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Article36

Swarms

Discussion paper for the Convention on Certain Conventional Weapons (CCW)

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On 28 March 2019, the UK Government announced the awarding of 2.5 million GBP for the development of 'swarm squadrons of network enabled drones capable of confusing and overwhelming enemy air defences'.[1] Such swarms exhibit autonomous behaviour and are pursued by several states, including to attack targets. The prospect of 'essentially unlimited numbers' of weaponized mini-drones has raised fears of 'scalable weapons of mass destruction'.[2] The UK's announcement thus lent a sense of renewed urgency to ongoing deliberations on 'lethal autonomous weapons systems' in the framework of the Convention on Certain Conventional Weapons (CCW), especially as the UK continues to oppose legal restrictions on autonomous weapons in that forum.[3]

Inspired by swarms of insects, flocks of birds and shoals of fish, 'swarming' as a military tactic can be traced back centuries.[4] More recently, technological advances have enabled the pursuit of swarms in the form of networked, mobile, autonomous munitions or robots (including unmanned naval, ground or aerial vehicles (UAVs), also called 'drones'). Such swarms, composed of dozens, hundreds or thousands of potentially very small units could find applications in policing, counter-piracy, port security and similar operations.[5] But this bulletin focuses on their potential applications in a military context, where swarms could fulfil a range of missions, in offensive, defensive and supporting roles.[6]

Defence analysts see the benefits of swarms mainly in their capacity to overwhelm enemy capabilities by their sheer numbers, as well as in their functioning as coordinated, distributed, autonomous systems. Proponents argue that they would 'bring greater mass, coordination, intelligence and speed to the battlefield'.[7] To realize this vision of swarm warfare, they propose new paradigms of military organization and command and control. Among other issues, swarms thus raise questions about the quality of human control over the use of weapons and their effects – questions that intersect with the ongoing debates on autonomous weapons and on armed drones.

This bulletin briefly summarizes reported military advances in swarming technologies as well as recent policy commentary on the topic. It flags potential risks from the perspective of international and human security and disarmament, and suggests some areas of concern. Some of these are relevant to the CCW, a 'hybrid treaty' that sits at the intersection of arms control, disarmament and humanitarian law:[8]

- Swarms implicated in the detection, selection and attack of targets raise acute questions about human control over the use of force, as well as pressing legal, ethical, security and other concerns at the centre of the debate on 'lethal autonomous weapons'. The emergent behaviour of swarms and the proposition that a single operator could control a potentially large swarm heightens these concerns.
- Swarms risk entrenching problems posed by the use of armed drones in present practice, including the expansion of armed force, patterns of humanitarian harm and challenges to the international rule of law.
- Swarms could take different forms that may not fit well into existing legal categories, creating uncertainty about the legal ramifications of their use. To prevent swarm development from eroding long-standing legal protections, states must reaffirm the central values enshrined in existing law and actively seek to clarify the legal and ethical boundaries in swarm development: agreed legal

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standards constraining autonomous weapons and armed drones are needed.

- Ongoing multilateral efforts aimed at the control of (armed) drones and autonomous weapons should attend to concerns raised by the prospect of swarms. They should also be attentive to how visions of swarm warfare may be drawn upon to undercut weapons control efforts in other areas.

Current state of play

As a military concept, swarming – converging on a target from different directions simultaneously, either with fire or in force – has a long history.[9] In recent years, some military analysts have argued for swarming to be recognized as a 'doctrine in its own right'.[10] Contemporary visions of swarm warfare draw on networked military forms of organization and technological advances, notably in the fields of information technologies, robotic systems, sensor networks and artificial intelligence. Central to this idea is the deployment of myriad, small, mobile, dispersed, autonomous units that are interconnected.[11] From a US vantage point, the recent emphasis on swarms following a period of heavy reliance on high-tech, precision-strike, stand-off capabilities, is often explained as a way of countering adversaries' increasing capacity to deny US forces access to and restrict movement within an area (anti-access, area-denial, A2/AD).[12]

Several militaries are working towards distributed, collaborative systems of interconnected robots that can move and act as an integrated entity capable of performing autonomously with only limited human intervention.[13] Such projects aim to harness the power of swarm intelligence – the collective, global behaviour that emerges from the local interactions (sensing, communication, etc.) among decentralized and self-organized units and between these units and their environment.[14] The units in a swarm cooperate to achieve a global task but operate without centralized control or global knowledge.[15] Even when the interactions of swarm units are governed by simple control rules, the swarm as a whole can exhibit complex, emergent behaviours.[16]

In contrast to present-day remotely piloted, larger drones, swarming drones would be highly autonomous, flying themselves and coordinating their actions to avoid collisions and maintain swarm cohesion.[17] One human operator could control an entire swarm as a single entity. According to Paul Scharre, '[h]uman commanders will need to control swarms at the mission level, giving overarching guidance, but delegating a wide range of tasks to autonomous systems'. He argues for a shift of human control to the swarm as a whole, respectively, to the mission level,[18] and explores several possible command and control models.[19]

Swarms could be composed of identical units or incorporate units of different types and sizes. These can, for example, consist of rotary or fixed-wing UAVs, which could also collaborate with maritime or ground drones, as well as with manned platforms. Such drones could carry various payloads including jammers for electronic warfare, sensors, tear gas or explosive warheads. They could be reusable (yet expendable) or single-use. In a use of force context, swarms could serve as 'multiple unmanned platforms and/or weapons deployed to accomplish a shared objective'.[20] The number of units in a swarm may vary, depending on its purpose. In current tests, swarms have incorporated from a couple to over 1000 units, but size could potentially extend further.

Analysts are discussing numerous potential applications of swarms in naval, air and land warfare, independently and in cooperation with other weapons systems. These include the following:

- Swarms could 'act as agile mines to protect perimeters around military assets'.[21] They also could serve to 'conduct ... a siege by targeting all vehicular traffic into or out of a populated area'.[22]
- Swarms could 'disperse over large areas to identify and eliminate hostile surface-to-air missiles and other air defenses',[23] assist in maritime interception or search for enemy submarines, aircraft carriers, fighter jets or other high-value targets, and launch 'saturation assaults' to overwhelm[24] or 'confuse, deceive or wear down enemy defences'.[25]
- Swarms could blanket an area with multiple sensors[26] and be used for intelligence-gathering, surveillance and reconnaissance.[27] They could even be used to explore buildings and locate enemy combatants or civilians in 'cluttered and adversarial environments'.[28]
- There could also be a role for swarms in acting as decoys with the aim of disorienting and disrupting attacking forces or confusing or jamming enemy radars, or to infiltrate command networks to perform cyberattacks.[29]
- Explosive ordnance detection and disposal, as well as medical assistance and logistics resupply are also envisaged.[30]

Militaries expect a number of potential benefits from swarms. According to NATO, 'swarms are scalable, tasks can be accomplished more quickly and they allow access to a broader set of sensors and tools'.[31] By sheer force of numbers, swarms offer the potential to 'saturate and overwhelm' enemy defences when focused against a single target or a few, or alternatively, disperse[32] to 'expand the total number of targets that a sortie could successfully take out'.[33] Their numbers also mean that some units could be expendable, thus able to 'serve as decoys, soaking up defensive fires and distracting attention from other swarm components'.[34] Expendability depends somewhat on their cost, however, a point on which analysts' expectations diverge.[35] By acting collaboratively – particularly in different functions such as electronic attacks, decoys and jamming alongside kinetic strikes[36] – proponents hope that swarms could 'outsmart' enemy forces. Whereas some commentators highlight that swarms would be relatively 'robust to failure', due to their lack of a 'critical command unit',[37] others warn that swarms may be be particularly vulnerable to electronic interference due to the need of swarms units to communicate with each other.[38]

Though swarms have not yet been deployed in operations, they have attracted significant investment, research and development in a number of states. Considerable hurdles remain, however, before swarms could be viably fielded. Real-life conditions such as weather and wind turbulence, as well as the difficulties of long-range communication, can affect the performance of swarms, and questions remain over the stability of larger or high-velocity swarms.[39] Despite technological advances, developing cost-effective means with the speed, agility and range necessary for utility in combat operations remains a challenge. There are also unresolved conceptual and doctrinal issues,[40] and there is resistance to unmanned platforms in some quarters due to the (financial) resources their development and maintenance

diverts from manned systems, and because of deeper-ingrained cultural attitudes of military personnel.[41]

In spite of these hurdles and the difficulty of determining the precise pace and extent of technological developments due to military secrecy, it appears from open-source material that several states have made significant strides towards developing swarms of varying sizes. The UN Secretary-General warned in a recent report that 'the widespread availability of [sophisticated remotely-piloted aerial vehicles] with swarming or other autonomous functions is plausible in the short term':[42]

- The US is thought to have been investigating the possibility of drone swarms for over a decade.[43] In 2018, the US Office of Naval Research awarded a contract of nearly USD 30 million to Raytheon, a major defence contractor, for the development of swarming UAVs as part of its LOCUST (Low-Cost UAV Swarming Technology) programme.[44] This followed the successful in-flight deployment in 2016 of a swarm of 103 Perdix micro-drones[45] that 'displayed collective decision making, adaptive formation flight, and self healing'.[46] The US Defense Advanced Research Projects Agency (DARPA) has also been furthering its 'Gremlins' programme, which 'seeks to show the feasibility of conducting safe, reliable operations involving multiple air-launched, air-recoverable unmanned systems', which will have 'coordinated, distributed capabilities'.[47] In 2017, DARPA announced that its Collaborative Operations in Denied Environment (CODE) project had demonstrated swarm abilities to 'adapt and respond to unexpected threats' and that their drones had 'efficiently shared information, cooperatively planned and allocated mission objectives, made coordinated tactical decisions, and collaboratively reacted to a dynamic, high-threat environment with minimal communication'.[48] The US Office of Naval Research CARACaS (Control Architecture for Robotic Agent Command and Sensing) project has also shown progress towards collective autonomy used for perimeter surveillance and protection. In 2016, a 13-boat swarm with 1 human operator demonstrated the ability to 'identify, surround and harass an enemy vessel with little human supervision'.[49]
- China, the leading manufacturer of small consumer drones, has had significant successes in swarming technologies. In 2017, it demonstrated the ability to launch the largest swarm to date – 1,108 individual drones, which appeared to operate with high levels of autonomy and reportedly have the ability to self-repair.[50] Though no official figures are publicly available, China is thought to be investing heavily in AI research and development, and the Chinese Academy of Sciences is currently drafting the Artificial Intelligence 2.0 Plan, which is expected to cover 'big data, intelligent sensing, cognitive computing, machine learning and swarm intelligence'.[51]
- The European Union and a number of individual European states have also dedicated research to the potential of swarms. The EU's efforts include the EuroSWARM project funded by the European Defence Agency, under which researchers aim to 'test and demonstrate the efficient and effective operation of unmanned swarm systems'.[52] The UK's Defence Science and Technology Laboratory has for nearly a decade funded research and development projects related to autonomy, including swarming and autonomous navigation for unmanned systems.[53] In February 2019, the UK's Defence Secretary announced funding to 'develop swarm squadrons of network enabled drones capable of confusing and overwhelming enemy air defences'.[54] France and Germany have awarded a €65 million contract to Dassault and Airbus for a two-year study to progress their Future Combat Air System (FCAS) programme, which envisages the development of a network of swarming UAVs as well as next-generation aircraft and other weapons.[55]
- According to David Hambling, the Republic of Korea, Israel, Turkey and Russia are all also working on swarming capabilities.[56]

Swarming technology has thus far been demonstrated in limited ways in controlled spaces, and has not been tested in complex, challenging and rapidly shifting environments as could be expected in combat or other operational situations. Nevertheless, DARPA has begun research to allow for micro-drone swarm operations within urban environments and built-up areas.[57] Plans exist for the use of swarms of explosive munitions in 'contested environments'.[58] The 'swarm attacks' with explosives-carrying drones by non-state armed groups that made headlines last year,[59] however, did not involve 'swarms' as understood in this paper, as the drones lacked the required inter-drone coordination, communication and self-organization.

Adverse effects and risks

Swarms pose a host of questions and concerns, some of which are also discussed in relation to autonomous weapons and armed drones. Key issues include the following:

- Like other autonomous systems, swarms raise questions about the quality and appropriate form of human control. Because there is no universal model for understanding what emergent behaviours will arise from simple rules,[60] it is questionable whether a person in charge of a swarm is able to sufficiently predict its behaviour to make the required ethical and legal assessments and be responsible for it.[61] In the context of an armed conflict, this lack of predictability poses a challenge to the protection of civilians against dangers arising from military operations.[62] These concerns are accentuated if swarms are to be used in populated areas and inside buildings.
- Insofar as swarms partake in attacks (as defined under international humanitarian law), for example by detecting, selecting or applying force to targets, their use raises pressing ethical, legal and other concerns.[63] At an Informal Meeting of Experts on Lethal Autonomous Weapons Systems (LAWS) held in 2016, the view was expressed that swarms 'would be inherently unpredictable',[64] and that this unpredictability could be 'exacerbated in situations where multiple systems or swarms of systems interact'.[65] In such situations, experts argued, 'it would be unclear how meaningful human control could be maintained over the use of force'.[66]
- In addition, the prospect of a single human operator commanding an entire swarm consisting of potentially large numbers of units[67] raises concern about the 'cognitive load' placed on individual operators.[68] Urgent questions may arise about the health and human rights of military personnel and others tasked with the control of such systems.[69]
- As with other advanced weapons systems, there is a concern that swarms could be vulnerable to spoofing, manipulation, hijacking and other electronic warfare attacks. The risk of such interferences may be elevated for swarms, compared to other modern weapons systems, due to their high degree of autonomy.[70]
- Swarms could also aggravate existing challenges raised by the

use of armed UAVs in present practice, notably in terms of harm caused to individuals and communities and the lack of transparency, oversight and accountability surrounding their use.[71] Swarms (of drones or munitions) could increase the potential for misuse, undermine legal protections under international humanitarian and human rights law, promote controversial surveillance and mass data collection,[72] further expand the use of armed force and erode the international rule of law.[73]

- Swarms may also pose challenges to international peace, security and stability. Analysts have warned that increasing autonomy and the accelerated pace of swarms could be 'exceptionally dangerous and destabilizing', lead to 'flash wars'[74] and increase conflict instability. There is also a concern that swarms may induce a shift in the 'offense-defense balance' that drives a destabilizing and costly arms race[75] and, by favouring the offensive, incentivizes pre-emptive first strikes that would place additional strain on the international rules for the maintenance of peace and security.[76] Finally, commentators have warned that swarm technologies would proliferate quickly,[77] and that swarms of armed micro-drones would also be accessible to non-state groups and individuals who could produce them with widely available technologies.[78]
- Swarms, respectively their units, may not fit neatly into existing regulatory categories. This creates legal uncertainty and controversy[79] and raises questions about the capacity of existing law, as applied in practice, to govern the development of swarms while upholding the values that the law was made to protect. Hambling points out that some small UAVs are 'designed as payload-carriers which could be fitted with a range of options on a mission-by-mission basis, while also being capable of being deployed to strike a target directly with a fixed explosive, making the distinction between UAVs and loitering munitions an arbitrary one'.[80] In the context of arms transfer controls, Matthew Bolton and Wim Zwijnenburg have raised questions about the legal categorization of small drones, asking whether the 'Switchblade' (often mentioned in relation to future swarms), which is described by the manufacturer as a 'miniature flying lethal missile' that 'can be operated manually or autonomously'[81] should be considered a 'combat aircraft', a 'missile' or a 'munition' for the purposes of the UN Register of Conventional Arms and the 2013 Arms Trade Treaty.[82] Questions about legal categories also arise in the context of international law applicable to air and missile warfare,[83] and considerable uncertainty persists in this regard in the area of maritime law and naval warfare, creating controversy about the legal ramifications of their use.[84]
- Another concern relates to the promise of swarms to bring 'mass' back to the battlefield,[85] with some analysts envisaging the deployment of 'billions – yes, billions – of tiny, insect-like drones'.[86] The prospect of 'saturating' territory with high numbers of small explosive devices, 'mining the airspace' and 'flooding' zones and buildings so that they are 'seemingly, everywhere and nowhere at once'[87] is alarmingly reminiscent of past practices that inspired legal prohibitions on area bombardment, cluster munitions and landmines due to their unacceptable humanitarian consequences.[88] Indeed, plans exist to develop 'a cluster payload', which can be launched from a guided multiple-launch rocket system and would 'consist of multiple deployable smart quad-copters capable of delivering small explosively formed penetrators (EFP) to designated targets'.[89] The 2008 Convention on Cluster Munitions places some restrictions on such developments, but many swarms may not fall within its purview.[90]
- As a consequence of the renewed enthusiasm for 'mass' and 'saturation', concern has arisen that swarms of explosive micro-drones could pose a post-conflict risk to civilians when they fail to explode as intended and become explosive remnants of war (ERW).[91] This risk is exacerbated if swarms are used in densely populated areas and inside buildings.[92] Children could be at a particular risk of harm from micro-drones resembling toys,[93] as has been the case with certain anti-personnel mines and cluster submunitions. Insofar as swarm units fit the definition of 'explosive ordnance', the 2003 Protocol V to the CCW and its Technical Annex set out responsibilities regarding the prevention, recording, clearance, removal and destruction of ERW and require precautionary measures for the protection of civilians. Maziar Homayounnejad points out that if swarm units can be likened to (remotely delivered) 'mines', the stricter standards (on recording for example) of the 1996 revised Protocol II to the CCW would apply.[94]
- Rather than being associated with cluster munitions, saturation bombardments and minefields, however, swarms are more commonly envisioned as enabling 'mass-*precision* attacks',[95] with proponents drawing inspiration from contemporary 'targeted killings' carried out with UAVs. This orientation raises concern about the normalization of what is, from a legal and ethical standpoint, a highly controversial practice.[96] Similarly, scenarios of 'slaughterbots'[97] – small, expendable, explosive weapons deployed in swarms to attack individual people – elaborated by opponents of autonomous weapons, call into question the long-standing legal protection of combatants against exploding projectiles and assumptions about what constitutes superfluous injury or unnecessary suffering.[98] Even commentators dismissing 'slaughterbots' as fanciful fail to acknowledge the transgression of established norms implied in these and similar swarm scenarios.[99]

Governance and regulation

Although swarms are clearly on the list of technologies militaries see on the horizon,[100] they have not, thus far, attracted focused attention in multilateral weapons control fora.[101] The UN Secretary-General's report on current developments in science and technology and their potential impact on international security and disarmament efforts mentions that '[g]roups of networked unmanned vehicles can act as swarms'[102] but does not expand further.

Scharre considers that many of the issues swarms raise 'can be addressed through better technology, concepts of operation or training'.[103] These include, for example, measures to ensure that a sufficient number of operators are available to command a swarm, as well as suitably designed interfaces, training to understand the behaviour and limits of swarm automation in real-world environments, as well as the modification of doctrine and organizational structures.[104]

Other commentators see value in multilateral governance measures, including regulations on swarms. Homayounnejad outlines how a range of technical measures, including design stipulations to prevent civilian harm from ERW caused by swarms of explosive munitions or micro-drones, can be introduced either by applying CCW Protocol V, the Convention on Cluster Munitions and/or instruments on landmines directly to swarms, or by drawing on these treaties to elaborate swarm-specific standards and criteria in national or international instruments. Such standards could limit the size of swarms.[105] They

could also aim to prevent explosive drones of toy-like appearance, set thresholds for reliability and detectability and specify required technical measures to reduce the risk of ERW and facilitate the location of ERW and their safe clearance. Homayounnejad concedes, however, that technical measures may run against the underpinning logic of creating huge numbers of explosive drones at a low cost.[106]

Efforts aimed at the control of armed drones and autonomous weapons also have a bearing on swarms.[107] These are extensively discussed elsewhere and are only dealt with in a cursory manner here:

- In the framework of the CCW, a Group of Governmental Experts currently debates 'possible options for addressing the humanitarian and international security challenges posed by emerging technologies in the area of lethal autonomous weapons systems'.[108] At the core of the debate is the imperative to ensure human control and accountability in the use force.[109] Options under consideration include the negotiation of a legally binding instrument stipulating prohibitions or regulations on 'lethal autonomous weapons systems'; a political declaration outlining principles for the use of autonomous systems and promoting transparency; as well as various proposals to promote compliance with international law through practical measures, best practice guides and information-sharing arrangements, including the promotion and harmonization of legal weapons reviews.[110]
- There is also growing interest in the elaboration of multilateral standards on armed UAVs, which could have a bearing on swarms. The UN Institute for Disarmament Research has recommended the initiation of a transparent and inclusive multilateral process on this issue,[111] and the EU has urged the promotion of 'a UN-based legal framework which strictly stipulates that the use of armed drones has to respect international humanitarian and human rights law'.[112] The US is reportedly leading a process to further develop a political declaration from 2016 for the export and subsequent use of 'armed or strike-enabled UAVs',[113] and efforts are underway to ensure export control regimes and the Arms Trade Treaty adequately capture existing and future armed drones, including drone swarms.[114]

More generally, swarms bring to the fore urgent questions about appropriate spatial and temporal constraints on the use of force (and surveillance), expectations in terms of human control and responsibility in the use of (armed) force and our evolving understanding of what is justifiable by military necessity and what constitutes unnecessary suffering or an affront to human dignity. Whereas a dedicated political process specifically to control swarms may not be expedient at this time, the many issues raised by swarms underscore the need to collectively address these underlying concerns in weapons control debates, and to do so in a manner that takes account of ongoing efforts aimed at developing swarms.

The scenarios presented by both proponents and opponents of swarms underscore the risk that long-standing normative constraints on the use of force could be eroded. Only if states reaffirm, in deliberations and practice, the values enshrined in existing laws and actively seek to clarify the legal ramifications of new weapons technologies, can procedures aimed at ensuring compliance with the law, such as legal reviews of weapons, effectively contribute to the control of weapons and to disarmament. Without this, existing legal criteria will continue to 'shift or soften'[115] as new practices and technologies of violence take hold. Clear, shared standards can help counter norm erosion. Adopting regulations on autonomous weapons, defining limits on the use of armed drones and agreeing on standards to respond to the harms they cause would go a long way in addressing concerns raised by swarms.

Finally, from the perspective of disarmament, the debate about swarms highlights the need for a wider conversation on military applications of developments in science and technology. The portrayal of swarms parallels the promissory discourse dominating discussions on other emerging weapons technologies. A more critical, reflexive engagement with developments in science and technology of relevance to disarmament could help address patterns of harm from armed violence, rather than perpetuating them with novel technologies.[116] Proposed changes to military paradigms 'necessitated' by visions of swarm warfare raise wider societal questions about how wars should be fought in the future and what role technologies should play in that regard. States should take the opportunity to share their views on these questions in their submissions to the UN Secretary-General's updated report on recent developments in science and technology and their potential impact on international security and disarmament efforts.[117]

END NOTES

1 UK Ministry of Defence et al, '£2.5m Injection for Drone Swarms', press release, GOV.UK, https://www.gov.uk/government/news/25m-injection-for-drone-swarms.

2 S. Russell et al, 'Why You Should Fear "Slaughterbots" – A Response', *IEEE Spectrum: Technology, Engineering, and Science News*, 23 January 2018, https://spectrum.ieee.org/automaton/robotics/artificial-intelligence/why-you-should-fear-slaughterbots-a-response. Framing concern about autonomous weapons and swarms in terms of 'weapons of mass destruction' can be critiqued on various grounds. But even commentators rejecting the scenario of terrorists launching thousands of 'slaughterbots' consider it 'a reasonable possibility' that they could release '[s]omething like a truck full of 50 drones' (P. Scharre, 'Why You Shouldn't Fear "Slaughterbots"', *IEEE Spectrum*, 22 December 2017, https://spectrum.ieee.org/automaton/robotics/military-robots/why-you-shouldnt-fear-slaughterbots).

3 D. Gayle, 'UK, US and Russia Among Those Opposing Killer Robot Ban', *The Guardian*, 29 March 2019, https://www.theguardian.com/science/2019/mar/29/uk-us-russia-opposing-killer-robot-ban-un-ai. Similarly, regarding Australia, see K. Finnane, 'Killerbots, Guided by Pine Gap, Same as Any Other Weapon?', *Alice Springs News Online*, 2 April 2019, http://www.alicespringsnews.com.au/2019/04/02/killerbots-same-as-any-other-weapon-argues-australia-at-un/.

4 S. J. A. Edwards, 'Swarming and the Future of Warfare', Dissertation in Partial Fulfilment of the Requirements of the Doctoral Degree in Public Policy Analysis, Pardee Rand Graduate School, 2005, pp. 179–286.

5 'On the homeland security front, security swarms equipped with chemical, biological, radiological, and nuclear (CBRN) detectors, facial recognition, anti-drone weapons, and other capabilities offer defenses against a range of threats' (Z. Kallenborn, 'The Era of the Drone Swarm Is Coming, and We Need to Be Ready for It', Modern War Institute, 25 October 2018, https://mwi.usma.edu/era-drone-swarm-coming-need-ready/.)

6 This bulletin does not address issues raised by satellite swarms. See, e.g., 'Satellite Swarms Dynamics and Control', European Space Agency, https://www.esa.int/gsp/ACT/projects/swarmcontrol.html; M. Bartels, 'Tiny Satellites Pose a Swarm of Opportunities – And Threats', Space.com, 5 December 2018, https://www.space.com/42621-tiny-satellites-offer-opportunities-and-threats.html.

7 P. Scharre, *Robotics on the Battlefield Part II: The Coming Swarm*, Center for a New American Security, October 2014, p. 5, https://s3.amazonaws.com/files.cnas.org/documents/CNAS_TheComingSwarm_Scharre.pdf?mtime=20160906082059. 'Swarming, coordinated action can enable synchronized attack or defense, more efficient allocation of assets over an area, self-healing networks that respond to enemy actions or widely distributed assets that cooperate for sensing, deception and attack' (ibid, p. 6).

8 The Preamble to the Convention on Certain Conventional Weapons (CCW), equally concerned with the prevention of unnecessary suffering, the protection of civilians, the ending of the arms race and disarmament attests to this. See, e.g., O. Bring, 'Regulating Conventional Weapons in the Future – Humanitarian Law or Arms Control?', 24(3) *Journal of Peace Research* (1987); K. Carter, 'New Crimes Against Peace: The Application of International Humanitarian Law Compliance and Enforcement Mechanisms to Arms Control and Disarmament Treaties', The Markland Group and Canadian Council on International Relations (eds), *Treaty Compliance: Some Concerns and Remedies*, 1998.

9 J. Arquilla and D. Ronfeldt, *Swarming and the Future of Conflict*, RAND Corporation, 2000, p 50, https://www.rand.org/pubs/documented_briefings/DB311.html. See also Edwards, 'Swarming and the Future of Warfare', p. 66 and Appendix A. 'Swarming involves the convergent action of several units that continue to attack by dispersing, maneuvering, and reinitiating combat (pulsing)' (ibid, p. 66).

10 Arquilla and Ronfeldt, Swarming and the Future of Conflict, pp. vii, 6, 43. Arquilla and Ronfeldt cite the tactics of 'generations of terrorists and criminals', the Zapatista movement and the International Campaign to Ban Landmines in support of their thesis (ibid, p. 2).

11 Edwards, 'Swarming and the Future of Warfare', p. 68.

12 See, e.g., R. Gorrell et al, 'Countering A2/AD with Swarming', Research Report Submitted to the Faculty in Partial Fulfilment of the Graduation Requirements for the Degree of Master of Operational Arts and Sciences, AIR Command and Staff College, Air University, 2016.

13 I. Lachow, 'The Upside and Downside of Swarming Drones', 73(2) *Bulletin of the Atomic Scientists* (4 March 2017) 96, https://doi.org/10.1080/00963402.2017.1290879.

14 On swarm robotics, see, e.g., H. Hamann, *Swarm Robotics: A Formal Approach*, 2018; G. Valentini, *Achieving Consensus in Robot Swarms*, 2017.

15 See, e.g., A. L. Alfeo et al, 'Swarm Coordination of Mini-UAVs for Target Search Using Imperfect Sensors', 12(2) *Intelligent Decision Technologies* (7 March 2018) 149–62, https://doi.org/10.3233/IDT-170317.

16 Lachow, 'The Upside and Downside of Swarming Drones', 97.

17 D. Hambling, *Change in the Air: Disruptive Developments in Armed UAV Technology*, UN Institute for Disarmament Research (UNIDIR), 2018, p. 5, http://www.unidir.org/files/publications/pdfs/-en-726.pdf.

18 Scharre, *The Coming Swarm*, pp. 35, 38. Scharre envisages that 'a human might task a swarm of missiles with a set of targets, but let the missiles coordinate among themselves to determine which missile will hit which target', or 'a human might task a group of vehicles to maintain coverage over an area ... and the vehicles might coordinate to determine how best to cover the area' (ibid, p. 36).

19 Ibid, p. 38.

20 Z. Kallenborn and P. C. Bleek, 'Swarming Destruction: Drone Swarms and Chemical, Biological, Radiological, and Nuclear Weapons', *The Nonproliferation Review* (2 January 2019) 4.

21 V. Boulanin and M. Verbruggen, *Mapping the Development of Autonomy in Weapon Systems*, SIPRI, November 2017, p. 63, https://www.sipri.org/sites/default/files/2017-11/siprireport_mapping_the_development_of_autonomy_in_weapon_systems_1117_1.pdf.

22 M. N. Schmitt and J. S. Thurnher, '"Out of the Loop": Autonomous Weapon Systems and the Law of Armed Conflict', 4 *Harvard Law School National Security Journal* (2013) 271, http://harvardnsj.org/wp-content/uploads/2013/01/Vol-4-Schmitt-Thurnher.pdf.

23 Kallenborn, 'The Era of the Drone Swarm Is Coming'.

24 E. Kania, 'Swarms at War: Chinese Advances in Swarm Intelligence', 17(9) *China Brief* (6 July 2017), https://jamestown.org/program/swarms-war-chinese-advances-swarm-intelligence/.

25 Boulanin and Verbruggen, *Mapping the Development of Autonomy in Weapon Systems*, p. 63.

26 K. Osborn, 'Air Force Developing Swarms of Mini-Drones', Military.com, 27 May 2015, https://www.military.com/defensetech/2015/05/27/air-force-developing-swarms-of-mini-drones.

27 Scharre, *The Coming Swarm*, p. 31.

28 Boulanin and Verbruggen, *Mapping the Development of Autonomy in Weapon Systems*, p. 63.

29 'Modern air-launched decoys like the Miniature Air-Launched Decoy, or MALD, are smaller and more capable than their predecessors. Able to fly complex routes and to carry out evasive manoeuvres, these systems are effectively single-use UAVs. These systems can carry a range of payloads. Some decoys like the MALD-J carry electronic warfare radar-jamming technology, and Raytheon has tested a version with a warhead to destroy defensive systems' (Hambling, *Change in the Air*, p. 3.)

30 UK Ministry of Defence et al, '£2.5m Injection for Drone Swarms'.

31 NATO, *Technology Trends Survey: Future Emerging Technology Trends*, NATO HQ Supreme Allied Commander Transformation, Defence Planning Policy and Analysis Branch, February 2015, p. 32, https://www.act.nato.int/images/stories/events/2012/fc_ipr/technology_trend_survey_v3.pdf.

32 Hambling, *Change in the Air*, p. 12.

33 Scharre, *The Coming Swarm*, p. 30.

34 T. Nurking, 'Wonders at the Threshold: Operational Priorities, Tensions and the Future of Military Platforms and Systems', Q. Ladetto (ed.), *Defence Future Technologies: What We See on the Horizon*, November 2017, 55.

35 Whereas it is often argued that swarms would be 'dramatically cheaper than standalone weapons systems' in service (e.g. Lachow, 'The Upside and Downside of Swarming Drones', 98. For a more nuanced argument about cost, see Scharre, *The Coming Swarm*, pp. 13–16. Shmuel has cautioned that '[n]othing can simultaneously be cheap, fast, maneuvrable, and have long range' (S. Shmuel, 'The Coming Swarm Might Be Dead on Arrival', War on the Rocks, 10 September 2018, https://warontherocks.com/2018/09/the-coming-swarm-might-be-dead-on-arrival/)

36 Scharre, *The Coming Swarm*, p. 30.

37 NATO, *Technology Trends Survey*, p. 32.

38 Kallenborn, 'The Era of the Drone Swarm Is Coming'.

39 G. Vásárhelyi et al, 'Optimized Flocking of Autonomous Drones in Confined Environments', 3(20) *Science Robotics* (18 July 2018) 2.

40 Shmuel argues that '[t]ruly large swarms will have to be made of simple machines, with either limited speed, limited range, limited protection (both physical and electronic), limited or cheap payload – and probably all of the above. If either the platform or its payload is not cheap and simple to mass produce, the very idea of the swarm – the multitude – will be undermined' (Shmuel, 'The Coming Swarm Might Be Dead on Arrival'). See also A. McCullough, 'The Looming Swarm', *Air Force Magazine*, http://www.airforcemag.com/MagazineArchive/Pages/2019/April%202019/The-Looming-Swarm.aspx, quoting the US Air Force acquisition chief: '[B]efore swarming can move "beyond the world of science and technology," ... questions do need to be answered: "How do you certify it? How do you test it and evaluate it? Who owns it? Is it a weapons system? Does the platform using it own the autonomy – and swarming and collaboration – or is there a program for swarming and collaboration that plugs that autonomy into all sorts of platforms?"'.

41 Hambling, *Change in the Air*, p. 2; Scharre, *The Coming Swarm*, p. 37.

42 UN General Assembly, Ways and means for making the evidence of customary

international law more readily available, Memorandum of the Secretariat, UN doc A/77/172, 14 February 2019, §77. See also McCullough, 'The Looming Swarm', citing a DARPA programme manager: '"This is something that can be implemented within the next year or two years and actually be used with our current weapons system, or derivatives of our current weapons system."'

43 In 2017, the US military completed its MAST (Micro Autonomous Systems and Technology) research programme, launched in 2008 with the goal of understanding technologies that enable autonomous micro-robots to work together (D. McNally, 'Army Completes Autonomous Micro-Robotics Research Program', US Army Research Laboratory, 25 August 2017, https://www.arl.army.mil/www/default.cfm?article=3065).

44 'Raytheon Gets $29m for Work on US Navy LOCUST UAV Prototype', *Naval Today*, 28 June 2018, https://navaltoday.com/2018/06/28/raytheon-wins-contract-for-locus-inp/. See also D. Smalley, 'News: Navy's Autonomous Swarmboats Can Overwhelm Adversaries', Office of Naval Research, 14 April 2015, https://www.onr.navy.mil/en/Media-Center/Press-Releases/2015/LOCUST-low-cost-UAV-swarm-ONR.

45 Perdix drones are 3D-printed and weigh 290 grams, with a wingspan of around 30 cm ('Perdix Fact Sheet', Office of the [US] Secretary of Defense, n.d., https://dod.defense.gov/Portals/1/Documents/pubs/Perdix%20Fact%20Sheet.pdf?ver=2017-01-09-101520-643).

46 J. Gimber, 'The Rise of the Drone Swarm', *UK Defence Journal*, 15 February 2019, https://ukdefencejournal.org.uk/the-rise-of-the-drone-swarm/.

47 DARPA, 'Friendly 'Gremlins' Could Enable Cheaper, More Effective, Distributed Air Operations', 28 August 2015, https://www.darpa.mil/news-events/2015-08-28.

48 'CODE Demonstrates Autonomy and Collaboration with Minimal Human Commands', DARPA, 19 November 2018, https://www.darpa.mil/news-events/2018-11-19.

49 Boulanin and Verbruggen, *Mapping the Development of Autonomy in Weapon Systems,* p. 31; D. Smalley, 'News – Autonomous Swarmboats: New Missions, Safe Harbors', Office of Naval Research, 14 December 2016, https://www.onr.navy.mil/en/Media-Center/Press-Releases/2016/Autonomous-Swarmboats.

50 S. N. Romaniuk and T. Burgers, 'China's Swarms of Smart Drones Have Enormous Military Potential', *The Diplomat,* 3 February 2018, https://thediplomat.com/2018/02/chinas-swarms-of-smart-drones-have-enormous-military-potential/; D. Hambling, 'If Drone Swarms Are the Future, China May Be Winning', *Popular Mechanics,* 23 December 2016, https://www.popularmechanics.com/military/research/a24494/chinese-drones-swarms/.

51 Boulanin and Verbruggen, *Mapping the Development of Autonomy in Weapon Systems,* p. 102. See also Kania, 'Swarms at War'.

52 European Defence Agency, 'Pilot Project EuroSWARM and SPIDER activities completed', 23 February 2018, https://www.eda.europa.eu/info-hub/press-centre/latest-news/2018/02/23/pilot-project-euroswarm-and-spider-activities-completed.

53 Boulanin and Verbruggen, *Mapping the Development of Autonomy in Weapon Systems*, p. 197.

54 UK Ministry of Defence and The Rt Hon Gavin Williamson CBE MP, 'Defence in Global Britain', speech by Defence Secretary Gavin Williamson, GOV.UK, 11 February 2019, https://www.gov.uk/government/speeches/defence-in-global-britain.

55 V. Insinna, 'French Air Force Chief: France and Germany Working on Export Controls for Future Fighter', *Defense News*, 8 February 2019, https://www.defensenews.com/global/europe/2019/02/08/french-air-force-chief-france-and-germany-working-on-export-controls-for-future-fighter/.

56 Hambling, *Change in the Air*, pp. 5–6.

57 'To … increase the effectiveness of small-unit combat forces operating in urban environments, DARPA has launched its new OFFensive Swarm-Enabled Tactics (OFFSET) program. OFFSET seeks to develop and demonstrate 100+ operationally relevant swarm tactics that could be used by groups of unmanned air and/or ground systems numbering more than 100 robots' (DARPA, 'OFFSET Envisions Swarm Capabilities for Small Urban Ground Units', 7 December 2016, https://www.darpa.mil/news-events/2016-12-07).

58 '[I]n the far-term, humans will form integrated teams with nearly fully autonomous unmanned systems, capable of carrying out operations in contested environments. This could include heterogeneous swarms of UAS directly supporting soldiers on the ground through ISR or aerial strikes' (US Department of Defense, Unmanned Systems Integrated Roadmap 2017–2042, 28 August 2018, p. 21, https://www.documentcloud.org/documents/4801652-UAS-2018-Roadmap-1.html#document).

59 T. Eshel, 'Russian Forces in Syria Repelled Massive Drone Attack on Hmeimim and Tartus', *Defense Update*, 8 January 2018, https://defense-update.com/20180108_uav_attack.html; 'Houthis Destroyed UAE Patriot System in Central Yemen With Swarm of Drones – Reports', *South Front*, 24 February 2018, https://southfront.org/houthis-destroyed-uae-patriot-system-in-central-yemen-with-swarm-of-drones-reports.

60 Scharre, *The Coming Swarm*, p. 26. See, e.g., Hamann, *Swarm Robotics*, pp. 96 et seq.

61 Lachow warns that '[w]hen a system is reacting in real time to a dynamically changing environment, and basing its decisions on a simple set of rules, it is possible that unanticipated behaviours will naturally arise' (Lachow, 'The Upside and Downside of Swarming Drones', 98). In 2018, the UN Secretary-General noted that due to the complexity of an artificial intelligence system, 'the outputs of such a system may never be entirely predictable or explainable. Moreover, this unpredictability means that when algorithms fail, they do so in ways an operator never would' (Report of the Secretary-General on current developments in science and technology and their potential impact on international security and disarmament efforts, UN doc A/73/177, 17 July 2018, §15).

62 Importantly, these challenges go beyond protection from attacks. See, in particular, C. Jenks and R. Liivoja, 'Machine Autonomy and the Constant Care Obligation', *Humanitarian Law & Policy*, 11 December 2018, https://blogs.icrc.org/law-and-policy/2018/12/11/machine-autonomy-constant-care-obligation/.

63 See, e.g., *Autonomous Weapons Systems: Technical, Military, Legal and Humanitarian Aspects*, expert meeting report, Geneva, Switzerland, 26 to 28 March 2014, ICRC, November 2014, https://www.icrc.org/en/document/report-icrc-meeting-autonomous-weapon-systems-26-28-march-2014; M. Brehm, *Defending the Boundary: Constraints and Requirements on the use of Autonomous Weapon Systems under International Humanitarian and Human Rights Law*, Academy Briefing no 9, Geneva Academy of International Humanitarian Law and Human Rights, May 2017, https://www.geneva-academy.ch/joomlatools-files/docman-files/Briefing9_interactif.pdf.

64 Report of the 2016 Informal Meeting of Experts on Lethal Autonomous Weapons Systems (LAWS), UN doc CCW/CONF.V/2, 10 June 2016, §40.

65 Ibid, §67.

66 Ibid, §68.

67 '[L]arge numbers of low-cost attritable robotics can be controlled en masse by a relatively small number of human controllers' (Scharre, *The Coming Swarm*, p. 14).

68 Ibid, p. 40.

69 The reconfiguration of human-machine relations could place unacceptable demands on operators. Scharre notes that '[h]uman performance modification technologies, including pharmaceuticals … or other modification techniques, such as transcranial direct current stimulation (tDCS), could allow humans to pay attention, process information and react faster' but cautions that ethical and social issues need to be addressed (ibid, p. 34). A former UN Special Rapporteur on extrajudicial, summary or arbitrary executions warned in respect of swarms 'that technology is being developed that is beyond humans' capacity to supervise effectively and in accordance with applicable law [and that u]nless adequate precautions are taken and built into systems, the likelihood increases that mistakes will be made which will amount to clear violations of the applicable laws' (Interim report by the Special Rapporteur on extrajudicial, summary or arbitrary executions, UN doc A/65/321, 23 August 2010, §41).

70 Z. Kallenborn and P. C. Bleek, 'Drones of Mass Destruction: Drone Swarms and the Future of Nuclear, Chemical, and Biological Weapons', *War on the Rocks,* 14 February 2019, https://warontherocks.com/2019/02/drones-of-mass-destruction-drone-swarms-and-the-future-of-nuclear-chemical-and-biological-weapons/. Scharre argues that '[w]hile autonomous systems may not be more susceptible to spoofing or cyber attacks, the consequences if an enemy were to gain control of a highly autonomous system – or an entire swarm – could be much greater' (P. Scharre, 'Counter-Swarm: A Guide to Defeating Robotic Swarms', War on the Rocks, 31 March 2015, https://warontherocks.com/2015/03/counter-swarm-a-guide-to-defeating-robotic-swarms/).

71 See, e.g., *Article 36, Drones in the Use of Force: A Way Forward*, Briefing Paper, October 2018, https://www.efadrones.org/wp-content/uploads/2018/10/A36-drones-use-of-force-way-forward.pdf.

72 'The Air Force has long discussed using swarms of miniaturized drones for attack and surveillance missions … commanders can use the swarm for a single objective, like a major attack, or disperse the bots across a region for 24/7 surveillance' (L. Seligman, 'How Swarming Drones Could Change the Face of Air Warfare', *Defense News,* 17 May 2016, https://www.defensenews.com/2016/05/17/how-swarming-drones-could-change-the-face-of-air-warfare/).

73 'Attritable UAVs can be used with even less political consequence than existing armed UAVs as they are so easily replaced. Another aspect of UAVs is that they are increasingly difficult to attribute' (Hambling, *Change in the Air*, p. 14.)

74 Scharre, *The Coming Swarm*, p. 33.

75 Lachow, 'The Upside and Downside of Swarming Drones', 100.

76 J.-M. Rickli, 'The Impact of Autonomous Weapons System on International Security and Strategic Stability', in Q. Ladetto (ed.), *Defence Future Technologies*, p. 63.

77 '[S]mall UAVs are not regulated and would not require an extensive scientific research or industrial base to produce. Manufacture would be relatively hard to spot – compared to the production of traditional military hardware such as manned aircraft, ships or ballistic missiles – as it would resemble any other consumer electronics assembly' (Hambling, *Change in the Air,* p. 12).

78 T. X. Hammes, *Technologies Converge and Power Diffuses: The Evolution of Small, Smart, and Cheap Weapons*, Policy Analysis, Cato Institute, 27 January 2016, p. 5, https://www.cato.org/publications/policy-analysis/technologies-converge-power-diffuses-evolution-small-smart-cheap#full.

79 E.g. J. Kraska and R. Pedrozo, 'China's Capture of U.S. Underwater Drone Violates Law of the Sea', Lawfare, 16 December 2016, https://www.lawfareblog.com/chinas-capture-us-underwater-drone-violates-law-sea.
80 Hambling, *Change in the Air*, p. 1.
81 AeroVironment, 'Switchblade', Datasheet, 2017, https://www.avinc.com/images/uploads/product_docs/SB_Datasheet_2017_Web_rv1.1.pdf.
82 M. Bolton and W. Zwijnenburg, 'Futureproofing the Draft Arms Trade Treaty: A Policy Brief', 21 March 2013, https://politicalminefields.files.wordpress.com/2013/03/futureproofing-the-draft-arms-trade-treaty-42.pdf.
83 Under what conditions is a swarm, respectively its components, a 'weapon', 'weapon system', 'unmanned aerial vehicle', 'unmanned combat aircraft', or a mixture thereof? See Program on Humanitarian Policy and Conflict Research, Commentary on the Manual on International Law Applicable to Air and Missile Warfare, Harvard University, 2010, pp. 54–56.
84 See, in particular, A. Norris, *Legal Issues Relating to Unmanned Maritime Systems*, US Naval War College, 2013, pp. 21–64, https://www.hsdl.org/?view&did=731705; M. N. Schmitt and D. S. Goddard, 'International Law and the Military Use of Unmanned Maritime Systems', 98(902) *International Review of the Red Cross* (August 2016) 567–92, Kraska and Pedrozo, 'China's Capture of U.S. Underwater Drone Violates Law of the Sea'.
85 Hammes, *Technologies Converge and Power Diffuses*, p. 9.
86 Scharre, *The Coming Swarm*, p. 20.
87 Ibid, pp. 10, 15, 20, 29.
88 In addition, saturation with explosive force is one of the counter-measures to swarms under discussion. Shmuel envisages engaging swarms 'with large volumes of dumb and cheap munitions' (Shmuel, 'The Coming Swarm Might Be Dead on Arrival'). Directed energy weapons are also explored as countermeasures, raising a host of concerns, including for the protection of infrastructure critical to civilian wellbeing. See, e.g., K. Mizokami, 'The Army's Real-Life "Phaser" Would Knock Out an Entire Drone Swarm with One Shot', *Popular Mechanics*, 14 November 2016, https://www.popularmechanics.com/military/weapons/a23881/the-army-is-testing-a-real-life-phaser-weapon/; Article 36, *Directed Energy Weapons*, Discussion Paper, November 2017, http://www.article36.org/wp-content/uploads/2019/06/directed-energy-weapons.pdf
89 K. Mizokami, 'The Army Wants Artillery Rockets That Blast Swarms of Tank-Killing Drones Into the Sky', *Popular Mechanics*, 7 February 2017, https://www.popularmechanics.com/military/weapons/a25090/army-rocket-launched-tank-killing-quadcopters/.
90 For a discussion, see M. Homayounnejad, *Autonomous Weapon Systems, Drone Swarming and the Explosive Remnants of War,* TLI Think! Paper 1/2018, Kings College London, 2018, pp. 47–61.
91 Ibid, p. 12.
92 Homayounnejad notes that although research into using drones in such environments has thus far focused on unarmed drones, 'the research potentially has applications for swarms of explosive munitions' (ibid, p. 10).
93 Ibid, p. 12.
94 Ibid, p. 33.
95 Hambling, *Change in the Air*, p. 14 (emphasis added).
96 See, e.g., N. Melzer, T*argeted Killing in International Law*, 2008; Study on Targeted Killings, Report of the Special Rapporteur on extrajudicial, summary or arbitrary executions, Philip Alston, Addendum, UN doc A/HRC/14/24/Add.6, 28 May 2010.
97 Russell et al, 'Why You Should Fear "Slaughterbots"'.
98 These norms are enshrined in the 1868 Declaration Renouncing the Use, in Time of War, of Explosive Projectiles Under 400 Grammes Weight (St. Petersburg Declaration).
99 See, e.g., Scharre, 'Why You Shouldn't Fear "Slaughterbots"' and Homayounnejad, who considers that deploying a 'one-gram shaped charge to puncture the human cranium … clearly offers law-abiding militaries a great deal of utility' (Homayounnejad, *Autonomous Weapon Systems, Drone Swarming and the Explosive Remnants of War,* pp. 10–11). Similarly, Kallenborn and Bleek put forth the view that 'the ability of drone swarms to serve as sophisticated chemical-and biological-weapon (CB) delivery systems could significantly increase the utility of these weapons' without any reference to the unequivocal, comprehensive bans under treaty and customary international law of chemical and biological weapons (Z. Kallenborn and P. C. Bleek, 'Swarming Destruction', 3).
100 Nurkin, 'Wonders at the Threshold', p. 55; *NATO, Technology Trend Survey: Future Emerging Technology Trends*, NATO HQ Supreme Allied Commander Transformation, Long Term Requirements Branch, September 2011, p. 52, http://indianstrategicknowledgeonline.com/web/Technology_Trend_Survey_Final%20Version_Publish.pdf.
101 In a report published in July 2018, the UN Secretary-General remarks in relation to the research agenda of UNIDIR that '[p]otentially important areas of inquiry do not always generate support from donors … because cutting-edge issues may not yet be on the multilateral disarmament agenda, for example, developments in drone swarming technology' (Thirty-Fifth Anniversary of the United Nations Institute for Disarmament Research: Report of the Secretary-General, 31 July 2018, UN doc A/73/284, § 29).
102 Report of the Secretary-General on current developments in science and technology and their potential impact on international security and disarmament efforts, §10.
103 Scharre, *The Coming Swarm*, p. 35.
104 Ibid, pp. 36, 41.
105 Homayounnejad, *Autonomous Weapon Systems*, pp. 61, 63.
106 Ibid, pp. 15, 18.
107 For example, there was a discussion of 'how meaningful human control could be applied over autonomous swarms' during the 2018 session of the CCW Group of Governmental Experts (GGE) (Report of the 2018 session of the Group of Governmental Experts on Emerging Technologies in the Area of Lethal Autonomous Weapons Systems, UN doc CCW/GGE.1/2018/3, 23 October 2018, §32).
108 For more information, see The United Nations Office at Geneva, '2019 Group of Governmental Experts on Lethal Autonomous Weapons Systems (LAWS)', https://www.unog.ch/80256EE600585943/(httpPages)/5C00FF8E35B6466DC125839B003B62A1?OpenDocument.
109 Scharre considers that '[w]hile militaries will need to embrace automation for some purposes, humans must also be kept in the loop on the most critical decisions, particularly those that involve the use of force or movements and actions that could potentially be escalatory in a crisis' (Scharre, *The Coming Swarm*, pp. 33 and 34). See also the website of the Campaign to Stop Killer Robots, https://www.stopkillerrobots.org.
110 Report of the 2018 session of the GGE on Emerging Technologies, §§28, 40–54.
111 UNIDIR, *Increasing Transparency, Oversight and Accountability of Armed Unmanned Aerial Vehicles*, 2017, p. 1, http://www.unidir.org/files/publications/pdfs/increasing-transparency-oversight-and-accountability-of-armed-unmanned-aerial-vehicles-en-692.pdf.
112 European Parliament recommendation to the Council on the 73rd session of the United Nations General Assembly, EU doc 2018/2040(INI), 5 July 2018, http://www.europarl.europa.eu/sides/getDoc.do?type=TA&reference=P8-TA-2018-0312&language=EN&ring=A8-2018-0230. See also The European Forum on Armed Drones, Call to Action, https://www.efadrones.org/call-to-action/.
113 U.S. Department of State, Joint Declaration for the Export and Subsequent Use of Armed or Strike-Enabled Unmanned Aerial Vehicles (UAVs), Media Note, 28 October 2016, https://2009-2017.state.gov/r/pa/prs/ps/2016/10/262811.htm.
114 '[A]rmed unmanned aerial vehicles are covered by categories IV and V of the [UN] Register [of Conventional Arms]' (Continuing operation of the United Nations Register of Conventional Arms and its further development: Note by the Secretary-General, UN doc A/68/140, 15 July 2013, p. 2). See also R. Stohl and S. Dick, *The Arms Trade Treaty and Drones*, Stimson Center, August 2018, p. 12: 'it is important for stakeholders to ask how to make controls over drone technologies sustainable. When thinking about technological innovations for UAVs – particularly outside military categories – it is helpful to identify characteristics of drones that pose particular security concerns that require greater oversight and control. These may include characteristics … such as … swarming capability', https://www.stimson.org/sites/default/files/file-attachments/Stimson_The%20Arms%20Trade%20Treaty%20and%20Drones_August%202018.pdf.
115 Schmitt and Goddard, 'International Law and the Military Use of Unmanned Maritime Systems', 579.
116 E.g., Homayounejad trusts that 'the technical features of LAWS munitions will raise the bar of what is "possible" and "practical"' in relation to recording and clearance requirements given the advanced data collection and storage capacities of such devices (Homayounnejad, *Autonomous Weapon Systems*, p. 34). Similar arguments were made about armed drones in respect of casualty recording. Yet, unprecedented technical capabilities for observing and documenting drone strikes have not thus far translated into greater transparency and accountability.
117 UNGA Res 73/32, 11 December 2018, operative §4.

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