MALE platforms that are actively marketed for export, such as the AVIC Wing Loong platform and the China Aerospace

Table 3. Medium-Altitude Long Endurance UAVs

Purpose
Intelligence, Surveillance, Reconnaissance (ISR): 33%
Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR): 63%
Weapons Systems: 60% (Precision Bombs, Air to Surface Missiles)

	Total (273)	Weaponized	Unarmed	ISR	ISTAR	EW	Relevant AI	Sector Specific Factors	Top Companies	Producer Countries (share of global total)	Operator
MALE Developed	33	20 60%	13 40%	11 33%	21 63%	3 25%	ATOL: 2 (6%) No piloting skills required: 1 Autonomous Flight: 2	Denied Area Access: 1 Can launch loitering munition: 1 (Belarus) Hybrid VTOL: 1	AVIC CASC General Atomics IAI	China: 12 (26%) Israel: 7 (21%) USA: 5 (15%)	Air Force Navy Army
MALE In Dev	8	6 75%	2 25%	1 12.5%	6 75%	2 25%	ATOL: 1 (Russia/ Orion) (12.5%)			Turkey: 2 (25%) USA: 1 China: 1	Air Force Navy Army Divisions
	EW is Electronic Warfare, ATOL is Automatic Take-off and Landing AVIC is Aviation Company of China, CASC is China Aerospace Science and Technology Corporation, IAI is Israel Aerospace Industries Total UAVs is dataset: 273/Total MALE UAVs: 41										

Source: UAV technical specifications complied by the authors between February and August 2019. Specifications for each UAV system gathered from manufacturer web sites and specialist UAV news web sites are listed in note 7.

Science and Technology Corporation (CASC) CH-4. CASC has established factories for the CH-4 platform in Pakistan, Myanmar, and Saudi Arabia.[18] In addition, China is developing a MALE UAV for early warning, a stealthy AWACS-empowered MALE platform, and the JY-300 Tian Shao.[19] This allows for greater situational awareness and battlefield intelligence on an inexpensive and agile platform.

It is noteworthy that China significantly leads the MALE export field (225), according to the Stockholm International Peace Research Institute arms transfer database for exports between 2012 and 2018, followed by Israel (137) and the United States (51).[20]

Tactical Unmanned Aircraft Systems

Tactical unmanned aerial systems function as air support for ground forces, providing situational awareness to the warfighter. Agility is a key factor of such systems, and a hybrid fixed-wing and vertical take-off (VTOL) capability is the growing trend. The advantage of fixed-wing over rotor-based systems is aerodynamic efficiency, because such systems can stay in the air longer and can scan a wider area. However, they have more difficulty hovering in one place. The hybrid-VTOL models that combine rotors with a fixed-wing design offer dual loitering and wide area scanning capabilities. Only 16 percent of

Table 4. Tactical Unmanned Aerial Systems

Purpose
Intelligence, Surveillance, Reconnaissance (ISR): 66%
Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR): 22.2%
Weapons Systems: 16% (Light Missiles)

	Total (273)	Weaponized	Unarmed	ISR	ISTAR	EW	Relevant AI	Sector Specific Factors	Top Companies	Producer Countries (share of global total)	Operator
TUAS Developed	36	6 16%	30 84%	24 66%	8 22.2%	1 2.7%	ATOL: 5 (13.8%) Autoflight: 3 Pattern of life recognition: 1 MUM-T: 1	Fixed Wing: 29 (80%) Hybrid VTOL: 7 (19.4%) Denied Area Access: 1 Perimeter Defense: 1 IED Detection: 1 Cargo drops: 1	Insitu (Boeing) L-3 Harris Latitude Textron IAI	USA: 12 (33%) China: 3 (8.3%) Israel: 3 (8.3%)	Navy Army Brigades
TUAS In Dev	4	2 50%	2 50%		2 50%	1 25%		Hybrid VTOL: 3 (75%) Fixed Wing: 1	Textron Luch Design Bureau Pterodynamics	USA: 2 (50%) Russia: 1 (25%) Latvia: 1 (25%)	Navy Army Brigades
	EW is Electronic Warfare, ATOL is Automatic Take-off and Landing, MUM-T is Manned/Unmanned Teaming Total UAVs is dataset: 273/Total TUAS: 40										

Source: UAV technical specifications complied by the authors between February and August 2019. Specifications for each UAV system gathered from manufacturer web sites and specialist UAV news web sites are listed in note 7.

platforms currently available are weaponized. The number increases to 50 percent when reviewing platforms in development.

Small Tactical Unmanned Aircraft Systems

Small tactical unmanned aircraft systems can be linked with unmanned ground sensors and automatically take off and fly to the sensor location, as seen with South Korea's Vivace system, or can locate and intercept cell-phone signals, as in the case of Israel's Aeronautics Orbiter 4 system.[21] The MBDA Spectre currently in development offers a small weaponized system suitable for contested environments.[22]

Table 5. Small Tactical UAS Systems

Purpose
Intelligence, Surveillance, Reconnaissance (ISR): 25%
Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR): 51%
Weapons Systems: 49% (Small Missiles in development)

	Total (273)	Weaponized	Unarmed	ISR	ISTAR	EW	Relevant AI	Sector Specific Factors	Top Companies	Producer Countries (share of global total)	Operator
STUAS Developed	49	0	49 100%	25 51%	24 49%	2 4%	ATOL: 4 (8%) Auto-mission: 1 MUM-T: 1 Object Recognition: 1 Sensor-link auto launch: 1 Interface simplification: 1 Machine vision: 1 (Vidar)	Catapult Launch: 23 (65%) Hand Launched: 18 (36%) Hybrid VTOL: 6 (12%) Cellular interception: 1 Denied Area Access: 4 Perimeter Defense: 2 Solar: 2 Cargo drops: 2	AeroVironment: 4 CASC: 4 Aeronautics: 3	USA: 17 (34%) Israel: 9 (18%) China: 5 (10%)	Navy Marines Army Battalions
STUAS In Dev	6	2 33%	4 66%	3 50%	2 33%	2 33%	Auto flight: 1 (16.6%) Swarming: 1 (16.6%) MUM-T: 1 (16.6%)	Hybrid VTOL: 4 Disguised: 1	MBDA Textron	USA Europe Russia	Navy Marines Army Battalions
	EW is Electronic Warfare, ATOL is Automatic Take-off and Landing, MUM-T is Manned/Unmanned Teaming CASC is China Aerospace Science and Technology Corporation, Total UAVs is dataset: 273/Total STUAS: 55										

Source: UAV technical specifications complied by the authors between February and August 2019. Specifications for each UAV system gathered from manufacturer web sites and specialist UAV news web sites are listed in note 7.

Loitering Munitions

Loitering munitions are a diverse segment of UAVs that can be piloted or pre-programmed to strike specific targets. The larger versions can loiter for longer, while smaller versions are mostly pneumatically tube-launched and have an air-time capacity of approximately 20 minutes. Such systems can weigh as little as 3 kilograms and can be piloted on a cell phone device. In addition, small multi-rotor variations are available. Many offer precise strikes with around a 1-meter radius, and others have anti-tank warhead capabilities.

Table 6. Loitering Munitions

Purpose
Weaponized: 100%

	Total (273)	Weaponized	Unarmed	ISR	ISTAR	EW	Relevant AI	Sector Specific Factors	Top Companies	Producer Countries (share of global total)	Operator
Loitering Munition Developed	32 Large: 8 Small: 24	32 100%	0			4 12.5%	Autonomous strike capability: 9 (28%) Semi-automatic flight: 9 (28%) AI enabled tracking: 4 (12.5%) Object identification: 3 (9.3%) Swarming: 4 (12.5%)	Pneumatic Tube launched: 16 (50%) Armor Piercing: 4 (12.5%) Vehicle launched: 5 (15%) Air Launched: 4 Small Rotor based: 3 Grenade design: 1 Mini helicopter: 1	IAI: 5 Uvision: 5	Israel: 13 (40%) USA: 4 (12.5%) China 4 (12.5%)	Air Force Navy Army Large-sized Battalions Small-sized Squads
Loitering Munition In Dev	5 Large: 2 Small: 3	5 100%	0				Swarming: 1 (20%) Autonomous Strike capability: 1 (20%)	Air launched: 2 Armor Piercing: 1 Pneumatic Tube Launched: 3		South Korea Turkey India	Air Force Navy Army Large-sized Battalions Small-sized Squads
	EW is Electronic Warfare, IAI is Israel Aerospace Industries Total UAVs is dataset: 273/Total Loitering Munitions: 37										

Source: UAV technical specifications complied by the authors between February and August 2019. Specifications for each UAV system gathered from manufacturer web sites and specialist UAV news web sites are listed in note 7.

Small loitering munitions can also be launched from vehicles or from larger flying devices. Developments add swarming capabilities for the control of multiple loitering munitions, such as Raytheon's Coyote, which combines different payloads into a single swarm system.[23] Israel is the leading developer and producer of loitering munitions, with 40 percent of the systems identified, with the United States and China following, both accounting for 12.5 percent. A prevalence of loitering munitions makes a new tactical modus operandi for ground troops necessary because the use of these UAVs affects the security of firing from cover.

Large Rotor-Based Platforms

Large rotor-based platforms include multi-rotor and mini-helicopter design features. Sixty percent of this segment is weaponized. China is the leading developer of the small helicopter design, offering missile launcher, machine gun, and small precision bomb capabilities. The Norinco Skysaker H300 and Ziyan Blowfish are examples.[24] Such systems are attractive alternatives for developing world armed forces seeking inexpensive close air support. China markets these systems to African and Middle Eastern countries.

Table 7. Large Rotor-Based Platforms

Purpose
Intelligence, Surveillance, Reconnaissance (ISR): 20%
Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR): 10%
Weapons Systems: 60% (Small missiles, Machine Guns, Grenades)

	Total (273)	Weaponized	Unarmed	ISR	ISTAR	EW	Relevant AI	Sector Specific Factors	Top Companies	Producer Countries (share of global total)	Operator
Rotor-based Large Developed	20	12 60% Armor Piercing: 9 (45%)	8 40%	4 20%	2 10%	1 5%	Autonomous mission capacity: 5 (25%) ATOL: 5 (25%) Teaming/ Swarming: 4 (20%) Auto in air replacement: 1 Fully autonomous combat capability: 1	Mini-Helicopter: 12 (60%) Multirotor: 8 (40%)	Norinco Ziyan Northrop Grumman	China: 7 (35%) USA: 3 (15%)	Navy Army/ Marines: Platoons
Rotor-based Large In Dev	2	1 50%	1 50%	1 50%				Mini-Helicopter: 1 Multirotor: 1			Navy Army/ Marines: Platoons
	EW is Electronic Warfare, ATOL is Automatic Take-Off and Landing Total UAVs is dataset: 273/Total Rotor-based platform: 22										

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Small Rotor-Based Platforms

Small rotor-based platforms are widely available in the commercial sector with advanced automation and video feed capabilities. In the military setting, small multi-rotors have the advantage of being an inexpensive option to provide localized situational awareness. The capability of such systems to carry a variety of sensor payloads that transmit to ground operators offers a variety of benefits. Such systems can be "tethered" to a power source to provide persistent ISR and grouped together as a swarm to provide perimeter defense. Importantly, they can autonomously conduct mapping operations in global positioning system (GPS)-denied environments. Exyn Technologies and Shield AI offer swarming multi-rotor systems to create maps in GPS-denied environments. The palm-sized Flir Black Hornet is equipped with thermal video and electro-optical capabilities for short range reconnaissance missions and has recently been deployed with the 82nd Airborne Division for use in Afghanistan.[25]

The weaponization of small multi-rotor platforms that can deploy payloads from the platform is a recent development and provides advantage over loitering munitions in that the platform itself is not destroyed in a given attack. The Australian company Skyborne released the Cerberus in 2019, a 6-kilogram platform capable of carrying payloads of miniature missiles, grenade launchers, or shotgun attachments.[26] South Africa's Rippel and the United Arab Emirate's Golden Group have collaborated to produce a small grenade launcher add-on that could be attached to existing small UAVs.[27] A

Table 8. Small Rotor-Based Platforms

Purpose
Intelligence, Surveillance, Reconnaissance (ISR): 83%
Weaponized: 10% (Small missiles, shotguns, Grenade Launchers)

	Total (273)	Weaponized	Unarmed	ISR	ISTAR	EW	Relevant AI	Sector Specific Factors	Top Companies	Producer Countries (share of global total)	Operator
Rotor-based small Developed	37	4	33	31 SSR: 22 83%	0	0	Percent: 6 (16%) Machine Vision: 5 (13.5%) Edge-AI: 4 (10%) Automated Perimeter detection: 2 Swarming: 1	IED detection: 1 Mapping: 1+	FLIR: 3 Elbit: 3 Aeraccess (France): 3	USA: 19 (51%) France: 7 (18%) Israel: 7 (18%)	Army/ Marines: Squads
Rotor-based small In Dev	2	0	2 100%	2 SSR: 22 60%			Autonomous image detection and classification: 1 (50%)	Self-charging UAV			Army/ Marines: Squads
	EW is Electronic Warfare, SSR is Surveillance Short Range Total UAVs is dataset: 273/Total Small Rotor-based platform: 39										

Source: UAV technical specifications complied by the authors between February and August 2019. Specifications for each UAV system gathered from manufacturer web sites and specialist UAV news web sites are listed in note 7.

flamethrower attachment has also been developed for the agricultural sector, which demonstrates a potential weapon system.[28]

Cargo and Transport UAVs

China's Tengdoen Technology is developing a 22-ton unmanned cargo plane, and the refitting of cargo helicopters with very simple remote-control interfaces has been demonstrated in the United States.[29] Smaller UAVs can make precision cargo drops, and glider UAVs can be launched from airplanes.[30] The military logistics implications of automated aerial cargo transfers are significant.

The potential of automated transport is shown in the commercial sector, with China's Ehang developing a "low altitude aerial vehicle" and the U.S. Kittyhawk pursuing a similar project that received funding from the Defense Innovation Unit.[31] While these are essentially "manned," the control interface is that of a simple UAV, as most of the flying processes are automated. While not military projects, these deserve mention because of the ease of adaptation of such systems for military purposes. Commercial non-military urban air mobility is the focus of enormous investment and clearly of significance in technological advances relevant to UAV development.[32]

AI in UAVs

The following sections focus on the key areas of AI relevant for UAVs and demonstrate their combined potential force multiplier effect. In the dataset analyzed, the following broad areas of application of AI in UAVs were found: air combat, machine vision, teaming, auto mission, swarming, and auto-flight. Figure 2 offers an indicator of the different instances where AI breakthroughs and UAVs crossover.

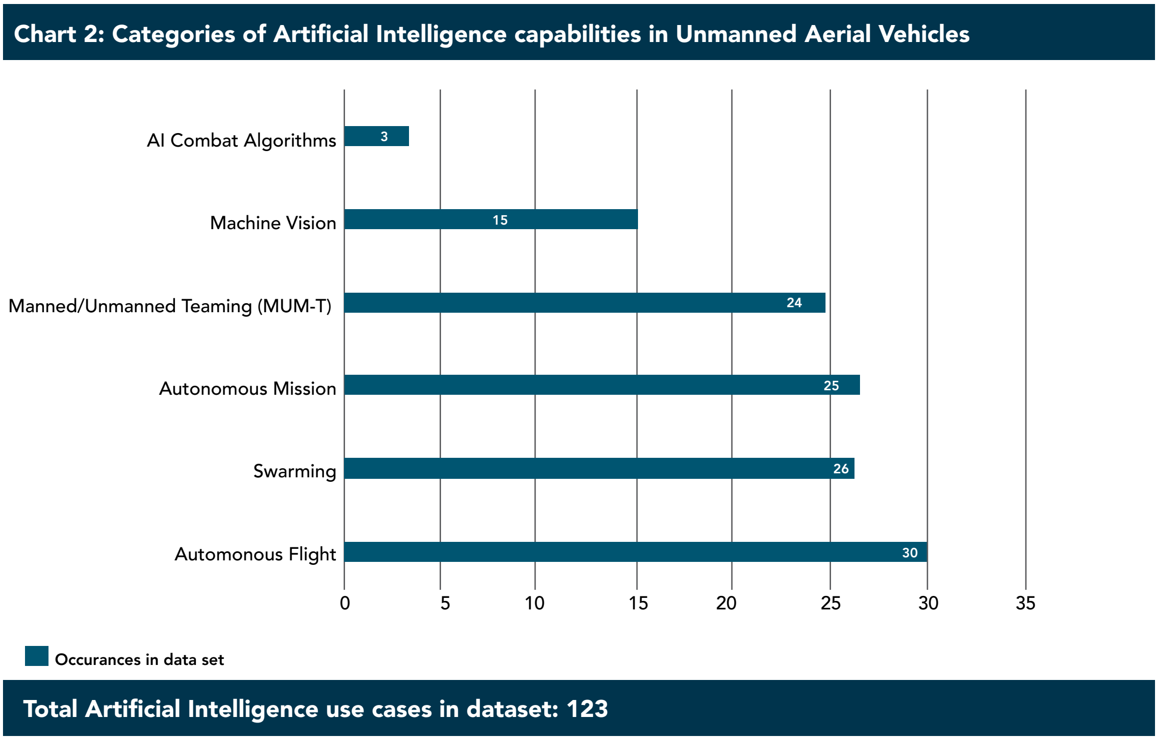
Table 9. Cargo and Transport UAVs

Purpose
Transport and Cargo delivery
Weaponized: 0%

	Total (273)	Weaponized	Unarmed	ISR	ISTAR	EW	Relevant AI	Sector Specific Factors	Top Companies	Producer Countries (share of global total)	Operator
Cargo & Transportation Developed	8	0	8				ATOL: 1 (12.5%)	V. Heavy (1.5 tons): 1 China Medium Heavy: 2 Light: 6	Star UAV Sunhawk	USA: 19 (51%) France: 7 (18%) Israel: 7 (18%)	China: 2 (25%)
Cargo & Transportation In Dev	10						ATOL: 4 (40%)	V. Heavy (22 tons): 1 China Passenger transport: 6 Helicopter re-fit: 3 Glider: 2	Ehang Kittyhawk Lockheed Martin	USA: 7 (70%) China: 2 (20%)	
	Total UAVs is dataset: 273/Total Cargo & Transport UAVs: 18										

Source: UAV technical specifications complied by the authors between February and August 2019. Specifications for each UAV system gathered from manufacturer web sites and specialist UAV news web sites are listed in note 7.

Figure 2. Artifical Intelligence in UAVs



Source: UAV technical specifications complied by the authors between February and August 2019. Specifications for each UAV system gathered from manufacturer web sites and specialist UAV news web sites are listed in note 7.

Air Combat Algorithms

Air combat algorithms have shown success in the combat simulator environment, as demonstrated by Psibernetix and the Air Force Research Laboratory (AFRL) in 2016 using "Genetic Fuzzy Trees" neural networks.[33] The advantage of such a system is that experienced human pilots can teach the AI system in an intuitive way. The Defense Advanced Research Projects Agency (DARPA) Air Combat Evolution program has created a competitive environment for AI developers to automate air-to-air combat, and AFRL and Lockheed Martin Skunk Works conducted a series of tests in 2017 that successfully demonstrated algorithmic control of an unmanned F-16 in an air-to-ground strike mission while adapting to complex challenges.[34]

Machine Vision

Machine vision refers to the automated classification of labelled data within a visual format.[35] It provides situational awareness capacity, such as object detection and classification, and when applied to multi-sensor fusion can detect and track in obscured environments, as well as being used for targeting purposes. Machine vision is also essential for vision-based navigation.

Certain aspects of machine vision are suited to smaller UAVs because of the close proximity to targets or the small areas they can survey. At this level, facial recognition, gait recognition, or reading license plates is possible. A tactical example for the use of machine vision was an urban combat exercise conducted in 2017 that utilized a thermal camera mounted on a small multi-rotor

UAV linked to a machine vision processing application. The system was able to identify a concealed sniper waiting in ambush and to advise the team of the threat.[36]

The integration of AI allows for the automated classification of sensor information in general. AI can process electro-optical sensor data for increased accuracy in targeting.[37] Synthetic aperture radar sensors can be empowered by AI for automated target recognition and tracking.[38] Lidar sensors combined with AI and mounted on small UAVs can quickly produce three-dimensional maps and identify hidden structures or find safe landing areas.[39] Also related to machine vision are the other areas of AI and sensor fusion that, when used together, can significantly enhance UAV detection capabilities to provide more accurate situational awareness.

Manned-Unmanned Teaming (MUM-T)

MUM-T has been recognized as a strategic priority for the three branches of the military for force multiplication, allowing individual warfighters to work as part of a collaborative network with unmanned aerial systems and allowing a single user to team with unmanned vehicles.

At the Air Force level, UCAV development is focused on creating "Loyal Wingmen;" using simple and intuitive interfaces, individual pilots will team with accompanying unmanned aircraft capable of autonomous decisionmaking to achieve strategic objectives. The lead Air Force project under way in 2019 is the "Skyborg," in which a pilot functions like a "quarterback in the sky that's working with a team that can call audibles and change what they do."[40]

This concept is a global trend and runs through current allied development projects such as Boeing's Air Force Teaming project in Australia, Europe's Future Combat Air System, and BAE's Taranis UCAV project. Ma Hongzhong, chief engineer of China Aerospace Science and Industry Corporation, explained that their Skyhawk Stealth UCAV has manned-unmanned capacity, and the Russian Sukhoi UCAV project has an emblem of a UCAV linked to a fighter jet on its tail, strongly suggesting it is also a MUM-T project.[41]

The Army has demonstrated MUM-T in attack helicopters teamed with Grey Eagle MALE UAVs or tactical UAVs such as the RQ-7 Shadow since 2014, with the purpose of extending controller range into contested environments, scouting, and conducting attacks beyond the line of sight.[42]

At the ground level, the Army vision for Manned/Unmanned teaming states that "autonomous unmanned systems will function as members of the formation executing tasks as well as providing oversight for subordinate systems. This capability will allow leaders to employ unmanned systems for critical and complex tasks such as establishing a mesh communication network or reconnoitering and mapping subterranean infrastructures."[43]

Automated Missions

The loitering munitions segment has UAVs available that can autonomously strike given targets using machine vision. A variety of Israeli and Turkish loitering munitions have autonomous capabilities, as the UAV can identify relevant targets that have been preapproved for strike. Chinese mini-helicopters available from Ziyan and Norinco can be preprogrammed to strike selected targets or conduct mission commands.[44] Autonomous cargo delivery is also a growing area of interest, with refitted helicopters being controlled by infantry on tablet interfaces.[45] In contested electromagnetic environments, preprogramming strike and ISR are viable strategies. As AI develops, AI-enabled UAVs will be able to perform more complex commands and behaviors.

Swarm of security drones with surveillance camera flying in the sky. 3D rendering image

Swarming

As General John Allen noted in 2017,

> *Here is where semi and autonomous systems are very important for us—re: a near-peer competition who has invested a lot in autonomous systems, and at a tactical or operational level you are going to have to deal with swarm after swarm of intelligent robots who not only have been trained to locate your position via virtue of your [electromagnetic] signature, but also facial recognition, recognizing flaws and weaknesses in defenses and jamming cyber, and worst, all cooperating with each other.*[46]

Swarming is a key area for AI and UAV development, requiring leveraging artificial intelligence for the calibration of swarm movements and tactics toward a given objective. Swarms are usually composed of small multirotor UAVs, mini-helicopters, or tube-launched loitering munition type devices with heterogenous capabilities, such as ISR, electronic warfare (EW), or munitions payloads as seen in Raytheon's Coyote.[47]

Many research projects have been developed for the air launch of swarms of small UAVs. Kratos and AeroVironment have signed a cooperation agreement to pair the Kratos attritable UTAP-Mako UCAV with AeroVironment's Switchblade loitering munitions.[48] MBDA Missile Systems has developed a glider missile carrier that can release small UAVs in a similar manner.[49] Such systems show potential for denied airspace where communication is not possible. DARPA's Collaborative Operations in Denied Environments project is researching how teamed UAV systems could collaborate autonomously with each other for three-dimensional targeting in denied airspace for strike purposes.[50] The U.S. Air Force Research Lab and India have established a cooperation agreement for research into air-launched swarm systems.[51] During the 2019 Mad Scientist workshop, former Deputy Secretary of Defense Robert Work suggested that a possible strategy for swarms would be to launch them in carrier projectiles from long-range artillery guns, an interesting idea for denied area penetration.[52]

At the ground level the challenge is to develop a system where the swarming missions of multi-rotor UAVs can be coordinated via a simple interface. DARPA is working on this capability under project OFFset—Offensive Swarm Enabled Tactics.[53]

Russia is developing swarm capabilities in the form of small multi-rotor UAVs equipped with explosive devices, nicknamed "*Jihadi Aviation*."[54] China is the current record holder for the largest drone swarm demonstration involving 119 small fixed-wing UAVs.[55] Mini-helicopter UAV manufacturers Norinco and Ziyan have demonstrated swarm tactics with mini-helicopters.[56]

The economical price of small loitering munitions and small multi-rotor UAVs make them relevant for force multiplication and situations where the chances of the UAV being destroyed or lost are high. The capacity for swarms to use local sensors to coordinate with each other and operate autonomously also makes them suited for contested environments. The usefulness of the UAVs depends on the AI software controlling them which, once developed, should not affect the overall production cost of such units.

The tactical possibilities of swarms with heterogenous payloads, sensors, and strike capabilities require creativity and the testing of such systems in war-game scenarios to assess their functionality.[57] A multinational exercise involving teaming ground units coordinating swarms of multi-rotor UAVs in a "Contested Urban Environment" was demonstrated in Canada in 2019. The swarm provided improved situational awareness, generated three-dimensional maps of the interiors of buildings and was able to drop ground sensors.[58]

Autonomous Flight

In current systems, the potentially dangerous takeoff and landing phases even of large UAVs have been increasingly automated and are made easier with VTOL-capable platforms. The development of automated flight is important for missions in contested airspace where a remote-control link is not possible.

Contested airspaces pose a challenge, as UAVs can be detected when emitting radio frequency transmissions, as well as operational failure in electromagnetic vacuums where GPS navigation is not possible. Cognitive visual navigation and image mosaicing are research areas where visual data and onboard AI processing are leveraged for autonomous navigation.[59] For small UAVs, autonomous flight is being explored with machine vision algorithms to scan and avoid obstacles.

Counter-UAV Systems

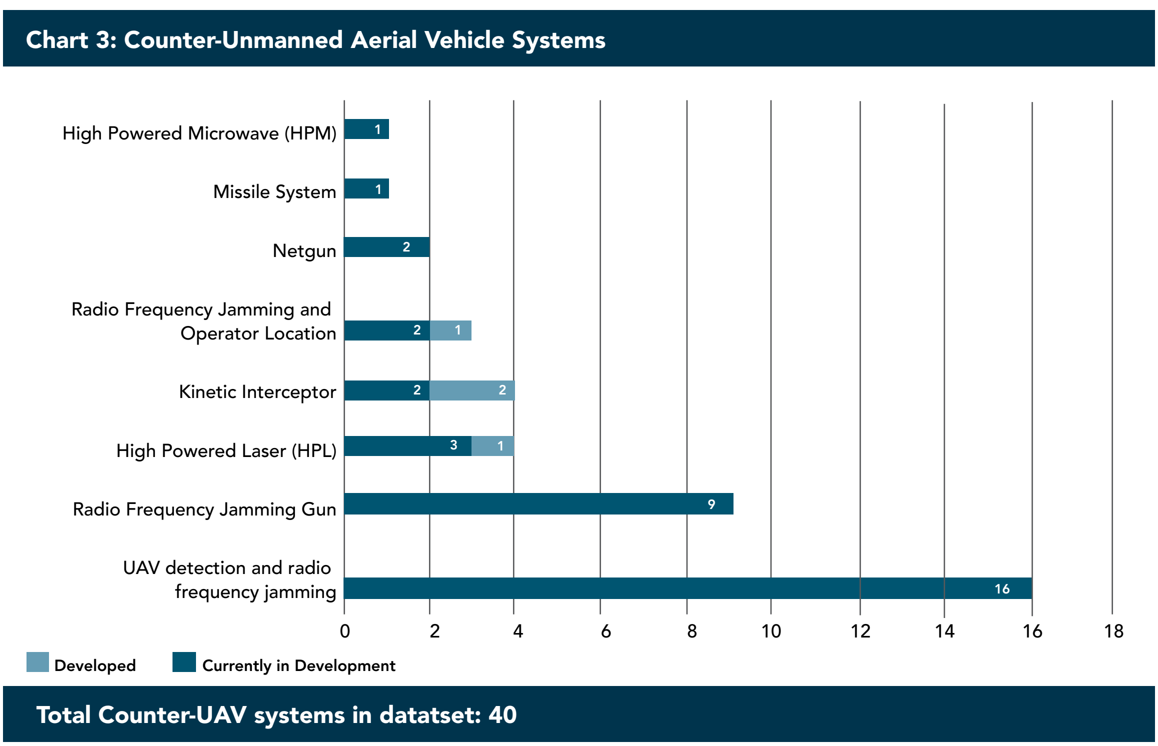
High-powered laser defense systems for UAVs have been developed by China, Israel, and the United States, and high-powered microwave deterrence systems are in development by the U.S. Army and Air Force.[60] Artificial intelligence is well integrated into counter-UAV systems in areas such as multi-sensor fusion, algorithmic radio frequency analysis, automated visual recognition, and pixel analysis, to name a few. Figure 3 offers a breakdown of counter-UAV systems identified.

AI and Electronic Warfare Systems for UAVs

Regarding UAVs as electronic warfare devices, radar systems can be empowered by AI to detect and mitigate threats through calculated frequency alterations, allowing for cognitive electronic warfare.[61] Machine-learning applied to radio frequencies (RFs) can automate classification of objects. A demonstration in Turkey showed multiple UAVs used to triangulate and accurately locate the operator of an RF signal.[62] Quantum radar is a growing area of interest for lowering the chances of control and communication interception; however, this research is still in the initial stages of development.[63]

Russia has advanced capabilities in this area, as demonstrated in Syria, Ukraine, and the Arctic region.[64] A counter-UAS system revealed in June 2019 creates "vacuum" spaces against aerial threats using a three-pronged approach of linked ground systems. The RB-301B Borisoglebsk targets ground-to-airborne communications, the Krasukha system jams airborne radars and AWACS signals, while the Zhitel system interferes with satellite navigation systems and mobile phone connections.[65] Russia also claims to have set up "an EW shield" along the Arctic coast capable of jamming satellite and drone communications, GPS signals, and other navigational system at ranges of up to 5,000 and 8,000 kilometers.[66] China has made unconfirmed claims

Figure 3. Counter-Unmanned Aerial Vehicle Systems



Source: UAV technical specifications complied by the authors between February and August 2019. Specifications for each UAV system gathered from manufacturer web sites and specialist UAV news web sites are listed in note 7.

to have developed "quantum radar technology" to detect stealth aircraft.[67] A long-range quantum-secured communication network between Beijing and Shanghai was demonstrated in 2017.[68] China's electronic warfare has been outlined by the U.S. Army Training and Doctrine Command:

> *The Chinese strategy, known as integrated network electronic warfare, combines EW, computer network operations, and nonlethal strikes to disrupt battlefield information systems that support an adversary's warfighting and power-projection capabilities.*[69]

The current battle network strategy for incorporating the force multiplication benefits of UAV situational awareness, exciting as they are, has emerged from an asymmetrical warfare context. Syria provided a first taste of new contested environments where there were setbacks as a consequence of Russian electronic warfare attacks.[70] Electronic warfare to disrupt a near-peer's manned/unmanned situational awareness and strike capability must be prioritized.

Creativity and applied cutting-edge research are needed to conceptualize a linked battle network of manned and unmanned systems. Wireless data transfer, GPS, and RF communications will be limited, and a sufficiently adaptive system will be necessary.[71] In addition, the challenge of advanced situational awareness capabilities from AI-empowered sensor networks offers challenges for the movement of persons and vehicles.

According to T.X. Hammes, at the operational level the fielding of advanced unmanned systems in a contested battle environment will lead to defensive tactics dominating battlefields where unmanned systems are prevalent. If any individual or vehicle creates a signature, it can be seen and attacked. Neither side will be able to maneuver freely. In Hammes's analysis, this offers the North Atlantic Treaty Organization (NATO) a strategic advantage in relation to the threat of Russian incursions into NATO-held territory.[72] This change in the character of war applies to any space where the technology of capable peers may be involved.

The prioritization of UAV platform acquisition and battle network development should be informed by these caveats. For such environments, Edge-AI, machine learning for vision-based navigation, and autonomous mission capabilities should be prioritized, as well as a battle network and modus operandi that require minimal data transfers.

A reorientation of the battle network for manned/unmanned integration toward highly contested electromagnetic environments should be a priority for UAV platform and battle network development goals and requirements, in order to offset the situational awareness and electronic warfare capabilities of competitors.

Coping with the Competition

This article has focused on the different types of unmanned aerial platforms, AI use cases, and development areas, as well as considerations for the future operating environment. We aim to have given the reader insight into the different elements of AI relating to unmanned systems through concrete and operational use case examples to provide an informed understanding of the manned and unmanned aerial potential available. This information can be used to understand and predict China's tactical use of AI and to identify and prioritize research areas of systems in the near-peer competition context.

Near-peer competition is the focus of the U.S. National Defense Strategy of 2018, which demands a coherent response and an adequate assessment of near-peer technological innovation trajectories. Within the specific platforms, China has an edge in AWACS-enabled platforms, an unknown capacity in UCAV platforms, a competitive MALE platform development market, and advanced mini-helicopter use. A greater challenge is China's integration of the systems approach designed to share information, such as the Strategic Support Force, established in 2015, which organizes space, cyber, intelligence, surveillance, and reconnaissance in the same command. The United States does not yet have equivalent integration.[73] China is actively pursuing the integration and widespread military adoption of AI, as part of its civil-military fusion approach. In addition, an Intelligent Unmanned Systems and Systems of Systems Science and Technology Domain Expert Group has been set up within the Peoples' Liberation Army.[74]

China's successful export-oriented approach to developing MALE UAVs suggests a wider impact of such technologies around the world and entrenches a dependence on Chinese operating systems among buyers.[75] China's Global Navigation Satellite System, *Beidou*, which aims to have total global coverage in 2020 as well as global communication infrastructure development, adds to an environment that enables China's force projection potential using a manned/unmanned strategy.[76]

China has demonstrated capability in appropriating advanced research and technology from around the world, translating this into its own military UAV platforms. It is the AI inside such systems that will be a key differential in the hyperwar context.[77] China is actively pursuing swarming capabilities, manned/unmanned teaming, and AI-enabled multi-sensor fusion, for example. China's track record of translating scientific research into military capabilities via civil-military fusion is proven.[78]

Based on the data presented in this article, the authors recommend an approach built on the combination of a centralized AI core and a decentralized AI nervous system inside the military and intelligence architectures. "Multidomain warfare involves colossal amounts of heterogenous data streams that can be exploited only with the help of AI. While the ability to manage this data colossus in real time promises tremendous advantages, failure to draw meaning from that information could spell disaster."[79]

UAVs are sensing organs that receive information from the external world. Currently, AI is moving forward on individual platforms; however, a centralized situational awareness AI core and a decentralized AI nervous system are required to synchronize and aggregate the overwhelming amount of sensor data necessary. A shift in thinking from a platform-centric approach to one creating the core architecture to syndicate such systems is essential:

> *AI-supported weapons, platforms, and operating systems rely on custom-built software and hardware that is specifically designed for each separate system and purpose. There is currently no master mechanism to integrate the scores of AI-powered systems operating on multiple platforms.*[80]

This AI core and nervous system priority must be part of both short-term and long-term planning, in recognition of its force multiplication potential. It also must be considered as a key element of any manned/unmanned strategy, to avoid being offset by a more AI-empowered and -integrated competitor. The AI core and AI nervous system must be recognized as a strategic necessity, be part of urgent short-term planning, inserted into all medium-term and long-term planning as the highest priority, and properly financed in budgetary allocations.

A second recommendation is to develop AI "horizontal open innovation coalitions." The AI research community is open and global, a horizontal open innovation ecosystem. The commercial sector operates with freedom of transit oriented by the principle goal of increasing profit, rather than matters of national security. The fruits of this garden are there for the taking, alongside the danger of the most advanced AI technology being offered up to military competitors. Such a reality requires a dramatic refocusing of resources to transfer relevant insight and technology toward strategic goals.

Understanding this dynamic necessitates a proactive approach to scout and recruit technological and scientific advances that translate into asymmetric advantages faster than China or Russia, as well as the creation of mechanisms to apply this advanced research to an ecosystem of relevant traditional and newly emerging AI-focused manufacturers and contractors.

Significant Intelligence Community–led industrial innovation research into applied artificial intelligence is imperative. This suggests an expanded global role for the institution of the Defense Innovation Unit, made actionable by informing the actions of a specially created funding framework for applied AI and innovation partnerships *globally*, including "tech scouting."

For technology laggards to compete with a more powerful competitor, they must establish horizontal open collaboration coalitions. This was the successful strategy used by General Motors, Daimler, Chrysler, and BMW, who formed a "Global Hybrid Alliance" in the face of superior technology and market share of Toyota. It was only by working together, pooling research and development capabilities, that they were able to rebound.[81]

The creation of such a horizontal open innovation coalition for defense AI is required to establish mutually beneficial technology investment partnerships among allied countries facing the threat of China's ascendance. This would require pooling intellectual, engineering, and financial capabilities from among allies in NATO, giving the institution a new raison d'être and maximizing the potential of their respective AI endeavors. In addition, alliances with Israel, Australia, South Korea, Japan, and India should be fostered to co-develop applied artificial intelligence for the unmanned defense industry capacity. NATO Allied Command Transformation Deputy Chief of Staff Lieutenant General Thomas Sharpy, USAF expressed the potential for the alliance to capitalize on synergies between member nations toward developing preparedness through enhanced cooperation:

> *One of the things that I see is the power of the alliance of 29 nations—this brings with it the intellectual capacity and the investment by the 29 nations, the leadership of 29, and the academic institutions and diversity of thought that 29 bring. It's an amazing opportunity for us to take all of that, synchronize it, consolidate it, and use it to figure out how we can be better, more effective, more efficient, and I think be a stronger deterrent for any potential adversary to think twice before they act.*[82]

A recent Defense Technology and Trade Initiative (DTTI) between the Air Force Research Laboratory and India's Defence Research and Development Organization to collaborate on a UAV swarm development program appears to be an example of a step in the right direction.[83] The DTTI states that it seeks to move "away from the traditional 'buyer-seller' dynamic toward a more collaborative approach and explore new areas of technological collaboration from science and technology cooperation through co-development and co-production."[84] Another relevant example is Softbank's Vision Funds. The first is valued at $100 billion and invests in artificial intelligence with contributions from Saudi Arabia's Public Investment Fund and the United Arab Emirates' sovereign wealth fund. Vision Fund Two also invests in artificial intelligence and is a $108 billion fund, with contributions from Kazakhstan's sovereign wealth fund and Microsoft.[85]

Such a plan requires a new form of cooperation and coordination between diplomatic and trade departments, the scientific community, defense equipment manufacturers, and outreach to the commercial sector, Intelligence Community, and defense institutions. While there are inherent risks involved in this approach, such alliances would be not only mutually beneficial but also are essential in the face of an ascendant China with a growing defense alliance with Russia. As senior defense thinkers have stated, risks must be taken in order to avoid the predictable failure of the path dependency based on a conservative and risk-averse culture.[86]

Killing Me Softly

Through quiet and steady innovation and expansion of their military topography, China is achieving a "killing me softly" impact on U.S. military capabilities. The danger of remaining laggards is illustrated by this examination of UAV technology and AI adaptations. We must be vigilant on all frontiers—not only those outlined by our geographies, but also the new frontiers created by advancements in technology and science.

We lift our eyes to the larger context of AI and the global military landscape where there are important calls for AI in weapons systems that could enable automated strikes to be regulated by international treaty, as proposed by Douglas Frantz, former Deputy Secretary-General of the Organisation for Economic Co-operation and Development:

> *Standards should be set for monitoring AI systems. Fundamental human rights should be specifically protected. A new international body should be created for oversight, similar to the International Atomic Energy Agency. AI is technology that must be controlled. The world reached a consensus in the 1960s and reined in an existential risk. It can be done again.*[87]

In the absence of such limiting international accords, we find ourselves in a contest for the future—a contest we must win. PRISM

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