

Armed uninhabited aerial vehicles and the challenges of autonomy

Douglas Barrie, Niklas Ebert, Oskar Glaese and Franz-Stefan Gady

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Cover

The Turkish Baykar Bayraktar TB2 UAV has been used in a number of recent wars, including successfully by Azerbaijan against Armenia during fighting in 2020. (Valery Sharifulin/TASS via Getty Image)

Introduction

Two decades ago, the notion of arming an uninhabited aerial vehicle (UAV) was little more than a niche pursuit. Today, at least 20 countries have weaponised UAV systems in their inventories, with other nations pursuing acquisition, while the capability is also proliferating to non-state actors. The air vehicles range from small, crude, hobbyist-style UAVs favoured by some non-state groups, to large, long-endurance platforms capable of being fitted with a range of sensors and air-to-surface weapons. Technological development continues apace with an increasing emphasis on greater automation and reducing the human workload, along with the emergence of a type of hybrid UAV and air-to-surface munition alongside the more established loitering munition. While uninhabited systems are increasingly embraced by many armed forces, they remain an uneasy subject in the wider public realm, where the perceived lack of human control remains an ethical issue. There also continues to be concern in the legal community regarding how increasingly automated – and perhaps one day autonomous – weapon systems fit within the law of armed conflict – legal concept rather than legislation, sometimes also referred to as international humanitarian law. These subjects were the focus of a 21–22 June 2021 seminar organised by IISS Europe to help further the debate and to better understand the implications of weapons-capable uninhabited systems. This paper reflects the discussions and many of the issues raised by the participants.

First use

While the emergence of the armed UAV is associated in the public mind with the US invasion of Afghanistan in response to al-Qaeda's 11 September 2001 murderous attacks, work was already underway to provide the MQ-1 *Predator* with an air-to-surface weapon. The first air-launch of an AGM-114 *Hellfire* missile from a *Predator* had taken place on 16 February 2001.¹ This, however, was not the first time the US had tested air-launched munitions from a UAV. In the early 1970s the BGM-34 family of what were then known as 'remotely piloted

The General Atomics MQ-1 *Predator* proved the armed UAV concept with its deployment in Afghanistan toward the end of 2001



(John Moore/Getty Images)

vehicles' had been used to experiment with the delivery of weapons. This culminated in the BGM-34C programme that was to fall foul of technical over-ambition and of strategic arms-reduction aims with the Soviet Union. In the case of the former the launch and recovery architecture to support the BGM-34C was ungainly, while in the case of the latter, the 1979 Strategic Arms Limitation Treaty II dealt with the BGM-34C as a cruise missile, rather than a UAV, and would count toward Washington's ceiling of these systems. Taken together, these put paid to the programme. It was a further 20 years before the US was to revisit putting weapons on a UAV.² Shortly after the 11 September 2001 attacks, armed *Predators* were deployed in Afghanistan.³

The introduction of a handful of armed *Predators* marked the beginning of a far wider adoption of armed UAVs that, as of 2021, has seen the commonplace use of such systems in conflicts. The first chapter of this paper considers the use of armed UAVs in: the short conflict between Armenia and Azerbaijan; the Russian-supported fighting in southeast Ukraine; and the civil wars in Libya and Syria. Armed UAVs have played a role in each, though to differing degrees and with varying levels of impact. For several of the actors involved it has provided an operational test environment in which to develop and refine tactics, techniques and procedures and to draw lessons for future developments.

The US, as an early adopter, remains at the forefront of UAV design and development. Today, however, numerous other states have UAVs with varying degrees of capability, and several of these states are producing armed systems. Notable amongst these are China and Turkey, which are also increasingly active so in the export market. Chapter Two will review the development of armed systems in China, Europe, Russia and the US, and likely or possible future paths.

Autonomous or otherwise

The armed UAV is synonymous to some of those concerned with the emergence of uninhabited and increasingly automated systems capable of lethal action with the populist vocabulary of the 'killer drone'.⁴ Concerns include whether the perceived reduced risk provided by using an armed UAV, with the operator far removed from the engagement, lowers the threshold at which governments will resort to using lethal force. Devolving the decision to use lethal force to an uninhabited platform, which is sometimes termed as a Lethal Autonomous Weapon System (LAWS), is a wider worry. Progress in software-based machine learning, often described as artificial intelligence (AI), and burgeoning interest in its use in uninhabited systems, is further adding to concern.⁵

Ethical and legal worries, however, are not the only challenges in the uninhabited arena. There remain technical challenges in the development of machine-learning systems that will provide the required level of reliability and assurance to further automate weapons-capable UAVs, and which could lead eventually to an autonomous system capable of mission planning and target search, location, verification, and engagement without any human intervention or oversight.⁶ A

further complication is the shift in the security environment from one in which counter-insurgency was the priority for the US and its allies to the re-emergence of peer or near-peer competition and the associated risk of state-on-state war. Uninhabited systems developed for the former threat environment are far less suited to what would be, in the event of a war, a highly contested domain.⁷ All these issues will be considered in Chapter Three.

In discussing armed UAVs and autonomous weapons systems there continues to be a lack of clarity around definitions. This paper will use the term 'armed UAV' in relation to any UAV capable of carrying a munition, while a direct-attack munition will be used in preference to 'kamikaze UAV', given that UAVs are generally designed with the normal intent of recovery. Defining a LAWS is yet more fraught, but for the purposes of this paper a LAWS is one that requires machine-based decision making (also referred to in the text as AI) to carry out a mission in a complex environment with no human support or intervention once deployed, with only a high level of mission command provided by a human prior to deployment. It must be able to independently implement a mission profile, including the capacity to locate and categorise legitimate targets and have the ability to abort an engagement should, for example, civilian casualties be disproportionate to the military advantage to be gained by the attack.

Armed UAVs are now part of the inventories of numerous countries, with the number of state operators only likely to grow. The extent to which the technology can be managed to ensure compliance with the Law of Armed Conflict, and to address legitimate public and legal concerns, remains a pressing question.

Chapter 1. Armed UAVs in recent wars

The spread of armed uninhabited aerial vehicles (UAVs) is readily apparent from recent wars, with models ranging from simple, near-hobbyist level air vehicles delivering improvised small munitions, to far larger, more complex systems with air platforms used to launch guided-bombs or short-range missiles at ground targets. Common to each, however, is the clear utility of armed UAVs in the conflict realm, if sometimes accompanied by overblown claims of being a singularly war-winning technology.

The short war between Armenia and Azerbaijan in 2020 was notable for the disparity in UAV capabilities between the two states. The latter had purchased intelligence, surveillance and reconnaissance (ISR) and armed UAVs and loitering munitions as part of a wider equipment-recapitalisation programme. Its forces had trained and exercised and been supported in their use of UAVs. UAV operations appeared integrated from the outset in operational planning. Armenia did not have a remotely comparable ISR or armed-UAV inventory, nor was it able to employ its ground-based air defence (GBAD) to effectively counter Azerbaijani UAV operations. Azerbaijan's employment of its UAV and loitering-munition inventory provided it with a clear advantage that contributed to the success of its armed forces in the conflict. The Armenian failure to deal with the UAV threat has acted as a prompt, were one needed, to numerous nations to redouble counter-UAV efforts.

The use of UAVs was also notable in Ukraine's war with Russian-supported separatists in the southeast of the country. While there has been only a very limited use of rudimentary armed UAVs, the utility of even small ISR UAVs in support of tube and rocket artillery was made evident. Russian 'volunteers' supporting the separatists have used ISR UAVs and artillery batteries on occasion to devastating effect against Ukrainian ground forces. The close coupling of ISR UAVs and artillery fire allowed a very short detection-to-engagement-and-assessment cycle, a demonstration that has been noted by some of Russia's peer rivals. A further likely effect was

to underscore to Moscow the need for it to begin to field armed UAVs. Ukraine acquired the Turkish weapons-capable *Bayraktar* TB2 in 2019.

Absent of traditional air power for the most part, the Second Libyan Civil War again showed the utility of armed UAVs, and the vulnerability of ground forces without adequate air defence. It also highlighted that the ground infrastructure required to enable UAV operations is itself a valuable target, with ground-control stations vulnerable to attack. Successfully engaging these is one way to substantially degrade an opponent's ability to operate its UAVs.

Traditional air power was present and significant in Syria's civil war. Russia's entry into the conflict in 2015 was a turning point. The Russian Aerospace Forces' contribution provided a considerable advantage to the Syrian government when engaging opposition forces. UAVs were for the most part used in an ISR role, although some of those may have on occasion been armed UAVs. The conflict was also notable for the use of improvised UAVs and simple direct-attack munitions in attacks on Russian bases. Moscow's involvement in the war provided it with the opportunity to trial and test numerous weapon systems in an operational environment. This included the Kronstadt *Inokhodets*-armed UAV that has begun to be introduced into service in 2021.

Armenia and Azerbaijan

Armenia and Azerbaijan renewed hostilities over the disputed territory of Nagorno-Karabakh in September 2020, with the latter state emerging as the victor in November 2021. The two states only made limited use of crewed combat aircraft during the 2020 war, due in part to the relatively small numbers of aircraft possessed by either.⁸ Within their respective inventories each also retained what were notionally capable surface-to-air missile (SAM) systems across several range categories which acted as a further disincentive. The presence of Turkish F-16s, deployed first to the Azerbaijani city of Ganja, later moved to Gaballa, and Russian Su-30SM *Flanker*

H-combat aircraft at the Russian air base in the Armenian capital Yerevan, also likely restrained crewed-aircraft activity on the part of both Armenia and Azerbaijan.⁹ This disincentive, however, did not extend to the use of UAVs, particularly with regard to Azerbaijan.

The war broke out on 27 September 2020 following months of tension and several armed clashes. The conflict began with an Azerbaijani offensive on Armenian defensive fortifications along the contact line separating Armenian-occupied Nagorno-Karabakh and Azerbaijan to the north. In the initial offensive, armed UAVs were used extensively in the attrition of Armenian air defences, and UAVs were also used in providing ISR support in the use of loitering munitions.¹⁰ Within the first two weeks Armenia had reportedly lost 60 SAM systems of a variety of types. This included, notably, an S-300 (RS-SA-10 *Grumble*) medium-to-long-range SAM that was destroyed using loitering munitions. The S-300 was positioned near the line of contact in the village of Shushikend.¹¹

Armenia's GBAD proved vulnerable to Azerbaijani attack for a number of reasons, including apparent shortcomings in Armenia's ability to identify and track UAVs by radar and in the claimed operational shortcomings of some Russian-supplied electronic warfare (EW) equipment.¹² More broadly, there appeared to be a lack of coordination and of even modest integration of Armenia's air defences. The extent to which Azerbaijani electronic countermeasures disrupted Armenian systems is also uncertain.

By 28 September, Azerbaijani forces had already broken through on the northern and southern flanks of the contact line and began to steadily push forward with armed UAVs providing close-air support. By 5 October, mechanised units and light infantry had seized several towns in the northern Tartar district and the southern Jabrayil district along the Iranian border in the Aras Valley.¹³

Armenian efforts to organise counter-attacks through large groupings of troops and equipment, including the use of UAVs to provide ISR support for strikes against massed targets and supply lines, were effectively

undermined.¹⁴ As a result, the Armenian forces suffered large losses and were unable to launch effective counter-attacks, resorting instead to missile attacks against Azerbaijani villages outside of the combat area in what appeared an attempt to deter further aggression.¹⁵ By 9 October Azerbaijani forces had seized towns in the Jabrayil and Fuzili districts bordering Iran and had reached the Armenian border.¹⁶

In the weeks following the collapse of the Russian-brokered 10 October 2020 ceasefire, it became clear that the Azerbaijani campaign in the north was diversionary as the brunt of Azerbaijani forces were focused on the southern theatre. The region remained contested but Azerbaijani forces slowly solidified control and advanced to the north before beginning their 23 October offensive on the Lachin corridor, a strategic pass connecting Armenia to the key cities of Susha and Stepanakert.¹⁷ Despite the Lachin Offensive eventually being repelled through an Armenian counter-attack supported by heavy artillery, it did enable Azerbaijani special forces to reach the key city of Susha. UAVs played little role, however, in the battle for the city, as a result of poor weather.¹⁸ With the loss of Susha on 8 November the regional capital of Stepanakert was within mortar range and key supply lines to the city running through the Lachin corridor were severed, making the Armenian military position even more difficult.¹⁹ On 10 November, the two sides agreed to a ceasefire, allowing Russian peacekeepers to enter the region and end the conflict.²⁰

The short war was notable for the use of armed UAVs alongside the more traditional ISR role, particularly on the Azerbaijani side. UAV losses totalled at least 22 UAVs destroyed and four captured.²¹ Armenia, by comparison, lost only six UAVs, reflecting the far-lower level of use.²²

Armenia's UAV inventory was primarily composed of domestically designed ISR UAVs and a small number of loitering munitions. Armenia did not field any armed UAVs.

Table 1.1: Armenia selected UAVs and loitering munitions

Name	Type/Country of Origin	Maximum Speed (km/h)	Endurance (hours except where specified)	Sensors/Payload
<i>Krunk</i> 25-1	ISR UAV, Armenia	140	3.5	EO/IR
X-55	ISR UAV, Armenia	130	1.5	EO
UL-300	ISR UAV/Loitering Munition, Armenia	120	3	

Azerbaijan fielded numerous types of ISR and armed UAVs, complemented by loitering munitions.

Israel and more recently Turkey have provided most of its inventory.

Table 1.2: Azerbaijan selected UAVs and loitering munitions

Name	Type/Country of Origin	Maximum Speed (km/h)	Endurance (hours except where specified)	Sensors/Payload
Hermes-900	MALE ISR UAV, Israel	Ca. 222	36	EO/IR/laser designator
Hermes-450	Tactical UAV, Israel	176	30	EO/IR laser designator
Heron TP	MALE UAV, Israel	407	30	EO/IR, laser designator
Aerostar	Tactical ISR UAV, Israel	200	12	EO
Thunder B	Tactical ISR UAV	133	24	EO,IR
Harop	Loitering Munition, Israel	416	9	EO/IR, passive radar homing, warhead
Skystriker	Loitering Munition, Israel	185	2	EO/IR, warhead
Orbiter 1k	Loitering Munition, Israel	130	2–3	EO/IR, warhead
Orbiter 2	Mini ISR UAV, Israel	120	4	EO
Orbiter 3	Tactical ISR UAV	120	7	E/O, laser designator
Kargu	Loitering Munition, Turkey	72	15 minutes	warhead
Bayraktar TB2	Armed UAV, Turkey	222	27	EO/IR, laser designator, MAM-family of munitions

Concepts of employment and doctrine

While both sides used UAVs, here the similarity ends. The Azerbaijani armed forces used UAVs effectively in armed and ISR roles, was proficient in their use of loitering munitions, and integrated these capabilities in wider force structures and as part of a pre-determined campaign plan, none of which can be said of Armenia.

With limited use of its crewed aircraft, Armenia relied in the main on its UAVs to provide tactical airborne ISR. The extent to which the UAVs were operated in a coordinated way in support of artillery – if at all – is unknown. Likewise, while it did have loitering munitions in its inventory, the extent to which there were attempts to use these – if at all – has yet to become clear.

Given the close defence ties between Azerbaijan and Turkey it is unsurprising that the former’s successful employment of armed UAVs and loitering munitions drew considerably on Turkish experience, tactics, techniques and procedures. In the decade leading up to the 2020 Nagorno-Karabakh war Azerbaijani forces had conducted numerous military exercises with the Turkish military. Shortly prior to the war Turkey supplied the *Bayraktar TB2* armed UAV, with Turkish military advisors assisting in training Azerbaijani UAV operators.²³ There also remains speculation that Turkish military personnel operated TB2s during the conflict.²⁴

With both country’s crewed aircraft activity partially curtailed in part by the presence of Turkish and Russian combat aircraft, the disparity in capability with regard to UAVs was made all the more apparent. Azerbaijan’s use of armed UAVs in the early days of the war as a central element of its efforts to counter Armenian GBAD exemplifies this.

The Azerbaijani operation to deal with Armenian air defence used UAVs for ISR and attack, with loitering munitions also employed against air-defence radars and SAM launchers. In the first few days of the conflict, Armenian air-defence radar and EW systems were targeted using the TB2 with the aim of creating a more permissive environment for air operations, even if these were to be mainly UAV based.²⁵

As well as operating Turkish-designed TB2s, the Azerbaijani’s had also acquired the Aselsan *KORAL* EW system from Turkey. This uses digital radio-frequency memory to jam or deceive threat radar systems. The extent that this contributed to Armenian difficulties in detecting and engaging Azerbaijani UAVs is not known; however, this was certainly an intention.²⁶ As well as using armed UAVs, loitering munitions and EW, Azerbaijan also flew the Antonov An-2 *Colt* as a radar decoy. Initially piloted at take-off, the crew would exit the aircraft and parachute to safety, while the aircraft would then continue into an area of interest in an attempt to get Armenian radars or GBAD to disclose positions.²⁷

Once it was assessed that the Armenian GBAD had been sufficiently degraded, armed UAVs and loitering munitions were used to attack Armenian ground forces.²⁸ Such targets included artillery positions, soldiers in assembly areas, armour and logistical supply lines. Smaller troop units could further use tactical UAVs for ISR and provide ISR support for precision fire to engage defensive fortifications.²⁹ The use of UAVs for close air support proved especially useful during the night, with low-light and night cameras providing ISR and the ability to engage troops on the ground.

Azerbaijani UAV activity also featured strongly in what is sometime dubbed ‘the battle of the narrative’ – the information campaign element of the Azerbaijani offensive.³⁰ Imagery of armed UAVs being used to engage Armenian military assets were spread online and throughout social media to suggest a technologically superior Azerbaijani military, with the implication of an inevitable victory for Baku.

Ukraine

Fighting between Ukrainian government forces and Russian-backed separatists broke out following the 2013–14 Euromaidan when pro-European Union protesters ousted president Victor Yanukovich and the ensuing March 2014 annexation of the Crimean Peninsula by Russia. In April 2014, pro-Russian separatists in eastern Ukraine removed local government authorities and declared independent republics in the Donetsk and Luhansk regions. In response Ukrainian government forces launched an ‘anti-terrorist operation’ in areas around the cities of Donetsk and Luhansk, with the aim of regaining control of the regions.³¹ During the same April-to-May period, Russian ‘volunteer’ fighters and mobile air-defence systems were filtered into the areas to bolster separatist ranks. From June onwards Russia began to supply separatist forces with mechanised armour and artillery systems.

The introduction of Russian SAM systems took a rapid toll on the Ukrainian Air Force.³² Losses included a small number of the Soviet-era Tupolev Tu-143 *Reys* jet-powered ISR UAVs operated by Ukraine.³³ The Russian intervention did not extend to crewed combat aircraft, while combat attrition constrained the Ukrainian Air

First acquired by the Ukraine in 2019, Kiev has since said that it intends to purchase 24 more Turkish *Bayraktar* TB2 UAVs



(Press Office of the President of Ukraine/Mykola Lararenko/Handout/Anadolu Agency/Getty Images)

Force. The belligerents instead made greater use of UAVs. Initially the advantage was with the separatists, with small ISR UAVs supplied by Moscow being used in support of also-Russian-supplied artillery. The potential effectiveness of ISR UAVs in combination with artillery, in this case rocket artillery, was apparent as early as an 11 July 2014 attack on a grouping of Ukrainian ground forces near the village of Zelenopillya. The UAVs were used for target location, with the resulting rocket attack causing Ukrainian casualties and the destruction of equipment.³⁴

Despite Russian support, the separatists increasingly lost territory to government forces, and by August 2014 the former were under growing pressure in both the Donetsk and Luhansk regions.³⁵ Heavy fighting in and around the town of Ilovaisk included a significant number of Russian ‘volunteers’, with the Ukrainian government stating its forces were facing Russian units, a claim Moscow denied. UAVs were again used effectively by Russia for artillery support. The severity of the fighting around Ilovaisk led to the Ukrainian government seeking a political resolution, resulting in the 5 September 2014 Minsk Protocol. The Battle of Ilovaisk marked the highest death toll of the Ukrainian armed forces.³⁶

The Minsk Protocol did not bring an end to the conflict, with sporadic exchanges of fire and occasionally far-heavier fighting, notably around Donetsk Airport. The Russian-supported separatists launched an offensive in January 2015, besieging the city of Debaltseve, a railway hub that was the easternmost territory controlled by the Ukrainian forces.^{37,38} Again, UAVs were used to support artillery fire, resulting in heavy Ukrainian casualties and a substantial number of civilian deaths. The Minsk II Agreement was signed in February 2015 following the fighting.

Having seen and suffered from the effectiveness of ISR UAVs, the Ukrainian armed forces began to try to redress the imbalance, with the emergence of a cottage industry composed of small technology companies,

initially funded partly by crowdfunding initiatives.³⁹ Ukraine has subsequently developed a range of tactical UAVs adopted across its military. Ukraine ordered the Turkish TB2 weapons-capable UAV in 2019, initially acquiring six, and in September 2021 Kiev stated it wanted to acquire 24 more.

Now widely used by all the parties involved in the fighting, UAV losses are likely to be relatively high, although

Table 1.3: Ukraine selected UAVs and loitering munitions

Name	Type/ Country of Origin	Maximum Speed (km/h)	Endurance (hours except where specified)	Sensors/ Payload
Leleka-100	ISR UAV, Ukraine	??	2.5	EO/IR
A1-SM Furia	Small ISR UAV, Ukraine	130	3	EO/IR
<i>Bayraktar</i> TB2	Armed UAV, Turkey	222	27	EO/IR laser designator MAM-family munitions
PD-1	ISR UAV, Ukraine	140	8	EO/IR
Raybird-3	ISR UAV, Ukraine	140	28	EO/IR, laser designator
FlyEye	Mini ISR UAV, Poland	170	3	EO camera
Warmate	Loitering Munition, Poland	150	1	
RQ-11B Raven	ISR UAV, US	??	2	EO/IR
AN-BK-1 Horlytsia	ISR UAV, Ukraine	230	7	EO/IR
Yatagan-2 (Scimitar)	Loitering Munition, Ukraine	-	-	Warhead
ASU-1 Valkyrie (Valkyrja)	ISR UAV, Ukraine	60 cruise speed	2	EO/IR
UA-BETA	ISR UAV, Ukraine	75	2	EO/IR

no accurate figures are available. It is conceivable that 200–400 UAVs have been lost so far during the conflict.⁴⁰

The Ukrainian armed forces operate a range of UAVs. As mentioned, Turkey, along with Poland, has been an external source of armed and ISR UAVs alongside the development of a domestic UAV sector. The latter generally produces small tactical UAVs adapted from store-bought systems.

The UAVs fielded by Russian ‘volunteer’ units and separatists have been used mainly for ISR, with some also having an EW role. The majority of the UAVs used are produced by the Russian defence industry. The *Forpost* is a Russian version of the Israeli *Searcher II*.

Table 1.4: Separatist Forces and Russian ‘volunteer’ units UAVs and loitering munitions

Name	Type/ Country of Origin	Maximum Speed (km/h)	Endurance (hours except where specified)	Sensors/ Payload
DJI <i>Phantom</i>	Small ISR UAV, China	36	Ca. 10 minutes	EO camera
Bird Eye 400/Zastava	ISR UAV, Israel/ Russia	83	1	EO/IR
Eleron-35v	ISR UAV, Russia	130	2	EO/IR
<i>Granat-1</i>	Micro ISR UAV, Russia	120	1	EO
<i>Granat-2</i>	Mini ISR UAV, Russia			EO/IR
<i>Granat-4</i>	ISR UAV, Russia	145	6	EO/IR, poss SIGINT
<i>Orlan-10</i>	MALE UAV, Russia	140	18	EO/IR, video, EW
Ptero-5E	ISR UAV, Russia		2	EO, laser designator
<i>Searcher</i> MkII/ <i>Forpost</i>	ISR UAV, Russia/ Israel	201	18	EO/IR, laser designator
Takhion	ISR UAV, Russia	??	6	EO/IR

Concepts of employment and doctrine

Separatists and Russian ‘volunteer’ units widely used UAVs in an ISR role to identify targets and to support tube- and rocket-artillery attacks. Armed UAVs, however, were not used, given Russia’s inability to provide such systems. UAVs were also used to draw fire from Ukrainian ground forces, and expose their position.⁴¹ The imagery and information being provided by UAVs appears capable of integrating into tactical command and control to improve situational awareness. Also notable

was the pace at which some attacks were carried out within a short period of the UAV information being received, with Ukrainian forces frequently taking fire within 15 minutes of their position being exposed.⁴²

This use of ISR UAVs for indirect fire by artillery has played an important role in separatist and Russian ‘volunteer’ tactics employed in eastern and southern Ukraine.⁴³ While armed UAVs were absent, separatist forces have used small UAVs to drop fragmentation grenades on targets.⁴⁴ Russian support for the separatists also extended to the use of EW to counter Ukrainian UAVs. Techniques included using frequency-specific jammers or flooding the operating frequencies of UAVs with white noise.⁴⁵ Datalink intercepts were also used to locate Ukrainian UAV ground-control stations.⁴⁶ Once exposed these could then be attacked.

Except for a few Soviet-era Tu-143 *Reys*, that may well have been stored prior to the war, Ukraine had no UAVs in its inventory when the conflict began. A cottage industry of small UAV-producing companies developed to address this gap. As a result, the Ukrainian military has deployed a range of tactical UAVs to perform similar missions to separatist and Russian ‘volunteer’ UAV units, namely ISR missions, to support ground forces and artillery.⁴⁷

Small UAVs were also modified to carry and drop grenades on ground forces, similar to those employed by separatist forces.⁴⁸ Despite the fact that Ukraine acquired weapons-capable UAVs from Turkey in 2019, direct UAV strikes have yet to be employed by the Ukrainian armed forces.⁴⁹ Ukrainian forces had less EW available than their opponents, with activity mainly aimed at countering UAV operations, including jamming.⁵⁰

Libya

Civil war broke out in Libya in 2014 following the disputed result of the 2014 election. While multiple actors were involved in the fighting, the two main groups were the United Nations-supported Government of National Accord (GNA) and the Libyan National Army (LNA). In the initial stages of the war, the LNA, backed by Egypt, Russia, the United Arab Emirates (UAE) and later France, consolidated power in the east of the country, while the GNA held limited control in the territory surrounding the capital city, Tripoli. Beginning in April 2019, the LNA began an offensive to take control of Tripoli, bolstered by military supplies from the UAE and Egypt and by Russian mercenaries from the Wagner Group.⁵¹

Air operations on both sides were initially limited to the use of a small number of ageing French and Soviet-era aircraft. The LNA capability improved, however, when it began to benefit from the support of the armed UAVs apparently operated on its behalf by the UAE from the

Al-Khadim air base in the east.⁵² The UAE has received the *Wing Loong* and *Wing Loong II* from China, with their first recorded use being on behalf of the LNA forces in the 2018 battle for Derna, a port city in eastern Libya.⁵³

The Emirati armed UAVs were also used effectively in the LNA’s 2019 offensive. By 2019, the GNA also had armed UAVs (the Turkish TB2) but in fewer numbers, with a lesser effect. The ground-control stations for the TB2s were also under threat from the LNA.⁵⁴ This disparity was also reflected in the number of UAV attacks recorded by the UN up to 2019, with over 800 attributed to the LNA and only 280 for the GNA in the same period.⁵⁵

Given such superiority, the LNA pushed forward to lay siege to Tripoli in April, the same month in which the offensive had begun. The LNA was unable, however, to rapidly overcome the GNA’s defences.⁵⁶ Instead the LNA used its armed UAVs to methodically attack GNA positions and targets within the city, resulting in civilian casualties.⁵⁷

The fortunes of the two main conflict parties began to shift in November 2019, when Turkey and the GNA concluded a military-cooperation accord.⁵⁸ One result was that Turkey began to increase the size of the UAV fleet

This *Pantsir-2S1 (RS-SA-22 Greyhound)* short-range air-defence system was captured by Libyan GNA, while numerous others were destroyed in UAV attacks.



(Mahmud Turkia/AFP via Getty Images)

at the GNA's disposal.⁵⁹ More importantly, it provided layered air defence around Tripoli, considerably reducing the threat to the UAV ground-control stations. The increased Turkish support saw the GNA break the siege, and equipped with a larger number of armed UAVs and with its own forces bolstered by Syrian mercenaries, it launched *Operation Peace Storm* in March 2020.^{60,61}

The target of the counter-attack was the Al-Watiya air base located outside of Tripoli, which was captured by LNA sympathisers in 2014 and used as a support hub for its air attacks. The base was retaken by the GNA in May, with the TB2s being used to attack *Pantsir-S1* (RS-SA-22) short-range air-defence systems during the siege of the Al-Watiya.⁶² Reporting at the time indicated that up to ten *Pantsir-S1* systems had been destroyed, though at the cost of a high GNA-UAV loss rate. The capture of the base by the GNA, however, allowed its forces to move beyond the Tripoli perimeter, ending the LNA siege in early June 2020.⁶³

By June 2020 GNA forces managed to secure most of the territory surrounding Tripoli and neighbouring districts in northwestern Libya, with armed UAVs and loitering munitions being used to attack retreating LNA

troops and logistics columns.⁶⁴ The arrival of Russian MiG-29 *Fulcrum* and Su-24 *Fencer* combat aircraft deployed at the Al Jufra Airbase further bolstered the LNA's air capabilities.⁶⁵ Fighting intensified between the GNA and LNA in June and July, with the risk of far greater foreign intervention, with Egypt and Turkey threatening to deploy troops to the conflict.⁶⁶ In August, however, the warring factions agreed a ceasefire, and in October the LNA and GNA agreed to terms to move towards establishing a unity government and requiring all foreign fighters to leave the country.

The number of UAVs lost by all participants during the war is not known. Reports indicate, however, that in 2020 alone 25 were destroyed.⁶⁷ During the conflict the GNA lost at least 18 UAVs, mainly TB2s, while the LNA lost at least ten UAVs, a mix of *Wing Loong* Is and *Wing Loong* IIs.

The LNA was supported in combat operations by several UAV types. The bulk of these were provided by the UAE, which operated Chinese UAV systems. Of these, the *Wing Loong* II was the most numerous platform.

The GNA, based out of Tripoli, received significant support from allies. Turkey provided and operated the TB2 armed UAV in support of the GNA.

Table 1.5: Libyan National Army selected UAVs and loitering munitions

Name	Type/ Country of Origin	Maximum Speed (km/h)	Endurance (hours except where specified)	Sensors/ Payload
Wing Loong I	MALE, China	280	20	EO/IR, laser designator, air-to-surface munitions
Camcopter S100 rotary UAVs	ISR UAV, Austria	240	6	EO/IR,
Mohajer-2	ISR UAV, Iran	200	2	EO/IR
Orbiter 3	Tactical ISR UAV	120	7	EO, laser designator

Table 1.6: GNA Forces selected UAVs and loitering munitions

Name	Type/ Country of Origin	Maximum Speed (km/h)	Endurance (hours except where specified)	Sensors/ Payload
Bayraktar TB2	MALE, Turkey	222	27	EO/IR laser designator, MAM-family of munitions
Kargu	Loitering Munition, Turkey	72	15 minutes	EO, warhead
Anka-S	MALE, Turkey	??	24	EO/IR, radar, laser-designator, MAM-family of munitions

Concepts of employment and doctrine

The LNA was able to rely on its UAE-provided UAV support for ISR and air-to-surface attack.⁶⁸ Armed UAVs were used against troop groupings, defensive fortifications and supply lines, contributing to LNA territorial gains while limiting the ability of the GNA to counter-attack.⁶⁹ Armed UAVs were also used to strike enemy UAV ground-control stations.⁷⁰ Prior to the deployment of Turkish air defences, Emirati UAVs gave the LNA an advantage, forcing the GNA to engage in more dispersed UAV operations.⁷¹

Faced with the GNA struggling in the face of the LNA's armed UAVs, Turkey intervened to provide its ally with comparable medium-altitude long-endurance (MALE) UAV capabilities. In a similar manner to the Emirati UAV use, Turkey operated UAVs and provided ISR and ground attack forces for the GNA in the latter stages of the war. Turkish UAVs were also used to counter the LNA's *Pantsir-S1* gun and missile air-defence systems with UAV losses traded against the destruction of these.

Reports suggest that UAV-based ISR was used as support when trying to engage the *Panstir-S1s*.⁷² Systems were targeted while being transported or in shelters and not deployed for combat. EW was also used in attempting to disrupt the communication frequency of LNA *Wing Loong* UAVs.⁷³

Before gaining improved air defences and larger UAV numbers later in the war, the GNA had to engage their UAV units in dispersed operations as the result of attacks on its own infrastructure.⁷⁴

The GNA is also reported to have utilised loitering munitions, such the Turkish STM Kargu-2 UAV, as part of its offensive operations. The GNA used loitering munitions to attack troop groupings and supply lines.

Syria

The Syrian civil war began in 2011 following the Arab Spring and the ensuing domestic revolt against the government of Bashar al-Assad. The conflict involved a range of rebel groups, jihadist organisations (such as Islamic State, also known as ISIS and ISIL), and foreign states, either directly or via proxy groups. Many of those involved operated a variety of UAV systems.

Several UAV-capable actors have intervened on the side of the Syrian government. Non-state actors such as the Lebanese Hizbullah, relying on Iranian-supplied UAV systems and having allied themselves to the cause of the Assad regime, conducted UAV strikes against Syrian jihadist groups near the Lebanese border, beginning in 2017.⁷⁵ Iranian UAVs are also reported to have been used against rebel targets near Aleppo in support of Syrian Army forces, beginning in early 2016.⁷⁶

Russian UAVs were introduced following the initial stage of the civil war, when the Assad regime fared badly as ISIS established territorial control over significant portions of Syria and neighbouring Iraq. To bolster its ally and ensure continuing access to Russian military bases present in the country, the Russian Air Force engaged in a bombing campaign beginning in 2015 to support Syrian ground forces and the small Russian contingent present within the country. Russian airstrikes, supported by UAV real-time surveillance, helped the Syrian Army, allowing it to retake the cities of Palmyra and Aleppo by the end of 2016.⁷⁷ In the case of Palmyra, following its recapture by ISIS in early 2017, Russian airstrikes allowed Syrian forces to retake the city.⁷⁸

Irrespective of the defeat of ISIS in 2017, and the end of its claim to territorial statehood, the Syrian conflict was far from over, particularly for Russian forces. On 31 December 2017, the Russian-controlled Khmeimim air base came under attack from very simple improvised direct-attack munitions, with the identity of the attackers remaining uncertain.⁷⁹ The attack took place when the EW systems of the base were apparently offline. The extent of the damage caused has never been confirmed, but the deaths of several soldiers was reported.⁸⁰ Only days later Khmeimim was attacked again using improvised direct-attack munitions, along with the Russian Tartus naval base. On this occasion, however, the Russian defence ministry reported that EW and air defence destroyed 13 of the improvised munitions.⁸¹ The attacks continued into 2019, when Russia is reported to have dealt with numerous attacks at the Khmeimim air base.⁸²

Turkey was also a notable actor in the Syrian civil war, with its ISR and armed UAVs employed. From August 2016 until March 2017, Turkey launched *Operation Euphrates Shield* across the border into northern Syria in what was officially a push to eliminate ISIS and ISIS-affiliated holdings in the border region.⁸³ This operation further served to contain the growth of the Kurdish People's Defense Units (YPG), a group viewed by Turkey as a terrorist organisation.⁸⁴

UAVs were primarily used to provide ISR support for Turkish Air Force efforts to locate and engage the militant groups with Turkish forces and allied Syrian rebels operating on the ground.⁸⁵ The Turkish government ended operations on 26 March 2017 after the border

region had been 'secured' and the towns of Jarabulus and al-Bab retaken from ISIS.⁸⁶ In January 2018, Turkey launched *Operation Olive Branch* in the Afrin province bordering Turkey in order to eliminate YPG control of the district, with Russia agreeing to allow Turkey use of the airspace above the region.⁸⁷ Turkish UAVs provided ISR support to artillery fire on the YPG positions, preceding attacks by Turkish and allied Syrian rebel ground forces.⁸⁸ During combat operations armed UAVs were used in an armed capacity but to also provide ISR support to Turkish attack helicopters.⁸⁹ In October 2019, Turkey launched *Operation Peace Spring* following the withdrawal of American troops from the border region of northeastern Syria. The aim of the operation was to remove the YPG and Syrian Defense Force (SDF) in the region to create a 30 kilometre security zone along the Turkish border.⁹⁰ Again, UAVs were used in support of Turkish Air Force airstrikes and artillery in preparation for a ground attack by Turkish forces and allied rebels.⁹¹ A Russian-brokered ceasefire on 18 October 2019 followed, with YPG and SDF forces withdrawing from the border regions of northeastern Syria and joint Russian–Turkish patrols taking place to secure the region from November onwards.⁹²

Turkish operations had so far created de facto security zones controlled by Turkish-backed rebel opposition forces around northern Syria along the Turkish border, including the northwestern province of Idlib which the Syrian government sought to eventually control. To prevent escalation between the two states on behalf of their proxies, Russia and Turkey signed the 2018 Sochi memorandum to create a demilitarised zone between opposition forces and the Syrian army.⁹³ Disagreements between the two sides led to the failure of the agreement and no security zone was established. Instead, Russian airpower was used to support a Syrian Army push up the M5 motorway towards Idlib province in May 2019.⁹⁴ In turn, Turkey began deploying soldiers to the region and supplying rebels with weapons systems, including shoulder-launched surface-to-air-missiles that impinged on Russian air operations in the region.⁹⁵ When airstrikes killed 34 Turkish soldiers in Idlib on 27 February 2020 and Syrian forces began to encroach on rebel positions, in response Turkey launched *Operation Spring Shield*, including the largest use of UAVs in the conflict.⁹⁶

Using TB2 and *Anka-S* UAVs, reported to number a little over a hundred in total, Turkey attacked many of the Syrian Army's Russian-supplied *Pantsir-S1* and other air-defence systems, as well as other Syrian forces present on the battlefield in the first few days of the operation.⁹⁷ The element of surprise played a role in the successful use of UAVs, as Russian and Syrian forces did not expect such a large Turkish presence in the airspace over Idlib.⁹⁸

Turkey also used the *KORAL* EW system against Syrian air defences and this, combined with inexperienced Syrian air-defence system operators, were further factors in allowing the use of armed UAVs to inflict considerable losses on the Syrian and Russian ground forces.⁹⁹ The Turkish military said it had destroyed '151 tanks, 47 howitzers, three jets, eight helicopters, three drones and eight air defense systems' before beginning ground operations against the Syrian military.¹⁰⁰ While this tactical success in the first few days of the conflict was considerable, once Syrian and Russian forces adapted and employed air defence and EW to counter Turkey's UAVs, their effect was somewhat eroded.¹⁰¹ The Syrian civil war provided Russia and Turkey with an operational test environment for ISR and armed UAVs, with some systems still under development deployed in order to examine their performance. Non-state actors used UAVs and direct-attack munitions in part to try to offset their lack of conventional air power. Given the numbers of actors involved, the widespread use of

Table 1.7: Russia selected UAVS and loitering munitions

Name	Type/ Country of Origin	Maximum Speed (km/h)	Endurance (hours except where specified)	Sensors/ Payload
Searcher MkII/ Forpost	ISR UAV, Russia/ Israel	201	18	EO/IR, laser designator
Orlan-10	MALE UAV, Russia	140	18	EO/IR, EW
Takhion	ISR UAV, Russia	??	2	EO/IR
Granat-4	ISR UAV, Russia	145	6	EO/IR, EW, SIGINT
Eleron-35V	ISR UAV, Russia	130	2	EO/IR,
Lancet	Loitering, Russia	110	40 minutes	EO seeker, warhead

UAVs, and the lack of declared losses, it is not possible to fully estimate the overall losses; the figure, however, is likely to be comparatively large, and likely over 100.¹⁰²

Russia deployed a number of domestically produced systems in the Syrian civil war. It also used the *Forpost* UAV, based on the Israeli *Searcher II*. All of these types were used for ISR. It tested the *Inokhodets* MALE UAV during the latter stages of the war, including in the use of air-to-surface weapons.

Table 1.8: Turkey selected UAVs and loitering munitions

Name	Type/ Country of Origin	Maximum Speed (km/h)	Endurance (hours except where specified)	Sensors/ Payload
Bayraktar TB2	Armed UAV, Turkey	222	27	EO/IR, laser designator, MAM-family of munitions
Anka-S	MALE Armed UAV, Turkey	??	24	EO/IR, laser designator, MAM-family of munitions

Table 1.9: IRGC or Hezbollah operated UAVs and loitering munitions

Name	Type/ Country of Origin	Maximum Speed (km/h)	Endurance (hours except where specified)	Sensors/ Payload
Shahed 129	Armed UAV, Iran	150 cruise speed	24	EO/IR, laser designator, Sadid family of munitions

Turkish involvement in the Syrian civil war included using the *Bayraktar* TB2 and Anka-S armed UAVs. These were employed for ISR and ground attack.

A number of Iranian UAVs were employed during the Syrian civil war. These were operated either by the Islamic Revolutionary Guard Corps (IRGC) or Hezbollah.

Iranian-produced UAVs have seen frequent use in Syrian airspace, either directly flown by Iranian IRGC operators or through Hezbollah as a proxy organisation. Of the UAVs listed below, only the Karrar and *Shahed-129* were reported to have been used for armed missions.

Along with the support of Russian-operated UAVs the government forces also used a number of Iranian designs.

Table 1.10: Syrian Government selected UAVs and loitering munitions

Name	Type/ Country of Origin	Maximum Speed (km/h)	Endurance (hours except where specified)	Sensors/ Payload
Mojaher 4	ISR UAV, Iran	180	3–5	EO/IR
Ababil-3	ISR UAV, Iran	200	4	EO/IR
Shahed 129	Armed UAV, Iran	150 cruise speed	24	EO/IR, laser designator, Sadid family of air-to-surface munitions

Concepts of employment and doctrine

The main use of Russian-operated UAVs in Syria was for ISR. Russia, as of 2021, was only beginning to introduce an armed UAV into service. UAVs were used to provide ISR support for crewed aircraft, including for battle-damage assessment following an attack.¹⁰³ UAVs were also used to support and adjust the fire of Russian and Syrian artillery strikes.¹⁰⁴ Russia also employed UAVs in an EW role.¹⁰⁵ Techniques included jamming and the suppression of communication links.¹⁰⁶

Turkish forces employed UAVs for ISR and ground attack during its involvement, with these capabilities more broadly integrated into its operations.¹⁰⁷ This included providing ISR support for attack helicopters used during the 2018 *Operation Olive Branch*.¹⁰⁸

Operation Spring Shield in 2020 is noteworthy for the way in which UAVs were used. During this operation armed UAVs were grouped together in significant numbers, described by Turkish officials as ‘swarms’, with an aim of overwhelming the opponent’s air defence and being used to attack Syrian Army positions.¹⁰⁹ Crewed combat aircraft involvement was more limited than perhaps might have been expected for this size of operation, with armed UAVs being employed as the primary surface-attack platform.¹¹⁰ This approach negated the need to try to ensure that Syrian ground-based air defence had been fully neutralised, given the limited used of crewed aircraft.¹¹¹ Instead, individual air-defence systems were targeted either on activation or pre-emptively using armed UAVs. While this resulted in the loss of some UAVs, it also removed the threat of the *Pantsir-S1* gun/missile mobile air-defence system.¹¹²

Turkey also reportedly used its armed UAVs to operate far beyond the front line and carry out attacks against Syrian military personnel or Iranian operatives identified by Turkish intelligence. Turkey has also used armed UAVs against key personnel in the YPG in Syria.¹¹³

The *KORAL* EW system was used widely in support of UAV operations to attempt to disrupt threat radars using, for example, jamming or signal-distortion techniques.¹¹⁴ Electronic intelligence was also used in support of UAV attacks by tracing the signals of mobile phones used by Syrian forces.¹¹⁵ Turkish *Anka-S* UAVs operating at high altitudes also played a role in relaying this information to precision-strike platforms, such as artillery or other UAVs like the TB2.¹¹⁶

Footage gained from Turkish UAV platforms further served a propaganda purpose to both domestic and foreign audiences.¹¹⁷

The Iranian IRGC and its allies such as the Syrian government and Hizbullah have utilised Iranian-supplied UAV platforms in Syria primarily for ISR missions. Hizbullah, in particular, used ISR UAVs to monitor the Lebanese–Syrian border. Hizbullah and the IRGC are reported to have carried out a limited number of armed-UAV attacks against Islamist militants and rebels.¹¹⁸ There are also claims that Iran has used loitering munitions against rebel targets in Syria, although the extent of these strikes and the platform in use cannot be confirmed.¹¹⁹

Islamist militants affiliated with ISIS have utilised improvised UAV and direct-attack munitions built from scratch or adapted from commercial models to provide ISR for offensive planning in Syria and neighbouring countries.¹²⁰ Footage collected by these UAVs has also served a propaganda purpose, such as demonstrating the armed strength of ISIS forces, for dissemination online and throughout social media.¹²¹

Chapter 2. Armed UAVs: selected development programmes

Armed uninhabited aerial vehicles (UAVs) are now established in the inventories of China's armed forces, some European states, and most obviously the United States, the first country to deploy such a system nearly two decades ago, while Russia is nearing their introduction. However, capabilities, export ambitions and policies differ between each.

China appears to take a transactional view of the sale of armed UAVs and has readily capitalised on markets where US export policy has meant it was not willing to release the technology, notably in the Middle East. Armed UAVs are now operated by the People's Liberation Army Air Force (PLAAF), with PLA ground forces also assumed to have a capability. State-owned Chinese industry and private companies continue to design and develop an array of small, medium and large UAVs, both for the domestic market and export. These are often shown with a considerable variety of air-to-surface munitions and missiles, although the 'standard' weapons package of the types most widely exported has been far narrower. How many of the weapons on display that have been integrated or even tested from the UAVs they are shown alongside is not clear. An increasingly diverse range of UAVs is being introduced into Chinese service with very long-endurance and high-speed UAVs entering service or in development.

Europe presents a mixed picture concerning the acquisition or development of armed UAVs. France, Turkey and the United Kingdom all operate armed systems: the first and last field the United States' General Atomics MQ-9 *Reaper*, while Turkey has pursued a successful national development programme with the likes of the Baykar *Bayraktar* TB2. While European states have long recognised the value of UAVs in the intelligence, surveillance, and reconnaissance (ISR) roles and their potential in the armed role, this has not been matched by development or acquisition. The still-fragmentary nature of the European defence-aerospace sector, differing national priorities and perspectives with regard to armed UAVs, and the availability, at least for some, of a class-leading

China's *Wing Loong* family of UAVs has secured several export sales and is being displayed with an increasingly wide range of weapon options



(Xiao/VCG via Getty Images)

system in the shape of the MQ-9, have repeatedly undermined pan-European programme efforts. France, Germany, Italy and Spain form the latest European constellation of states to attempt to develop a weapons-capable medium-altitude long-endurance (MALE) UAV, although the system will not enter service until near the end of the 2020s.

Russia has been forced to play catch-up with its rivals, the result of the damaging effects of the collapse in defence expenditure in the 1990s which continued into the early years of the 21st century. At the forefront of 'drone' development in the 1960s, 1970s and into the 1980s, the winding-up of the Soviet Union in December 1991 effectively ceased UAV development. Moscow is only now on the brink of introducing armed UAVs into service, almost 20 years after the US. It has also lost out to China in the export market, where under different circumstances it might have been expected to be able to compete.

The earliest publicly acknowledged adopter of armed UAVs, the US, remains the leading exponent of their use and their continuing development. The MQ-1 *Predator* and MQ-9 *Reaper* have become synonymous in the public eye with the armed UAV. With almost 300 MQ-9s in the airforce inventory, the US is likely the largest single operator of armed MALE UAVs. With the Department of Defense's focus moving from counter-insurgency

(COIN) and counter-terrorism operations to the more traditional concern of state-on-state warfare and peer or near-peer rivalry, the requirements for the development and upgrade of armed UAVs have changed. Irrespective of its strong position in terms of platform development and use, Washington has taken a restrictive approach to the export of armed UAVs, to the advantage of the competition, particularly China. The Trump administration relaxed on national policies somewhat, but whether an ongoing conventional arms export policy review by the Biden administration again changes the United States' approach is yet to become clear.

China

US reticence and Russian incapability offered China a window of opportunity in the 2010s into the armed-UAV market, an opportunity which it has seized. Along with developing a variety of armed systems for China's armed forces, the country's UAV manufacturers have made inroads into the export arena in Africa, Central Asia and the Middle East.¹²²

Beijing's success was in part facilitated by Washington's restrictive policy on the export of armed UAVs and the former's absence from the Missile Technology Control Regime (MTCR), an arms-control regime that included the sale of UAVs, of which the US is a founding member. Originally, the 1987 MTCR was established to curtail the proliferation of ballistic and cruise missile-technologies capable of being used for the delivery of weapons of mass destruction. Within the MTCR, cruise missiles are considered a subset of 'unmanned aerial-vehicle systems' that also includes 'target drones' and 'reconnaissance drones'. Key performance parameters for the most restrictive MTCR category cover the capability to deliver a 500-kilogram payload to a range of at least 300 km,¹²³ a restriction that includes some armed UAVs.

The MTCR now has 35 signatory nations, and while China discussed membership for near-on a decade from the early 2000s, it was never able to join. As a consensus-based regime, unanimity is required to accept a new member and by 2010 not all MTCR signatories were convinced that China was in a position to adequately meet the requirements for joining.¹²⁴ As a result, Beijing has gone its own way, but irrespective of Beijing's claims

that it adheres to its own version of MTCR it has been able to adopt a transactional approach to the sale of UAVs in general and armed UAVs in particular, which in some cases would be considered MTCR Category I systems where there is a 'presumption of denial'.

Several Middle Eastern states, including the United Arab Emirates (UAE) and Saudi Arabia, have approached the US over the purchase of armed UAVs. As early as 2004 the issue was raised by the UAE, while it was brought up by Saudi Arabia in 2009. Both were turned down since Washington considered that the UAV of interest, the *Predator*, was an MTCR Category I system. An unintended consequence was that Saudi Arabia and the UAE would instead look to Beijing, and both now operate Chinese armed UAVs.¹²⁵

While there are numerous Chinese companies offering UAV designs, Chengdu with its GJ-family and China Aerospace Science and Technology Corporation (CASC) with its CH-series of UAVs have so far been the main providers. The former's GJ-1 and GJ-2 are in service with the PLA armed forces,¹²⁶ while the latter's CH-series has been exported more widely. Chengdu has also exported the GJ-series under the banner of the *Wing Loong I* and *Wing Loong II*, though to a limited number of countries in comparison to CASC.

Countries operating Chinese armed UAVs include Algeria, Egypt, Iraq, Indonesia, Kazakhstan, Myanmar, Nigeria, Pakistan, Saudi Arabia, Sudan, Turkmenistan and the UAE.¹²⁷ Jordan also acquired Chinese UAVs, namely the CH-4B, but has withdrawn these from service.¹²⁸ Pakistan, China's closest defence partner, has unsurprisingly acquired armed UAVs from Beijing. Known domestically as the *Burraq*, this UAV appears identical to the CH-3, while its main armament – the Burq – looks to be the Chinese AR-1 missile.¹²⁹ The *Burraq* was first shown by Pakistan in 2014, following a Chinese offer to sell the CH-3 in 2012. In 2021, Islamabad was believed to have begun to take delivery of the CH-4B, a larger UAV than the CH-3, and capable of carrying more weapons.¹³⁰ It may also operate the *Wing Loong I* and *Wing Loong II*. Other CH-3 operators include Myanmar, Nigeria, Turkmenistan, and Zambia, while Algeria operates both the CH-3 and CH-4.^{131,132,133,134,135}

Beijing has been 'open' about its armed-UAV ambitions, at least in the sense of displaying most of its UAV

designs with an array of weapons at recent Airshow China events, held biennially in Zhuhai. What is less certain is which guided bombs and missiles amongst the many displayed in front of the UAVs have been integrated. In terms of exports, the AR-1 semi-active laser-guided missile, first shown in 2008, appears to form part of the baseline weapons package for the CH-3 and CH-4. The missile was developed by the China Academy of Launch Vehicle Technology, which is part of CASC. The FT-9 50-kg guided bomb looks also to be part of the regular weapons package associated with the CH-3 and CH-4.¹³⁶ The export variant of the GJ-1, the *Wing Loong*, has been seen fitted with the short-range *Blue Arrow 7* (KD-10) anti-tank and anti-infrastructure missile.¹³⁷

The *Wing Loong* and CH-families are not the only armed UAVs China has exported. It has sold the turbojet-engine powered WJ-600 to Turkmenistan, while it is 'co-developing' a large twin-boom UAV with Saudi Arabia, with the Tengden TW328 serving as the basis for the Saudi Al Eqab UAV family.^{138,139} The TW328 family includes twin-engine and tri-motor designs similar to models of the Al Eqab. The UAV has a reported endurance of up to 35 hours with a payload of weapons or other stores in excess of 1,000 kg.¹⁴⁰ CASC took the opportunity of Air Show China 2021 to unveil the latest member of its CH-family, the CH-6. This is a large turbofan-powered UAV capable of carrying a substantial weapons payload.¹⁴¹ The CH-6 appears to be intended, at least in part, for the export market.

At the other end of the performance spectrum, China continues to develop a variety of loitering munitions. Its ASN-301 system draws heavily on the Israeli *Harpy* anti-radar system,¹⁴² while the WS-43 also continues to be offered as an export product. The weapon, which has a 220-kg warhead, has a range of up to 60 km with an endurance of 30 minutes.¹⁴³ It is not clear whether this system has already been introduced into service or is still in development. A further product, which has the export designation CH-901, is a small loitering munition capable of being launched in 'swarms'.¹⁴⁴ As with the WS-43, its status concerning PLA adoption is not known.

Irrespective of the fate of particular projects and their adoption, or otherwise, by the PLA, armed UAVs

– in their many guises – will increasingly feature in the China's inventory and export offerings.¹⁴⁵

Europe

Despite a long-established and capable defence-aerospace industry, Europe has lagged behind, and, for at least some countries, has also been more cautious in its acquisition or development of armed UAVs. Contributing factors to the lacuna include industrial and political rivalries, differing priorities within European air forces and inter-service rivalries at the national level, and concern among some European nations over the ethical implications of armed uninhabited systems. Of those European nations that do operate armed UAVs, all – with the notable exception of Turkey – have the US General Atomics MQ-9 *Reaper*.

The UK was the first European nation to acquire the MQ-9 *Reaper* to support operations in Afghanistan. Royal Air Force operation of what eventually came to be ten MQ-9s began in 2007, with their first use in the armed role in 2008.¹⁴⁶ The UK MQ-9s came with the standard US weapon package of the AGM-114 *Hellfire* and the GBU-12 *Paveway II*. Italy requested the MQ-9 in 2009, and in 2015 appeared to have decided to arm its *Reapers*; however, as of late 2021, this had not occurred.^{147,148}

France followed suit in opting for the MQ-9 in 2013, and in 2017 took the decision to also acquire weapons for the UAV. The French MQ-9s are now operated with the GBU-12 laser-guided 227-kg bomb.¹⁴⁹ Spain selected the MQ-9 in 2015, but only for ISR, while the Netherlands finally ordered the UAV in 2018, with the option of arming these being kept open.^{150,151}

If Washington's reticence to sell armed UAVs provided Beijing with a market opportunity, Europe's repeated failure to launch one or more domestic MALE UAV programmes meant the default platform of choice became the US MQ-9, although so far only the UK and France operate the system in the armed role.

Europe nations have, for the better part of two decades, attempted to pursue development of a medium-altitude long-endurance UAV, for both ISR and armed roles, but have struggled to establish a stable multinational programme. The latest effort, a four-nation project led by Germany, is intended to deliver from 2028.¹⁵² The other partners in the programme are France, Italy

and Spain, with French interest in the *Eurodrone* including both ISR and armed roles.¹⁵³

France had previously partnered with the UK on a project known as *Telemos* to develop a MALE UAV. This effort was part of the Lancaster House Treaties signed between London and Paris in 2010. One of the proposed collaborative programmes was to co-develop a MALE UAV, with BAE Systems and French defence company Dassault as the two industrial partners. In 2012, however, the project was dropped in favour of pursuing an uninhabited combat air vehicle (UCAV) programme together.¹⁵⁴ The MALE UAV and the UCAV had originally been seen as running in tandem, but funding limitations led to the former being cancelled in favour of the latter. The Anglo-French UCAV effort fizzled out in 2018.

The British requirement for a ‘deep and persistent’ armed ISR UAV was part of a broader ISR ambition known variously as DABINETT and then SOLOMON. In the case of the latter, Scavenger was the name given to the armed-ISR element of the programme.¹⁵⁵ Prior to *Telemos*, BAE Systems had designed and test-flown *Mantis*, a comparatively large MALE UAV demonstrator aimed at meeting UK Ministry of Defence needs.¹⁵⁶ *Mantis* was viewed, at least within BAE, as also providing a starting point for *Telemos*; neither, however, came to fruition. London instead opted to continue to look to the US with the decision to purchase the MQ-9B, known in the UK as *Protector*. The UAV is due to enter service in 2024. Unlike the previous acquisition, however, UK weapons will be integrated with the UAV. It will carry the MBDA *Brimstone* 3 short-range air-to-surface missile and the *Paveway* IV dual-mode guided bomb.¹⁵⁷ The US has been restrictive in allowing non-US weapons to be integrated on its UAV, and London’s ability to introduce its own systems may well be the first approval of this.

While most of Europe either dithered in pursuing an armed ISR UAV, turned to the US, or in the case of Germany, continued to debate the ethics and morality of weaponised uninhabited systems at length, Turkey pressed ahead with the development and introduction into service of armed UAVs. Ankara’s UAV ambitions were part of a far wider governmental push to develop the country’s defence industrial base. In export terms, the UAV effort has paid dividends. The *Bayraktar* TB2 armed UAV has emerged as an export

France was the second export customer for the armed variant of the General Atomics MQ-9 Reaper; the UK was the first



(Mehdi Fedouach/POOL/AFP via Getty Images)

rival to equivalent Chinese systems, with Turkey also taking a comparatively relaxed approach to the release of the technology.¹⁵⁸ The TB2 was used to considerable effect by Azerbaijan during the short war with Armenia in 2020, providing further ammunition for marketing campaigns.¹⁵⁹ Turkey has also developed and operates the *Anka-S* armed UAV.

Development of the TB2 was accompanied by that of a dedicated suite of UAV weapons. Turkish guided-weapons specialist Roketsan produced the MAM family of small air-to-surface munitions which form the baseline weapons package accompanying any sale of the TB2.¹⁶⁰

Turkey is also nearing the introduction of the Akinci into service, a larger twin-engine MALE UAV. This has a considerably larger weapon payload than the TB2 and greater endurance.¹⁶¹ Turkey is also a MTCR-signatory state, and as such the Akinci would appear to be a Category I class system. Ankara’s ability to export the system has been improved somewhat by Washington’s 2020 decision to relax its approach to the export of UAVs that it previously would have viewed as falling within Category I of the regime.¹⁶²

Russia

Russia is attempting to rapidly address its lack of armed UAVs, the result of an extended period of under-investment in uninhabited systems, that itself was only a small part of the wider collapse in defence expenditure in the 1990s and into the first decade of this century.

While Tupolev and Yakovlev developed a variety of short-, medium-, and long-range ISR UAVs in the 1960s

Russia has been attempting to begin to catch up on UAV development, including with its twin-engine *Altius* programme



(Russian Defence Ministry/TASS via Getty Images)

and 1970s, with plans for follow-on systems put in place in the 1980s, the end of the Soviet Union put paid to the latter. In 2009, Moscow had to turn to an Israeli-designed system, the *Searcher II*, known in Russia as *Forpost*, for its first post-Soviet medium-size tactical ISR UAV.¹⁶³

The year after the *Searcher* decision, the Russian Ministry of Defence began acquisition projects for medium- and long-endurance UAVs, and, likely at the same time, for a tactical UAV.¹⁶⁴ The Kronshtadt *Inokhodets* is a single-engine MALE with a maximum take-off weight (MTOW) of 1,000 kg, while the twin-engine Ural Civil Aviation Plant *Altius* has a MTOW of around 6,000 kg.¹⁶⁵ Originally shown as ISR-only platforms, both the *Inokhodets* and *Altius* have now been displayed with air-to-surface weapons. Both programmes, however, have faced considerable delays in entering service. The smallest of the three, the Luch *Korsar*, is also lagging well behind the original development schedule.

There is little reason to believe that Russia's armed forces had either failed to recognise or not wanted to acquire ISR and latterly armed UAVs; rather, what scant resources were available in the late 1990s and early 2000s was directed elsewhere. Furthermore, at the industrial level, the two design bureaus traditionally associated with UAV projects, Tupolev and Yakovlev, had struggled in the post-Soviet era. Projects at each were cancelled and experienced personnel left.¹⁶⁶

Having watched the US adopt and then quickly adapt ISR UAVs for the armed role in its Afghanistan campaign and the wider (and poorly named) 'Global

War on Terror', Russia's armed forces gained additional insight during its short war with Georgia in 2008.¹⁶⁷ The latter operated the Israeli *Hermes 450* MALE UAV in the ISR role, and Moscow did not have anything comparable. Shortly after the war Russia was to remedy this with its own Israeli deal.¹⁶⁸

A decade after the Georgian war, Moscow was testing some of these UAVs it had developed in an operational environment. The *Inokhodets* was trialled in Syria in 2019, including for air-to-surface missions.¹⁶⁹ An initial batch of seven systems, each including three air vehicles and an operator ground station, was due to be delivered to the defence ministry by the end of 2021.¹⁷⁰ A larger twin-engine weapons-capable UAV, known as a the *Inokhodets-RU*, is now in development, with deliveries intended from 2023.¹⁷¹ The initial operation standard of the *Altius*, the *Altius-RU*, is also due to begin hand-over to the defence ministry by the end of the 2021.¹⁷²

Contracts for the *Inokhodets-RU*, and for the *Forpost-R*, were signed during the *Armiya 2021* defence exhibition held in the Moscow region in August 2021. At the same time, weapons contracts were inked for a range of UAV weapons, although no detail of what this covered was made public.¹⁷³ There are, however, at least three potential providers of UAV weaponry: Tactical Missile Corporation (KTRV), KB Mashinostroyeniya (KBM) and Kronstadt Group. KTRV is the largest designer and producer of air-launched guided weapons, bringing together several tactical weapons companies, while KBM's focus has been on anti-armour weapons. Kronstadt Group is a newcomer to the munitions sector, but as the designer of the *Inokhodets* and the *Inokhodets-RU*, is likely looking to utilise this to expand its business footprint.

The Russian guided-weapons sector appears to have initially been slow in addressing the emerging market for UAV weapons. In part, this may again have been down to having to recover from nearly two decades of limited domestic investment, and more recently, in the case of KTRV, of prioritising Russian Air Force weapons requirements for crewed combat aircraft as adequate defence-ministry funding began to flow again.

The Kh-50 small, guided glide-bomb and the Item 85 missile also known as Kh-MD (MD being the Russian acronym for short-range) were on display on the KTRV

stand at *Armiya 2021*. Several munitions were shown along with the *Altius-M* UAV. While these were covered, the shapes included those resembling the Item 85 short-range missile and the KTRV KAB-250 guided bomb. The KBM Item 305 was shown for the first time at *Armiya 2021*, and while associated with upgrades of Russia's two attack-helicopter designs, the missile may also have UAV applications. Given its size, and weighing in at 105 kg, it is better suited to the *Altius-M* and the *Inokhodets-RU*. The Item 305 has range of 14 km.¹⁷⁴

With the possible exception of the Kh-50, all of the other munitions mentioned above were initially designed for crewed combat aircraft or helicopters. Kronstadt Group's family of small guided-bombs were almost certainly designed from the outset for UAV applications. It displayed models of the KAB-50 50-kg guided-bomb and the UPAB-50 guided glide-bomb in front of the *Inokhodets* shown at *Armiya 2020*. The UAV was presented in its export guise and referred to as *Orion*.¹⁷⁵

Altius-RU and *Inokhodets-RU* are destined for the air force, and in the case of the former, also for the navy. The *Korsar*, meanwhile, is likely to be an army asset.

Syria has also provided a test environment for some of the loitering munitions Moscow has in development. The Zala Group's Lancet-3 loitering munition has been used by Russian special forces in engagements in Syria. The weapon has a range of 40 km, with an endurance of 40 minutes.¹⁷⁶

Like China, Russia will introduce increasingly armed UAVs into the inventory of its armed forces. Unlike Beijing, however, Moscow will struggle to easily establish a similar footprint in the export market. Irrespective of its Soviet-era prowess with uninhabited systems, the lack of research and development in the 1990s and early 2000s means that Russia is not able to initially address the emerging export market for armed UAVs.

US

The US was the first nation to deploy an armed UAV in combat operations, and today it remains at the forefront of uninhabited-systems design, development, and operation. Irrespective of the growing capabilities of some other states in the armed UAV realm, Washington will remain a bellwether for capability and will be the supplier of choice for many of its allies. Accessing

armed-UAV systems may also become less difficult for some allies, given recent changes in US export regulations.¹⁷⁷ Nowadays, the US, under the rubric of the MQ-Next banner, has been looking at its future MALE UAV requirements with a mission-set more aligned to operations in a contested air environment. The US Air Force has almost 300 MQ-9 *Reapers* in its inventory, the MQ-1 *Predator* having been retired. The MQ-9 is being developed to provide greater utility in emerging threat environments, while the air force also scopes out its future armed MALE capability. The US Army and US Marine Corps are also MQ-9 operators.

The *Predator* and *Reaper* were used widely in US operations in Afghanistan and Iraq in ISR and armed roles, as well as more broadly in Washington's Global War on Terror. The drawdown in US operations in the Middle East and the reduced emphasis on COIN and counter-terrorism is being offset by the re-emergence of peer or near-peer rivalry and the increased risk of state-on-state war. This is also reflected in US considerations regarding its future UAV needs, where systems are increasingly seen as having to be capable of operating in a contested, or highly contested, air domain.

US requirements are being driven by rival states like China and Russia, which in turn respond to developments – or how they view developments – in Washington. Beijing and Moscow continue to invest in, and field, capable surface-to-air missile (SAM) systems nested within what are intended to be integrated air- and missile-defence architectures. Subsequently, there is greater emphasis on UAV survivability in penetrating and operating within defended airspace where there is a considerable SAM threat. Some of the system elements that may emerge as follow-ons to the MQ-9 may well have a direct role in countering threat SAMs in the Suppression of Enemy Air Defence role.

The US Air Force (USAF) is pursuing several options to develop the next generation of UAVs. This development is mostly directed towards a family of systems which will encompass expendable, attritable and survivable concepts, all of which will almost certainly be capable of carrying weapons.

One aim is to lower the cost of next-generation UAVs, with this having been a research and development driver for some time. Work has encompassed airframes,

Variants of the MQ-9 Reaper are in service with the USAF, US Army and US Marine Corps. What will eventually succeed the MQ-9 in the US inventory has yet to become clear



(Franz J. Marty/SOPA Images/LightRocket via Getty Images)

engines, sensors and weapons. Initial plans for a successor to the MQ-9 began almost as soon as the system itself was operational. Known originally as MQ-X, the programme for the successor platform was envisioned as yielding several platforms from 2020 onwards, each iteration building on and improving upon its predecessor. The MQ-9 would still be used to conduct operations within its ISR/close-air support role, while what were referred to as the MQ-Ma, MQ-Mb and MQ-Mc would increasingly take on additional, increasingly complex tasks. Although this programme was stopped in 2012, it appeared that its eventual successor, the MQ-Next programme, would take on a similar profile.¹⁷⁸

The MQ-Next concept was revealed in June 2020, with the goal of delivering a weapons-capable UAV that would prove more survivable than the MQ-9, while also being cheaper to procure, operate and upgrade.¹⁷⁹ The industry responses mostly focused on improving the MQ-9's 'hunter/killer' role, albeit with a focus on

improved survivability and the concept designs suggesting some low-observable features.¹⁸⁰ However, a subsequent request for information (RFI) by the USAF in March 2021 suggested a much narrower focus on a new mission, that of High-Value Airborne Asset Protection (HVAAP).¹⁸¹ Within this scenario, multiple long-range, armed UAVs would accompany and protect valuable airborne assets such as tankers, e.g. the Air Force's KC-46 or expensive sensor platforms such as the F-35. The second RFI therefore shifted the focus towards a counter-air capability which it envisions to be fielded by 2026–27 on existing platforms and on next-gen UAVs from 2030 onwards. Yet, HVAAP is only envisioned as a first 'apex' capability. While capabilities beyond HVAAP have not yet been defined, it is likely that they will encompass tasks that were originally envisioned for the MQ-Mb and MQ-Mc projects, such as SEAD and missile defence.

So far, the main challenge appears to be combining affordability, both in terms of procurement and maintenance, with the desired mission requirements. Ideally, the MQ-Next concept will combine the software developed in programmes such as Skyborg and Collaborative Operations in Denied Environment (CODE) with hardware from the Low-Cost Attributable Strike Unmanned Aerial System Demonstration (LCASD) programme, such as the Low-Cost Attributable Aircraft Technology (LCAAT) XQ-58 *Valkyrie* and Low-Cost Attributable Aircraft Platform Sharing (LCAAPS) common chassis. Both hardware and software will be characterised by modularity and an open-system architecture, enabling a spectrum of UAVs tailored to mission needs. Ideally this combination will result in a continuously evolving cycle of MQ-Next designs and configurations.

Chapter 3. Autonomous weapon systems: technical, ethical and legal issues

Several technical challenges remain, delaying the deployment of autonomous UAVs by armed forces in the near term.

Firstly, battery power remains a pressing issue that constrains how long UAVs can remain in flight and contribute to military missions.¹⁸² While autonomous UAVs can be pre-programmed, AI-enabled autonomous UAVs require machine learning for navigation-data processing and fusing data from a wide range of sensors. This is very power intensive and negatively impacts the lifespan of UAV batteries.¹⁸³ Notably, machine-learning algorithms have been billed as a possible solution to this problem by allowing UAVs on low power to navigate home or to remote charging points.¹⁸⁴ The battery-power issue will likely be particularly acute in a highly contested operating environment, where existing navigation systems such as GPS may not be usable, and autonomous UAVs would need to rely on machine-learning algorithms to fuse data from a range of sensors to correlate the best course of action. This further increases power demands on the UAV's battery life.¹⁸⁵

Secondly, there are technical challenges to integrating autonomous UAVs into wider networks in a future internet of military things (IoMTs) including bandwidth and latency issues that could prevent the timely sharing of real-time critical mission data between platforms and operators. For example, encrypted data links needed for information security can introduce control latency.¹⁸⁶ Autonomous UAVs also continue to remain vulnerable to detection in highly contested environments. To date, there is no reliable method to exchange large amounts of data in real time between a network of autonomous UAVs without the risk of detection. One solution could be upgraded low probability of detection (LPD)/low probability of intercept communications (LPIC). For now, LPD/LPIC is only capable of sharing small amounts of data but, at the same time consumes large amounts of battery power.

Thirdly, there remains the technical challenge of integrating autonomous UAVs with existing aerial platforms

as, for example, seen with the USAF's 'Loyal Wingman' concept.¹⁸⁷ Integration challenges include lack of interoperability between communication systems and software language.¹⁸⁸ The present limited processing power of crewed 'legacy' aircraft is also a constraining factor when it comes to acting as command nodes or relay stations for autonomous UAVs further impeding their operational use under emerging crewed-uninhabited operating concepts.

The technical challenge: AI and machine learning

Integrating narrow AI/machine-learning (ML) into weapons systems and platforms come with several challenges, broadly related to data collection and classification, as well as data processing and human 'trust' in these systems. This has hampered the deployment of AI-enabled autonomous platforms to date. As one analysis succinctly put it: 'Regardless of what you might think about AI, the reality is that just about every successful deployment has either one of two expedients: it has a person somewhere in the loop, or the cost of failure, should the system blunder, is very low'.¹⁸⁹

Progress in AI and ML development over recent years rests on the increasing availability of big data in today's society and advances in distributed networking and cloud computing. However, rapid advances in the fielding of autonomous UAV platforms may be constrained by three additional factors. Firstly, there is a perennial shortage of trained data scientists for labelling data and 'training' AI/ML algorithms.¹⁹⁰ Secondly, there is a continuing lack of access to the computing power needed for the development of AI/ML training sets.¹⁹¹ Thirdly, data integrity also remains important. Should AI be trained using data sets which potentially could have been compromised by malign actors, then trust in the AI's decision-making process may be low among operators.¹⁹²

Additionally, the issue of trust goes far beyond the integrity of datasets and is the central issue at the heart of the challenges that come with AI and ML techniques.¹⁹³

AI/ML algorithms use statistics to approximate patterns in massive amounts of data. Basic ML algorithms require a lot of labelled data to work or human input to make statistical inferences. This is also known as supervised learning. Unsupervised learning, part of a subcategory called deep learning, is where less human input is needed when it comes to processing data and making predictions, but it is more power-intensive. AI/ML can correlate data, but it cannot infer causality. As causality is generally needed for explanations, this constitutes a core problem in the deployment of autonomous UAVs. Furthermore, the complexity of AI/ML algorithms and the speed of their decision-making processes is so great that for most individuals AI represents a sort of 'black box'.¹⁹⁴ Therefore most AI decision-making processes remain inexplicable to human operators, resulting in a low level of trust. As a result, human operators are less likely to deploy AI-enabled systems, including autonomous UAVs, for critical missions.¹⁹⁵ Making AI decisions more comprehensible to humans, and vice versa, remains a challenge. This has been made more difficult by the fact that AI-enabled systems, when placed in real-world conditions, have proved to be fallible.¹⁹⁶

The technical challenges: UAV swarms

There are a range of technical challenges that will likely limit the realisation of UAV swarms in the near term.

Firstly, hardware limitations need to be overcome to effectively field UAV swarms. Battery power, already a problem with UAVs operating independently, becomes all the more an issue for autonomous UAV swarms.¹⁹⁷ Swarms are realistically expected to be composed of smaller UAVs only able to carry a limited payload with a small battery. Yet power demands on swarm UAVs will likely be high, given the need for the nodes to communicate with one another and transmit data back to the swarm operator to even perform ISR missions. Should these swarm UAVs eventually be equipped with weapons systems or other payloads, then space for battery will be even more limited even as energy demands increase.

Secondly, communication issues outlined in the previous section are only amplified when it comes to autonomous UAV swarms. Bandwidth will be in limited supply in contested future operating environments. As such, real-time transmission of data within

an autonomous UAV swarm and from the swarm to, for example, intelligence, surveillance and reconnaissance (ISR) assets within an IoMTs will be extremely challenging. An alternative of edge computing, made possible through cloudlets on cooperating UAVs, would allow on-board analysis of data collected by UAV swarms before transmission, thus allowing less data that needs to be transmitted. However, this has the flip side of increasing energy consumption.¹⁹⁸

Thirdly, there are also challenges to command and control of UAV swarms.¹⁹⁹ For example, in a centralised structure, one node will function as the leader from which all others take their lead, which in essence makes the control of the swarm on a global level easier for the human operator. However, this centralised structure also has weaknesses, first among which is that the loss of the leader will hamstring the swarm in its entirety. Additionally, communication with the swarm will run through the leading node, causing latency issues as the leader is the focal point for data uploads and further leading to higher bandwidth demands. In comparison, a decentralised structure allows nodes to collectively decide on how to execute missions or perform collective actions. This structure has the benefits of lower bandwidth needs and more robustness in the face of enemy counter-measures, as there is not one single node as the point of failure.²⁰⁰ However, this programming naturally results in a loss of human control over the behaviour of the swarm and nodes will make decisions on the basis of the data collected from their on-board sensors and pre-stored data – which may not reflect current operational developments in the battlespace.

Fourthly, it remains unclear to what degree AI/ML algorithms can successfully adapt and reconfigure to real-live battlespace conditions as AI/ML algorithms are developed in synthetic environments.²⁰¹ The extent to which these environments and synthetic data reflect battlespace conditions would be unclear until the moment of operational deployment, further undermining trust, given that it remains an open question whether the ML/AI behind autonomous UAV swarms will behave in a similar manner in deployment as in synthetic training environments.

Fifthly, there is also the challenge of the cognitive abilities of the human operator. Due to the speed and

complexity of UAV swarms as they increase in size, the human brain is unable to comprehend the placement and geographic orientation of all nodes on the UAV.²⁰² The human operator will likely lose situational awareness and suboptimal control of the UAV swarm will ensue unless the entire operation can be executed with no human operator in command. The same is true in reverse, given the delegation of control into a more decentralised structure, where increased autonomy will still result in the operator losing situational awareness as their attention will not be required at all times.

National developments

China

China is pursuing AI-enabled capabilities as means of improving its offensive and defensive military capabilities, among which autonomous UAVs are expected to play a role.²⁰³ Publicly-available details on this capability, however, are limited.

Claims have emerged of elements of autonomy within several platforms already available to Chinese forces – or for export. The GJ-2 UAV, the domestic version of China's *Wing Loong II* export, is capable of autonomously identifying the enemy and carrying out threat analysis, according to Ziyan UAV, the UAV's designer.²⁰⁴ The US Department of Defense has also raised concerns about China's willingness to export systems with autonomous capabilities.²⁰⁵

China has been rapidly pushing its development of AI-enabled UAV swarms forward. In 2016, the China Electronics Technology Group (CETC) was demonstrating advances in swarm intelligence at the Zhuhai Airshow, and in 2017 CETC demonstrated advances in swarm technology by flying 119 fixed-wing UAVs in complex formations.^{206, 207} In 2020, China tested a swarm of 200 munitions (resembling the CH-901 loitering munitions) in combat simulations.²⁰⁸ In the same year, EHang showcased a swarm of 1180 UAVs in which the UAVs coordinated their flights autonomously.²⁰⁹

China's pursuit of uninhabited combat air vehicles (UCAV) is also likely supporting interest in the application of machine-based decision making. For example, the GJ-11 has been in development for around a decade. This is a large long-range UCAV which, given its mission profile, will likely require some element of AI.^{210,211}

China has so far produced a small number of the GJ-11 uninhabited combat air vehicle that is likely still being tested



(Zoya Rusinova/TASS via Getty Images)

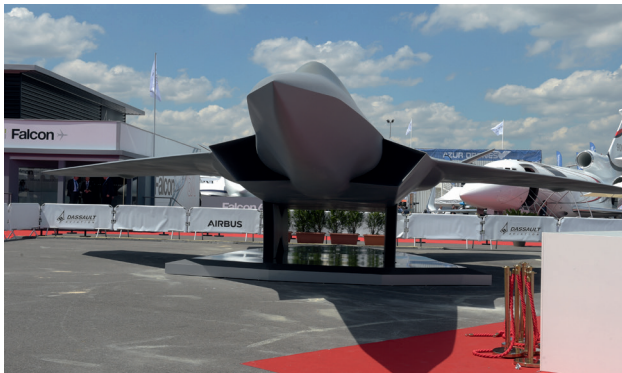
Another example of note is China's Dark Sword UCAV project, which may be more akin to a 'loyal wingman' concept and which foresees human-machine teaming as a significant force multiplier for the PLAAF.²¹² Nevertheless, details as to when these platforms will be fielded remain scarce.

Europe

Not only autonomous but also armed UAVs remain a contentious topic in some European countries. Germany remains divided over whether to acquire armed UAVs. European defence companies are pushing ahead with the development of various machine-learning-enabled platforms with the potential for autonomous deployment, as, for example, seen in elements of both European future combat air programmes.

The Future Combat Air System (FCAS) programme between France, Germany and Spain is intended to integrate a variety of platforms into a networked whole conceived of as a 'system of systems' linked within an Air Combat Cloud.²¹³ At the centre of the programme lies the Next Generation Weapon Systems (NGWS), composed of a new Next Generation Fighter (NGF) and remote carriers.²¹⁴ The NGF itself will be crewed, with the possibility of uninhabited flight if necessary.²¹⁵ It remains unspecified as to whether the NGF will be able to perform autonomous missions. The remote carriers will be weapons-capable uninhabited platforms seen as part of the human-machine teaming concept with the NGF. Given that perfect connectivity between NGF and the remote carrier will not always be ensured, and that multiple carriers may sometimes

The Dassault-led combat aircraft element of the French, German and Spanish Future Combat Air System is intended to be operated alongside uninhabited 'remote carriers'



(Eric Piermont/AFP via Getty Images)

function as part of a swarm, there is an expectation that they will possess a degree of autonomy.²¹⁶ However, French reluctance to use the term 'autonomous' in reference to uninhabited platforms and the objection of some in German politics to autonomous weapon systems leaves a question mark over whether these platforms will be introduced.²¹⁷ While exact dates remain unclear, the NGWS is expected to be fielded starting in the early 2040s, barring production complications or political disagreements.²¹⁸ The United Kingdom, under the banner of its Future Combat Air System project, with Sweden and Italy also involved, is also looking at a next-generation capability that blends crewed and uninhabited platforms. Again, autonomous capabilities will be part of the overall effort.

Further European research and development programmes include Airbus's swarm trials in Germany, using Do-DT25 UAVs controlled by a pilot in a combat aircraft.²¹⁹ The company is playing a leading role in the FCAS programme, along with Dassault, which leads the NGF element of the project.²²⁰ The German defence ministry and Airbus intend to conduct further tests on crewed-uninhabited teaming concepts and technology, and the European Defence Agency is intending to support similar research as of 2022.²²¹ In Spain, Escribano has announced that it will demonstrate its newly developed UAV-swarmling technology in October 2021.²²² Funding for the project has been provided by the Spanish Ministry of Defence as part of the RAPAZ programme (phase II) to develop ISR-capable drone-swarm capabilities.²²³ French *Icarus* UAVs, built by the company Parrot Anafi, are already being marketed as

an AI-enabled swarm for security applications.²²⁴ The Royal Air Force and Italian defence contractor Leonardo announced in 2020 that they had worked together to test autonomous UAV swarms carrying EW payloads.²²⁵

Russia

In terms of deploying autonomous UAVs, the Russian defence industry is still in the early developmental stages and is in the process of catching up with other major military powers, including the US and China. Notably, Russia has utilised its role in the Syrian conflict to field-test several AI-enabled UGVs and is further reported to be deploying AI-enabled UAVs such as the Sukhoi S-70.²²⁶

Russia's conceptual emphasis on the use of UAVs seems to focus on the development of AI-enabled UAV swarms, of which several are in their testing phase. In 2018, early swarm trials are reported have been conducted by Russian defence-research institutions such as the Advanced Research Foundation.²²⁷ In 2020, during the Kavkaz military drills, the Russian MoD tested UAV 'swarms' composed of several UAVs deployed in the Syrian conflict, the *Forpost*, *Orlan-10* and *Eleron-3* UAVs among others.²²⁸ None of these, however, has any element of machine learning.

Additional AI-enabled UAV swarm concepts are being explored within the Russian defence industry. Researchers at the Zhukovsky-Gagarin Air Force Academy are developing a swarm concept known as *Staya-93* ('*Staya*' meaning 'flock') which will see dozens of UAVs deployed in a swarm armed with explosive payloads.²²⁹

The Kronstadt design bureau is advancing its version, known as *Molniya* ('Lightning'), which involved launching jet-powered low-observable UAVs from carrier aircraft (both crewed and uninhabited), to conduct a wide range of missions encompassing ISR, electronic warfare and ground-attack missions.²³⁰ In 2018, the state-owned defence company Radio-Electronic Technologies Group announced that it would develop a helicopter capable of controlling UAV swarms by 2025. The same company has also made it known that it is working to incorporate AI algorithms within these UAVs.²³¹ In 2021, the Russian MoD announced that it would be developing a heavy UAV designed for anti-submarine warfare. Equipped

with the necessary weapons and sensors to locate and engage enemy submarines, these AI-enabled UAVs would function within a swarm to achieve their objective more effectively as a networked whole.²³² A further proposal by the MoD envisions the deployment of jet-powered UAVs from Russia, derived from the new under-development PAK DA bomber, expected to be in service by the end of the decade.²³³

While these projects are far from being the capability to deploy fully autonomous UAVs, when coupled with Russia's advances in autonomous UGV technology, one can see that Russia has clear ambitions to incorporate AI-enabled platforms into its air capabilities. It is also worth considering that Russia has announced major advances in AI-enabled command and control (C2), in the form of its Battle Management Information System, which allows the networking of uninhabited platforms and satellites for information collection and assessment for commanding officers.²³⁴ Given these advances, Russia is likely to field AI-enabled UAVs of some sort within its future network-centric force structure.

US

In 2016, the Air Force Research Laboratory initiated the Low-Cost Attritable Strike Unmanned Aerial System Demonstration (LCASD) programme. The Kratos XQ-58 Valkyrie, a jet-powered UAV with an internal weapons bay, emerged as part of a sub-effort known as the Low-Cost Attritable Aircraft technology (LCAAT) programme. While cost estimates as to what constitutes an attritable aircraft vary, the US\$3 million that Kratos envisions for the Valkyrie is at the lower end of the spectrum.^{235,236}

With next-generation UAVs such as Kratos' platform, the USAF hopes to bring mass to the battlefield at reasonable cost. This effort is also sustained by another sub-programme of LCASD, known as the Low-Cost Attritable Aircraft Platform Sharing (LCAAPS) project under which Boeing, GA-ASI, Lockheed Martin and Northrop Grumman are working towards developing two expendable (attritable) UAV platforms, derived from a common chassis.²³⁷

With a pivot back to great-power competition and a renewed focus on high-intensity warfare, UAVs are having to be adapted to changing threat perceptions. There

is increasing emphasis on automation, machine-based decision-making, and machine-to-machine interaction as means of proving greater utility and survivability for UAVs in a contested environment.

While UAVs such as the MQ-9 continue to require a remote pilot for at least elements of the flight, ongoing efforts are aimed at introducing increased automation on future platforms. To this end, the United States is pursuing several programmes, one of which is the USAF's Skyborg project, begun in October 2018. The aim of the project is to develop a government-owned 'autonomy core system' that can then be combined with low-cost, attritable UAVs. Such a system, if developed at an affordable cost, could provide part of the mass likely to be needed in a high threat environment where combat losses would seem inevitable.²³⁸

Skyborg was flown for the first time on 21 April 2021 on a Kratos UTAP-22 UAV.²³⁹ A further test was conducted on 24 June, using DA-ASI's MQ-20 *Avenger* ER. During this flight the control system made 'choices' regarding navigation decisions, communicated with other aircraft and also performed basic manoeuvres with a crewed aircraft.²⁴⁰ Albeit tested with these two systems, Skyborg is explicitly not restricted to a particular type of platform. To that end, the programme emphasises an open-systems architecture and modularity.²⁴¹

In a similar vein, DARPA's CODE programme seeks to enable a group of largely autonomous UAVs to work together under the supervisory control of a human operator.²⁴² Previously, the USAF has experimented with one operator directly controlling more than one UAV, and the initial MQ-X programme still envisioned that each platform would be controlled by a human operator, but during experiments this has proven impractical, even in a relatively benign environment.²⁴³ Instead, CODE will allow UAVs to operate autonomously, continuously assessing their environments and states and presenting the mission commander with recommendations for coordinated action.²⁴⁴ In March 2019, it was announced that the programme would move from DARPA to the US Navy's Naval Air Systems Command, marking another step towards operationality.²⁴⁵ On 28 October 2020, CODE was flown on a GA-ASI *Avenger* UAV, joining up and coordinating with five simulated UAVs for an air-to-air search.²⁴⁶

Ethical and legal concerns

There is nothing new about remote killing. Soldiers have been attempting to extend the distance of engagements between themselves and their opponents for centuries. What was new about the use of uninhabited aerial vehicles (UAVs) in exercising lethal force was that it gave the appearance of wielding this force with impunity given the remoteness of those in control. Public worry was compounded by the prospect of increasingly devolved lethal decision-making to machine-based judgement, with the human no longer just remote but completely removed from the decision-making loop.

The environment in which armed UAVs were first employed only further fuelled concern. In its Global War on Terror a US intelligence agency, rather than the armed forces, initially wielded the use of armed UAVs, with limited wider transparency on decision-making. The apportioning of control to the Central Intelligence Agency was a concern not just for the public, but also for some within allied forces, whose view was that this capability should remain within the armed forces only. Washington used the unbounded nature of the conflict to carry out UAV strikes against those who were deemed to be 'high value targets' across borders and in states with which it was not at war. The result was considerable debate as to the 'legality' of the targeted killings, particularly in Pakistani territory, and also as to which legal rules should be applied to this activity.²⁴⁷ All of this was compounded by inevitably high-profile civilian deaths resulting from targeting errors, and disputes as to whether 'drone strikes' were killing many more civilians than intended targets.²⁴⁸ What was not part of the core argument was whether armed UAVs were per se in contravention of the legal conventions meant to govern a state's military activity.

Armed and useful

It is difficult to dispute the military utility of armed uninhabited systems, though assertions that they will be transformative in the way in which wars are fought should be treated with caution. Remotely piloted or operated armed UAVs were in the first instance simply a further extension of the platform's ISR role when fitted with a laser target designator. Rather than be used to locate and illuminate a target for a crewed platform,

The use of armed UAVs has become an emotive issue for some, with concern, and confusion, over what constitutes a lethal autonomous weapon system



(Wolfgang Kumm/DPA/AFP via Getty Images)

most often a combat aircraft, the UAV would instead also carry a weapon for release following the confirmation of a target. The authority for these activities remained with the human operator; they were simply removed from the immediate combat environment. From a political and military perspective this had the initial attraction of reducing the casualty risk for one's own forces. This asymmetry, however, courted problems: if effective, as it has been seen to be, it would encourage other states and non-state actors, to pursue similar capabilities. While far removed from the operational theatre, UAV operators would be legitimate military targets for an adversary, with the possibility of attacks on home territory, and for some at least there was a question of a loss of moral authority if one was able to kill with impunity (see, for example, M. Shane Rizza, *Killing Without Heart*).

Such concerns and questions are to do with the use of the technology, rather than the technology itself. As such these issues apply to the way in which armed UAVs are employed and their tacit acceptance, or otherwise, in civil society. The issues are more complicated and arguably fundamental regarding autonomous weapon systems.

The activities and legitimacy of combatants during war is covered by the law of armed conflict (LOAC); this is made up of the appropriate international law and any relevant national law of the combatants. There has been and continues to be considerable debate as to the use of armed UAVs and autonomous weapons systems within the context of LOAC.²⁴⁹ Armed UAVs and autonomous weapons, however, are not synonymous. While there is no internationally agreed definition of

what constitutes a lethal autonomous weapons system (LAWS), presently fielded armed UAVs are not autonomous. These systems require human agency in their use in selecting, identifying and engaging targets. An autonomous armed UAV would arguably have the capacity to operate, independently select and engage a target within a broad range of parameters without any human oversight or approval. Software-based machine-decision making would replace human activity in the engagement cycle. As such, the issues regarding armed UAVs which require human operation or oversight and autonomous armed systems are different to a degree. Machine-based decision-making is an essential element of the latter at a level that up until now has remained the purview only of humans – the decision to exercise lethal force and the approving the use, or using, weapons as a result. LAWS has become the term often used to describe this emerging class of military equipment, as it is a less weighted term than ‘killer robot’ which has been popularised in the public domain.²⁵⁰

Pinning down autonomy

One challenge, however, remains the lack of an agreed definition of an autonomous system in the military context. The UK Ministry of Defence suggests that an autonomous system can be described as one which is able to: ‘sense and understand their environment, decide how to respond, and then perform tasks to achieve goals, overseen by humans.’²⁵¹ The US Department of Defense provides a similar description suggesting a: ‘weapon system that, once activated, can select and engage targets without further intervention by a human operator.’²⁵²

Both are reasonable, but they are also broad, open to differing interpretations, and in a key aspect, possibly contradictory. While the UK description retains the element of human oversight, this is absent the DoD’s generic description. The latter, however, does also offer up a second class of ‘human-supervised autonomous weapon systems that are designed to allow human operators to override operation.’²⁵³ In the case of the UK and in the latter of the two US definitions, neither is genuinely autonomous in that human agency is still involved even if only in a supervisory role.

There are legal and practical implications concerning human oversight of an ‘autonomous’ weapons system.

Regarding the former, it makes adhering to the existing international laws that cover armed conflict less problematic, but in the case of the latter, makes it more so. One of the practical interests in autonomy at the military level is the worry that the electromagnetic environment is only going to become more contested, with access and use no longer necessarily a given. The present generation of armed UAVs are fitted with datalinks to provide operator control or oversight and to relay ISR imagery in support of activity. Datalinks, however, are potentially vulnerable to electromagnetic attacks.²⁵⁴ This would not be the case with an autonomous armed UAV, where an operational datalink would not be required for target identification and attack, since these decisions would be made onboard the air vehicle, based on software algorithms.

All the main principles of the law of armed conflict are applicable to armed UAVs and LAWS, though the emphasis and the extent of the difficulty differs. These principles are proportionality, military necessity, distinction, avoiding unnecessary suffering and precaution. The language of LOAC, however, is open to debate and differing interpretation depending on one’s perspective, whether the wider war under consideration is deemed legitimate or not, and more generally regarding whether the use of state-sanctioned killing – that is, war – is ever acceptable. Some of the debate around armed UAVs and autonomous systems has arguably been created by those who do not consider the use of military force to ever be acceptable, while for others the concern is to do with trying to ensure the legitimacy of their use through an agreed application of LOAC and normative behaviour.

Legal limits

The present generation of armed UAVs do not appear to fundamentally fall foul of LOAC in terms of either distinction or unnecessary suffering. An autonomous weapons system, however, capable of complex decision-making in the identification and selection of targets in a broad rather than narrow context – (‘narrow’, for example, being an active-radar guided missile in the terminal phase of an engagement where the guidance software independently tracks and locks on to the target) – raises more questions.

In part the difficulty is the result of the differing pace of developments, and at times the way in which a technology emerges from the research and development (R&D) environment and into service. Software-based complex decision-making, the short-hand often used is AI, has been the focus of R&D for decades, but only within the past ten or so years has its potential use as the basis for autonomous weapons gained traction and speed.²⁵⁵ The laws governing the conduct of war do not move at the same pace. This is only compounded by the swiftness of development in information technology applicable to military applications, including the cyber realm. There is a clear risk that autonomous weapons systems will be introduced and used well in advance of the international law-making and the legal community's ability to keep up.

This is not to say the challenge has gone unrecognised. A significant international body struggling with the implications of LAWS in the context of LOAC and International Humanitarian Law is the United Nations Group of Governmental Experts on LAWS. This expert group was established in 2013 under the purview of the UN Convention on Certain Conventional Weapons and has met annually since 2014.²⁵⁶ Signatory states include China, France, Germany, Italy, Russia, Spain, the UK and the US.

The 2019 GGE adopted 11 'Guiding Principles' it had agreed concerning international humanitarian law (rather than LOAC) and LAWS.²⁵⁷ One of the principles was: 'Human responsibility for decisions on the use of weapons must be retained since accountability cannot be transferred to machines. This should be considered across the entire life cycle of the weapons system.'²⁵⁸

In a submission to the GGE the UK noted: 'the human role in an autonomous weapon system is a fundamentally important factor when determining if a systems can be used in accordance with IHL. Identifying where and how control could exist, and how it might be impacted is crucial to furthering our collective understanding.'²⁵⁹ London has previously informed the GGE it 'has no intention of developing systems that could unilaterally employ lethal force without human involvement'.²⁶⁰ What constitutes 'involvement' and 'responsibility', however, remains open to debate.

In preparation for the 2021 GGE a Chair's paper was issued proposing a number of areas for consideration. These include tighter 'characterizations' of autonomy as related to weapons systems that attempted to better describe the role or absence of human agency. A fully autonomous weapon system is one that is 'designed to operate outside a responsible chain of human command and control,' while a partially autonomous weapon system is one that is 'designed to operate within a responsible chain of human command and control'.²⁶¹

Of the two categories of LAWS outlined above it is the former that poses the most obvious challenge within the context of LAOC or IHL. Its operation outside of human responsibility would appear to make the principle of distinction in the context of human accountability within international law problematic. In the case of a fully autonomous weapon system, as suggested by the Chair, this would imply a system developed from the outset with machine-based lethal decision-making as a goal, outside of any human agency, posing the problem of accountability.

The second category, however, also constitutes a challenge, if of a different order. This is arguably in part dependent on the extent of 'human command and control' in the use of the weapon. In the Chair's paper the overarching description of an autonomous weapon system is one that 'can, through the use of sensors, computers and algorithms, perform the critical functions of selecting and engaging to apply force against targets without intervention by a human operator or without permanent human involvement or control'.²⁶²

In the case of the partially autonomous system, it is arguably key to determine where human agency would be required within 'a responsible chain of command and control'. In terms of the principle of discrimination, the case continues to be made by some that human oversight is required²⁶³

Debates regarding armed UAVs and the potential emergence of a fully or partially autonomous subset of this class of systems are unlikely to be resolved anytime soon at either governmental or societal levels. It is quite likely that for some the issues will never be resolved at all, since one – and possibly likely – outcome is a compromise which leaves considerable room for interpretation at the national level with regard to any agreed

norms of activity. This, however, should not negate the importance of the ongoing discussions and arguments.

The Kargu conundrum

In a 2021 United Nations Security Council report on the Libyan civil war the Turkish Kargu-2 small rotary armed UAV was described as a 'lethal autonomous weapons system.'²⁶⁴ Describing the Kargu-2 as such exemplifies the definitional difficulty, if not confusion, over what is meant by full autonomy in a weapon. Kargu manufacturer STM describes the UAV as having 'fully autonomous navigation' while it includes an 'automatic target

recognition system'.²⁶⁵ Promotional material for the Kargu states that the 'precision strike missile is fully performed by the operator' with a human-in-the loop in the decision-making process. The latter description would not seem to meet the broad threshold for a LAWS. The UN report, however, said: 'The lethal autonomous weapons systems were programmed to attack targets without requiring data connectivity between the operator and the munition: in effect, a true "fire, forget and find" capability.' Even if correct, and it is a claim STM contests, it remains debatable whether the Kargu does meet the criteria for a fully autonomous weapon.²⁶⁶

Conclusion

Armed UAVs in their many guises are an established element of the weapon inventories of numerous states, and this number will almost certainly grow. Their utility, however, has also attracted the attention of non-state actors, posing questions as to how to counter such a threat.

First used as part of counter-insurgency operations in a permissive air environment, emphasis is shifting amongst some states as to how armed UAVs can be operated in a contested air domain when faced with layers of ground-based air defence. Revised concepts of operation, higher levels of attrition, low-cost large numbers, or swarms, and low-observable airframes are being considered or developed in response to a more demanding environment. The counter-insurgency or counter-terrorism application, however, has not disappeared, with armed UAVs continuing to be used in these roles.

The adoption of armed UAVs remains contentious at least in some states, with debate as to their ethical legitimacy, and whether their use can be accommodated within the law of armed conflict. The increasing prevalence of armed UAVs, however, suggests that this debate continues to favour the argument that such weapons do not contravene the laws governing war.

Far more fraught, however, are the issues surrounding LAWS, with even a definition in dispute. A genuinely autonomous system would, for instance, remove any human involvement in the identification and discrimination of possible targets in a complex environment, with engagements prosecuted without human oversight. Human input would be limited to high-order mission commands prior to the deployment. The machine-based lethal decision process would need to address key aspects of the law of armed conflict to remain in compliance.

While technical, ethical and legal issues remain pertinent as UAVs continue to develop, the first is likely to be at least in part resolved to the point where LAWS can be deployed, in advance of any universal resolution to the last two. There is a risk that the lack of consensus will see some nations introduce into service what some others will consider to be autonomous weapons, and that there may be differing thresholds for the use of such systems.

Talks in international fora on lethal autonomous weapons may be making only slow progress in addressing the challenges these systems present. The alternative, however, is far less attractive.

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The International Institute for Strategic Studies – UK

Arundel House | 6 Temple Place | London | WC2R 2PG | UK

t. +44 (0) 20 7379 7676 **f.** +44 (0) 20 7836 3108 **e.** iiss@iiss.org www.iiss.org

The International Institute for Strategic Studies – Americas

2121 K Street, NW | Suite 600 | Washington, DC 20037 | USA

t. +1 202 659 1490 **f.** +1 202 659 1499 **e.** iiss-americas@iiss.org

The International Institute for Strategic Studies – Asia

9 Raffles Place | #49-01 Republic Plaza | Singapore 048619

t. +65 6499 0055 **f.** +65 6499 0059 **e.** iiss-asia@iiss.org

The International Institute for Strategic Studies – Europe

Pariser Platz 6A | 10117 Berlin | Germany

t. +49 30 311 99 300 **e.** iiss-europe@iiss.org

The International Institute for Strategic Studies – Middle East

14th floor, GBCORP Tower | Bahrain Financial Harbour | Manama | Kingdom of Bahrain

t. +973 1718 1155 **f.** +973 1710 0155 **e.** iiss-middleeast@iiss.org
