Ingvild Bode & Tom Watts

Loitering Munitions and Unpredictability

Autonomy in Weapon Systems and Challenges to Human Control

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AutoNorms

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Written by **Dr Ingvild Bode**, Center for War Studies, University of Southern Denmark and **Dr Tom Watts**, School of Politics and International Relations, Royal Holloway, University of London.

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About the authors

Dr Ingvild Bode is Associate Professor at the Center for War Studies, University of Southern Denmark and a Senior Research Fellow at the Conflict Analysis Research Centre, University of Kent. She is the Principal Investigator of the European Research Council-funded "AutoNorms" project, examining how autonomous weapons systems may change international use of force norms. Her research focuses on understanding processes of normative change, especially through studying practices in relation to the use of force, military Artificial Intelligence, and associated governance demands.

Dr Tom F.A. Watts is a Leverhulme Early Career Researcher based at the Department of Politics, International Relations, and Philosophy at Royal Holloway, University of London. His current project titled "Great Power Competition and Remote Warfare: Change or Continuity in Practice?" (ECF-2022-135) examines the relationship between the use of the strategic practices associated with the concept of remote warfare, the dynamics of change and continuity in contemporary American foreign policy, and autonomy in weapons systems.

Contents

Abbreviations

AI	artificial intelligence
AT	automatic target recognition
AWS	autonomous weapon systems
CCW	1980 UN Convention on Conventional Weapon Systems
GCS	Ground Control Station
GGE	Group of Governmental Experts
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
IAI	Israel Aerospace Industries
ICRC	International Committee of the Red Cross
IHL	international humanitarian law
LM	loitering munition
RPA	remotely piloted aircraft
SEAD	Suppression of Enemy Air Defence
SIPRI	Stockholm International Peace Research Institute
UAV	uncrewed aerial vehicle
UNIDIR	United Nations Institute for Disarmament Research
VTOL	Vertical Take Off and Landing

Executive summary

Loitering munitions – expendable uncrewed aircraft which can integrate sensor-based analysis to hover over, detect and explode into targets – are an increasingly prominent feature of modern battlefields. Existing studies have examined whether these technologies are changing the character of contemporary warfare, how the proliferation of loitering munitions impacts regional (and global) security dynamics, and what this may mean for the force structure of militaries across the world. Building on our earlier study of air defence systems, this report has a different focus. It examines the global acquisition and fielding of loitering munitions in the context of the debates about autonomous weapon systems (AWS).[1] More specifically, it uses available open-source material to investigate whether the use of autonomous and automated technologies as part of the global development, testing, and use of loitering munitions since the 1980s has impacted emerging standards of human control over the use of force.

Most existing loitering munitions are advertised as being operated in line with "human-in-the-loop" principles. The operators of these platforms are presented as being required to authorise strikes against system-designated targets, monitor the platform's operation through a two-way datalink and remote ground control station, and retaining an "abort/wave-off" capability to stop a strike if battlefield conditions change. Because humans rather than sensor inputs are responsible for the release of force, such systems cannot neatly be classified as AWS. This distinguishes many loitering munitions from the earlier Israel Aerospace Industries (IAI) Harpy system which, designed to conduct Suppression of Enemy Air Defence operations, is often described as an AWS.

Despite this, the global practices of acquiring and operating loitering munitions clearly highlight the trend towards increasing autonomy in the targeting functions of weapon systems and how this affects human control over the use of force. We argue that the integration of automated or autonomous technologies in loitering munitions has created practical challenges and precedents regarding the quality and form[2] of human control exercised over specific targeting decisions. In particular, this process *already* appears to have reduced the quality of control and situational judgement which human agents can exercise over certain weapons in specific targeting decisions. The sensor-based targeting used on certain types of loitering munitions as mobile platforms with increasing geographical and temporal range appears to have created heightened unpredictability concerning where, when, and against whom force is used. This potentially makes human control over specific targeting decisions more nominal than meaningful. It also raises questions related to compliance with various legal and ethical norms.

1 Ingvild Bode and Tom Watts, "Meaning-Less Human Control. The Consequences of Automation and Autonomy in Air Defence Systems" (Oxford and Odense: Drone Wars UK & Centre for War Studies, University of Southern Denmark, February 2021).

2 The authors wish to express our thanks to Daan Kayser for drawing the addition of "form" to our attention.

Throughout this report, three major areas of concern are highlighted:

- (1) Greater uncertainties regarding when and where force is used and how human agents exert control over specific targeting decisions (i.e. the situational and decision-making dimensions of human control);
- (2) The use of loitering munitions as anti-personnel weapons and in populated areas;
- and (3) Inattention to the potentially unpredictable, indiscriminate, and wide area effects[3] associated with the fielding of loitering munitions.

These research findings are based on two sources of analysis: first, a new open-source catalogue detailing the integration of automated and autonomous functions in a global selection of 24 different loitering munitions which have been acquired by at least 16 states. This includes loitering munitions developed by companies in states which have (historically) been closely associated with the development of these technologies (e.g. China, Israel, Russia, the United States, Turkey), as well as by other manufacturers in, e.g., Australia, Poland, Taiwan, and the United Kingdom (UK). Similarly, our catalogue includes platforms which have risen to international prominence given their use in recent conflicts, some of which may already be familiar to the reader. These include the AeroVironment Switchblade 300, the IAI Harpy, and the STM Kargu-2, amongst others. As with our earlier study of air defence systems,[4] to the extent which is possible from open-source material, this catalogue is designed to extend the international debates on how autonomy in existing weapon systems is altering social norms of human control over targeting decisions.[5] It does so by documenting the use of automated and autonomous technologies in these systems rather than detailing the technical design features already catalogued in existing studies.

Second, we provide in-depth case studies detailing how loitering munitions have been used in three recent conflicts: the Libyan Civil War (2014-2020), the 2020 Nagorno-Karabakh War, and the War in Ukraine (2022-). These case studies allow us to explore different sites and modes of operating loitering munitions across a range of conflict parties. They also allow us to draw out the three principal areas of concern we associate with current practices of loitering munitions usage: greater uncertainties regarding situational and decision-making dimensions of human control; the use of these systems as anti-personnel weapons and in populated areas; and potential indiscriminate, wide area effects.

As a starting point for the creation of new safeguards to not only protect but improve the quality and form of human control exercised over specific targeting decisions, we make a series of recommendations for the various actors participating in the international debates on AWS and for states developing and using loitering munitions. These recommendations are underpinned by our overall assessment that there is a clear and pressing need to regulate the integration of automated and autonomous targeting in weapons, including loitering munitions, in a legally binding international treaty.[6] Our recommendations overlap with proposals put forward by the International Committee of the Red Cross (ICRC).[7]

3 "Wide area effects" can mean (1) effects that might occur within a wide area and (2) how high-explosive warheads may directly affect a wide area.

4 Tom Watts and Ingvild Bode, "Automation and Autonomy in Air Defence Systems Catalogue (v.1)," 2021, https://zenodo.org/record/4485695#.Y86g9nbP2Uk

5 Ingvild Bode, "Practice-Based and Public-Deliberative Normativity: Retaining Human Control over the Use of Force," *European Journal of International Relations* online first (2023), https://doi.org/10.1177/13540661231163392.

6 Article 36, "Sensor-Based Targeting Systems: An Option for Regulation" (London: Article 36, November 2021), https://article36.org/wp-content/uploads/2022/01/Sensor-based-targeting.pdf.

7 ICRC, "ICRC Position on Autonomous Weapon Systems and Background Paper," 2021, https://www.icrc.org/en/document/icrc-position-autonomous-weapon-systems.

In particular, our analysis of practices of using loitering munitions as a type of autonomous weapon underscores potential future *trends* in military development identified by the ICRC: loitering munitions appear to have been used to target human beings and a wider variety of military objects over time; these systems are mobile rather than fixed in place; and they have been "used in cities where civilians would be most at risk".[8]

What also comes strongly out of our open-source analysis are data limitations that have a fundamental impact on our understanding of the precise quality of human control exercised in operating loitering munitions. Amongst other things, this highlights the need for greater transparency in this area.

Based on our findings, **we urge states to develop and adopt legally binding international rules on autonomy in weapon systems**, including loitering munitions as a category therein. **We recommend that states**:

- **Affirm, retain, and strengthen the current standard of real-time, direct human assessment of, and control over, specific targeting decisions when using loitering munitions and other weapons integrating automated, autonomous, and AI technologies as a firewall for ensuring compliance with legal and ethical norms.**
- **Establish controls over the duration and geographical area within which weapons like loitering munitions that can use automated, autonomous, and AI technologies to identify, select, track, and apply force can operate.**
- **Prohibit the integration of machine learning and other forms of unpredictable AI algorithms into the targeting functions of loitering munitions because of how this may fundamentally alter the predictability, explainability, and accountability of specific targeting decisions and their outcomes.**
- **Establish controls over the types of environments in which sensor-based weapons like loitering munitions that can use automated, autonomous, and AI technologies to identify, select, track, and apply force to targets can operate. Loitering munitions functioning as AWS should not be used in populated areas.**
- **Prohibit the use of certain target profiles for sensor-based weapons which use automated, autonomous, and AI technologies in targeting functions. This should include prohibiting the design, testing, and use of autonomy in weapon systems, including loitering munitions, to "target human beings" as well as limiting the use of such weapons "to objects that are military objectives by nature".**[9]
- **Be more forthcoming in releasing technical details relating to the quality of human control exercised in operating loitering munitions in specific targeting decisions. This should include the sharing, where appropriate, of details regarding the level and character of the training that human operators of loitering munitions receive.**

8 ICRC, "ICRC Position on Autonomous Weapon Systems," 6.
9 ICRC, "ICRC Position on Autonomous Weapon Systems," 2.

1 Introduction

This report investigates whether the use of automated, autonomous, and AI technologies[10] as part of the global development, testing, and usage of loitering munitions since the 1980s has impacted emerging practices and social norms of human control over the use of force. Loitering munitions are expendable uncrewed aircraft which can integrate sensor-based analysis to hover over, detect and explode into targets. Previous research suggests that manufacturers in up to 24 states are producing these systems.[11] On the basis of the available open-source information, we argue that the integration of automated, autonomous, and AI technologies in loitering munitions may diminish the quality of human control exercised over specific targeting decisions. This is an important contribution to the international regulatory debate on autonomous weapon systems (AWS) because this process has, over time, set important and problematic precedents for what counts as an "acceptable" quality and form of human control that have neither been openly acknowledged nor scrutinised. Our analysis illustrates that the global development and fielding of loitering munitions draws attention to particular problems and challenges, highlighting areas in need of regulation.

The integration of automated, autonomous, and AI technologies into loitering munitions forms part of a wider, potentially transformative trend in warfighting: the development of AWS – weapons "where force is applied automatically on the basis of a sensor-based targeting system".[12] AWS have been subject to much academic, practitioner, and civil society debate.[13] In an era of renewed great power competition, technological developments in the field of AI have assumed a major geopolitical importance.[14] More importantly for the purposes of our analysis, military applications of autonomy appear to be altering how human agents control and direct the use of military force, potentially reordering aspects of the relationship between technology and humans in war.[15]

Within these debates, it is still commonly assumed that the challenges generated by the weaponization of autonomy and AI will materialise in the near to medium term future. Regardless of how reassuring such thinking may be, it does not hold up to scrutiny. As this report emphasises in the specific case of loitering munitions,

10 The precise distinction between what counts as automated and autonomous function or an AI technology is not always well defined and is politically contested. We use all three terms throughout the report to highlight that our analysis captures a wide range of technologies that animate autonomy in weapon systems. Our understanding of these terms are defined in section 2.

11 Gettinger, "Phoenix Ghosts are part drones, part missiles. How does that change combat?".

12 Article 36, "Sensor-Based Targeting Systems: An Option for Regulation," 2.

13 For useful introductions to these debates, see Ingvild Bode and Hendrik Huelss. *Autonomous Weapon Systems and International Norms.* (Montreal: McGill-Queen's University Press, 2022). Denise Garcia. "Lethal artificial intelligence and change: The future of international peace and security." *International Studies Review* 20, no. 2 (2018): 334-341. Benjamin M. Jensen, Christopher Whyte, and Scott Cuomo. «Algorithms at war: the promise, peril, and limits of artificial intelligence.» *International Studies Review* 22, no. 3 (2020): 526-550.

14 Anna Nadibaidze. "Great power identity in Russia's position on autonomous weapons systems." *Contemporary Security Policy* (2022): 1-29; Rubrick Biegon. and Tom FA Watts. "Remote Warfare and the Retooling of American Primacy." *Geopolitics* 27.3 (2022): 948-971; Eric Schmidt. "AI, Great Power Competition & National Security." *Daedalus* 151, no. 2 (2022): 288-298; Austin Wyatt. «Charting great power progress toward a lethal autonomous weapon system demonstration point.» *Defence Studies* 20, no. 1 (2020): 1-20.

15 Lucy Suchman, "Algorithmic Warfare and the Reinvention of Accuracy," *Critical Studies on Security* 8, no. 2 (2020): 175–87; Elke Schwarz, "The (Im)Possibility of Meaningful Human Control for Lethal Autonomous Weapons Systems," *ICRC Humanitarian Law & Policy* (blog), August 29, 2018, http://blogs.icrc.org/law-and-policy/2018/08/29/im-possibility-meaningful-human-control-lethal-autonomous-weapon-systems/.

Soldier monitors visual feed of a Switchblade-300. **Source:** U.S. Marine Corps

the decades long process of integrating sensor-based targeting into weapons via automated, autonomous, and, to a limited extent, AI[16] technologies has *already* reduced the quality of control and situational judgement which human agents can exercise over specific targeting decisions.

Loitering munitions hold a particularly significant place in the debates on AWS. Some loitering munitions designed to conduct Suppression of Enemy Air Defence operations, such as the IAI Harpy, are widely considered as being an example of an AWS capable of automatically applying force via sensor-based targeting without human intervention after activation.[17] Loitering munitions have been developed as anti-radiation systems, anti-armour systems, and anti-personnel systems. The notable role played by these technologies in recent conflicts in Nagorno-Karabakh, Libya, and Ukraine has generated widespread public and military interest.[18] The development of the loitering munition has been compared to the introduction of the machine gun and the airplane during the early twentieth century.[19] Analysts are increasingly concerned with what operational implications the proliferation and use of these technologies may have on the modern battlefield, including what the fielding of these systems means for the survivability of tanks and air defence systems.[20]

16 Currently fielded loitering munitions appear to integrate AI technologies to a very limited extent. We could only find references to the integration of AI technologies for the Lancet-3 and the Kargu-2. Tom Watts and Ingvild Bode, “Automation and Autonomy in Loitering Munitions Catalogue (v.1),” April 2023, https://doi.org/10.5281/zenodo.7860762.

17 Whether systems such as the Harpy have been fielded in an autonomous mode remains unclear, however. ICRC, “ICRC Position on Autonomous Weapon Systems,” 5.

18 For an overview of the use of loitering munitions and uncrewed systems as part of the 2020 Nagorno-Karabakh conflicts, see Joël Postma. “Drones over Nagorno-Karabakh.” Atlantisch Perspectief 45, no. 2 (2021): 15-20.

19 J. Noel Williams, “Killing Sanctuary: The Coming Era of Small, Smart, Pervasive Lethality,” War on the Rocks, September 8, 2017, https://warontherocks.com/2017/09/killing-sanctuary-the-coming-era-of-small-smart-pervasive-lethality/; Thomas Kutz, “Lethal Unmanned Aircraft Systems: Democratizing Air Power” (Newport, RI: Naval War College, 2022), https://apps.dtic.mil/sti/pdfs/AD1174712.pdf.

20 Justin Bronk, Nick Reynolds, and Jack Watling, “The Russian Air War and Ukrainian Requirements for Air Defence” (London: RUSI, November 7, 2022), https://rusi.org/explore-our-research/publications/special-resources/russian-air-war-and-ukrainian-requirements-air-defence; Elisabeth Gosselin-Malo, “Loitering Munitions in Ukraine: Not Game-Changing, but Headache-Inducing,” Shephard News, May 26, 2022, https://www.shephardmedia.com/news/uv-online/loitering-munitions-in-ukraine-not-game-changing-but-headache-inducing/.

Our report, in contrast, picks up our earlier call for "more in-depth studies of the emerging standards of … human control produced by the use of other existing weapon systems with automated and autonomous features".[21] In part because of the speed at which these platforms are proliferating, loitering munitions are described as "a test-bed for using weapons on a battlefield independent of human control".[22] Many existing loitering munitions require human approval before conducting a strike. Such systems do not necessarily qualify as AWS. They are important to study, however, because they speak to the trend of increasing autonomy in weapon systems and the changes to the quality and form of human control exercised in warfare that result from creating greater spatial and temporal distance between humans and their exercise of deliberative, context-specific judgment over the use of force.[23]

This study is based on novel, in-depth research into how automated, autonomous, and AI technologies are used to support targeting and mobility functions in loitering munitions. It has been written for the various stakeholder groups participating in the international debate on AWS: state officials, nongovernmental organisations, academics, journalists, and interested members of the public. Throughout this analysis, we unpack some of the problematic features generated by the use of automated, autonomous, and AI technologies in loitering munitions for the exercise of human control in specific targeting decisions. Three principal areas of concern are highlighted, the various impacts of which are magnified by the ongoing global proliferation of these technologies.

1 Uncertain quality of human control

Loitering munition manufacturers generally characterise their platforms as being operated with a "human-in-the-loop". This means that human agents are required to visually verify targets before authorising strikes and, in a capability advertised for many systems, can "wave off" a strike if battlefield conditions change (e.g., civilians enter the combat zone). Yet, it is important to note that some loitering munitions currently in service appear to have the latent technical capability to identify, track, select, and strike targets autonomously. When operating with this functionality, loitering munitions can be characterised as AWS. Further, the promotional material produced by many manufacturers presents loitering munitions as being capable of operating in GPS-denied environments, as well as alluding to some potential capacity to strike targets without human intervention. Similarly, military leaders such as Ukraine's Lieutenant Colonel Yaroslav Honchar have noted that Ukraine "already conducts fully robotic operations, without human intervention".[24] This suggests that the human operator may not always retain an ability to (visually or by other means) verify targets before a strike, underscoring a set of fundamental uncertainties regarding whether (and if so how) loitering munitions may operate without human assessment of sensor inputs.[25]

The principle that these systems are operated with "humans-in-the-loop" is accepted. This principle needs to be affirmed and retained

21 Ingvild Bode and Tom Watts, "Meaning-Less Human Control. The Consequences of Automation and Autonomy in Air Defence Systems" (Oxford and Odense: Drone Wars UK & Centre for War Studies, University of Southern Denmark, February 2021), 4.

22 Kelsey Atherton, "Loitering munitions preview the autonomous future of warfare," Brookings, August 4th, https://www.brookings.edu/techstream/loitering-munitions-preview-the-autonomous-future-of-warfare/

23 ICRC, "ICRC Position on Autonomous Weapon Systems and Background Paper," 5.

24 Yaroslav Gonchar, "Підполковник Ярослав Гончар: Наша Буденність Така: Вислужився Поважний Генерал, Зайняв Високу Посаду, Але На Комп'ютері Навіть Word Не Опанував," UNIAN, October 13, 2022, https://www.unian.ua/war/aerorozvidka-v-ukrajini-yak-pracyuyut-operatori-droniv-na-viyni-interv-yu-z-yaroslavom-goncharom-12010002.html.

25 Article 36, "Sensor-Based Targeting Systems: An Option for Regulation," 2.

As it stands, the principle that these systems are operated with "humans-in-the-loop" is accepted. This principle needs to be affirmed and retained. It also needs to be strengthened as the quality and form of that human control may still be adversely affected by the following factors:

a The human operators of loitering munitions are often depicted as making decisions in a sterile and organised environment without immediate stress or risk of physical harm. These depictions stand in stark contrast to how we could expect these systems to be used in real-world combat situations. Soldiers using small canister launched loitering munitions which can often be transported in a backpack, for example, will operate in close proximity to the risks and stress associated with frontline fighting. These high-pressure situations heighten the challenges inherent to human-machine interaction. We must account for the fact that the actual use of these technologies will be more complex than the generally sanitized images presented in many advertisements.

b The fact that many loitering munitions appear to have been designed with a latent capability to engage in sensor-based targeting without human intervention is noteworthy even if the final decision to fire is made by a human operator. Under stressful and rapidly changing battlefield conditions, it is possible that humans, in verifying a given target, may uncritically trust the system's outputs – a finding suggested by previous investigations of automation bias/over-trust.[26] In certain situations, human operators may lack sufficient situational awareness to meaningfully assess targets suggested to them by the system. Humans may also experience a significant cognitive workload in operating systems integrating such complex technologies.[27] Furthermore, it is not inconceivable that access to this latent technical capability may lead to its eventual use by conflict parties.

The fact that many loitering munitions appear to have been designed with a latent capability to engage in sensor-based targeting without human intervention is noteworthy even if the final decision to fire is made by a human operator

2 Use as anti-personnel weapons and in populated areas

The earliest loitering munitions, such as the IAI Harpy, were principally designed to search out and destroy enemy radar systems. A more recent trend in loitering munition development has been the design of smaller, anti-personnel platforms that are intended for operations in populated areas. Of the 24 loitering munitions we examined in our catalogue, 14 have anti-personnel target profiles and 18 are advertised for use in populated, urban areas. As argued throughout this report, this trend has potentially significant repercussions for shaping the quality and form of human control exercised over specific targeting decisions:

a Loitering munitions armed with fragmentation warheads have been used in populated areas, including in cities, where civilians and civilian objects are present, thereby putting them at risk of being unlawfully targeted. Various objects, such as military vehicles and radar systems, have become more easily machine-recognisable and therefore more vulnerable in combat to weapons integrating autonomy to support targeting functions. As a consequence, we may see the increasing use of such systems, including loitering munitions, in populated areas because "any opponent facing down autonomous systems is best served by 'clutter' that impedes its use".[28] This dynamic, we suggest, may increase the risk of various forms of civilian harm.

26 Raja Parasuraman and Dietrich H. Manzey, "Complacency and Bias in Human Use of Automation: An Attentional Integration," *Human Factors: The Journal of the Human Factors and Ergonomics Society* 52, no. 3 (June 2010): 381–410.

27 Thomas J. Alicia, Brian T. Hall, and Mikhail Terman, "Synergistic Unmanned Manned Intelligent Teaming (SUMIT) Final Report. Technical Report FCDD-AMT-20-09" (US Army Devcom Aviation & Missile Center, November 2020).

28 Jack MacDonald, "What If Military AI Is a Washout?," *Jack MacDonald* (blog), June 23, 2021, https://jackmcdonald.org/book/2021/06/what-if-military-ai-sucks/.

b The design of some loitering munitions as anti-personnel weapons marks a significant change in the target profiles used in these systems. This trend possibly contrasts with safeguarding ethical principles of humanity and compliance with international humanitarian law, such as distinguishing between civilians and combatants.[29] First, making such legal judgments is in principle a *human* obligation under the law. Second, the change in target type away from objects that are military objectives by nature matters because such objects have a more enduring bond to military identity than human beings. In other words, categorising an armoured fighting vehicle as a military objective by nature as part of a loitering munitions' targeting algorithm may be reasonable because the likelihood of that vehicle being in civilian usage is low. However, the same argument does not apply to objects whose identity is fluid: objects that are military objectives by location, purpose, or use – such as bridges – or, indeed, human beings.[30] Further, legal experts have raised recognizing combatants as *hors de combat* as a particular challenge when using AWS and as serving as grounds for prohibiting the development and usage of anti-personnel target profiles.[31]

The design of some loitering munitions as anti-personnel weapons marks a significant change in the target profiles used in these systems

3 Potential indiscriminate and wide area effects

Many analysts and weapon manufacturers champion loitering munitions as being precise and accurate weapons. Certain types of portable loitering munitions can indeed be installed with comparatively small warheads, particularly when compared to older, unguided munitions. But the emphasis on precision aligns loitering munitions with a longer (and, at times, problematic) narrative about the pursuit of ever greater levels of accuracy in war,[32] deserving of greater scrutiny.

Precision is a relative and politicized notion which has been used to justify investments in new automated weapon technologies.[33] Whilst such claims may not always be inaccurate, the companies' manufacturing loitering munitions have a vested, commercial interest in promoting the narrative that the integration of automated, autonomous, and AI technologies increases the precision and accuracy of their systems. As the ICRC highlights, autonomy in weapons, including in loitering munitions, leads to "more generalized decision-making in targeting, with less knowledge about the eventual target(s), and the precise timing and/or location of the resulting application(s) of force".[34] In our assessment, loitering munitions can therefore potentially have indiscriminate effects. This, in principle, may result in civilians and civilian objects inadvertently becoming subject to the use of force.[35]

Further, because the precise location where force will be applied is unclear at the point of launch and in flight, the system can "appl[y] explosive force somewhere within a wide area".[36] These potential wide-area effects associated with loitering munitions have two dimensions:

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29 ICRC, "ICRC Position on Autonomous Weapon Systems and Background Paper," 2.

30 Laura Bruun, Marta Bo, and Netta Goussac, "Compliance with International Humanitarian Law in the Development and Use of Autonomous Weapon Systems. What Does IHL Permit, Prohibit and Require?" (Stockholm: SIPRI, 2023), 11, 16, https://www.sipri.org/sites/default/files/2023-03/ihl_and_aws.pdf.

31 Bruun, Bo, and Goussac, "Compliance with International Humanitarian Law in the Development and Use of Autonomous Weapon Systems," 11, 16.

32 Suchman, "Algorithmic Warfare and the Reinvention of Accuracy."

33 Suchman.

34 ICRC, "ICRC Position on Autonomous Weapon Systems," 5.

35 We would like to thank Richard Moyes for advancing our analysis on wide area effects. See also ICRC, "Explosive Weapons with Wide Area Effects: A Deadly Choice in Populated Areas," January 2022, 7, https://www.icrc.org/en/document/civilians-protected-against-explosive-weapons.

36 PAX and Article 36, "Explosive Weapons - Factors That Produce Wide Area Effects" (PAX, Article 36, June 2018), 13.

- The anti-personnel and anti-armour loitering munitions surveyed in our catalogue have an operational endurance of between 15 minutes and 6 hours and an operational range of between 5 and 50km. This means that the geographical area in which a strike might occur can encompass a radius of up to 50km. Within that radius, the sensors installed onto loitering munitions acquire data, for example weight, heat-shapes, acoustic and radar signature, image and object recognition, but also movement patterns.[37] If something within that radius matches the loitering munitions' pre-programmed target profile, it may become a target against which force is used. This means that loitering munitions can have wide area effects comparable to those that have been identified as problematic for other explosive weapons described as being inaccurate. This is because, at the moment of launch and when the loitering munition is in the air, its specific target is unclear. This "produce[s] significant variations in where a warhead might land".[38]
- Some loitering munitions such as the Turkish-manufactured Kargu-2 and the Russian-manufactured Lancet-3 can reportedly be equipped with thermobaric warheads. Notably, and problematically, these are also the only two systems in our catalogue that may integrate AI technologies in targeting. Thermobaric warheads are fuel-air explosives. These weapons create an explosion that significantly exceeds those associated with condensed explosives, such as TNT.[39] Thermobaric warheads, in comparison to conventional warheads, have a larger blast and fragmentation radius when detonated, which is a key "driver of wide area effects".[40] Such thermobaric blasts are "twelve to sixteen times more destructive than conventional high explosives against targets with large surface areas".[41] The scale of the blast created depends on the size of the warhead. The Kargu-2 and the Lancet can only carry warheads weighing at a maximum of 1.3kg and 3kg. Because of their high explosive content, even the use of thermobaric warheads at this scale brings with it more significant potential to threaten harm to the civilian population,[42] as well as risk the destruction of civilian infrastructure/sites which fall under the hard protection of international humanitarian law (IHL), such as hospitals and schools.[43]

The principle that sensor-based targeting may have diminished human control over the use of force is not a novel finding. An obvious example of this are landmines where we can see very strong evidence of diminished human control.[44] Building on earlier studies, our analysis suggests that the practices of using loitering munitions deviate significantly from those associated with other existing weapons featuring autonomous technologies in targeting. Air defence systems, for example, are limited to targeting military objects and are fixed in place to protect military installations or warships from attack. By contrast, loitering munitions are mobile, can include target types beyond military objectives, and are used in populated areas. Loitering munitions can hover over the battlefield and strike certain target profiles once detected. This contributes towards a new level of

37 Article 36, "Target Profiles", 2019, https://article36.org/wp-content/uploads/2019/08/Target-profiles.pdf; Automated Decision Research, "Autonomous Weapons and Digital Dehumanisation", November 2022, https://automatedresearch.org/news/report/autonomous-weapons-and-digital-dehumanisation-a-short-explainer-paper/

38 PAX and Article 36, "Explosive Weapons - Factors That Produce Wide Area Effects," 13.

39 AOAV, "What Is a Thermobaric Bomb?," Action on Armed Violence, March 1, 2022, https://aoav.org.uk/2022/what-is-a-thermobaric-or-vacuum-bomb/.

40 PAX and Article 36, "Explosive Weapons - Factors That Produce Wide Area Effects," 9.

41 Human Rights Watch, "Chechnya Conflict: Use of Vacuum Bombs by Russian Forces," Human Rights Watch, February 1, 2000, https://www.hrw.org/news/2000/02/01/chechnya-conflict-use-vacuum-bombs-russian-forces#.

42 Accurately assessing the scale of this possible harm depends on several contextual factors, including the rules of engagement under which these systems are operated and what weapon systems other than loitering munitions may be used to conduct this type of attack. We want to thank Justin Bronk for bringing these factors to our attention.

43 PAX and Article 36, "Explosive Weapons - Factors That Produce Wide Area Effects," 10.

44 The authors would like to thank Neil Davison for suggesting this example.

complexity in human-machine interaction because of the possible changes in the operational environment between the time when a loitering munition is activated and when authorisation is requested from a human operator to conduct a strike. The targeting decisions associated with using loitering munitions are shaped by the parameters established in pre-programmed target profiles and the human operators who may or may not supervise targeting decisions. As our analysis highlights however, these technologies generate new and significant uncertainties regarding where, when, against whom, and under what conditions force is used.

According to manufacturers, loitering munitions are "becoming a core required capability of leading armies worldwide".[45] As our later analysis suggests, militaries across the world are increasingly acquiring and deploying these systems. But that does not preclude making regulatory choices. As of now, loitering munitions only appear to have latent autonomous targeting capabilities, meaning that releasing force requires human authorisation. This development underlines both the urgent need but also the timely opportunity for new legally binding rules to regulate autonomy in weapons, including loitering munitions as a category therein.

Militaries across the world are increasingly acquiring and deploying these systems. But that does not preclude making regulatory choices

The remainder of our analysis unfolds in six steps. In Section 2, we introduce our definitions of several of the key terms used throughout this report including automation, autonomy, and AI. Our understanding of the relationship between autonomy, human control, and unpredictability in specific targeting decisions is also outlined. This is done to contextualise our subsequent analysis of how the global use of loitering munitions integrating automated, autonomous, and, to a limited extent, AI technologies already appears to have shaped the exercise of human control in certain use of force situations.

Section 3 begins by introducing our definition of a loitering munition as a distinct type of expendable uncrewed aircraft integrating sensor-based analysis which are designed to hover over, detect, and crash into targets. We then summarise how autonomy and automation have been integrated into loitering munitions, as well as introducing some of the general challenges which these systems present to the operational and the decision-making dimensions of human control.

Section 4 examines the trends in the global development and testing of automated, autonomous, and AI technologies in loitering munitions. We start by introducing some of the design features common to these weapons. We then introduce the novelty of, and contribution made by, our qualitative data catalogue of 24 loitering munitions to the ongoing international debate on AWS. This section of our report also outlines the methodology used to generate this catalogue.

Section 5 provides an in-depth analysis of how the recent battlefield use of loitering munitions illustrates the three areas of concern identified above. Three conflicts are studied in detail: the Libyan Civil War, the 2020 Nagorno-Karabakh War, and Russia's full-scale invasion of Ukraine. Our analysis shows that practices of using loitering munitions set precedents for greater uncertainty along the situational and the decision-making dimensions of human control. The growing use of such platforms as anti-personnel weapons and in populated areas, and their potential to have indiscriminate and wide area effects, is also highlighted.

Finally, section 6 offers a critical conclusion and summarises our policy recommendations.

45 GBP Aerospace and Defence. 'Growing Interest in Uvision's Hero-120 Loitering Munition', GBP Aerospace and Defence, February 19, 2020, https://gbp.com.sg/stories/growing-interest-in-uvisions-hero-120-loitering-munitions-systems/

2 Key Terms and Concepts:

Artificial Intelligence, Autonomy, Automation and (Un)predictability and the Use of Force

The language used in the international debates on autonomous weapon systems (AWS) is both contested and politicised. This section of our report therefore introduces some general definitions of the terms underpinning our analysis: artificial intelligence (AI), autonomy, automation, and machine learning. We then build on these definitions to examine the relationship between autonomy, human control, and the (un)predictability of the use of force.

2.1 Artificial Intelligence, autonomy, and automation

AI is not a singular technology, and neither is it a weapon in itself. Rather, it is a technological enabler which impacts many societal domains, such as transport, education, care, security, and health.[46] From a broad, technical standpoint, AI can be defined as the attempt "to create machines or things that can do more than what is programmed into them".[47] This definition indicates that AI has become an umbrella term for an entire field of scientific inquiry ranging from natural language processing to computer vision.[48] Autonomy can be broadly defined as the "ability of a machine to perform a task without human input".[49] An autonomous system, "once activated, can perform some tasks or functions on its own".[50] Autonomous systems use sensors to perceive the environment before using a software component, typically in algorithmic form, to search for patterns in this data. The analysis of these sensory inputs informs the systems' outputs and the actions taken in pursuit of a goal established by a human programmer.[51] Autonomous systems can choose between multiple courses of action to complete designated tasks. They are thus capable of operating without direct human input. Three different dimensions to autonomy can be distinguished: (1) the complexity of the task delegated to the machine; (2) the character of human-machine interaction when the machine is conducting its designated task, particularly as it relates to the degree of required human input; and (3) the complexity of the machine's output-producing processes.[52]

Automation is a notion which is related to, and often conflated with, autonomy. Some argue that a technical distinction can be drawn between autonomy and

46 Mark Coeckelbergh, "Artificial Intelligence: Some Ethical Issues and Regulatory Challenges," *Technology and Regulation* 1 (2019): 31–34.

47 Timnit Gebru, "Don't Fall for the AI Hype," Tech Won't Save Us Podcast with Paris Marx, January 19, 2023, https://techwontsave.us/episode/151_dont_fall_for_the_ai_hype_w_timnit_gebru.

48 Ingvild Bode et al., "Algorithmic Warfare: Taking Stock of a Research Programme," *Global Society*, forthcoming 2023.

49 Scharre and Horowitz, "An Introduction to Autonomy in Weapon Systems," 5.

50 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 5.

51 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 8-11.

52 Scharre, *Army of None*, 27-29.

automation, but understandings of automation and autonomy differ across domains. There are also political dimensions to how these terms are used in the international debates regarding AWS. Actors may, for example, prefer to use the term automation, even when referring to what could also be called autonomy, because it implies a higher degree of familiarity and predictability.[53] According to cognitive robotics professor Alan Winfield, automation means "running through a fixed pre-programmed sequence of action".[54] In this sense, automation implies a set of less complex actions than autonomy because automated systems may follow a linear/scripted sequence of measures – i.e. when "A" happens follow procedure "B".[55] Rather than establishing a perhaps futile clear-cut distinction between automation and autonomy, we prefer the concept of sensor-based systems because it encompasses automation, autonomy, and AI. Systems integrating these technologies all rely on sensors and software to detect and identify objects.[56] Importantly, automated and autonomous technologies increase system complexity and trigger shared concerns when integrated into targeting functions.

2.2 Autonomy, automation, and human control in weapon systems

At the United Nations Convention on Certain Conventional Weapons (CCW) Group of Governmental Experts (GGE) and elsewhere, the terms lethal autonomous weapon systems (LAWS) and autonomous weapon systems (AWS) are used to discuss the integration of automated, autonomous, and, to a limited extent, AI technologies into a variety of weapon systems.[57]

Group of Governmental Experts on LAWS at the UN-CCW in session, July 2022. **Source:** Ingvild Bode

AWS are defined by some as "systems that, when in use, apply force automatically, at a time and place that is determined by matching sensor inputs from the environment against encoded profiles of intended target-types, without human assessment of those sensors inputs".[58] AWS differ from remotely-controlled, uncrewed weapon systems, such as Medium-Altitude Long-Endurance drones like current versions of the MQ-9 Reaper, which are, as of now, remotely piloted and controlled by human agents through remote split operations. In essence, an AWS is any weapon which, once activated, is capable of sensing and acting within a designated area (whatever its geographical extent) to detect and strike targets which meet operator designated target profiles. Such target profiles can, however, only ever be a technical approximation of the 'target' the user intends to strike.[59]

Automated and autonomous technologies, as well as AI, can be integrated into a range of different functions used as part of a weapon system. Research conducted by Vincent Boulanin and Maaike Verbruggen at the Stockholm International Peace Research Institute (SIPRI) highlights five autonomous functions which can be part

53 Ingvild Bode, "Emergent Normativity: Communities of Practice, Technology, and Lethal Autonomous Weapon Systems," *Global Studies Quarterly*, forthcoming 2023.

54 Winfield, *Robotics: A Very Short Introduction*, 12.

55 M. L. Cummings, "The Human Role in Autonomous Weapon Design and Deployment," in *Lethal Autonomous Weapons: Re-Examining the Law and Ethics of Robotic Warfare*, ed. Jai Galliott, Duncan MacIntosh, and Jens David Ohlin (Oxford: Oxford University Press, 2021), 277.

56 Article 36, "Sensor-Based Targeting Systems: An Option for Regulation."

57 The GGE's mandate covers "emerging technologies in the area of LAWS", but an increasing number of stakeholders, such as the ICRC and civil society organisations, use the more general term AWS. Amongst other reasons, this is because non-lethal uses of autonomy have significant legal and ethical ramifications deserving of careful consideration.

58 Article 36, "Sensor-Based Targeting Systems: An Option for Regulation," 2.

59 The authors want to thank Neil Davison for making this point.

of AWS: (1) mobility; (2) targeting; (3) intelligence; (4) interoperability; and (5) health management.[60] Our analysis of loitering munitions focuses on the use of automated, autonomous, and, to a limited extent, AI technologies to support mobility and targeting functions. This discussion helps contextualise an important trend in the recent development of autonomy in weapon systems: the design of more mobile weapons which provide a different set of challenges to human control than older platforms, such as air defence systems, which are generally operated in fixed locations.[61]

(Mobility). Automated, autonomous, and AI technologies can be used to enable the mobility of AWS, defined as "functions which allow the system to govern and direct its own motion within its operating environment without direct involvement of a human operator".[62] This use of automated, autonomous, and AI technologies reduces human workload by eliminating the need to manually control and direct the platform's movements. This frees up the operator to focus on the completion of other tasks, and in principle reduces the risk of accidents.[63]

Some weapon systems integrating autonomy, including loitering munitions, are installed with a homing capability which enables platforms to track and follow operator designated targets.[64] Such systems can also be installed with autonomous navigation features. These include waypoint navigation: a capability which enables a system to traverse a predesignated route by following a set of geographical coordinates entered by the operator.[65] Larger uncrewed systems, such as the Northrop Grumman manufactured MQ-4C Triton high-altitude surveillance drone, are similarly capable of autonomously planning navigational routes to designated locations with a set of parameters established by human operators.[66] Given the greater presence of civilians and/or civilian objects in these areas and thus the increased likelihood of interacting with the complex behaviours of human agents, autonomous navigation features generally work less effectively in urban areas.

(Targeting). Automated, autonomous, and AI technologies can also be used to support targeting functions, defined as a machine's ability to search for, identify, and strike a category of object.[67] This can involve the use of automatic target recognition (ATR) software which works by searching for specified targeting signatures in sensor data, whether this be collected via electro-optical and/or infrared camera(s), radar, or another type of sensor.[68] The use of ATR can increase the range of targets that can be detected, as well as the speed at which they can be identified.[69] ATR software can, in principle, be programmed to detect a range of military related objects including tanks, airplanes, missiles, radars, improvised explosive devices, and minefields.[70] ATR works via matching sensor inputs against operator designated target profiles, "a pattern of sensor data that is taken to represent a target" and triggers "a specific application of force being undertaken by the system".[71]

According to some analysts, most existing ATR software is "rather rudimentary".[72] For the most part, these programmes are only capable of reliably detecting larger and clearly specified objects such as tanks, missiles, and radar installations. Using

60 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 19-35.
61 Kayser, "Increasing Autonomy in Weapons Systems," 2.
62 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 21.
63 Defence Science Board, 'Task Force Report: The Role of Autonomy in DoD Systems,' Department of Defence, July 2012, https://irp.fas.org/agency/dod/dsb/autonomy.pdf, 15, 33.
64 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 22.
65 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 22.
66 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 22.
67 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 24.
68 Schachter, *Automatic Target Recognition*, 1.
69 Schachter, *Automatic Target Recognition*, 1.
70 Schachter, *Automatic Target Recognition*, 2.
71 Article 36, "Target Profiles," 4.
72 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 24.

target recognition programmes to detect human targets and to distinguish between civilians and combatants is very demanding.[73] This is because determining the legal status of a person, and therefore whether someone can be targeted, is context dependent.[74] The performance of ATR can also be reduced by a range of environmental factors, including the degree of background "clutter", the weather, and enemy decoy efforts.[75] For these reasons, most ATR software is operated with a "human-in-the-loop" since humans are "much better than ATRs at tasks requiring consultation, comprehension, and judgement".[76] There is also a legal requirement for humans to make certain context specific judgments, especially with regard to discrimination, proportionality, and precautions in attack.[77] As the various technologies associated with this software continue to be tested and developed, it is not inconceivable that more autonomous ATR programmes will be installed into various different types of weapon systems, including loitering munitions.

(Human control) Recent technical developments in automated, autonomous, and AI technologies have prompted major civil society, practitioner, and scholarly debate on the changing role of human cognition in war. Often, the extent to which humans remain in direct control over specific targeting decisions is conceptualised using the "in, on, and out" of the loop model (see table 1). For "in-the-loop" systems, humans either (a) deliberate about specific targeting decisions before initiating a strike, often through visual inspection of targets; or (b) choose from a list of targets generated by the system for potential attack. In "on-the-loop" systems, humans (c) approve attacks against targets identified by the system; or (d) have a time-restricted veto. In "out-of-the-loop" systems, the system selects targets based on pre-programmed target profiles and initiates attacks without direct human involvement.[78]

Table 1: Levels of human control (based on Sharkey 2016)

(a) humans deliberate about specific targeting decisions before initiating an attack, often through a visual inspection of the target	in-the-loop
(b) humans choose from a list of targets generated by the system to attack	in-the-loop
(c) humans approve attacks against targets identified by the system	on-the-loop
(d) the system selects targets and allocates humans a time-restricted veto before commencing an attack	on-the-loop
(e) the system selects targets based on pre-programmed target profiles and initiates attacks without direct human involvement	out-of-the-loop

2.3 Machine learning

Machine learning is an important technique of AI which could transform how loitering munitions and other types of AWS are operated and deployed. In technical terms, machine learning refers to the "development of computers and robots capable of adapting to their environment and improving performance based on past experiences and training rather than a pre-programmed model of the

73 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 7.
74 ICRC, "ICRC Position on Autonomous Weapon Systems and Background Paper."
75 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 25; Schachter, *Automatic Target Recognition*, 5; Scharre, *Army of None*, 84.
76 Schachter, *Automatic Target Recognition*, xiv.
77 Bruun, Bo, and Goussac, "Compliance with International Humanitarian Law in the Development and Use of Autonomous Weapon Systems," 5; Vincent Boulanin et al., "Limits of Autonomy in Weapon Systems. Identifying Practical Elements of Human Control." (SIPRI & ICRC, June 2020), 5.
78 Based on Sharkey, "Staying in the Loop," 34–37.

world".[79] Machine learning requires access to large volumes of training data in order to draw conclusions and propose solutions to problems specified by humans which the system uses to search for patterns. Amongst other methods, machine learning can involve the use of deep learning, defined as a "specific technique based on neural networks, which draws on knowledge of the human brain, statistics and applied maths".[80]

Kargu-2.
Source: Wikimedia Commons

The use of machine learning algorithms in commercial research fields including medicine, agriculture, and the automotive industry has produced a series of scientific developments.[81] The speed at which machine learning algorithms can complete certain tasks, coupled with the anxiety states may have that their adversaries are developing these technologies, suggests that machine learning algorithms may become a feature of warfighting, if under certain controls. Because of the difficulties involved with certifying the safety of such software, it is claimed that there are "no weapon systems in active service that have the capacity to deliver lethal force and use AI powered by machine learning".[82] As discussed in greater detail in the fifth section of our report however, the Turkish defence company STM has previously advertised the Kargu-2 as being installed with "real-time image processing capabilities and machine learning algorithms" to facilitate strikes against fixed and moving targets.[83]

Hypothetically, machine learning could support the operation of entire systems or be used to support specific functions such as mobility and targeting.[84] Machine learning is far from a technological silver-bullet, however. The safety of machine learning algorithms in a military context requires a large amount of accurate training data which can be difficult to obtain.[85] This "data dependence" may produce "brittle" AWS which only reliably work in environments that directly match training data.[86] In this way, the military use of machine learning algorithms could produce weapons that exhibit incomprehensible, unethical, or unlawful behaviours. As Arthur Holland Michel observes:

> *If a machine learning system can adjust itself in real time while executing a mission—a technique that is gaining favour as a means of continuously improving the system's performance and further enabling autonomous operations in complex environments—that system's specific outputs may be harder to predict as it may acquire new unanticipated behaviours that have not been tested.*[87]

79 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 91.

80 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 17.

81 O. Y. Al-Jarrah et al., "Efficient Machine Learning for Big Data: A Review," 2015, https://doi.org/10.48550/ARXIV.1503.05296.

82 Boulanin, Brockmann, and Richards. "Responsible Artificial Intelligence Research," 8.

83 James Felton, "An Autonomous Weaponized Drone 'Hunted Down' Humans Without Command For First Time," IFL Science, May 31 2021, https://www.iflscience.com/an-autonomous-weaponized-drone-hunted-down-humans-without-command-for-first-time-59879; Daniel Van Boom, "Autonomous drone attacked soldiers in Libya all on its own," CNET, May 31 2021, https://www.cnet.com/culture/autonomous-drone-attacked-soldiers-in-libya-all-on-its-own/.

84 ICRC, "Artificial intelligence and machine learning in armed conflict: A human-centred approach," June 6 2019, https://blogs.icrc.org/new-delhi/wp-content/uploads/sites/93/2019/06/ai_and_machine_learning_in_armed_conflict-icrc-1.pdf, 2.

85 Gregory C. Allen, "Russia Probably Has Not Used AI-Enabled Weapons in Ukraine, but That Could Change," Center for Strategic and International Studies, May 26 2022, https://www.csis.org/analysis/russia-probably-has-not-used-ai-enabled-weapons-ukraine-could-change

86 Zachary Kallenborn, "Applying arms-control frameworks to autonomous weapons," Tech Stream, October 5 2021, https://www.brookings.edu/techstream/applying-arms-control-frameworks-to-autonomous-weapons/

87 Michel, "The Black Box, Unlocked," 7.

Machine learning algorithms can also have weaknesses which operators cannot anticipate, stop, or comprehend.[88] This can include what Arthur Holland Michel frames as the "blackbox problem": situations in which a human operator can observe the actions taken by AWS integrated with machine learning algorithms, but not understand the logic informing these outputs, nor why one set of actions was taken rather than others.[89] In this way, the integration of machine learning algorithms into AWS could bring "a new dimension of unpredictability to these weapons, as well as concerns about lack of explainability and bias".[90] To better understand these dynamics and provide important context for this report's analysis of loitering munitions and human control, the relationship between unpredictability and human control is discussed in greater detail below.

2.4 Unpredictability and human control

Unpredictability is an inherent feature of the conduct and consequences of war. As captured in Carl von Clausewitz's conceptualisations of friction and chance, commanders cannot know how, where, and when an adversary may choose to fight.[91] The integration of automated, autonomous and AI technologies into weapon systems can generate new uncertainties about when, where, and against whom military force is used.[92] According to Arthur Holland Michel, predictability refers to the "extent to which a system's outputs or effects can be anticipated".[93] The authors of a recent Alan Turing Institute Centre for Emerging Technology and Security report on the predictability of AI systems similarly approach this issue in terms of the "degree to which one can answer the question: what will an AI system do?"[94]

The predictability of machines integrating automated, autonomous, and AI technologies has both technical and operational dimensions

The predictability of machines integrating automated, autonomous, and AI technologies has both technical and operational dimensions.[95] It concerns not only the accuracy of the actions which are taken but whether such outcomes are consistent with the system's design and can be anticipated by human agents.[96] The technical dimensions of predictability relate to a system's ability to complete a specified task with the same accuracy and reliability as it had in testing, previous use, and/or when provided with training data.[97] It therefore revolves around issues such as the accuracy, transparency, explainability, and interpretability of system outputs.[98]

The operational dimension of predictability, on the other hand, "refers to the degree to which an autonomous system's individual actions can be anticipated".[99] This can be influenced by multiple factors. These include the complexity of the environment in which these systems are deployed, interactions with potential adversaries, and the operator's understanding of how and why systems may reach particular outcomes.[100] As Arthur Holland Michel notes:

88 Scharre, *Army of None*, 188.
89 Michel, "The Black Box, Unlocked," iii.
90 ICRC, "Artificial intelligence and machine learning in armed conflict," 3.
91 Clausewitz, on war. Alan Beyerchen, "Clausewitz, nonlinearity, and the unpredictability of war." *International Security* 17, no. 3 (1992): 59-90.
92 Boulanin, Davison, Goussac and Carlsson, "Limits on Autonomy in Weapon Systems," ix.
93 Michel, "The Black Box, Unlocked," 5.
94 Mariarosaria Taddeo, Marta Ziosi, Andreas Tsamados, Luca Gilli, and Shalini Kurapati "Artificial Intelligence for National Security: The Predictability Problem," CETaS Research Reports, September 2022, 13.
95 See also ICRC, "Autonomy, Artificial Intelligence and Robotics: Technical Aspects of Human Control," August 2019, 10–12.
96 Taddeo, Ziosi, Tsamados, Gilli, and Kurapati, "Artificial Intelligence for National Security," 4.
97 Michel, "The Black Box, Unlocked," 5.
98 Taddeo, Ziosi, Tsamados, Gilli, and Kurapati, "Artificial Intelligence for National Security," 14.
99 Michel, "The Black Box, Unlocked," 5.
100 Michel, "The Black Box, Unlocked," 7; Taddeo, Ziosi, Tsamados, Gilli, and Kurapati, "Artificial Intelligence for National Security," 14-15.

> *Operational unpredictability is particularly inherent in systems designed to handle a wide range of inputs, complex environments and dynamic conditions. Not only is it hard to anticipate what such a system will encounter, it may be difficult (especially in the case of learning-based systems) to anticipate exactly how the system will respond to this environment, because such AI systems may achieve their goals in ways that are not necessarily logical or reasonable by human standards.*[101]

The degree of unpredictability involved with the operation of systems integrating automated, autonomous, and AI technologies varies. Amongst other factors, it can be influenced by: (1) the complexity of the task delegated to the system (i.e. *what* the system is expected to do); (2) the complexity of the environment in which the system is operating (i.e. *where* the system is expected to complete its designated task); and (3) the number of systems interacting together (i.e. *how many systems* are working in tandem or in the same environment).[102] In this way, "[p]redictability is partly a characteristic of the technology, but more fundamentally it is a characteristic of the interaction between that technology and the specific environment within which it will operate".[103]

The process of delegating tasks to automated, autonomous, and AI technologies creates unpredictability because the designers of such technologies cannot foresee every possible output a system will produce or obstacle it will encounter.[104] From a technical standpoint, the operators of such systems cannot be completely certain that, once activated, AWS will perform as designed.[105] The predictability of AWS could have major implications for the degree and quality of control which human agents exercise over specific targeting decisions, as well as the international regulatory debates on these technologies.[106] For example, it could mean that systems strike unanticipated target types and/or use force at unforeseeable times and places. Such unpredictability could make it difficult to attribute responsibility for the actions taken by weapon systems.[107]

Soldier at training course for Hero loitering munitions. **Source:** U.S. Marine Corps

Human control and human-machine interaction have become major reference points amongst the many international stakeholders participating in the international debates at the GGE. There is a broad agreement around the risks arising from sensor-based systems applying force automatically without human assessment.[108] Many stakeholders (including the authors) promote the codification of an obligation for human-machine interaction requirements, including human judgement and control, as part of a regulatory framework that would also prohibit the development and usage of weapon systems integrating autonomous technologies not meeting this standard.[109]

101 Michel, "The Black Box, Unlocked," 5.
102 Michel, "The Black Box, Unlocked," 6-7.
103 Article 36, "Key Elements of Meaningful Human Control," 4.
104 Michel, "The Black Box, Unlocked," 5.
105 Taddeo, Ziosi, Tsamados, Gilli, and Kurapati, "Artificial Intelligence for National Security," 4.
106 Michel, "The Black Box, Unlocked," 1.
107 Taddeo, Ziosi, Tsamados, Gilli, and Kurapati, "Artificial Intelligence for National Security," 10.
108 Boulanin, Davison, Goussac and Carlsson, "Limits on Autonomy in Weapon Systems," 1-2; Article 36, "Sensor-Based Targeting Systems", 2.
109 Bode and Watts, "Meaning-Less Human Control"; Rosert and Sauer, "How (Not) to Stop the Killer Robots." ICRC, "ICRC Position on Autonomous Weapon Systems"; Human Rights Watch, "Stopping Killer Robots. Country Positions on Banning Fully Autonomous Weapons and Retaining Human Control" (New York: Human Rights Watch, August 10, 2020), https://www.hrw.org/report/2020/08/10/stopping-killer-robots/country-positions-banning-fully-autonomous-weapons-and; Article 36, "Sensor-Based Targeting Systems: An Option for Regulation."

A focus on human-machine interaction and control has helped broaden the international debate on AWS beyond narrow definitional questions around autonomy to a more thoughtful exploration of how these technologies may be reshaping the character and quality of human control over the use of force.[110] Nonetheless, the notion remains subject to many competing understandings and misinterpretations. Many states parties underline that human control should extend across the development, deployment, and use of weapon systems. This approach to human control is also visible in the so-called iceberg diagram, a publication by the United Nations Institute for Disarmament Research (UNIDIR) that distinguishes between political, strategic, operational, and tactical planning phases each featuring human control.[111]

The design and use of loitering munitions challenges and often undermines the ability of humans to remain in control over specific targeting decisions

In 2020, two sets of stakeholders published operationalisations of human control: first, the Stockholm International Peace Research Institute (SIPRI) in collaboration with the International Committee of the Red Cross (ICRC),[112] and second, the Campaign to Stop Killer Robots.[113] These reports distinguished between three dimensions of human control: (1) a technological dimension that enables human control via the design of weapon parameters, for example, limits on target type and programming of target profiles; (2) a situational dimension that sets operational limits to the ways weapon systems are used to enhance human control, for example through setting geographical (where?) and temporal (when and for how long?) limits; and (3) a decision-making dimension that sets out acceptable forms of human-machine interaction through ensuring appropriate human supervision, for example by making certain that human operators or decision-makers understand "what will fall within a target profile, where 'what falls within' includes both intended and unintended objects of attack".[114] As both reports argue, retaining an appropriate quality of human control necessitates covering multiple components across all three dimensions. These three dimensions of human control correlate with methods that military commanders have traditionally used to limit the degree of unpredictability and/or the challenges in anticipating and controlling the effects from the use of autonomy in weapon systems.[115]

In examining the relationship between predictability and human control in the case of loitering munitions, we concentrate on the situational and the decision-making dimensions. Whilst recognising the importance of the technological dimension of human control, this decision has been informed by the limits of what the available open-source data can tell us about these systems' technical capabilities and the rules of engagement under which they are operated. For these reasons, we pay particular attention to how the design and use of loitering munitions challenges and often undermines the ability of humans to remain in control over specific targeting decisions in two ways: first, by making the spatial and temporal use of force more unpredictable e.g. by expanding both these notions (i.e. the situational dimension); and second, by 'setting' limits to the quality of how direct human supervision can be exercised (i.e. the decision-making dimension).

110 Boulanin, Davison, Goussac and Carlsson, "Limits on Autonomy in Weapon Systems," 3.

111 UNIDIR. "The Human Element in Decisions about the Use of Force," 2020, https://unidir.org/sites/default/files/2020-03/UNIDIR_Iceberg_SinglePages_web.pdf

112 Vincent Boulanin, Neil Davison, Netta Goussac, and Moa Peldán Carlsson, "Limits of Autonomy in Weapon Systems. Identifying Practical Elements of Human Control," (Stockholm International Peace Research Institute and International Committee of the Red Cross, 2020), https://www.sipri.org/sites/default/files/2020-06/2006_limits_of_autonomy.pdf.

113 Campaign to Stop Killer Robots. "Key Elements of a Treaty on Fully Autonomous Weapons. Frequently Asked Questions," February 2020, https://www.stopkillerrobots.org/wp-content/uploads/2020/04/FAQ-Treaty-ElementsvAccessible.pdf.

114 Article 36, "Target Profiles," 7.

115 Kayser, "Increasing Autonomy in Weapons Systems," 1.

3 Loitering munitions:

Definitions, autonomy, and human control

The study of loitering munitions invites a certain definitional ambiguity. These technologies are widely described as a "sort of hybrid between unmanned aircraft and traditional missiles"[116] and a type of "suicide" drone.[117] This section of our report introduces our definition of a loitering munition as an expendable uncrewed aircraft which can integrate sensor-based analysis to hover over, detect, and crash into targets. By defining loitering munitions in this way, we recognise that these technologies share several properties with other types of uncrewed weapons such as missiles and drones. What differentiates loitering munitions is how they combine certain design characteristics: loitering munitions are highly mobile and comparatively low-cost systems which are expendable and can be developed for use in large numbers. We then introduce how automated, autonomous and, potentially, AI technologies are used to support the operation of loitering munitions, paying particular attention to the widely studied IAI Harpy and Harop systems. We conclude this discussion by summarising some of the general challenges which the use of loitering munitions that integrate automated and autonomous technologies in targeting present to the situational and the decision-making dimensions of human control.

Soldier launching a Switchblade-300.
Source: Wikimedia Commons

3.1 What is a loitering munition?

Loitering munitions are expendable uncrewed aircraft which can integrate sensor-based analysis to hover over, detect, and crash into targets. These weapons can vary significantly in their size, weight, and technological sophistication. The first generation of loitering munitions, such as the IAI Harpy, were equipped with anti-radiation seekers. These systems were developed during the 1980s and early 1990s to conduct Suppression of Enemy Air Defence (SEAD) operations.[118] They were designed to "hit targets that you know are there, but not exactly where, because they might be relocatable".[119] Aided by advances in computing and sensor technologies, more portable loitering munitions have since been developed for use

116 Joseph Trevithick, "Ship-Launched Version of the Israeli Harop Suicide Drone Will Be Sailing with an Asian Navy," The Drive, 3 February 2021, https://www.thedrive.com/the-war-zone/38690/ship-launched-version-of-the-israeli-harop-suicide-drone-will-be-sailing-with-an-asian-navy

117 For a thoughtful discussion of the inaccuracies of the "kamikaze drone" terminology, see Heather Penney, "Stop calling Switchblades 'drones' — it's causing policy confusion," Defense News, 6 June 2022, https://www.defensenews.com/opinion/commentary/2022/06/06/stop-calling-switchblades-drones-its-causing-policy-confusion/

118 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 53.

119 Murdo Morrison, "The changing face of Israel's UAV sector," Flight Global, https://www.flightglobal.com/flight-international/the-changing-face-of-israels-uav-sector/136938.article

by special operation forces and infantry units. Systems such as the AeroVironment Switchblade 300, the STM Kargu-2, and the WB Group Warmate are often presented as an alternative to the use of other types of weapons such as artillery, mortars, and grenades. The use of electro-optical/infra-red camera(s) and remote ground control stations enables the operators of these systems to supervise their use.

Loitering munitions are expendable uncrewed aircraft which can integrate sensor-based analysis to hover over, detect, and crash into targets

Dan Gettinger and Arthur Holland Michel, authors of arguably the most influential existing study of these technologies, define loitering munitions as a "type of unmanned aerial vehicle designed to engage beyond line-of-sight ground targets with an explosive warhead".[120] A key feature of these weapons is the ability to remain airborne over a battlefield, extending the time which soldiers have to "decide when and what to strike".[121] In principle, this capability enables attacks against time sensitive and mobile targets. Those operating loitering munitions are not necessarily required to know the precise time and location of an attack when they launch these weapons.

Dan Gettinger and Arthur Holland Michel note that loitering munitions "blur the line between drone and missile".[122] IAI, a leading global developer of loitering munitions, similarly describe the Harpy and Harop systems as "combining capabilities of an UAV [Uncrewed Aerial Vehicle] and a missile".[123] Loitering munitions share several technical properties with precision-guided munitions, defined as "explosive projectiles that can actively correct for initial-aiming or subsequent errors by homing in on their targets or aim-points after being fired, released, or launched".[124] In the case of homing munitions, automation can be used to support mobility functions, enabling the munition to "lock-on-to" and navigate toward moving targets.[125] Loitering munitions can be installed with similar homing and tracking features. Loitering munitions are also single use technologies. Once they have been used to attack a target, they are destroyed and cannot be recovered.

Despite these similarities, loitering munitions and precision-guided munitions can differ in important ways. First, loitering munitions can be launched with a larger window for when and where the projectile will detonate. The operators of these systems can anticipate what broad category of target may be attacked (e.g. tanks, armoured vehicles, air defence systems). Nonetheless, they can be uncertain of the precise time and location at which an attack will take place. This differs from homing munitions which "have a very limited ability in time and space to search for targets".[126] Similarly, unlike many traditional types of missiles, those operating loitering munitions can "wave-off" strikes and, in some cases, even recover the platform if it has not detonated.[127]

Loitering munitions also share several design features with drones which, amongst other names, are referred to as UAV and Remotely Piloted Aircraft (RPA). Drones are a broad set of reusable technologies which can be defined as "aircraft of varying size that do not have a pilot on board and are instead controlled by someone on the ground".[128] Like drones, human operators can remotely pilot

120 Gettinger and Michel, "Loitering Munitions in Focus," 1.
121 Gettinger and Michel, "Loitering Munitions in Focus," 1.
122 Gettinger and Michel, "Loitering Munitions in Focus," 1.
123 IAI, "Harpy NG: Anti-Radiation Loitering Weapon System," IAI, 2019, https://www.iai.co.il/drupal/sites/default/files/2019-05/HARPY%20Brochure.pdf; IAI, "Harop Loitering Munition System".
124 Based on B. D. Watts, Six Decades of Guided Munitions and Battle Networks (Centre for Strategic and Budgetary Assessments: Washington DC, March 2007), pp. ix-18 referenced in Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 47.
125 Scharre, *Army of None*, 42.
126 Scharre, *Army of None*, 42.
127 Gettinger and Michel, "Loitering Munitions in Focus," 4; Pilch, Altmann and Suter, "Survey of the Status of Small Armed," 9.
128 Boyle, *The Drone Age*, 7.

loitering munitions from radio line of sight, helping protect soldiers from the risks of certain types of physical harm. Loitering munitions can similarly be designed to remain airborne for extended periods of time to conduct strike and/or reconnaissance missions. In the case of larger systems, the operational endurance of drones is an order of magnitude greater than that of loitering munitions. The Northrop Grumman RQ-4 Global Hawk, for example, can remain airborne for over thirty hours,[129] more than 100 times that of the Switchblade 300 loitering munition.[130] The operational range of many loitering munitions is comparable to that of certain small classes of reconnaissance drones such as the backpackable AeroVironment RQ-11 Raven which, with a weight of 2.2kg, can remain airborne for over 75 minutes.[131]

Soldier launching RQ-11 Raven.
Source: Wikimedia Commons

Whilst acknowledging these similarities, loitering munitions have tended to generally be more expendable and cheaper to procure than many classes of larger armed drones. In the future, these factors may enable loitering munitions to be used in greater numbers for two reasons.

First, unlike many categories of drones including Medium Altitude Long Endurance platforms such as the MQ-9 Reaper, which are designed to carry weapons such as AGM-114 Hellfire II missiles, loitering munitions are installed with a warhead in the platform's fuselage. This warhead can, relative to certain types of precision guided munition and missiles, be comparatively small, enabling loitering munitions to be used to conduct close air support operations. This is an important distinction to make because, as Grégoire Chamayou explains, the "drone is not a projectile, but a projectile-carrying machine".[132] A loitering munition, in contrast, is more akin to a projectile and cannot be reused after a strike because the platform has been destroyed. Expendability – the fact that loitering munitions self-destruct during an attack – differentiates many types of drones from loitering munitions.

Expendability – the fact that loitering munitions self-destruct during an attack – differentiates many types of drones from loitering munitions

Second, loitering munitions can often be cheaper to procure than certain classes of larger armed drones. The cost of an AeroVironment Switchblade 300, for example, has been estimated as being as low as $6,000[133] but is more likely to

129 Northrop Grumman, "Global Hawk: Vigilance for a Changing World," https://www.northropgrumman.com/what-we-do/air/global-hawk/#:~:text=Able%20to%20fly%20at%20high,of%20weather%20%E2%80%93%20day%20or%20night

130 AeroVironment, "Switchblade 300," 2023, https://www.avinc.com/tms/switchblade

131 AeroVironment, "Raven B RQ-11," 2022, https://www.avinc.com/images/uploads/product_docs/Raven_Datasheet_05_220825.pdf

132 Chamayou, *Drone Theory*, 27.

133 Ken Dilanian, Dan De Luce, and Courtney Kube, 'Biden admin will provide Ukraine with killer drones called Switchblades,' NNC News, March 15, 2022, https://www.nbcnews.com/politics/national-security/ukraine-asks-biden-admin-armed-drones-jamming-gear-surface-air-missile-rcna20197

be somewhere in the region of $50,000.[134] This is a fraction of the estimated $32 million cost of certain MQ-9 Reaper variants,[135] and the approximate $140,000 average unit cost of an AGM-114 Hellfire II missile.[136] According to some loitering munition manufacturers, the low(er) cost of these systems is "part of the disruptive nature"[137] of these technologies – it places them broadly within the same price bracket as backpackable uncrewed reconnaissance platforms such as the RQ-11 Raven which cost approximately $35,000 per unit.[138] To be sure: loitering munitions are not universally cheaper to procure or field than weapon systems which may provide roughly similar battlefield purposes. The 'sophistication' of the warhead and sensors installed onto the platform, as well as the degree of the system's hardening against electronic warfare attacks, can have a major impact on their price.[139] As such, it is the *comparatively* lower cost of many smaller loitering munitions which helps enable the use of these technologies by lower echelon forces such as infantry platoons, which can be provided with their own strike and air support capabilities.

Taken together, the expendability of these platforms coupled with their comparatively low(er) unit cost invites the prospect of large numbers of loitering munitions being used simultaneously. This may include the possible development of loitering munition "swarms"[140] which could be used to saturate the defensive capabilities of certain targets. As one Western security official describes it: "[f]or an outlay that is a fraction of the cost of a conventional air force, you can populate the skies above a theatre of operations with highly accurate and enduring weaponry".[141] Consistent with such claims, the Turkish weapon manufacturer STM advertise the Alpagu loitering munition as being "used as a herd, and integrat[ed] with various platforms".[142] As part of the KERKES development project aimed at developing the use of the company's uncrewed systems for use in GPS-denied areas,[143] STM also describe the Kargu-2 platform as being tested with "advanced machine vision capabilities" and "swarm algorithms" in order to be operated "both as a single platform and as part of a swarm of up to 20 platforms".[144] Officials at the American loitering munition manufacturer AeroVironment have similarly described the development of "cooperative engagements" between platforms as being the "next big wave" in loitering munition development.[145]

134 The authors are grateful to Dan Gettinger for this observation.

135 David Hambling, "Why the Air Force Needs a Cheaper Reaper," Forbes, June 10, 2020, https://www.forbes.com/sites/davidhambling/2020/06/10/why-the-air-force-needs-a-cheaper-reaper/?sh=7a57bec9946f

136 This figure includes "training support, technical support, spare and repair parts as well as logistical support". The Defence Post, 'AGM-114 Hellfire Missile Ultimate Guide: Capabilities, Variants, and Cost,' The Defence Post, March 22, 2021, https://www.thedefensepost.com/2021/03/22/agm-114-hellfire-missile/

137 Bill Carey, "Raytheon Further Develops Multi-Mission Coyote UAS," June 17, 2017, AIN Online, https://www.ainonline.com/aviation-news/defense/2017-06-17/raytheon-further-develops-multi-mission-coyote-uas

138 Army Technology, "RQ-11 Raven Unmanned Aerial Vehicle," July 2022, https://www.army-technology.com/projects/rq-11-raven/#:~:text=Each%20Raven%20costs%20around%20%2435%2C000,%2C%20the%20UK%2C%20and%20Spain.

139 The authors would like to thank Justin Bronk for this observation. See also Justin Bronk, "Given interest in the Iranian Shahed-136...," Twitter, 26 September 2022, https://twitter.com/Justin_Br0nk/status/1574414794396143616

140 Many of the "swarm" capabilities currently advertised by weapon manufacturers are "either remote controlled or preprogramed". Many companies are pursing research and development programmes to use autonomy to support swarming. Kayser, "Increasing Autonomy in Weapons Systems," 2-3. Whilst this issue falls beyond the scope of this report to explore, for a more detailed discussion of emerging technologies in the domain of autonomy and swarming, see Article 36, "Swarms," March 2019; Zachary Kallenborn, "InfoSwarms: Drone Swarms and Information Warfare." *The US Army War College Quarterly: Parameters* 52, no. 2 (2022): 87-102.

141 Cahal Milmo, "How 'kamikaze drones' are rewriting the rules of war in the battle for Ukraine," Inews, June 25, 2022, https://inews.co.uk/news/kamikaze-drones-valuable-weapon-both-sides-russia-ukraine-war-1706286

142 STM, "New domestic-made UAV set to join Turkish arsenal," June 15 2020, https://www.stm.com.tr/en/media/press-releases/new-domestic-made-uav-set-join-turkish-arsenal

143 STM, "STM Delivers Kerkes Project," October 10 2022, https://www.stm.com.tr/en/media/press-releases/stm-delivers-kerkes-project

144 STM, "AA Tours State of the Art Turkish UAV Maker," June 20, 2020, https://www.stm.com.tr/en/media/press-releases/aa-tours-state-art-turkish-uav-maker

145 Andrew Eversden, "Bigger, faster, longer': As market grows, loitering munition makers eye next evolution," July 21, 2022, https://breakingdefense.com/2022/07/bigger-faster-longer-as-market-grows-loitering-drone-makers-eye-next-evolution/

3.2 How are automated and autonomous technologies used in loitering munitions?

Whilst it is difficult to determine the exact technical capabilities of many systems from the information available in the public domain, some loitering munitions are understood to qualify as weapons that "detect targets and apply force to them based on sensor inputs".[146] Analysts have described these systems as a "bridge between today's precision-guided weapons that rely on greater levels of human control and our future of autonomous weapons with increasingly little human intervention".[147] Many loitering munitions can be launched without their operators knowing the specific location or time at which an attack will take place. The operator(s) of these systems designate a geographical area over which the platform flies. Through this interaction with the environment, the platform's onboard sensors (including, in some cases, electro-optical and infrared cameras and/or radio frequency seekers) search for objects which match predesignated target profiles (e.g. those of tanks, armoured vehicles, radar systems).

> **Many loitering munitions can be launched without their operators knowing the specific location or time at which an attack will take place**

Automated and autonomous technologies can be used in loitering munitions to support targeting functions, for instance the identification, detection, and categorisation of objects (tanks, airplanes, missiles, radars). In this way, it is possible for these systems to "operate with a high degree of autonomy".[148] Some loitering munitions designed to conduct SEAD operations, once activated, appear to be capable of identifying, selecting, and striking objects which meet pre-programed target profiles without further human assessment.[149]

Obfuscating the classification of all loitering munitions as AWS, many other types of systems are carefully advertised as being designed to be operated under various forms of human supervision. The electro-optical and infrared camera(s) installed onto many loitering munitions are presented as enabling the remote supervision of their operation, including human assessment and authorisation before a strike. This means that, in principle, the operators of these systems assess specific targeting decisions before authorising attacks against objects identified by the system. Furthermore, as discussed in more detail in the fourth section of this report, many loitering munitions are advertised as being installed with an "abort/wave-off" capability. This enables the operators of these platforms to abort strikes if battlefield conditions change between the time when a potential target is detected and when a strike is authorised (e.g. a non-combatant enters the combat zone).[150]

Automated and autonomous technologies can also be integrated into loitering munitions to support mobility functions. These capabilities can include: (1) waypoint navigation;[151] (2) homing;[152] and (3) autonomous navigation.[153] WB Group's Warmate 'family' of loitering munitions, for example, is advertised as being installed with a "wide range of autonomous flight modes" including an "auto mode" in which the platform follows a route specified by the human

146 Kayser, "Increasing Autonomy in Weapons Systems," 1.

147 Atherton, "Loitering munitions preview the autonomous future of warfare".

148 Peter Burt, "Loitering munitions, the Ukraine war, and the drift towards 'killer robots'," Drone Wars UK, 8 June 2022, https://dronewars.net/2022/06/08/loitering-munitions-the-ukraine-war-and-the-drift-towards-killer-robots/

149 Boulanin and Verbruggen, 'Mapping the Development of Autonomy in Weapons Systems,' 53.

150 Gettinger and Michel, "Loitering Munitions in Focus," 4.

151 Army Technology, "Coyote Unmanned Aircraft System (UAS)," August 1 2018, https://www.army-technology.com/projects/coyote-unmanned-aircraft-system-uas/; Greg Waldron, 'KAI developing suicide combat UAV,' Flight Global, September 28 2012, https://www.flightglobal.com/kai-developing-suicide-combat-uav/107220.article; MBDA, "MBDA readies Fire Shadow on back of programme successes," MBDA, September 15 2011, https://www.mbda-systems.com/press-releases/2971/; Rafael, "Spikefire Fly: Miniature Tactical Loitering Weapon".

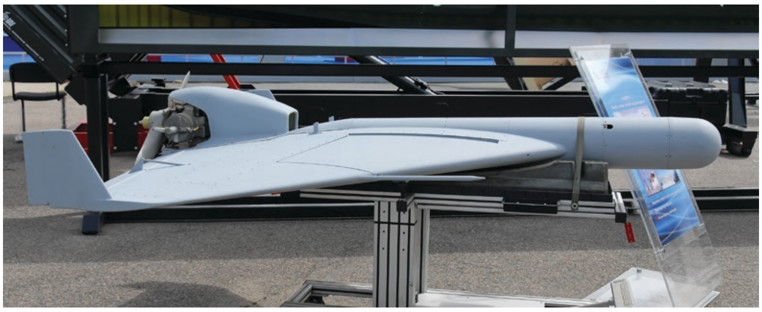
152 Hambling, "Israel Is Already Selling Kamikaze Micro-Drones".

153 IAI, "Harpy Loitering Munition System," IAI, https://www.iai.co.il/p/harpy; IAI, "Harop Loitering Munition System," https://www.iai.co.il/p/harop.; IAI, "Rotem: Loitering Munition based on a Light Multi-Rotor Platform,"

operator; a "loiter flight mode" in which the platform navigates itself around a designated area; a "cruise mode" in which the platform flies "in a straight line in the direction that the camera is facing"; and a "search mode" which "is use[d] for slow diving flight necessary for proper target selection".[154] During a July 2020 interview with *The Drive*, AeroVironment's chief marketing officer Steve Gitlin provided further insight into how automated and autonomous technologies can be used to support mobility functions in loitering munitions:

> *Similar to the way our tactical unmanned aircraft systems operate, unlike radio-controlled devices, the operator is not flying the aircraft, the operator's simply indicating what he wants to look at, what he wants the camera to be pointing at, and the onboard computer flies the aircraft to that point and maintains on target. We have a similar capability in our tactical unmanned aircraft systems. You could lock in on a target and the aircraft will basically maintain position on that target, autonomous.*[155]

We can move toward a clearer understanding of how automated and autonomous technologies can be part of operating loitering munitions through a brief discussion of the IAI Harpy and Harop – two of the oldest and most widely discussed loitering munitions. Whilst it is not possible to verify whether and when these systems are operated in autonomous or manual modes, our discussion of the Harpy and Harop helps contextualise some of the major recent trends in loitering munition development practices.



Harpy. **Source:** Jastrow via Wikimedia Commons

Considered by some to be the "first loitering munition",[156] the IAI Harpy was developed by the Israeli military during the 1980s and 1990s to counter the proliferation of increasingly sophisticated air defence systems. Variants of the Harpy have been sold to China,[157] India,[158] South Korea,[159] and Turkey.[160] Chile is also suspected to have purchased this system.[161] IAI advertise the Harpy, which is installed with an advanced radio-frequency seeker, as having a communication range of 200km and an operational endurance of nine hours.[162] Once launched, the Harpy navigates toward an operator designated "loitering area" through the use of preprogramed flight routes or GPS coordinates.[163] The platform then searches for radar signatures which match prespecified frequency bands.[164] In this way, "[t]he human launching the Harpy decides to destroy any enemy radars within a general area in space and time, but the Harpy itself chooses the specific radar it targets".[165] If a match is found, the Harpy can home-in-on and destroy the emitting signal without the operator's direct supervision. If the emitting radar signature is shut down or lost, then the Harpy's strike can be automatically aborted, and the platform will

154 WB Group, 'Warmate: Loitering Munition System,' 6.
155 Rogoway, "We Talk Suicide Drones and the Future of Unmanned Warfare with AeroVironment's Steve Gitlin".
156 Charlie Gao, "The Ultimate Weapon of War No One Is Talking About," The National Interest, January 25 2019, https://nationalinterest.org/blog/buzz/ultimate-weapon-war-no-one-talking-about-42497
157 Flight International, "IAI sells Harpy drones to China," 5 November 2002, Flight Global, https://www.flightglobal.com/iai-sells-harpy-drones-to-china/45569.article
158 Charlie Gao, "The Ultimate Weapon of War No One Is Talking About," National Interest, January 25, 2019, https://nationalinterest.org/blog/buzz/ultimate-weapon-war-no-one-talking-about-42497
159 Alvite Singh Ningthoujam, "Israel-South Korea Relations: The Military Dimension." *Contemporary Review of the Middle East* 4, no. 2 (2017): 168-192, 177.
160 Gao, "The Ultimate Weapon of War No One Is Talking About".
161 Scharre, *Army of None*, 47.
162 IAI, "Harpy Loitering Munition System".
163 Boulanin and Verbruggen, 'Mapping the Development of Autonomy in Weapons Systems,' 54; Stefano D'urso, "Let's Talk About the Israel Air Industries Loitering Munitions and What They're Capable Of," The Aviationist, January 2019, https://theaviationist.com/2022/01/07/iai-loitering-munitions/
164 D'urso, "Let's Talk About the Israel Air Industries Loitering Munitions and What They're Capable Of".
165 Scharre, *Army of None*, 48.

re-enter its "loiter pattern".[166] Since its first development, the Harpy has undergone multiple design upgrades including the development of a datalink to facilitate remote target designation sometime during the early 2000s.[167]

Harop. **Source:** Julian Herzog via Wikimedia Commons

IAI began developing the Harop during the late 1990s,[168] and the platform was first unveiled at the Aero-India 2009 Air show.[169] Similar to the Harpy, the Harop is advertised as being designed for "[a]utonomous platform operation"[170] and it can be fielded to conduct SEAD operations, amongst other missions. Unlike the Harpy however, the Harop is installed with an electro-optical/infrared sensor.[171] IAI describes the Harop as an "electro-optically guided attack weapon" designed to operate with a "[human]-in-the-loop".[172] This enables the Harop's operator to guide the platform using its two-way data-link, monitor its flight path, and authorise strikes against specified targets.[173] The Harop is thus described as being "manually targeted through an electro-optical sensor".[174] Used in this capacity, the operator can reportedly "direct the selected Harop to the target area and use the video feed to select a target and to initiate the attack".[175] This mode of operation is advertised as being used to strike "time-critical, high-value, relocatable targets".[176] According to IAI:

> *The HAROP LMs [loitering munition] are programmed before launch by the GCS [Ground Control Station] to autonomously fly to a pre-defined "Holding Area", where they loiter…[t]he operator directs the selected [loitering munition] to the target area and uses the video image to select a target, and to attack it. The HAROP tracks the target and then dives on it, detonating the warhead upon impact. If required, the attack can be aborted and the operator can re-attack with the same [loitering munition].*[177]

This description suggests that the operators of more recently developed loitering munitions like the Harop which are installed with electro-optical/infrared cameras can exercise control at multiple stages of the targeting process. First, they designate the *geographical area* around which the platform loiters through selecting both the location of the system's launch and/or the designation of a loitering area. Second, operators can intervene to alter the platform's flight path during its flight toward (and within) its designated "holding area" to move the platform to a different area of operation. Third, prior to the authorisation of an attack, the Harop's operator visually inspects the target and reaches an assessment of the appropriateness of using force. And fourth, if the situation on the ground changes, the human operator can in principle "wave-off" and abort an attack.

166 D'urso, "Let's Talk About the Israel Air Industries Loitering Munitions and What They're Capable Of"; IAI, 'Harpy Loitering Munition System', IAI, https://www.iai.co.il/p/harpy

167 Flight Global, "IAI develops Harpy with datalink add-on," 11 December 2000, Flight International, https://www.flightglobal.com/iai-develops-harpy-with-datalink-add-on/35309.article

168 Tyler Rogoway, "Meet Israel's 'Suicide Squad' of Self-Sacrificing Drones," The Warzone, 29 September 2021, https://www.thedrive.com/the-war-zone/4760/meet-israels-suicide-squad-of-self-sacrificing-drones

169 Defence Update, "Israel Unveils "Harop" Loitering Anti-Missile Drone," 10 January 2009, https://defense-update.com/20090110_harop.html

170 IAI, "Harop: Multi-mission Long Range Loitering Munition System," October 2022, https://www.iai.co.il/sites/default/files/2022-10/HAROP%20Brochure.pdf

171 D'urso, "Let's Talk About the Israel Air Industries Loitering Munitions and What They're Capable Of"; IAI, "Harop Loitering Munition System".

172 IAI, "Harop Loitering Munition System".

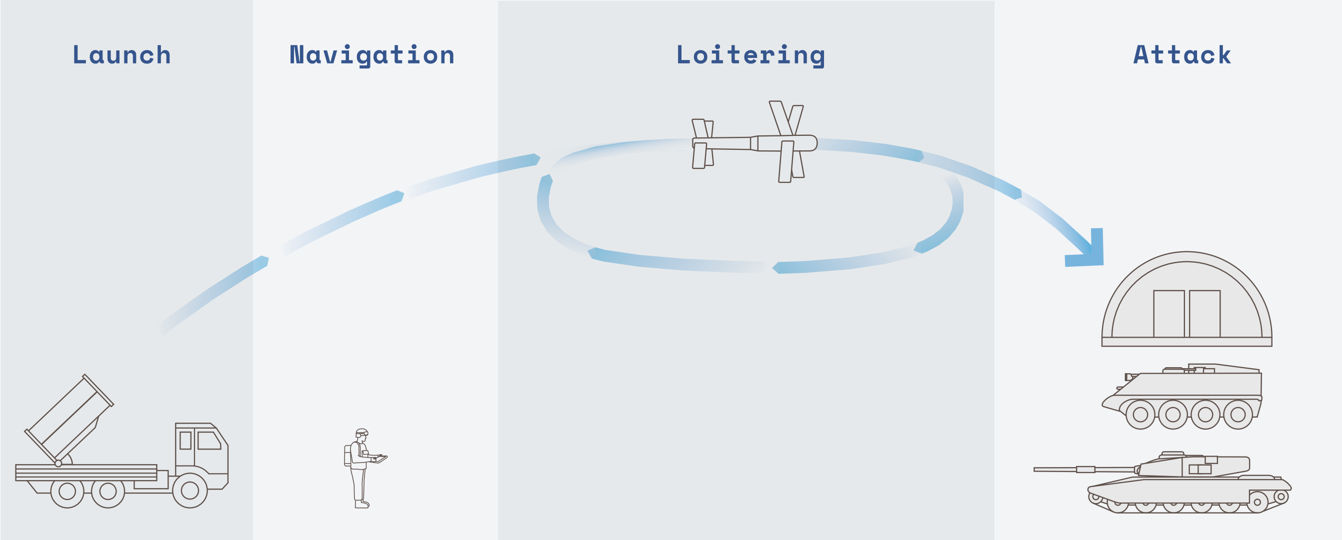
173 D'urso, "Let's Talk About the Israel Air Industries Loitering Munitions and What They're Capable Of".

174 Joël Postma, "Drones over Nagorno-Karabakh." *Atlantisch Perspectief* 45, no. 2 (2021): 15-20: 16.

175 Stefano D'urso, "Let's Talk About the Israel Air Industries Loitering Munitions and What They're Capable Of".

176 IAI, "Harop: Multi-mission Long Range Loitering Munition System," October 2022, https://www.iai.co.il/sites/default/files/2022-10/HAROP%20Brochure.pdf

177 IAI, "Harop Loitering Munition System".



3.3 What does the use of automated and autonomous technologies in loitering munitions mean for human control over targeting decisions?

The global proliferation and use of weapons integrating automated, autonomous and, potentially, AI technologies has generated concerns about the quality and character of human control over targeting decisions. These concerns are not specifically connected to the global development, testing, and fielding of existing weapon systems such as loitering munitions, and instead originate in the wider debate on AWS. These concerns can be grouped into five categories which run across both the situational and the decision-making dimensions of human control: (1) unpredictability, (2) unpredictability in populated areas, (3) loss of moral agency, (4) potential for wide area effects, and (5) cognitive overload.

The use of loitering munitions can make the spatial and temporal dimensions of specific targeting decisions more unpredictable

Unpredictability: The use of loitering munitions can make the spatial and temporal dimensions of specific targeting decisions more unpredictable. As discussed above, loitering munitions are not always fired at a specified and known target. Rather, such systems appear to be designed to loiter over the battlefield, within a potentially broad geographical area, to search for prespecified target profiles. For some analysts, this capability is an important part of these systems' potentially transformative impact on contemporary warfare.[178] At the same time however, it can create "uncertainty regarding specifically when and where force will occur", particularly in areas with high numbers of civilians present.[179] Moreover, it may loosen the distance and link between human intention and consequences.[180] The ambiguity concerning precisely when and where force will be used has direct consequences for the ability of humans to exercise control along the decision-making dimension of human control. As noted in one Article 36 report:

> *Our ability to understand the context is directly linked to both the size of the area within which the technology will operate, and the duration over which it will operate. For any given environment, it follows logically that greater area and longer duration of independent operation by a technology result in reduced predictability and so reduced human control.*[181]

178 Williams, "Killing Sanctuary: The Coming Era of Small, Smart, Pervasive Lethality."
179 Kayser, "Increasing Autonomy in Weapons Systems," 2.
180 Boulanin, Davison, Goussac and Carlsson, "Limits on Autonomy in Weapon Systems," 12.
181 Article 36, "Key Elements of Meaningful Human Control," 4.

Unpredictability in populated, urban areas: Loitering munitions such as the Rafael Spike Firefly and the IAI Rotem L are designed for use in urban areas.[182] Weapon manufacturers claim that loitering munitions can be "highly efficient in urban territories" with "precision, pinpoint strikes reduc[ing] casualties of civilians to a minimum".[183] What such claims overlook, however, is the increased levels of unpredictability which the use of these technologies in populated, urban areas could generate. The urban environment is complex. It is an unstructured and dynamic environment that may be only partially observable via sensors and may be difficult to comprehend.[184] These characteristics make populated areas harder to model.[185] Deploying a system integrating autonomous or even AI technologies in this kind of complex environment increases the likelihood of that system "encounter[ing] inputs for which it was not specifically trained or tested".[186] As Roff and Moyes argue: "[a] less predictable, reliable and transparent weapon technology, operating in a more complex environment, over a wider area and for a longer period of time will likely reduce a human commander's ability to meaningfully predict outcomes".[187] This is significant because the commander's ability to predict outcomes as accurately as possible when choosing to use a weapon system is key for making "context-dependent and time-bound" assessments about necessity, proportionality and distinction regarding specific targeting decisions, and consequently for compliance with international humanitarian law.[188] The risk of weapon systems integrating autonomous or AI technologies potentially "diminish[ing] a military commander's ability to foresee the consequences of the use of force in an attack" has been raised by many states parties at the CCW.[189]

Loss of moral agency: Despite integrating automated and autonomous technologies to support mobility and targeting functions, as noted above, most loitering munitions are currently designed to operate with a human "in" or "on the loop". The operators of these systems appear to be required to assess targets and authorise potential strikes. It is not inconceivable that technological and/or political changes could lead to the loosening (if not outright abandonment) of this requirement, however. Given the challenges researchers face in verifying how loitering munitions with autonomous functions are operated in battlefield contexts,[190] it would be difficult to know whether this threshold has been crossed. AeroVironment officials, for example, have remarked that "[t]he technology to achieve a fully autonomous mission with Switchblade pretty much exists today".[191] The ongoing war in Ukraine, it has been suggested, could provide the impetus for the software changes required for existing systems to, once activated, identify, track, and strike targets with limited human supervision.[192]

The possible use of loitering munitions to "autonomously" attack human beings without operator approval would constitute a moral hazard resulting from a loss of moral agency. As Kelsey Atherton suggests, whilst older generations of loitering munitions such as the IAI Harpy have the technical capacity to attack clearly specified military targets such as radar systems without direct supervision, "[w]hen a flying

182 IAI, "ROTEM LTM Assault Vertical Take-off & Landing (VTOL) Loitering Munition," 2019, https://www.iai.co.il/sites/default/files/2019-05/ROTEM%20Brochure.pdf; Rafael, "Spike FireflyTM Miniature Tactical Loitering Munition," 2019, https://www.rafael.co.il/wp-content/uploads/2019/03/FIREFLY.pdf;

183 Hambling, "Israel Is Already Selling Kamikaze Micro-Drones That Will Change Modern Warfare".

184 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 13.

185 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 13.

186 Michel, "The Black Box, Unlocked," 7.

187 Roff and Moyes, "Meaningful Human Control," 4.

188 Boulanin, Davison, Goussac and Carlsson, "Limits on Autonomy in Weapon Systems," 6.

189 Boulanin, Brockmann and Richards, "Responsible Artificial Intelligence Research", 3.

190 Zachary Kallenborn, "If a Killer Robot Were Used, Would We Know?" Bulletin of the Atomic Scientists, June 4, 2021, https://thebulletin.org/2021/06/if-a-killer-robot-were-used-would-we-know/.

191 Frank Bajak and Hanna Arhirova, "Drone advances in Ukraine could bring dawn of killer robots," AP News, January 3, 2023, https://apnews.com/article/russia-ukraine-war-drone-advances-6591dc69a4bf2081dcdd265e1c986203

192 Bajak and Arhirova, "Drone advances in Ukraine could bring dawn of killer robots,"; Morgan Meaker, "Ukraine's War Brings Autonomous Weapons to the Front Lines," Wired, February 24, 2023 https://www.wired.co.uk/article/ukraine-war-autonomous-weapons-frontlines

robot instead uses these tools to hunt people, it becomes a profound question of responsibility and the laws of war".[193] A human can engage in flexible, adaptable, and embedded decision-making regarding specific targeting decisions, including the exercise of mercy and restraint.[194] This does not mean that all humans in war engage in this kind of decision-making, but there is always the prospect that they do. This option is removed with an AWS, which "applies force when the data received as input from its sensors matches the parameters of the target profile".[195] Whilst beyond the scope of our analysis to fully explore, this process could also have legal ramifications including for the obligation to provide context specific judgements regarding the use of force.[196]

Although loitering munitions are often described as precise weapons by militaries and weapon manufacturers, a wide range of machine-recognisable objects could become potential targets, if programmed into the system's target profile

Potential wide area effects: Although loitering munitions are often described as precise weapons by militaries and weapon manufacturers, a wide range of machine-recognisable objects could become potential targets, if programmed into the system's target profile. This scenario resembles the wide area effects associated with other explosive weapons and can therefore be identified as problematic. In the case of loitering munitions, the problem relates to uncertainties about where precisely attacks will happen, as such platforms "may land anywhere within a wide area".[197] Proponents of loitering munitions could argue that the platforms' loiter capabilities may "enable increased capacity to discriminate between combatants and non-combatants compared to equivalent weapons such as mortars, rockets, and small missiles".[198] Yet, compared to these other types of weapon systems, loitering munitions (as with AWS more broadly) introduce "more generalized decision-making in targeting" along with an uncertainty about the precise geographic location of a strike.

Cognitive overload: The possibility of delegating labour-intensive tasks has long been a major push-factor for integrating further automated and autonomous technologies into weapon systems. In theory, automated and autonomous technologies could "relieve" operators from menial/repetitive actions, allowing them to concentrate on a smaller range of key tasks involved in targeting. Yet, the perspective that integrating autonomous technologies facilitates tasks conducted by human operators has been criticised as a typical "myth" of developing autonomous systems.[199] Oftentimes, automated and autonomous technologies can make the task of human operators simultaneously minimal and more complex because it requires operators to have a functional understanding of both the anticipated outcomes of using systems integrated with autonomous functions and what the operational limits of these systems may be.[200] The potential development of loitering munition "swarms" raises additional issues as a single human operator may be tasked with overseeing a group of these systems to exploit the perceived battlefield advantages presented by these technologies. WB Group, for example, claim that a single operator can "effectively control" up to ten Warmate platforms "simultaneously for coordinated attacks".[201] But this can quickly position a human operator in a situation of cognitive overload, especially with time as an exacerbating factor. Humans could be expected to operate systems at machine speed, allowing them only a brief (or no) window to review a time-sensitive target.[202] This has a significant impact on the critical mental space which the operators of such systems have to contextualise and deliberate on target prompts.[203]

193 Atherton, 'Loitering munitions preview the autonomous future of warfare'.
194 Boulanin, Davison, Goussac and Carlsson. "Limits on Autonomy in Weapon Systems," 13.
195 Boulanin, Davison, Goussac and Carlsson. "Limits on Autonomy in Weapon Systems," 13.
196 The authors are grateful for Neil Davidson for drawing our attention to this issue.
197 PAX and Article 36, "Explosive Weapons - Factors That Produce Wide Area Effects," 1.
198 Gettinger and Michel, 'Loitering Munitions in Focus', 3.
199 Jeffrey M. Bradshaw et al., "The Seven Deadly Myths of 'Autonomous Systems,'" *IEEE Intelligent Systems* 28, no. 3 (2013): 58.
200 Bode and Watts, "Meaning-Less Human Control: Lessons from Air Defence Systems for Lethal Autonomous Weapons".
201 Defence Turkey, "WB Group: 'We Are Ready to Cooperate with Turkish Companies for 3rd Markets with Turkish Systems!'", February 19 2022, https://www.defenceturkey.com/en/content/wb-group-we-are-ready-to-cooperate-with-turkish-companies-for-3rd-markets-with-turkish-systems-4980
202 Michel, "The Black Box, Unlocked," 17.
203 Ingvild Bode and Tom Watts, "Meaning-Less Human Control. The Consequences of Automation and Autonomy in Air Defence Systems" (Oxford and Odense: Drone Wars UK & Center for War Studies, February 2021).

4 Our catalogue of automated and autonomous technologies in loitering munitions

This section of the report introduces our catalogue of how automated and autonomous technologies have been integrated into loitering munitions and summarises some of its major findings for the debates on AWS. We begin by introducing five hardware components common to the 24 loitering munitions included in our catalogue: (1) launch systems; (2) Global Navigation Satellite Systems (GNSS); (3) ground control stations; (4) sensors; and (5) warheads. This discussion provides further insight into how these components are controlled and operated and should help the reader navigate the structure of this report's accompanying catalogue. The contribution made by our qualitative catalogue to the debates on the integration of automated and autonomous technologies into the targeting systems of loitering munitions is then introduced. This includes a discussion of the methodology used to generate our catalogue entries, as well as a reflection on the various challenges involved with working with open-source data in this area. The third and final part of this section summarises some of the major trends in the global development and proliferation of loitering munitions.

4.1 Loitering munition hardware components

As introduced in section 3, loitering munitions are an expendable type of uncrewed aircraft integrating sensor-based analysis to hover over, detect, and crash into targets. These weapon systems can perform different military functions. Larger types of loitering munitions can weigh over 100kg and are designed to conduct SEAD operations. As previously discussed, Israeli companies began developing this category of loitering munition during the 1980s. The miniaturisation of key system subcomponents has reduced the size and weight of these weapons. Announced in February 2019 for example, the Mini Harpy is described by IAI officials as being designed to attack "fast-moving targets that 'blink' for a few seconds at a time".[204] Equipped with both a radio-frequency seeker and electro-optical/infrared camera(s), the Mini Harpy has an advertised weight of 40kg[205] – which is significantly less than the original Harpy variant which weighs a reported 130kg.[206]

204 Yaakov Lappin, "IAI announces new Mini Harpy loitering munition", Janes, 19 February 2019, https://www.janes.com/defence-news/news-detail/iai-announces-new-mini-harpy-loitering-munition

205 IAI, "Mini HARPY: Multi-Purpose Tactical Loitering Munition", IAI, https://www.iai.co.il/p/mini-harpy

206 Peter Felstead, "What are Loitering Aerial Munitions?", Key Aero, 8 January 2023, https://www.key.aero/article/what-are-loitering-aerial-munitions

Given impetus by the counterinsurgency campaigns fought in Iraq and Afghanistan, the focus of much loitering munition development since the early 2010s has shifted toward the design of smaller systems used to support infantry and special operation forces.[207] Many of these newer generation of loitering munitions can be carried by soldiers in the field. This portability is understood to increase the tactical value of these platforms. As US Marine Corps Commandant General David H. Berger describes it, loitering munitions can provide frontline ground forces a tool for "strik[ing] targets beyond the range of their organic mortars [and] artillery with precision".[208] Newer loitering munitions, which often weigh around 10kg, are designed to find and locate a range of objects including armoured vehicles, light-skinned vehicles such as trucks, mortar and artillery positions, and tanks. Some platforms, including the Zala Aero Lancet-3, can also be designed to attack warships, extending the use of these weapons into the maritime domain.[209]

Many of these newer generation of loitering munitions can be carried by soldiers in the field

Hero-400 staged at a training exercise. **Source:** U.S. Marine Corps

Despite these differences, the 24 loitering munitions included in our catalogue generally share five common hardware components: (1) a launch system; (2) a GNSS; (3) a ground control station; (4) a sensor payload; and (5) a warhead. To help the reader navigate this report's accompanying catalogue, these hardware features are introduced below.

Launch system: Loitering munitions can be launched either horizontally or vertically. Most horizontally launched loitering munitions achieve the acceleration needed for flight in one of two ways: a rail-mounted catapult system, the portability of which varies based on the size and weight of its accompanying loitering munition; and a pneumatic launch canister, for use with smaller loitering munitions which have been designed with a tandem wing configuration in which the platform's wings can be folded into its fuselage.[210] Both launch methods involve trade-offs.[211] Rail-mounted catapult systems are often (but not always)

207 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 53.

208 Dan Gettinger, "Phoenix Ghosts are part drones, part missiles. How does that change combat?," Bulletin of the Atomic Scientists, 1 June 2022, https://thebulletin.org/2022/06/phoenix-ghosts-are-part-drones-part-missiles-how-does-that-change-combat/

209 Naval News, "Russian loitering munition Lancet hits Ukrainian Gyurza M class gunboat for first time," Navy Recognition, 4 November 2022, https://www.navyrecognition.com/index.php/naval-news/naval-news-archive/2022/november/12438-russian-loitering-munition-lancet-hits-ukrainian-gyurza-m-class-gunboat-for-first-time.html

210 Pilch, Altmann and Suter, "Survey of the Status of Small Armed," 17. Whilst not discussed here, some classes of loitering munitions with conventional and cruciform wing configurations can also be launched from canisters. We are grateful to Dan Gettinger for this observation.

211 Other loitering munitions included in our catalogue such as the China Aerospace Science and Technology Corporation's WS-43 can be launched via a multiple launch rocket system. China Military Drone Alliance, "WS-43 Loitering Munition System," China Military Drone Alliance, https://www.militarydrones.org.cn/ws-43-loitering-munition-system-p00202p1.html. The Drone40 system included in our catalogue can launched from a 40mm grenade launcher. Voskuijl. 'Performance analysis and design of loitering munitions,' 328.

vehicle mounted and enable the launch of heavier types of loitering munitions, the aeronautical design of which is not restricted to a tandem wing configuration.[212] The self-contained and generally smaller size of canister launch systems, in contrast, enables groups of these launchers to be installed onto ground vehicles, warships and, in some cases, the wings of crewed and uncrewed aircraft.[213] Vertically launched loitering munitions such as the Rafael Spike Firefly and the IAI Rotem do not require specialised launch equipment. They can generate the lift needed for flight through the use of propellers installed onto the platform's fuselage.[214] The manufacturers of such Vertical Take Off and Landing (VTOL) loitering munitions advertise these weapons as having been designed for the "unique mission profile of urban combat".[215] The lower payload carrying capacity and speed of vertically launched loitering munitions is offset by the capability these systems have to hover in place and navigate around obstacles in urban areas.[216]

Loitering munition launch system. **Source:** Kenchen945 via Wikimedia Commons

Global Navigation Satellite System: Loitering munitions are often fitted with a GNSS, perhaps the most well-known of which is the Global Positioning System (GPS).[217] These technologies, which are vulnerable to enemy jamming and spoofing,[218] are installed to "determine the aircraft's position and to navigate between waypoints" through transmitting signals to orbiting satellites.[219] They can also enable the entry of coordinates for use when attacking stationary targets at fixed locations,[220] providing a capability similar to that of a cruise missile. In the case of the Switchblade 300, AeroVironment advertise the platform as being designed to provide its operator "[c]ursor-on-Target GPS coordinates for information gathering, targeting, or feature/object recognition".[221] Some loitering munitions such as the Aeronautics Orbiter 1K are advertised as being "[f]ully

212 Voskuijl. "Performance analysis and design of loitering munitions," 327-328.
213 Voskuijl. "Performance analysis and design of loitering munitions," 328.
214 Voskuijl. "Performance analysis and design of loitering munitions," 328.
215 Rafael, "Spikefire Fly: Miniature Tactical Loitering Weapon," Rafael, https://www.rafael.co.il/wp-content/uploads/2019/03/FIREFLY.pdf
216 Pilch, Altmann and Suter, "Survey of the Status of Small Armed," 19; Voskuijl, "Performance analysis and design of loitering munitions," 4.
217 Other major GNSS systems include China's BeiDou navigation satellite system, the European Union's Galileo system, and Russia's global navigation satellite system. Pilch, Altmann and Suter, "Survey of the Status of Small Armed," 23.
218 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 23; Pilch, Altmann and Suter, "Survey of the Status of Small Armed," 23.
219 Pilch, Altmann and Suter, "Survey of the Status of Small Armed," 23.
220 Army Technology, "Coyote Unmanned Aircraft System (UAS)," August 1 2018, https://www.army-technology.com/projects/coyote-unmanned-aircraft-system-uas/; P.C. Katoch, "Turkey's Swarm Drones," SP's Aviation, July 20 2020, https://www.sps-aviation.com/experts-speak/?id=471&h=Turkeys-Swarm-Drones
221 AeroVironment, "Switchblade 300 Loitering Missile," AeroVironment, Inc., https://www.avinc.com/images/uploads/product_docs/Switchblade_300_Datasheet_220114.pdf

operational in GPS denied areas".[222] This can be achieved through the manual piloting of the system via the use of electro-optical sensor(s).[223] Automated and autonomous technologies can also be used to support the operation of loitering munitions (and other weapon systems) in GPS-denied areas. As explained by AeroVironment's President and CEO Wahid Nawabi: "[g]reater levels of autonomy, delivered through these advanced technologies, will minimize the ability of electronic countermeasures to affect our loitering missile systems, while also expanding mission capabilities".[224]

Ground control station: Loitering munitions are equipped with ground control stations (also referred to as a "control unit"[225] and a "fire control unit",[226] amongst other names). These ground control stations generally take the form of "ruggedized laptops or tablets", but can also be integrated into consoles installed within aircraft, ground vehicles, and warships.[227] They relay information to the system's operator including the loitering munition's altitude, location, airspeed, and sensor feed.[228] The control station functions as the "human-machine interface allowing communication with the [loitering munition] as well as its control".[229] These stations can be installed with command functions which enable the human operator to "plan missions",[230] assume manual control of flight, and enter coordinates for way-point navigation.[231] In a process which one Elbit Systems official describes as "really just dragging and dropping an icon on the screen",[232] the ground control station also provides the conduit through which the human operator can select and visually inspect targets before a strike. In the case of tactical loitering munitions such as the STM Kargu-2 and the AeroVironment Switchblade, this capability is enabled through the use of a line-of-sight control link which connects the ground control station to the platform.[233]

Sensors: Loitering munitions are equipped with sensors to support navigation and targeting functions. Advancements in sensor technologies since the first development of loitering munitions have widened the range of detectable target profiles as well as improved the quality of the information which can be collected.[234] Loitering munitions are generally installed with two types of sensors: an electro-optical camera which provides colour and greyscale video footage; and an infrared camera for use in low-light conditions and for detecting heat signatures.[235] Anti-radiation loitering munitions are installed with radio-frequency seekers in addition to, or in place of, electro-optical and infrared

Loitering munitions are equipped with sensors to support navigation and targeting functions

222 Aeronautics, "Orbiter® 1K Loitering Munition UAS," Aeronautics, https://aeronautics-sys.com/wp-content/themes/aeronautics/pdf/Orbiter_1K_Brochure_EN_web1.pdf

223 David Hambling, "AeroVironment Aims to Disrupt Industry with New Loitering Missile," 1 October 2020, Forbes, https://www.forbes.com/sites/davidhambling/2020/10/01/new-loitering-missile-aims-to-destroy-targets-and-disrupt-industry/?sh=47e76a71390f

224 Hambling, "AeroVironment Aims to Disrupt Industry with New Loitering Missile".

225 Rafael, "Spikefire Fly: Miniature Tactical Loitering Weapon".

226 AeroVironment, "Switchblade 300 Loitering Missile".

227 Pilch, Altmann and Suter, "Survey of the Status of Small Armed," 24.

228 Pilch, Altmann and Suter, "Survey of the Status of Small Armed," 24.

229 Pilch, Altmann and Suter, "Survey of the Status of Small Armed," 24.

230 AeroVironment, "AeroVironment Introduces Family of Loitering Missile Systems Featuring New Switchblade 600, Delivering Precision Strike Capabilities at the Battlefield's Edge," AeroVironment, Inc., October 1, 2020, https://www.avinc.com/resources/press-releases/view/aerovironment-introduces-family-of-loitering-missile-systems-featuring-new

231 Pilch, Altmann and Suter, "Survey of the Status of Small Armed," 24.

232 Sebastian Sprenger, "Elbit Systems pitches SkyStriker drone in emerging market of loitering munitions," Defence News, June 21, 2017, https://www.defensenews.com/digital-show-dailies/paris-air-show/2017/06/21/elbit-systems-pitches-skystriker-drone-in-emerging-market-of-loitering-munitions/

233 Stew Magnuson, "Loitering Munitions Proliferate as Tech Changes Battlefield," 8 September 2022, National Defence, https://www.nationaldefensemagazine.org/articles/2022/8/9/loitering-munitions-proliferate-as-tech-changes-battlefield; Joseph Trevithick, "Turkey Now Has Swarming Suicide Drones It Could Export," The Drive, 18 June 2020, https://www.thedrive.com/the-war-zone/34204/turkey-now-has-a-swarming-quadcopter-suicide-drone-that-it-could-export

234 Magnuson, "Loitering Munitions Proliferate as Tech Changes Battlefield".

235 Pilch, Altmann and Suter, "Survey of the Status of Small Armed," 27-28.

cameras. Loitering munitions can also be fitted with laser designators and range finders.[236] Given these capabilities, many loitering munitions are advertised as being dual purpose weapons, being designed to conduct both strike and reconnaissance operations. In the case of the Rafael manufactured Spike Fire for example, the system's warhead can be replaced by an additional battery to double its loiter and reconnaissance time from fifteen to thirty minutes.[237] Some loitering munitions can also relay targeting information back to human operators,[238] in addition to receiving targeting information from other systems.[239]

Fragmentation warhead used on a crashed Russian KUB.
Source: Ukraine Weapons Tracker

Warheads: Loitering munitions are installed with a warhead which detonates on impact with a target or, in the case of airburst weapons, directly above it. The type of warhead installed determines what category of target the loitering munition can be used to attack.[240] Loitering munitions can be installed with fragmentation warheads, designed to project "fragments" on impact to maximise the lethality of strikes against enemy soldiers; high-explosive warheads which can create destructive blast and fragmentation effects, particularly when used in populated areas;[241] or armour piercing warheads, designed for attacks against enemy tanks and armoured vehicles. Some systems, such as the STM Kargu-2 included in our catalogue,[242] can also reportedly be installed with thermobaric warheads, defined as a type of weapon which ignites a cloud of fuel explosive to create blast vacuum effects and is designed for use in enclosed spaces such as buildings.[243] Many loitering munitions are designed with modular features which enable different warhead types to be installed depending on the mission requirement. The WB Group Warmate, for example, can be installed with either a high explosive anti-personnel warhead or an anti-tank warhead to attack armoured vehicles.[244]

Many loitering munitions are designed with modular features which enable different warhead types to be installed depending on the mission requirement

4.2a Catalogue structure and case selection

Loitering munitions have proliferated globally since the first development of these weapons during the 1980s. Dan Gettinger estimates that the number of states producing these weapons more than doubled from 10 in 2017 to almost 24 by mid-2022.[245] Israel remains the most globally significant loitering munition developer. At the same time, a new generation of companies based in countries including Turkey and Poland have made significant inroads in the design and the export of these technologies. At least four of the permanent members of the United Nations (UN)

236 Pilch, Altmann and Suter, "Survey of the Status of Small Armed," 27-28.
237 Rafael, "Spikefire Fly: Miniature Tactical Loitering Weapon".
238 Magnuson, "Loitering Munitions Proliferate as Tech Changes Battlefield".
239 The ZALA Aero Group Lancet-3, for example, can reportedly receive targeting information from other reconnaissance platforms such as the Orlan-10 surveillance drone. Владимир Щербаков, "Российские крылатые камикадзе," January 12 2023, https://www.ng.ru/nvo/2023-01-12/1_1220_kamikaze.html ZALA Aero chief designer Alexander Zakharov has similarly claimed that the KUB, another loitering munition manufactured by the company, can be provided targeting information from the unified tactical level control system and the Sagittarius reconnaissance, control and target designation complex. Антон Лавров, "«Мы сделали ставку на нанесение массированных ударов»," December 10, 2021, https://iz.ru/1262096/anton-lavrov/my-sdelali-stavku-na-nanesenie-massirovannykh-udarov
240 Pilch, Altmann and Suter, "Survey of the Status of Small Armed," 29; Voskuijl, "Performance analysis and design of loitering munitions," 326.
241 Geneva International Centre for Humanitarian Demining, "Explosive Weapon Effects Overview Explosive Weapon," 2017, https://www.gichd.org/fileadmin/GICHD-resources/rec-documents/Explosive_weapon_effects_web.pdf
242 David Hambling, "Turkish Military To Receive 500 Swarming Kamikaze Drones", 17 June 2020, Forbes, https://www.forbes.com/sites/davidhambling/2020/06/17/turkish-military-to-receive-500-swarming-kamikaze-drones/?sh=71b5b25b251a; Trevithick, "Turkey Now Has Swarming Suicide Drones It Could Export".
243 BBC News, "What Is a Thermobaric or Vacuum Bomb?," BBC News, March 10, 2022, https://www.bbc.com/news/business-60571395.
244 WB Group, "Warmate: Loitering Munition System," WB Group, https://docs.tuyap.online/FDOCS/23351.pdf, 4.
245 Gettinger, "Phoenix Ghosts are part drones, part missiles".

Security Council have also developed loitering munitions: the US, the UK, Russia, and China.[246] States including Azerbaijan[247] and India[248] have also domestically manufactured loitering munitions under license from foreign defence companies, adding a further dimension to the global proliferation of these technologies.

Mirroring our earlier study of air defence systems,[249] our catalogue of automated and autonomous technologies in loitering munitions is structured to detail trends in the global design, testing, and fielding of these systems. This catalogue consequently has a narrower focus than some existing quantitative datasets which code the integration of autonomy and automation into a series of weapon systems including air defence systems, active protection systems, and guided munitions.[250] As part of this report, we have compiled the available open-source information on the use of automated and autonomous technologies to support targeting and mobility functions in a single (but globally significant) category of weapon: loitering munitions. Rather than quantifying and coding these findings, we have detailed them through the creation of a qualitative catalogue which presents this information to the reader. Through this contribution, we have aimed to extend the study of how the operation of existing weapon systems which use automated and autonomous technologies may have already impacted the character and substance of human control over specific targeting decisions.

Several existing studies provide information on the technical details of loitering munitions, for instance, the operational endurance, payload weight, and wingspan length of these systems. These include notable contributions from Dan Gettinger and Arthur Holland Michel,[251] Mathias Pilch, Jürgen Altmann, and Dieter Suter,[252] Mark Voskuijl,[253] and a forthcoming report by Dan Gettinger on "one-way attack drones".[254] Some information on the performance characteristics of loitering munitions is included in our catalogue for reference purposes. As noted above however, our principal focus is on detailing the use of autonomy and automation to support targeting and mobility functions.

The structure of our catalogue is closer to Daan Kayser's 2021 PAX report which examines the integration of autonomous technologies into 10 weapon systems, including uncrewed aerial, ground, and naval systems.[255] Four of the ten systems

246 American, British, Chinese, and Russian practices of loitering munition are examined throughout this report and its accompanying catalogue. At time of writing in early 2023, France, the other permanent member of the United Nations Security Council, is reportedly considering purchasing the Switchblade 300 loitering munition from the American defence manufacturer AeroVironment. Vivienne Machi, "France requests Switchblade loitering munition to fill 'urgent' capability gap", Defence News, June 22 2022, https://www.defensenews.com/unmanned/2022/06/22/france-requests-switchblade-loitering-munition-to-fill-urgent-capability-gap/

247 In 2009, the Israeli defence company Aeronautics formed a joint venture with the Azerbaijani based company Azad Systems. This agreement allowed Aeronautics designed uncrewed systems to be manufactured within Azerbaijan. In 2016, this licensing agreement was expanded to include the production of the Orbiter 1K loitering munition. Ayaz Rzayev, "Assessing Azerbaijan's indigenous defense industry capabilities", The Defence Post, 7 May 2018, https://www.thedefensepost.com/2018/05/07/azerbaijan-defense-industry-indigenous-opinion/

248 In a joint venture with the Israeli defence company Elbit Systems, the Bangalore based company Alpha Design Technologies Private Limited has been reportedly manufacturing the SkyStriker loitering munition since 2021. Chethan Kumar, "Army to get 100+ 'sky strikers' for Balakot-type missions from Bengaluru," 3 September 2021, The Times of India, https://timesofindia.indiatimes.com/india/army-to-get-100-sky-strikers-for-balakot-type-missions-from-bengaluru/articleshow/85879001.cms

249 Tom Watts and Ingvild Bode, "Automation and Autonomy in Air Defence Systems Catalogue (v.1)".

250 This includes influential contributions from Vincent Boulanin and Maaike Verbruggen published with the Stockholm International Peace Research Institute in 2017 which mapped the use of autonomy in 381 different systems and a further dataset compiled by Heather Roff which coded 18 "autonomous" capabilities found in 284 weapons systems. While Heather Roff's dataset was originally available for download at the Arizona State University, it appears to have now been removed. For an overview of its major findings, see Heather M. Roff, "Weapons Autonomy Is Rocketing," Foreign Policy, September 28, 2016, https://foreignpolicy.com/2016/09/28/weapons-autonomy-is-rocketing/. See also Boulanin and Verbruggen, 'Mapping the Development of Autonomy in Weapons Systems'.

251 Gettinger and Michel, "Loitering Munitions in Focus".

252 Pilch, Altmann and Suter, "Survey of the Status of Small Armed".

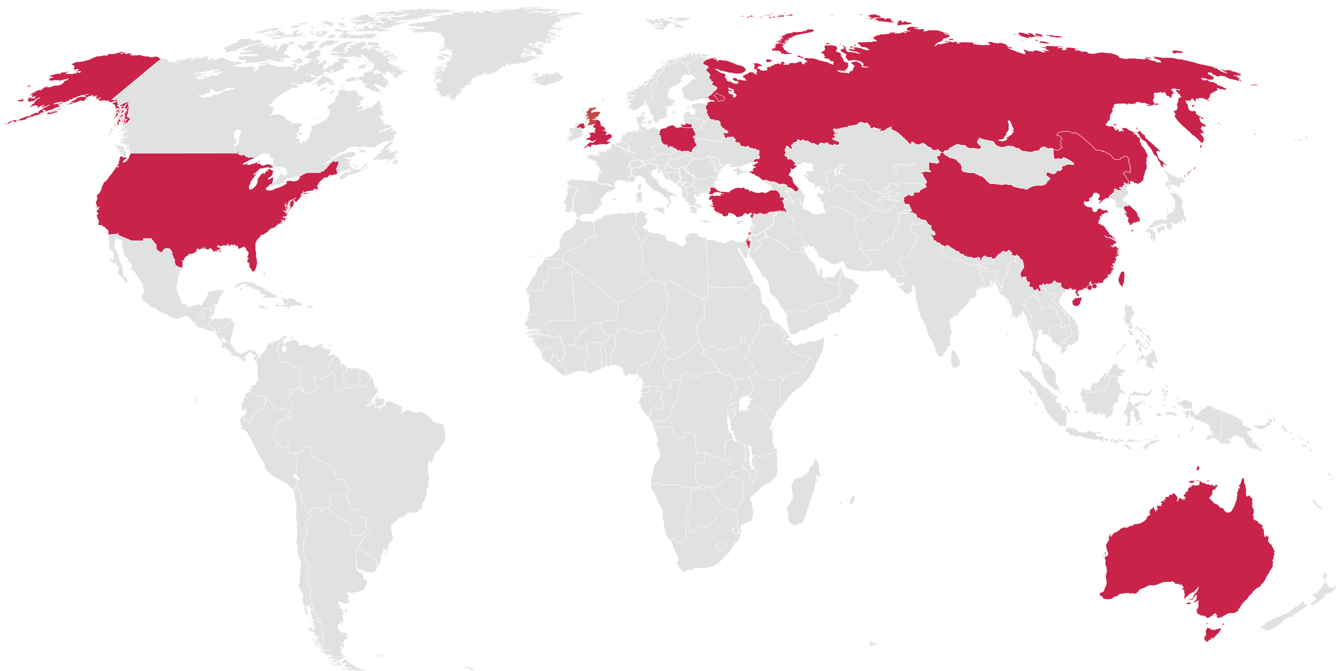
253 Voskuijl, "Performance analysis and design of loitering munitions".

254 Dan Gettinger, "One-Way Attack Drones: The Loitering Munitions of Past and Present", forthcoming 2023, Vertical Flight Society.

255 Kayser, "Increasing Autonomy in Weapons Systems".

discussed in Kayser's report are loitering munitions: the Drone40, the Kargu-2, the KUB-BLA, and the Mini-Harpy. In this way, Kayser's study provides important context to our analysis. Amongst other contributions, it highlights the global trend toward increases in the time and geographical area within which loitering munitions can operate, as well as a widening of the target profiles which these systems have been designed to strike.[256] The structure of our catalogue, however, is underpinned by the assessment that the design, development, and operation of this particular type of weapon system generates a distinct set of challenges to human control over specific targeting decisions which are deserving of deeper scrutiny. To this end, our catalogue focuses solely on loitering munitions. In addition to including a greater number of these systems than included in Kayser's study (24 vs. 4), we also disaggregate the discussion of the use of automated and autonomous technologies to support targeting and mobility functions. As illustrated in figure 1, our catalogue contains 24 loitering munitions developed by companies based in 10 states.

Figure 1: Country of origin of the loitering munitions included in our catalogue



Country of manufacture	Number of platforms included in our catalogue	Platform(s)
Australia	1	Drone 40
China	2	CH-901 Rainbow (FH-901), WS-43
Israel	8	Harop, Harpy, Hero-30, Hero-120, Orbiter 1K, ROTEM L, SkyStriker, Spike Firefly
Poland	1	Warmate
Russia	2	KUB-BLA, Lancet-3
South Korea	1	Devil Killer
Taiwan	2	Chien Hsiang, Fire Cardinal
Turkey	2	Alpagu, Kargu-2
United Kingdom	1	Fire Shadow
United States	4	Battlehawk, Phoenix Ghost, Switchblade 300, Switchblade 600

256 Kayser, "Increasing Autonomy in Weapons Systems," 1-2.

Our case selection was informed by three factors. First, it was important to include a significant number of systems produced by the 'traditional' global leaders in loitering munition development. Our catalogue includes eight systems manufactured by Israeli companies including IAI, Elbit Systems, and Rafael. These Israeli companies are amongst "the leading developer[s] and producer[s] of loitering munitions",[257] and remain market leaders in this design field. Our catalogue also includes four systems manufactured by American defence companies: the Textron Defense Systems Battlehawk, the AEVEX Aerospace Phoenix Ghost, and the AeroVironment Switchblade 300 and 600. These systems are important to include because American defence companies have helped drive the development of more portable loitering munitions designed for use by infantry forces.[258]

Second, our case selection was informed by the inclusion of systems from the newer generation of loitering munition developers which have emerged since the early 2010s. Turkey has been described as a "powerhouse of drone development and production".[259] Our catalogue includes two systems produced by the Turkish defence company STM: the Alpagu and the Kargu-2. Moreover, our catalogue includes Chinese (CH-901 Rainbow [FH-901], WS-43), Polish (Warmate), Russian (KUB-BLA, Lancet-3), South Korean (Devil Killer), and Taiwanese (Chien Hsiang, Fire Cardinal) manufactured systems. In addition to being increasingly prominent loitering munition manufacturers and exporters, as with the US and Israel, these states are leading developers of autonomous weapon technologies.[260]

Non-state groups including Hezbollah, the Houthi movement, and the Islamic State have operated uncrewed systems.[261] Houthi forces based in Yemen reportedly used the Iranian manufactured Samad 2 and Samad 3 as part of a September 2019 attack against Saudi Arabian oil installations, and some have classified these systems as loitering munitions.[262] The study of non-state uses of loitering munitions integrating autonomous technologies is left for future research. We have taken this decision in recognition of the different drivers and scale of non-state uses of uncrewed systems, as well as in acknowledgment that many non-state groups appear to have either modified commercially available "off-the-shelf" technologies or been supplied these weapons by state actors.[263] Due to data limitations regarding the use of automated and autonomous technologies in these systems and uncertainties regarding whether they should be classified as loitering munitions, Iranian manufactured systems such as the Shahed 136 have also been omitted from our catalogue.[264]

257 Norine MacDonald and George Howell. "Killing Me Softly." *Prism* 8, no. 3 (2019): 102-127: 111.

258 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 53.

259 Trevithick, "Turkey Now Has Swarming Suicide Drones It Could Export".

260 Justin Haner and Denise Garcia. "The Artificial Intelligence Arms Race: Trends and World Leaders in Autonomous Weapons Development." *Global Policy* 10, no. 3 (2019): 331-337.

261 Ash Rossiter, "Drone Usage by Militant Groups: Exploring Variation in Adoption." *Defense & Security Analysis* 34, no. 2 (2018): 113-126; Håvard Haugstvedt and Jan Otto Jacobsen. "Taking fourth-generation warfare to the skies? An empirical exploration of non-state actors' use of weaponized unmanned aerial vehicles (UAVs—'drones')." *Perspectives on Terrorism* 14, no. 5 (2020): 26-40; Yannick Veilleux-Lepage and Emil Archambault. «A Comparative Study of Non-State Violent Drone use in the Middle East.» (2022). https://icct.nl/app/uploads/2022/12/Drones-in-the-Middle-East-Full-Report-Final-Ready-to-Publish.pdf

262 Voskuijl, "Performance analysis and design of loitering munitions,"332-333.

263 Pilch, Altmann and Suter, "Survey of the Status of Small Armed," 6; Haugstvedt and Jacobsen, "Taking fourth-generation warfare to the skies?," 26.

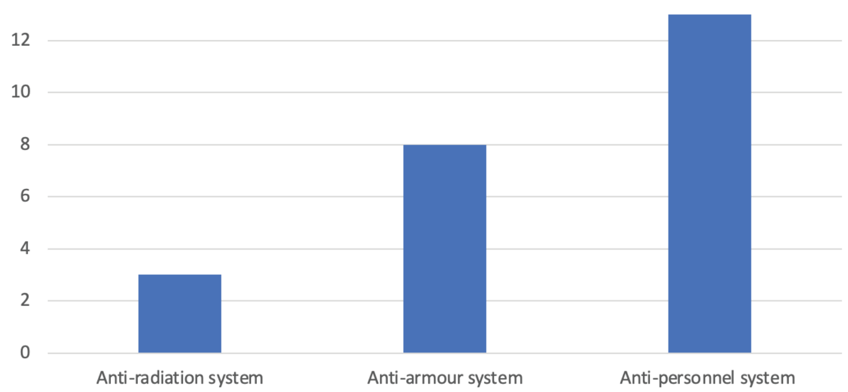
264 The Shahed 136 weighs approximately 200kg and is equipped with a fragmentation warhead. Russia has reportedly ordered at least 2,400 of these platforms from Iran, the first of which had been delivered by September 2022. The Geran-2 (as the modified Shahed 136 is known in Russian military service) has been widely used by the Russian military. According to analysts, the Shahed-136 is incapable of striking moving targets: it is used to conduct attacks against stationary targets via the entry of preloaded coordinates into Russia's Global Navigation Satellite System and/or the use of an inertial navigation system. The Shahed-136 and Geran-2 can possibly receive updated Global Navigation Satellite System coordinates in flight thereby enabling other targets to be attacked. As Marcel Plichta suggests, the Shahed-136 can be classified as a "One Way Attack drone" rather than as a loitering munition. Army Recognition, "Shahed-136: Loitering munition / Kamikaze-Suicide drone - Iran", Army Recognition, 9 December 2022, https://www.armyrecognition.com/iran_unmanned_ground_aerial_vehicles_systems/shahed-136_loitering_munition_kamikaze-suicide_drone_iran_data.html; Ashish Dangwal, "Russia Has 'Upgraded' Iranian Shahed-136 Kamikaze Drones To Boost Its Lethality & Accuracy — Military Experts", The EurAsian Times, 19 October 2022, https://eurasiantimes.com/hitting-bulls-eye-russia-has-upgraded-iranian-shahed-136-kamikaze/; John Hardie and Ryan Brobst, "Iranian Shahed-136 Drones Increase Russian Strike Capacity and Lethality in Ukraine", Long War Journal, 18 October 2022, https://www.longwarjournal.org/archives/2022/10/iranian-shahed-136-drones-increase-russian-strike-capacity-and-lethality-in-ukraine.php; Marcel Plichta, "I keep seeing misconceptions about what the Shaheds are and how they're used", Twitter, 1 January 2023, https://twitter.com/plichta_marcel/status/1609686038129119234/photo/1

And third, consistent with this report's focus on examining whether the global development, acquisition, and *usage* of loitering munitions has impacted emerging standards of human control over the use of force, our case selection was informed by the inclusion of systems which have been used in combat. Amongst others, this includes (1) the Kargu-2, which a March 2021 UN Panel of Experts on Libya report suggested may have been used to attack militias associated with Khalifa Haftar without immediate human supervision; (2) the Harop, Orbiter 1K, and SkyStriker systems which have been used in combat operations between Armenia and Azerbaijan over the contested Nagorno-Karabakh region; and (3) the Lancet-3, KUB, Drone40, Phoenix Ghost and Switchblade 300 fielded as part of the ongoing War in Ukraine. Our catalogue also includes systems which have not entered operational service, whether this be because the system's development was cancelled (e.g. the MBDA Fire Shadow) or because the system appears to have failed to secure enough orders to enter serial production (e.g. the Textron Defense Systems Battlehawk and the Korea Aerospace Industries Devil Killer). The inclusion of these systems widens our study of loitering munition development practices, providing deeper insights into the trends and development pathways animating the evolving design of these technologies.

To provide a clearer structure to our analysis, we make a broad distinction between three categories of loitering munitions: those principally designed to conduct (1) anti-personnel, (2) anti-armour, and (3) anti-radiation operations. This typology requires two qualifications. As with the larger category of uncrewed systems,[265] analysts have yet to agree a universal classification scheme for loitering munitions. Some researchers categorise these technologies based on the size of the platform's fuselage and wingspan.[266] These characteristics and principal target types are often correlated. Anti-radiation systems such as the IAI Harpy which are designed to detect and attack enemy radar systems tend to be significantly larger and heavier than anti-personnel systems such as the backpack portable UVision Hero-30 which is advertised as being "ideal for anti-personnel missions".[267] The modular warhead design of many loitering munitions also means that several systems can be configured to conduct attacks against multiple target types.[268] Organising our catalogue entries around each system's primary target profile, we argue, provides a framework for drawing more concise inferences about the global trends in the design of these technologies, as well as how this may have impacted emerging standards of human control over specific targeting decisions.

To provide a clearer structure to our analysis, we make a broad distinction between three categories of loitering munitions: those principally designed to conduct (1) anti-personnel, (2) anti-armour, and (3) anti-radiation operations

Figure 2: Breakdown of loitering munitions in catalogue by type



265 Pilch, Altmann and Suter, "Survey of the Status of Small Armed," 10.
266 Pilch, Altmann and Suter, "Survey of the Status of Small Armed," 10.
267 UVision, "Hero-30," UVision, https://uvisionuav.com/portfolio-view/hero-30/
268 In such cases, we have ordered our catalogue entries around what we understand to be the system's *principal* target type. UVision, for example, advertise the Hero-120 loitering munition as being "[i]deal for anti-tank missions, or other strategic objectives". For this reason, we have classified the Hero-120 as an anti-armour system. UVision, "Hero-120".

Type of loitering munition	Definition	Catalogue entries
Anti-radiation (3)	Loitering munitions principally designed to detect and attack radar systems	Chien Hsiang, Harop, Harpy
Anti-armour (8)	Loitering munitions principally designed to attack tanks and armoured vehicles	Devil Killer, Fire Shadow, Hero-120, Lancet-3, Phoenix Ghost, SkyStriker, Switchblade 600, Warmate, WS-43
Anti-personnel (13)	Loitering munitions principally designed to attack soldiers and soft-skinned vehicles	Alpagu, Battlehawk, CH-901 Rainbow (FH-901), Drone40, Fire Cardinal, Hero-30, Kargu-2, KUB-BLA, Orbiter 1K, ROTEM L, Spike Firefly, Switchblade 300

As illustrated in table 2, our catalogue entries are divided into 10 sections. This structure presents some of the major performance characteristics of the 24 loitering munitions included in our catalogue, the development status and history of these systems, and the use of automated and autonomous technologies to support targeting and mobility functions. The full catalogue is available via this link: https://doi.org/10.5281/zenodo.7860762

Table 2: Catalogue index

System manufacturer	Lists this platform's principal developer and country of origin.
System user(s)	Lists states which have purchased this platform.
System range	**Operational range**: Lists this platform's maximum range (kilometres). **Operational endurance**: Lists the time which this platform can remain airborne.
Launch	**Platform weight**: Lists this platform's maximum take-off weight (kilograms). **Wingspan**: Lists this platform's wingspan length (meters). **Launch method**: Lists how this platform is launched, e.g. pneumatic launch canister, rail-mounted catapult system, rotary power. **Delivery method(s)**: Lists the other vehicles from which this loitering munition can be launched, e.g. aircraft, ground vehicles, warships.
Payload	**Sensors**: Specifies the type of sensor which can be installed onto this platform e.g. electro-optical and infrared camera(s), radio-frequency seeker. **Warhead**: Specifies the type of warhead which can be installed onto this platform e.g. anti-armour warhead, fragmentation warhead, high-explosive warhead, thermobaric warhead.
Platform variant(s)	Summarises this platform's development and testing history, funding and production information, and any major operational deployments.
Development status	Lists information on the status of this platform's development including whether it has entered operational service, remains in development, or has been cancelled.
Development history	Briefly summarises the loitering munition's development history, production and funding information, and operational history.
Target type	Lists the different types of targets which this platform can attack, e.g. radar and air-defence systems, tanks and armoured vehicles, light skinned vehicles.
Integration of autonomous and automated technologies	Autonomous attack: Presents information on the use of autonomy and/or automation to support targeting functions including the tracking of moving targets and the use of target recognition software. Human control over targeting: Presents information on the role human operators play in this platform's targeting processes including whether the platform is advertised as being designed to operate with a "human-in-the-loop" and is installed with an "abort/wave off" capability. Autonomous flight: Presents information on the use of autonomy and/or automation to support mobility functions including whether this platform is installed with way-point navigation and autonomous navigation capabilities.

4.2b Catalogue research design and qualifications

Our catalogue of the integration of automated and autonomous technologies into 24 loitering munitions has been constructed from a range of open-source materials. This exercise involves certain methodological trade-offs deserving of three important qualifications.

First, as Daan Kayser also observes,[269] there are gaps in some of the information which is publicly available on the technical design details and use of weapons integrating automated and autonomous technologies. Prior to Russia's February 2022 invasion of Ukraine, Aevex Aerospace Phoenix Ghost's loitering munition was "shrouded in mystery".[270] Neither its manufacturer nor US government officials had released much information on this system. This would later be compiled by analysts and journalists.[271] In the case of at least two loitering munitions included in our catalogue – the Chien Hsiang and Fire Cardinal manufactured by Taiwan's National Chung-Shan Institute of Science and Technology – geopolitical factors have also impacted data availability. As Wim Zwijnenburg and Foeke Postma observe, "[g]iven the political and military tensions in the region, technical specifications for many Taiwanese drones are rarely published in the public domain".[272] Whenever possible, we have retained these entries in our catalogue, even if there are significant gaps in the open-source data which is available regarding the use of autonomy in these loitering munitions. This is with the belief that some – if limited – information about the integration of automated and autonomous technologies into these systems can make a timely contribution to the international debate in this area.

Autonomy is a contested notion which has meant different things, to different actors, at different times

Second, autonomy is a contested notion which has meant different things, to different actors, at different times. The various stakeholder groups involved with the real-world development and regulatory debates on weapons integrating automated and autonomous technologies – whether these be states parties deliberating at the UN CCW, government bureaucracies, or weapon manufacturers – have defined this notion in a manner which advances their perceived interests.[273] Depending on the audience, weapon manufactures may "play up the sophistication and autonomy of their products in marketing, and downplay them when scrutinised by international bodies such as the United Nations".[274] It is important to acknowledge that weapon manufacturers may exaggerate the "autonomous" capabilities of their systems,[275] whether this be with the aim of increasing export orders or making their systems appear more technologically sophisticated than they actually are. These factors have complicated our creation of a catalogue of automated and autonomous technologies in loitering munitions. This is because what is listed as an "autonomous" capability in one open-source reference could be different from how we understand this notion (see Section 2) and how autonomy may actually be used in that system. As Michael Horowitz notes:

269 Kayser, "Increasing Autonomy in Weapons Systems," 3.

270 Sakshi Tiwari, "Joe Biden's 'Spooky' Gift to Ukraine – US Officials Say 1st Batch of Phoenix 'Ghost' Drones To Arrive Today", The EurAsian Times, 29 April 2022, https://eurasiantimes.com/americas-spooky-gift-to-ukraine-1st-batch-of-phoenix-ghost-drones/

271 See, for example, Gettinger, "Phoenix Ghosts are part drones, part missiles".

272 Wim Zwijnenburg and Foeke Postma, "Unmanned Ambitions: Security implications of growing proliferation in emerging military drone markets", July 2018, PAX, https://paxforpeace.nl/media/download/pax-report-unmanned-ambitions.pdf, 33.

273 Bode and Watts, "Meaning-Less Human Control," 12-13; Kayser, "Increasing Autonomy in Weapons Systems", 3.

274 Quoted in House of Lords, Select Committee on Artificial Intelligence, "AI in the UK: Ready, Willing and Able?" Report of Session 2017-19 (London: House of Lords, April 16, 2018), https://publications. parliament.uk/pa/ld201719/ldselect/ldai/100/100.pdf, 26.

275 Peter Burt, "Loitering munitions, the Ukraine war, and the drift towards 'killer robots'." Drone Wars UK, 6 August 2022, https://dronewars.net/2022/06/08/loitering-munitions-the-ukraine-war-and-the-drift-towards-killer-robots/

> *[t]he companies that produce these loitering drones talk up their autonomous features, but often the autonomy involves flight corrections and manoeuvring to hit a target identified by a human operator, not autonomy in the way the international community would define an autonomous weapon.*[276]

And third, the weight given to the publicly available information on the possible technical capabilities of loitering munitions must be qualified by uncertainties regarding the Rules of Engagement under which these systems are operated. It is not possible from the available open-source material to conclusively determine whether how autonomous technologies *could* be used in a certain loitering munition correlates with how autonomous technologies *are* fielded in these systems. This ambiguity underpins much of the media debate on the purported use of "killer robots" in Libya and Ukraine. As Zachary Kallenborn highlights, it is extremely difficult to verify whether (and if so how) autonomy may have been used in a system's targeting processes.[277] As such, whilst the systems included in our catalogue may have latent automated and autonomous technologies in targeting functions, we cannot claim to know whether these capabilities are used in practice.

Whilst recognising these factors, our catalogue entries draw from a range of different types of open-source material summarised in Table 3. To the extent to which it has been possible, we have been careful to scrutinise the 'trustworthiness' of the open-source material used to construct our catalogue. In the case of media reports, it is important to acknowledge the "possibility of inaccurate information being either mistakenly posted or posted in a deliberate attempt to mislead the reader and thus influence public opinion".[278] Whenever possible, we have thus attempted to first use the material published by weapon manufacturers and defence ministries to populate our catalogue entries. In the case of the Chinese (CH-901 Rainbow [FH-901], WS-43) and Russian (KUB-BLA, Lancet-3) loitering munitions included in our catalogue, we have also received translation support from native Mandarin and Russian speakers.[279] This step has been taken to reduce the risk of translation errors and the possible (re)circulation of incorrect information about the systems included in our catalogue.

Table 3 Summary of the open-source materials used to populate our catalogue

Brochures, factsheets, promotional material, and other marketing material published by the loitering munition's manufacturer.
Press releases and other material published by defence ministries and other government bodies involved with the development of loitering munitions.
Media reports from reputable international news and defence outlets including *Army-Technology*, *The Drive*, *Flight Global*, *Janes Defence Journal*, *Shephard Media* and *UAS Vision*. When appropriate, we have also drawn from national news outlets in India, South Korea, and Taiwan, amongst other countries.
Other catalogues of weapons integrating autonomous and automated technologies including those with a particular focus on loitering munitions.
Open-source intelligence published on social media sites such as *Twitter*.

276 Will Knight, 'Russia's Killer Drone in Ukraine Raises Fears About AI in Warfare', Wired, 17 March 2022, https://www.wired.com/story/ai-drones-russia-ukraine/

277 Zachary Kallenborn, "Was a flying killer robot used in Libya? Quite possibly", Bulletin of the Atomic Scientists, 20 May 2021, https://thebulletin.org/2021/05/was-a-flying-killer-robot-used-in-libya-quite-possibly/

278 Haugstvedt and Jacobsen, "Taking fourth-generation warfare to the skies?" 29.

279 The authors would like to thank Guangyu Qiao-Franco and Anna Nadibaidze for this assistance. Any mistakes remain our own.

4.3 Summary of our findings

As previously discussed, the earliest loitering munitions were large and comparatively heavy platforms designed to locate and attack clearly specified military targets such as radar systems. Since the early 2010s however, there has been a clear global trend toward the development of smaller and more portable systems designed for use by special force and infantry units. Consistent with this dynamic, smaller loitering munitions such as the STM Kargu-2 have been specifically designed for use as part of "asymmetric warfare and anti-terrorism operations".[280] The Textron Defense Systems Battlehawk, a tactical loitering munition developed to compete for orders from the US Army's Lethal Miniature Aerial Missile System programme which began in 2008, was also designed to conduct strikes "against personnel and light vehicle targets in irregular environments".[281] The AeroVironment Switchblade 300, which would secure the bulk of the orders from the US Army's Lethal Miniature Aerial Missile System programme, was reportedly used in combat by American special operation forces in Afghanistan, Iraq, and Syria.[282] In being designed for use in such complex irregular warfare settings, this category of tactical loitering munition fulfils a different set of military functions than earlier SEAD systems such as the IAI Harpy. As suggested in our accompanying catalogue, an increasing number of states appear to be purchasing and fielding these systems.

The Israeli weapons manufacturer UVision, for example, advertises the Hero-30 as being "ideal for anti-personnel missions".[283] UVision similarly market its larger Hero-120 platform as being designed to conduct "pinpoint strikes against anti-armor, anti-material and *anti-personnel targets* including tanks, vehicles, concrete fortifications and *other soft targets* in populated urban areas".[284] Of the 24 systems included in our catalogue, 14 can be equipped with a fragmentation warhead designed for anti-personnel strikes.[285] The development and use of such anti-personnel systems matters because it underlines a widening of the target profiles which loitering munitions have been fielded to identify, track, and strike.

Similar dynamics are seen in the development of loitering munitions intended to operate in populated areas. Rafael Advanced Defence Systems promote its Spike Firefly loitering munition as being designed to meet the "unique mission profile of urban combat".[286] This platform is described as being specifically intended for "fighting in a tactical urban environment, where situational awareness is limited, the enemy is behind cover, and stand-off precision engagement is critical".[287] IAI's Rotem-L loitering munition is similarly marketed as having "[e]xcellent capabilities dealing with Low Signature Enemy in Urban and Complex Environment", in addition to "[o]bstacle avoidance for urban operations".[288] Other systems included in our catalogue which are described by their manufacturers as being

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280 Airforce Technology, "Kargu Rotary-Wing Attack Drone," Airforce Technology, June 4, 2021, https://www.airforce-technology.com/projects/kargu-rotary-wing-attack-drone/

281 Army Technology, "Textron's BattleHawk completes US Army demonstration," May 24, 2012, Army Technology, https://www.army-technology.com/news/newsbattlehawk-army-demonstration/

282 David Hambling, "The U.S. Is Upgrading Its Tiniest Killer Drones," Popular Mechanics, October 12 2016, https://www.popularmechanics.com/military/research/a23346/us-upgrading-tiniest-killer-drones/; Rueben Dass, "Militants and Drones: A Trend That is Here to Stay," RUSI, 6 September 2022, https://rusi.org/explore-our-research/publications/commentary/militants-and-drones-trend-here-stay

283 UVision, "Hero-30".

284 Emphasis added. UVision, "Hero-120".

285 Listed in alphabetical order, these systems are the Alpagu, Battlehawk, CH-901 Rainbow (FH-901), Drone 40, Hero-30, Hero-120, Lancet-3, Kargu-2, KUB-BLA, Orbiter 1K, ROTEM L, Spike Firefly, Switchblade 300, and the Warmate.

286 Rafael, 'Spikefire Fly: Miniature Tactical Loitering Weapon,' Rafael, https://www.rafael.co.il/wp-content/uploads/2019/03/FIREFLY.pdf

287 Robin Hughes, "IDF acquires Spike Firefly loitering munition", Janes, 4 May 2020, https://www.janes.com/defence-news/news-detail/idf-acquires-spike-firefly-loitering-munition

288 IAI, "ROTEM Loitering Munition based on a Light Multi-Rotor Platform", IAI, https://www.iai.co.il/p/rotem

designed for urban warfare operations include the UVision Hero-30 and Hero-120, the IAI Harop, and the MBDA Fire Shadow.[289] The design of loitering munitions for use in populated areas marks another important trend in the development of systems integrating autonomy to support targeting functions. As examined in section 2, the operation of loitering munitions in populated, urban areas may increase the degree of system unpredictability due to the complexity of these environments.

Another major trend in the global testing and development of these technologies is the integration of loitering munition launchers onto a range of other vehicles and aircraft. The development of canister launched systems which can be carried by an individual soldier has been a major advance in loitering munition design. It has enabled the fielding of a new generation of more portable loitering munitions including the AeroVironment Switchblade 300, IAI ROTEM L, and the Rafael Spike Firefly. This innovation has also helped facilitate the launch of loitering munitions from a range of crewed and uncrewed aircraft – a development which, by significantly increasing the combat radius of these systems,[290] could amplify the unpredictability generated by their use.

For example, there are versions of the STM manufactured Alpagu loitering munition which can be "launched from armed unmanned aerial platforms".[291] The CH-901 Rainbow (FH-901) loitering munition can, according to Chinese news reports, similarly be launched from under the wings of other uncrewed systems.[292] WB Group have promoted a specially designed launch-pod that enables the Warmate TL to be launched from uncrewed aircraft and, in the future, helicopters possibly including the Sikorsky S-70i Black Hawk.[293] According to analysts, this capability provides the Warmate with a "greatly extended range", converting it into a "stand-off weapon".[294] The American drone company Kratos has similarly tested the launch of the AeroVironment Switchblade from its tactical Airwolf uncrewed aircraft.[295] According to Kratos company officials, the airborne-launch of the Switchblade "extend[s] the terminal utility range of that Switchblade by orders of magnitude".[296] These design features may pose new challenges to human control because they help widen the geographical area within which a strike could occur.

As Kelsey Atherton notes, loitering munitions have been at the "forefront of autonomous lethality" for decades.[297] In the second section of this report, we unpacked how autonomy and automation have been used to support mobility and targeting functions. As we discussed, mobility functions are those which "allow the system to govern and direct its own motion within its operating environment without direct involvement of a human operator".[298] Targeting functions, on the other hand, relate to a system's ability after its activation to search for, identify, and strike a specified category of object.

289 Tom Watts and Ingvild Bode, "Automation and Autonomy in Loitering Munitions Catalogue (v.1)," April 2023, https://doi.org/10.5281/zenodo.7860762, 11, 15, 17, 42.

290 Pilch, Altmann and Suter, "Survey of the Status of Small Armed," 24-26.

291 STM, "New domestic-made UAV set to join Turkish arsenal," STM, 15 June 2020, https://www.stm.com.tr/en/media/press-releases/new-domestic-made-uav-set-join-turkish-arsenal

292 Fan Wei and Liu Xuanzun, "China unveils its version of Switchblade suicide drone in action," 8 September 2022, Global Times, https://www.globaltimes.cn/page/202209/1274963.shtml

293 Juliusz Sabak, "Aircraft-borne Variant of Warmate TL Loitering Munitions," 23 January 2021, Defence 24, https://defence24.com/industry/aircraft-borne-variant-of-warmate-tl-loitering-munitions

294 Sabak, "Aircraft-borne Variant of Warmate TL Loitering Munitions".

295 AeroVironment, "Kratos' New Airwolf Combat Drone Has Launched A Switchblade Loitering Munition in Flight," September 22 2021, https://www.avinc.com/resources/av-in-the-news/view/kratos-new-airwolf-combat-drone-has-launched-a-switchblade-loitering-muniti.

296 Joseph Trevithick, "Kratos' New Airwolf Combat Drone". 21 September 2021, The Warzone, https://www.thedrive.com/the-war-zone/42465/kratos-new-airwolf-combat-drone-has-launched-a-switchblade-loitering-munition-in-flight

297 Atherton, "Loitering Munitions Preview the Autonomous Future of Warfare".

298 Boulanin and Verbruggen, "Mapping the Development of Autonomy in Weapons Systems," 21.

Following reports that suggested that Kargu-2 loitering munitions may have been used to attack targets without human supervision as part of the Libyan Civil War, the CEO of the system's manufacturer STM Hakan Güleryüz stressed that "[o]ur homegrown autonomous AI drone technology is mostly used for navigation purposes".[299] This remark speaks to a wider trend in loitering munition development. All 24 of the loitering munitions included in our catalogue appear to have been installed with at least some autonomous and/or automated navigation capability.[300] This is generally used for systems to navigate toward (and within) an operator designated area of operation without the need for the system to be manually piloted. The operator instead monitors the platform's operation using the systems ground control station which can be used to alter its course and direction.

UVision, for example, market its Hero-30 and Hero-120 loitering munitions as being installed with "sophisticated navigation methods" (possibly including "sophisticated on board navigation algorithms") which enable the operation of these systems in GPS denied environments.[301] According to Elbit Systems, the SkyStriker platform "uses autonomous navigation during its cruising and loitering phases".[302] The Turkish defence manufacturer STM similarly advertises its Alpagu platforms as being designed to conduct "fully autonomous navigation via [the company's] unique flight control system".[303] Moreover, many of the systems included in our catalogue appear to be installed with a way-point navigation capability.

Most of the loitering munitions included in our catalogue are advertised as being designed to be operated with a human-in-the loop. Some loitering munition manufacturers such as DefendTex have stressed that their systems "will never be autonomous, fully acquire and prosecute target without authorisation and confirmation from the human".[304] Consistent with such claims, loitering munitions operators are often presented as being required to designate and/or confirm a target before executing a strike. Furthermore, a majority of the systems included in our catalogue have either been advertised or described as being installed with an "abort/wave-off" capability which enables the operators of these platforms to abort a strike if battlefield conditions change between the time when a potential target is detected and when a strike is authorised (e.g. a non-combatant enters the combat zone). In the case of anti-radiation loitering munitions such as the IAI Harpy and the Chien Hsiang which are not installed with an electro-optical sensor, if an emitting radio frequency is lost or switched off, a strike will be automatically aborted, and the system will re-enter its "loiter pattern".

Notwithstanding this, our catalogue suggests that autonomous and automated technologies have possibly been integrated into the targeting functions of many currently fielded loitering munitions. Whilst it is not possible to verify these claims on the basis of our review of the available open-source material, at least eight of the systems included in our catalogue appear to be advertised or described

299 Tayfun Özberk, "Turkish drone maker denies autonomous strike capability," 16 July 2021, Shepard, https://www.shephardmedia.com/news/uv-online/turkish-drone-maker-denies-autonomous-strike-capab/

300 As discussed in the second section of this report, there are important technical differences between autonomy and automation. Many loitering munition manufactures appear to use these notions interchangeably when marketing the navigation capabilities of their systems, however.

301 UVision, "Hero-120".

302 Elbit Systems, "Sky-Striker. Tactical Loitering Munitions for Covert and Precise Airstrikes" (Elbit Systems Ltd., July 2018), https://elbitsystems.com/landing/wp-content/uploads/2018/07/Sky-Striker.pdf.

303 STM, "Tactical Mini UAV Systems," https://www.stm.com.tr/uploads/docs/1660293328_tacticalminiuavsystems.pdf?, p.4.

304 Kelsey D. Atherton, "A Drone with a Can-Doom Attitude," C4ISRNET, June 5, 2019, https://www.c4isrnet.com/unmanned/2019/06/05/a-drone-with-a-can-doom-attitude/.

as having being installed with some form of target (or object) recognition software.[305] The processes of tracking and navigating toward operator designated targets (including during the terminal phase of a strike) are also widely advertised as being highly automated. In the case of the AeroVironment Switchblade loitering munitions for example, the systems are marketed as "already incorporate[ing] a certain level of autonomy…. one can simply designate a target and the Switchblade will track that target even if it moves, without the operator redirecting it".[306] Other systems are advertised as being installed with "autonomous" attack modes. The WB Warmate, for example, is installed with a "[f]ully autonomous attack mode on selected target[s] based on on-board video tracking system".[307] Elbit Systems, likewise, describe its SkyStriker platform as being a "fully autonomous LM [Loitering Munition] that can locate, acquire and strike operator-designated targets".[308]

In short: at the time of writing (April 2023), loitering munitions offer a nuanced picture on the extent to which autonomy has been integrated into weapon systems. On the one hand, most manufacturers of the loitering munitions examined in the report clearly require human inspection and approval of specific targets prior to the release of force. This suggests that direct, real-time human control of the targeting functions of loitering munitions integrated automated and autonomous technologies is a widely accepted principle. On the other hand, the loitering munitions we examined also appear to have a latent capability to identify, select, track, and strike targets without further human intervention. The design of such systems therefore clearly speaks to the global trend toward the integration of greater levels of autonomy into weapons systems.

305 Listed in alphabetical order these are the Alpagu, the Devil Killer, the Drone 40, the Fire Cardinal, the Kargu-2, the KUB-BLA, the Switchblade 300, and the Switchblade 600

306 "AeroVironment- Rapidly Deployable UAV Situational Awareness for International Defence Forces with combined lethality," November 2020, Defence & Security Systems International, https://www.defence-and-security.com/features/featureaerovironment--rapidly-deployable-uav-situational-awareness-for-international-defence-forces-with-combined-lethality-8376335

307 WB Group, "Warmate: Loitering Munitions System," June 2017, https://www.wbgroup.pl/app/uploads/2017/06/warmate_eng_large_22q2.pdf, p.3.

308 Elbit Systems, "Sky-Striker. Tactical Loitering Munitions for Covert and Precise Airstrikes".

5 Loitering munitions in action and areas of concern

To extend our study of how the global development and fielding of loitering munitions since the 1980s may have impacted emerging standards of human control over the use of force, this section of our report examines the use of these weapons in three case studies: (1) the Libyan Civil War (2014-2020), (2) the Nagorno-Karabakh War (September-November 2020), and (3) the War in Ukraine (February 2022-). These cases have been selected for detailed analysis because of their prominence in the scholarly debates and media coverage given to loitering munitions.[309] Libya is widely reported as being the site of the first combat use of an *autonomous* weapon due to a strike which may have involved Kargu-2 loitering munitions. Both the 2020 Nagorno-Karabakh War and the ongoing War in Ukraine have been called "drone wars"[310] and have been associated with "a new age of warfare".[311] The dynamics of using loitering munitions with sensor-based targeting in these conflicts are therefore indicative of current trends in the development of autonomy in weapon systems that deserve detailed empirical scrutiny.

The dynamics of using loitering munitions with sensor-based targeting in these conflicts are therefore indicative of current trends in the development of autonomy in weapon systems that deserve detailed empirical scrutiny

This section thus develops our report's overall analysis by illustrating the three areas of concern we identified regarding the operation of loitering munitions integrating autonomous and automated technologies. First, the use of such platforms creates significant uncertainties around both the situational and the decision-making dimensions of human control. Second, as particularly underlined in the War in Ukraine, the cases highlight a growing trend towards using such platforms in populated areas. Third, these cases emphasize how loitering munitions have the potential to create indiscriminate and wide area effects associated with the uncertainty about when and where targets will be struck within a wide geographical area.

309 Gregory C. Allen, "Russia Probably Has Not Used AI-Enabled Weapons in Ukraine, but That Could Change," Center for Strategic and International Studies, May 26, 2022, https://www.csis.org/analysis/russia-probably-has-not-used-ai-enabled-weapons-ukraine-could-change; David Hambling, "Efforts to Regulate 'killer Robots' Are Threatened by War in Ukraine," New Scientist, July 13, 2022, https://www.newscientist.com/article/2327965-efforts-to-regulate-killer-robots-are-threatened-by-war-in-ukraine/; Zachary Kallenborn, "Was a Flying Killer Robot Used in Libya? Quite Possibly," Bulletin of the Atomic Scientists, May 20, 2021, https://thebulletin.org/2021/05/was-a-flying-killer-robot-used-in-libya-quite-possibly/; Samuel Bendett and Jeffrey Edmonds, "Russian Military Autonomy in Ukraine: Four Months In," Center for New American Security, July 2022, https://www.cna.org/reports/2022/07/russian-military-autonomy-in-ukraine-four-months-in; Heiko Borchert, Torben Schuetz, and Joseph Verbovszky, "Beware the Hype. What Military Conflicts in Ukraine, Syria, Libya, and Nagorno-Karabakh (Don't) Tell Us About the Future of War," DAIO Study (Hamburg: Defense AI Observatory, 2021), https://defenseai.eu/wp-content/uploads/2023/01/DAIO_Beware_the_Hype.pdf; Michael Kofman, "A Look at the Military Lessons of the Nagorno-Karabakh Conflict," Russia Matters, December 14, 2020, https://www.russiamatters.org/analysis/look-military-lessons-nagorno-karabakh-conflict.

310 Cahal Milmo, "How 'kamikaze Drones' Are Rewriting the Rules of War in the Battle for Ukraine," i News, June 25, 2022, https://inews.co.uk/news/kamikaze-drones-valuable-weapon-both-sides-russia-ukraine-war-1706286.

311 Frank Bajak and Hanna Arhirova, "Drone Advances in Ukraine Could Bring Dawn of Killer Robots," AP News, January 3, 2023, https://apnews.com/article/russia-ukraine-war-drone-advances-6591dc69a4bf2081dcdd265e1c986203.

5.1 The Libyan Civil War (2014-2020)

In the context of the Libyan Civil War, loitering munitions were chiefly deployed by the Government of National Accord (GNA) from 2019 onwards. At this stage of the war, there was only one other armed faction to contend with: the Libyan National Army (LNA) commanded by General Khalifa Haftar.[312] Both factions received external military support: the GNA from Turkey and the LNA from Russia. Although the Kargu-2 loitering munition had been used by GNA forces to strike a Russian designed Pantsir-S short-range air defence system, it should be noted that the LNA had not operated this system as part of an integrated air defence network, thereby limiting their ability to defend the Pantsir-S from aerial strikes.[313]

In May 2021, a report authored by a UN Panel of Experts on Libya regarding the Libyan Civil War in the period between October 2019 and January 2021 received significant global media attention because it characterised the Kargu-2 loitering munition as an AWS.[314] The Kargu-2 is a quadcopter manufactured in Turkey by STM Defense Technologies Engineering and has been operational with the Turkish military since 2018.[315] Previously, the Kargu-2 had been deployed by Turkey along the Turkish-Syrian border.[316] Weighing 7kg, the Kargu-2 is a small platform that has a range of 10km and an operational endurance of 30 minutes.[317] Having been designed for anti-terrorist operations,[318] the Kargu-2 can strike various objects such as "convoys of light vehicles, parked aircraft, radar dishes and sensor systems, ammunition and fuel dumps".[319]

The UN report alleged that, in March 2020, forces affiliated with the GNA had used the Kargu-2 to strike LNA associated militias without immediate human supervision.[320] The passage amounts to one paragraph in a report which is over 500 pages in length. Given the attention it has received, this paragraph is worth quoting in full:

> *Logistics convoys and retreating HAF [Haftar Affiliated Forces] were subsequently hunted down and remotely engaged by the unmanned combat aerial vehicles or the lethal autonomous weapons systems such as the STM Kargu-2 [...] and other loitering munitions. 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.*[321]

The media coverage given to this report presents this incident as being the first time a loitering munition was used to "autonomously" target military personnel on the battlefield.[322] This claim has generated substantial debate about the *novelty*

312 Wolfram Lacher, "Libya's Fragmentation: Structure and Process in Violent Conflict" (London, I.B. Tauris, 2020).

313 Master Seargant Daniel S. Nasereddine, "The Dawn of the Loitering Munitions Era," Mad Scientist Laboratory, June 14, 2021, https://madsciblog.tradoc.army.mil/333-the-dawn-of-the-loitering-munitions-era/.

314 Maria Cramer, "AI Drone May Have Acted on Its Own in Attacking Fighters, UN Says," The New York Times, June 3, 2021, https://www.nytimes.com/2021/06/03/world/africa/libya-drone.html.

315 STM, "Export of KARGU Attack UAV Systems by STM, Turkey's Manufacturer of Tactical Mini UAVs," STM, July 21, 2021, https://www.stm.com.tr/en/media/press-releases/export-kargu-attack-uav-systems-stm-turkeys-manufacturer-tactical-mini-uavs.

316 Lt. General P.C. Katoch, "Turkey's Swarm Drones," SP's Aviation, July 20, 2020, https://www.sps-aviation.com/experts-speak/?id=471&h=Turkeys-Swarm-Drones.

317 STM, "Kargu Combat Proven Rotary Wing Loitering Munition System," STM, 2022, https://www.stm.com.tr/en/kargu-autonomous-tactical-multi-rotor-attack-uav.

318 UAS News, "Kargu Rotary Wing Attack Drone," sUAS News - The Business of Drones, November 23, 2020, https://www.suasnews.com/2020/11/kargu-rotary-wing-attack-drone/.

319 Katoch, "Turkey's Swarm Drones."

320 Watts and Bode, "Automation and Autonomy in Loitering Munitions Catalogue (v.1), 45.

321 UN Security Council, "Final Report of the Panel of Experts on Libya Established Pursuant to Security Council Resolution 1973 (2011). UN Document No. S/2021/229," March 8, 2021, para. 63.

322 Joe Hernandez, "A Military Drone with a Mind of Its Own Was Used in Combat, UN Says," NPR, June 1, 2021, https://www.npr.org/2021/06/01/1002196245/a-u-n-report-suggests-libya-saw-the-first-battlefield-killing-by-an-autonomous-d?t=1624343501511; Alyse Stanley, "The Age of Autonomous Killer Robots May Already Be Here," Gizmodo, May 30, 2021, https://gizmodo.com/flying-killer-robot-hunted-down-a-human-target-without-1847001471.

of the sensor-based targeting systems integrated into the Kargu-2 (and other loitering munitions).[323] Most probably, this was not the first time that loitering munitions have been used on the battlefield as our later discussion of Azerbaijan's use of the Harop in 2016 underlines (section 5.2).

Prior to the publication of the 2021 UN report on the Libyan Civil War, STM had advertised the Kargu-2 as being installed with "both autonomous and manual modes"[324] and utilising "real-time image processing capabilities and deep learning algorithms".[325] A promotional video released by the company in April 2018 presented the Kargu-2 as providing its operator with the "[a]bility to autonomously fire-and-forget through entry of the target coordinates" and offering "[a]utonomous and precision hit with minimal collateral damage".[326] In the same promotional material, the Kargu-2 is depicted as utilising "real time target detection"[327] capabilities via what appears to be its identification of a stationary pick-up truck which is then struck.

Prior to the publication of the 2021 UN report on the Libyan Civil War, STM had advertised the Kargu-2 as being installed with "both autonomous and manual modes"

The promotional material released by STM regarding the Kargu-2 since the publication of the UN report, in contrast, presents the platform's technological capabilities in different terms. Here, the Kargu-2 is described as being "capable of performing fully autonomous navigation" but that its "[p]recision strike mission is fully performed by the operator, in line with the Man-in-the-Loop principle".[328] Further, while the 2018 promotional video about the Kargu-2 published on YouTube referred to the system as an "autonomous rotary wing attack drone",[329] more recently published promotional material describes it as a "rotary wing attack drone loitering munition system".[330] The reference to autonomy has notably been dropped in manufacturer references to the Kargu-2. According to a July 2021 STM press release, "[e]ach mission (both ISR [Intelligence, Surveillance, and Recognition] and is performed under the complete control of the human operators, limiting the platform's autonomy to navigational purposes only".[331] This (re) framing of the platform's use of autonomy is consistent with comments made by the company's CEO Hakan Güleryüz following the publication of the UN Report. As Güleryüz describes it, "[a]t STM, we always think ethically a human should be involved in the loop".[332] Although STM still claims that the Kargu-2 utilises an "Automatic Target Recognition System",[333] the technical specifications of this capability appear to have not been documented.

According to 2020 news reports about this platform, the Kargu-2 is installed with "deep learning algorithms to locate, track, and identify targets without human assistance" and uses facial recognition.[334] Generally, media articles discussing the Kargu-2 include explicit references to AI. At times, it has been described as being "powered by artificial intelligence".[335] Analysts contributing to the debates on AWS

323 Watts and Bode, "Automation and Autonomy in Loitering Munitions Catalogue (v.1), 44-45.
324 STM, "KARGU - Autonomous Tactical Multi-Rotor Attack UAV," Youtube, April 28, 2018, https://www.youtube.com/watch?v=Oqv9yaPLhEk.
325 Sema Susar, "KARGU UAV System," Defence Turk, April 6, 2020, https://en.defenceturk.net/kargu-uav-system/.
326 STM, "KARGU - Autonomous Tactical Multi-Rotor Attack UAV."
327 STM, "KARGU - Autonomous Tactical Multi-Rotor Attack UAV."
328 STM, "Tactical Mini UAV Systems" (STM, 2021), https://www.stm.com.tr/uploads/docs/1644928865_taktik-mini-iha-eng.pdf?
329 STM, "KARGU - Autonomous Tactical Multi-Rotor Attack UAV."
330 STM, "Tactical Mini UAV Systems."
331 STM, "Export of KARGU Attack UAV Systems by STM, Turkey's Manufacturer of Tactical Mini UAVs."
332 Quoted in Sinan Tavsan, "Turkish Defense Company Says Drone Unable to Go Rogue in Libya," NIKKEI Asia, June 20, 2021, https://asia.nikkei.com/Business/Aerospace-Defense/Turkish-defense-company-says-drone-unable-to-go-rogue-in-Libya.
333 STM, "Tactical Mini UAV Systems."
334 Yerepouni, "Turkish Army to Receive 500 Swarming Drones with Facial Recognition Feature: Report," Yerepouni - Armenian Independent News, June 19, 2020, https://advance-lexis-com.proxy1-bib.sdu.dk/api/document?collection=news&id=urn:contentItem:605H-K2K1-F11P-X29H-00000-00&context=1516831.
335 Cramer, "AI Drone May Have Acted on Its Own in Attacking Fighters, UN Says."

(typically with a focus on international security and/or emerging technologies) similarly draw attention to the Kargu-2's use of "AI-driven image recognition"[336] software and its "machine learning-based object classification"[337] to support targeting functions.

From this, it could be inferred that the integration of automated, autonomous, and AI technologies into the Kargu-2's targeting functions has shifted over time. In our assessment however, what is most likely to have changed is not the system's actual technical functionalities but rather the language its manufacturer (and others) have used to describe these capabilities. The timing of these changes coincides with, and was likely prompted by, the UN report's discussion of the Kargu-2's purported use without human control in Libya.

The principle that STM thought these changes were necessary gives us important insights into the role of perception in the AWS debate. It appears as if, following the publication of the UN report and the global media coverage that it received, STM no longer believed it appropriate to publicly describe its system as being "autonomous", instead choosing to highlight its operation in line with "human-in-the-loop" principles. Prior to the publication of the UN report, the manufacturer may have judged the state of debate differently and therefore prioritised the marketing potential of advertising the integration of autonomous and AI technologies.[338]

Following the publication of the UN report and the global media coverage that it received, STM no longer believed it appropriate to publicly describe its system as being "autonomous"

Further, there are important details about the Kargu-2's mode of operation in Libya that the UN report does not include. For example, it is not outright stated whether the strikes conducted by the Kargu-2 led to human harm or death.[339] This is implied within the report, as it refers to the "continual harassment from the unmanned combat aerial vehicles and lethal autonomous weapons systems" as "a *highly effective* combination in defeating" the Pantsir.[340] Similarly, "significant casualties" in the battle are mentioned.[341] Second, the report does not explicitly state whether the Kargu-2 was believed to be operating in an autonomous or manual mode. The report only notes that "the lethal autonomous weapons systems were programmed to attack targets without requiring data connectivity between the operator and the munition".[342] This suggests that the Kargu-2 may be technically capable of tracking and striking targets autonomously[343] - an observation that is further corroborated by how STM described the system's functionality prior to May 2021. It nonetheless remains unclear whether the platform was actually used in an autonomous mode.[344]

STM officials publicly denied that the Kargu-2 platform had conducted any "autonomous" strikes in Libya. Speaking in June 2021, STM's then CEO Hakan

336 Nathaniel Allen and Marian "Ify" Okpali, "Artificial Intelligence Creeps on to the African Battlefield," Brookings Tech Stream, February 2, 2022, https://www.brookings.edu/techstream/artificial-intelligence-creeps-on-to-the-african-battlefield/.

337 Hitoshi Nasu, "The Kargu-2 Autonomous Attack Drone: Legal & Ethical Dimensions," Articles of War, June 10, 2021, https://lieber.westpoint.edu/kargu-2-autonomous-attack-drone-legal-ethical/.

338 Perhaps inadvertently, this incident highlights the salience of the human control principle along its situational and decision-making dimensions as it plays out in international media and the international public. After all, a series of international surveys conducted on behalf of the Campaign to Stop Killer Robots in up to 28 countries in 2021, 2018, and 2017 showed that negative public attitudes towards the use of AWS have been stable. By aligning its system with the human-in-the-loop language, the manufacturer appears to have been intended as reputational damage limitation. Ipsos, "Global Survey Highlights Continued Opposition to Fully Autonomous Weapons," Ipsos, February 2, 2021, https://www.ipsos.com/en-us/global-survey-highlights-continued-opposition-fully-autonomous-weapons.

339 Nasu, "The Kargu-2 Autonomous Attack Drone: Legal & Ethical Dimensions."

340 UN Security Council, "Final Report of the Panel of Experts on Libya Established Pursuant to Security Council Resolution 1973 (2011). UN Document No. S/2021/229," 17.

341 UN Security Council, "Final Report of the Panel of Experts on Libya," 17.

342 UN Security Council, "Final Report of the Panel of Experts on Libya," 17.

343 Nurbanu Hayir, "Defining Weapon Systems with Autonomy: The Critical Functions in Theory and Practice," *Groningen Journal of International Law* 9, no. 2 (2022): 263.

344 Kallenborn, "If a Killer Robot Were Used, Would We Know?"

Güleryüz insisted that "[o]ur homegrown autonomous AI drone technology is mostly used for navigation purposes as well as designating and differentiating humans, animals, vehicles, etc. Therefore, it is not capable of launching fully autonomous attacks on targets".[345] The language used here is similar to how other weapon manufacturers describe the integration of autonomous technologies in their loitering munitions, for example the Alpagu and the Hero-30.[346] As Güleryüz put it: "[u]nless an operator pushes the button, it is not possible for the drone to select a target and attack".[347] A spokesperson for STM underlined that the Kargu-2 "cannot attack a target until the operator tells it to do so", while further characterising information used in the UN report as "speculative, unverified" and "not to be taken seriously".[348] STM maintain that autonomy is principally used to support navigational tasks, not to conduct strikes. This explicitly contradicts how STM marketed the Kargu-2's technological capabilities prior to the publication of the UN report.[349]

Warheads for the Warmate platform. **Source:** VoidWanderer via Wikimedia Commons

Aside from the Kargu-2, other loitering munitions may also have been used during the Libyan Civil War. An image posted on social media in April 2020 appears to show a Polish-manufactured Warmate platform.[350] The identity of the state or non-state group which operated this platform is unknown, as is the extent to which Warmates have been used in Libya. WB Group confirmed to the Polish defence publication MILMAG Military Magazine that the image showed a "dismantled fuselage of a Warmate combat unmanned aerial vehicle".[351] MILMAG speculated that this Warmate platform had likely been damaged before it could be used.[352] Both MILMAG and other defence publications have speculated that this particular Warmate could have been provided by Turkey, which purchased Warmates in 2018.[353] At 5.3kg, the Warmate has a range of 30km and an operational endurance of 60 minutes.[354] This larger radius sets the system apart from comparably sized anti-tank guided missiles.[355] The Warmate's intended targets are "light armoured vehicles, fortifications, and infantry".[356]

Different variants of the Warmate loitering munition appear to be capable of operating in manual and autonomous modes. On the one hand, the manufacturer describes the Warmate as having a human-in-the-loop and "being semi-autonomous during a strike".[357] A human operator assesses a target "before launching a strike" via "a daylight or thermal camera".[358] Therefore, according

345 Tayfun Özberk, "Turkish Drone Maker Denies Autonomous Strike Capability," Shephard, July 16, 2021, https://www.shephardmedia.com/news/uv-online/turkish-drone-maker-denies-autonomous-strike-capab/.

346 Watts and Bode, "Automation and Autonomy in Loitering Munitions Catalogue (v.1), 31, 41

347 Tavsan, "Turkish Defense Company Says Drone Unable to Go Rogue in Libya."

348 Quote in Bajak and Arhirova, "Drone Advances in Ukraine Could Bring Dawn of Killer Robots."

349 STM, "KARGU Autonomous Rotary Wing Attack Drone," STM, February 22, 2018, https://www.stm.com.tr/uploads/docs/1579732425_kargu-en.pdf?

350 Abraxas Spa, "Time to Check Foreign Sales of the WB Electronics Warmate Loitering Munition," Twitter, April 15, 2020, https://twitter.com/AbraxasSpa/status/1250341263695417346?ref_src=twsrc%5Etfw%7Ctwcamp%5Etweetembed%7Ctwterm%5E1250341263695417346%7Ctwgr%5E%7Ctwcon%5Es1_&ref_url=https%3A%2F%2Fdefence24.com%2Fpolish-loitering-munitions-in-libya.

351 MilMag, "Polish Warmate Found in Libya," The Military Magazine, April 15, 2021, https://milmag.pl/en/polish-warmate-found-in-libya/.

352 MilMag, "Polish Warmate Found in Libya".

353 MilMag, "Polish Warmate Found in Libya"; TVP World, "Polish Army to Receive 100 Drones in 2018," TVP World, June 2, 2018, https://tvpworld.com/37474331/polish-army-to-receive-100-drones-in-2018.

354 WB Group, "WARMATE Loitering Munitions," WB Group, n.d., https://www.wbgroup.pl/en/produkt/warmate-loitering-munnitions/.

355 WB Group, "WARMATE Loitering Munitions".

356 WB Group, "The First Sets of WARMATE in the Service of the Polish Army," WB Group, November 20, 2017, https://www.wbgroup.pl/en/aktualnosci/the-first-sets-of-warmate-in-the-service-of-the-polish-army/?highlight=WARMATE.

357 WB Group, "Warmate. Loitering Munition System," n.d., https://docs.tuyap.online/FDOCS/23351.pdf.

358 WB Group, 2.

to WB Group, the human operator "has full control and bears full responsibility" for its operation.[359] On the other hand, WB Group advertise the larger Warmate 2 variant as being capable of operating in a "fully autonomous attack mode" which the system can use "on selected targets based on on-board video tracking systems".[360]

In sum, the pattern of loitering munitions use in the Libyan Civil War highlights significant uncertainties surrounding the quality of human control exercised along the decision-making component. The fact that STM, the manufacturer of the Kargu-2, has changed how it described the system's technological functionalities after it drew significant press attention illustrates that manufacturer communications are changeable. Loitering munitions appear not to have been used in populated areas in Libya. But both the Kargu-2 and the Warmate are designed to be used against a variety of military objects, including vehicles, thereby illustrating a trend towards an expanding number of targets that such systems can identify and select. The loitering munitions used in Libya also underline trends towards greater system mobility and geographical range that can lead to indiscriminate and wide area effects. The range (max. 10km, Kargu-2; max. 30km, Warmate) and operational endurance (max. 30 minutes, Kargu-2; max. 60 minutes, Warmate) of the systems used indicate that objects and personnel in this radius could become targets. In addition, both the Kargu-2 and the Warmate can be equipped with thermobaric warheads.[361] Although they do not appear to have integrated such warheads in Libya, their potential to include this payload underlines a further area of concern regarding their wide area effects because of the blast radius involved with the operation of thermobaric weapons.

The loitering munitions used in Libya also underline trends towards greater system mobility and geographical range that can lead to indiscriminate and wide area effects

5.2 The 2020 Nagorno-Karabakh War

The Nagorno-Karabakh War between Armenia and Azerbaijan (27 September – 10 November 2020) saw the Azerbaijani use of various Israeli-manufactured loitering munitions including the Harop (occasionally also referred to as Harpy-2), the Orbiter 1K, and the SkyStriker (see table 5).[362] Armenia deployed its indigenously developed HRSH loitering munitions but to little apparent military avail.[363] Azerbaijan's use of drones, such as the Turkish-manufactured Bayraktar TB-2, to destroy Armenian air defence systems and tanks has received significant media attention.[364] The use of loitering munitions in this conflict has led some analysts and media commentators to characterise the 2020 Nagorno-Karabakh War as a potential watershed moment regarding the use of mobile weapon systems integrating automated, autonomous, and AI technologies in targeting.[365] Azerbaijan's celebration of their use of various types of uncrewed technologies

359 WB Group, "WARMATE Loitering Munitions."

360 WB Group, "WARMATE. Loitering Munitions System" (WB Group, 2022), https://www.wbgroup.pl/app/uploads/2017/06/warmate_eng_large_22q2.pdf.

361 Watts and Bode, "Automation and Autonomy in Loitering Munitions Catalogue (v.1), 44, 61.

362 SIPRI, "SIPRI Arms Transfers Database," Stockholm International Peace Research Institute, March 14, 2022, https://www.sipri.org/databases/armstransfers; Shaan Shaikh and Wes Rumbaugh, "The Air and Missile War in Nagorno-Karabakh: Lessons for the Future of Strike and Defense," Center for Strategic and International Studies, December 8, 2020, https://www.csis.org/analysis/air-and-missile-war-nagorno-karabakh-lessons-future-strike-and-defense; Douglas Barrie et al., "Armed Uninhabited Aerial Vehicles and the Challenges of Autonomy" (London: The International Institute for Strategic Studies, December 2021).

363 Joel Postma, "Drones over Nagorno-Karabakh," *Atlantisch Perspectief* 45, no. 2 (2021): 15; Barrie et al., "Armed Uninhabited Aerial Vehicles and the Challenges of Autonomy," 6. Unfortunately, there are no technical details publicly available about these platforms.

364 Shaikh and Rumbaugh, "The Air and Missile War in Nagorno-Karabakh: Lessons for the Future of Strike and Defense."

365 Robyn Dixon, "For Azerbaijan, Drones Proves Decisive in Contested Enclave," The Washington Post, November 12, 2020, https://www.washingtonpost.com/world/europe/nagorno-karabkah-drones-azerbaijan-aremenia/2020/11/11/441bcbd2-193d-11eb-8bda-814ca56e138b_story.html; Ulrike Franke, "Auf Dem Weg in Den Autonomen Krieg," Der Hauptstadtbrief, December 27, 2020, https://www.derhauptstadtbrief.de/auf-dem-weg-in-den-autonomen-krieg/.

in this conflict via daily posts on the Defence Ministry's website and on big screens in the capital Baku informed such discourse.[366] Following this line of argument, the 2020 Nagorno-Karabakh War "has become the most powerful example of how small and relatively inexpensive attack drones can change the dimensions of conflicts".[367] The comparatively low cost of these platforms, combined with perceptions of their military utility, are understood as being major factors contributing to the proliferation of these technologies.[368]

Table 5: Azerbaijan's Loitering Munitions[369]

Name	Purchased in	Estimated inventory
Harop	2014-2016	50
Orbiter 1K	2016-2019	80
SkyStriker	2016-2019, Azerbaijan have also manufactured this system domestically	100

Loitering munitions appear to have been used to strike Armenian ground targets including artillery positions, soldiers in assembly areas, armour, and logistic supply lines

Because of the wide range of uncrewed weapon systems in Azerbaijani military service, it is difficult to assess with certainty which loitering munitions may have been used in this conflict, whether these systems integrated automated, autonomous or AI technologies in targeting, and if the use of these platforms led to losses of life. Yet, due to their widespread use, drone and loitering munition strikes will likely account for a share of the 4,000 Armenian soldiers killed in this conflict.[370] Open-source intelligence suggests that Azerbaijan's loitering munitions contributed to significant Armenian military losses including tanks, infantry fighting vehicles, self-propelled artillery, multiple rocket launchers, surface-to-air missile systems, radars, trucks, and jeeps.[371] Yet, such open-source intelligence does not specify the types of loitering munitions used to conduct these particular strikes. This means that any of the systems in Azerbaijan's possession could conceivably have been used.[372] At first, Azerbaijan appears to have used loitering munitions primarily to destroy Armenian radars and SAM (surface-to-air-missile) launchers. As the war progressed, loitering munitions appear to have been used to strike Armenian ground targets including artillery positions, soldiers in assembly areas, armour, and logistic supply lines.[373]

The Harop seems to have played a prominent role in this conflict.[374] According to Hikmet Hajiyev, an Azerbaijani foreign policy advisor, the platform had been "very effective[ly]" used against the Armenian military during this conflict.[375] The Harop is designed to home in on radar-emitting targets including air defence systems. The platform has electro-optical and infrared cameras allowing it to strike a wider

366 Dixon, "For Azerbaijan, Drones Proves Decisive in Contested Enclave"; Postma, "Drones over Nagorno-Karabakh."

367 Dixon, "For Azerbaijan, Drones Proves Decisive in Contested Enclave."

368 Malcolm Davis, "Cheap Drones versus Expensive Tanks: A Battlefield Game-Changer," RealClear Defense, October 22, 2020, https://www.realcleardefense.com/articles/2020/10/22/cheap_drones_versus_expensive_tanks_a_battlefield_game-changer_581536.html; Richard Walker, "Germany Warns: AI Arms Race Already Underway," Deutsche Welle, June 7, 2021, https://www.dw.com/en/artificial-intelligence-cyber-warfare-drones-future/a-57769444.

369 SIPRI, "SIPRI Arms Transfers Database."

370 Franke, "Auf Dem Weg in Den Autonomen Krieg."

371 Oryx, "The Fight for Nagorno-Karabakh: Documenting Losses on the Sides of Armenia and Azerbaijan," Oryx, September 27, 2020, https://www.oryxspioenkop.com/2020/09/the-fight-for-nagorno-karabakh.html.

372 Dixon, "For Azerbaijan, Drones Proves Decisive in Contested Enclave."

373 Barrie et al., "Armed Uninhabited Aerial Vehicles and the Challenges of Autonomy," 7; Gustav Gressel, "Military Lessons from Nagorno-Karabakh: Reason for Europe to Worry," European Council on Foreign Relations, November 24, 2020, https://ecfr.eu/article/military-lessons-from-nagorno-karabakh-reason-for-europe-to-worry/; Frank-Stefan Gady and Alexander Stronell, "What the Nagorno-Karabakh Conflict Revealed about Future Warfighting," World Politics Review, November 19, 2020, https://www.worldpoliticsreview.com/articles/29229/what-the-nagorno-karabakh-conflict-revealed-about-future-warfighting.

374 Postma, "Drones over Nagorno-Karabakh," 16.

375 Quoted in The Times of Israel, "Azerbaijan Praises 'Very Effective' Israeli Drones in Fighting with Armenia," The Times of Israel, September 30, 2020, https://www.timesofisrael.com/liveblog_entry/azerbaijan-praises-very-effective-israeli-drones-in-fighting-with-armenia/.

set of targets, including in populated areas, giving human operators the capacity to abort a strike.[376] Weighing 135kg, the Harop is significantly larger than loitering munitions such as the STM Kargu-2 used in Libya. It also has a much wider range of 200km and an operational endurance of 9 hours.[377]

Video footage posted online suggests that the Harop was utilised in October 2020 to destroy the 36D6 Tin Shield radar used as part of an Armenian operated S-300 air defence system.[378] The Harop is also suspected to have been used to strike S-300 air defence systems as part of an operation in which the Azerbaijani military used converted Antonov An-2 biplanes as bait to draw out the location of Armenian radars.[379] As Joël Postma explains:

> *Azerbaijan reportedly converted a number of old Soviet Antonov-2 biplanes into remotely piloted vehicles and flew them into the range of Armenia's air defenses. As the air defense systems, such as SA-8 Gecko, SA-13 Gopher and SA-10 Grumble, tracked, and engaged the AN-2s, the HAROP picked up the radar signal and self-destroyed into the target.*[380]

Because of its use of an electro-optical guidance system, the IAI characterises the Harop as a "human-in-the-loop" system.[381] This contrasts with the IAI Harpy, a predecessor system to the Harop, which is described as "a fire and forget autonomous weapon" that can strike pre-programmed targets without human assessment.[382] In the case of the Harop, the operator "directs the selected [platform] to the target area and uses the video image to select a target, and to attack it".[383] Despite this, analysts have described the Harop as an "anti-radiation weapon that autonomously homes in on radar emitters."[384] It may be that the Harop has the technical capability to strike targets without human assessment, but is currently operated with a "human-in-the-loop".

Other media reports point to the Azerbaijani use of the Orbiter 1K[385] and the SkyStriker during this conflict. Footage posted on social media in October 2020 appears to show an Azerbaijani Orbiter-1K platform having crashed in (or having been disabled over) Nagorno-Karabakh,[386] as well as to support a strike against an Armenian artillery position.[387] There are unconfirmed reports that the Azerbaijani military also deployed its fleet of SkyStriker loitering munitions during this

376 Stefano D'Urso, "Let's Talk About the Israel Air Industries Loitering Munitions and What They're Capable Of," The Aviationist, January 7, 2022, https://theaviationist.com/2022/01/07/iai-loitering-munitions/.

377 IAI, "HAROP Loitering Munition System."

378 Military News, "Armenian S-300 Being Destriyed by Azerbaijan Drone IAI Harop Israel," YouTube, October 9, 2020, https://www.youtube.com/watch?v=IaLeYemgLjc; Global Defense Corp, "Azerbaijan Uses Harpy-2 Drone to Destroy Another S-300 SAM Site in Armenia," Global Defense Corp, October 26, 2020, https://www.globaldefensecorp.com/2020/10/26/azerbaijan-used-harpy-2-drone-to-destroy-another-s-300-sam-site-in-armenia/.

379 Ragip Soylu, "Azerbaijan-Armenia Conflict: How Baku Destroyed Russian S-300s with Israeli Suicide Drones," Middle East Eye, March 3, 2021, https://www.middleeasteye.net/news/azerbaijan-armenia-russia-israel-suicide-drones-destroy.

380 Postma, "Drones over Nagorno-Karabakh," 16.

381 IAI, "HAROP Loitering Munition System."

382 D'Urso, "Let's Talk About the Israel Air Industries Loitering Munitions and What They're Capable Of."

383 IAI, "HAROP Loitering Munition System."

384 Postma, "Drones over Nagorno-Karabakh," 16.

385 Zachary Kallenborn, "Drones Are Proving to Have a Destablizing Effect," RealClear Defense, December 9, 2020, https://www.realcleardefense.com/2020/12/09/drones_are_proving_to_have_a_destabilizing_effect_652512.html; L-L Dao, T Werkmeister, and J-P Tarani, "Haut-Karabakh: Israel Fournit Bien Des Drones à l'Azerbaidjan Pour Frapper Des Cibles Arméniennes," Franceinfo, October 17, 2020, https://www.francetvinfo.fr/monde/israel/video-haut-karabakh-israel-fournit-bien-des-drones-a-lazerbaidjan-pour-frapper-des-cibles-armeniennes_4144151.html.

386 Rob Lee, "Looks like an Israeli-Made Orbiter-1K or Orbiter 2 UAV Crashed in Nagorno-Karabakh," Twitter, October 4, 2020, https://twitter.com/ralee85/status/1312757203087044610.

387 Seth J. Frantzman, "How Azerbaijan's Drones Show What the Future of War Looks Like," Newsweek, October 7, 2020, https://www.newsweek.com/how-azerbaijans-drones-show-what-future-war-looks-like-opinion-1536487; Abraxas Spa, "Orbiter 1K Confirmed in Use," Twitter, October 1, 2020, https://twitter.com/AbraxasSpa/status/1311587269602611200?ref_src=twsrc%5Etfw%7Ctwcamp%5Etweetembed%7Ctwterm%5E1311587269602611200%7Ctwgr%5E%7Ctwcon%5Es1_&ref_url=https%3A%2F%2Fwww.jpost.com%2Fmiddle-east%2Fisraeli-drones-in-azerbaijan-raise-questions-on-use-in-the-battlefied-644161.

conflict.[388] Some claim that the SkyStriker was "extensively used ... to strike moving targets including armoured personnel carriers".[389] According to Oryx's open-source analysis of Azerbaijani military losses during this conflict, three SkyStriker platforms had crashed and had been captured.[390]

The Orbiter 1K weighs 13kg, has a range of 100km and an operational endurance of 2,5 hours.[391] At 35kg, the SkyStriker has a range of 100km while its operational endurance ranges from 1-2 hours, depending on the weight of the warhead it is equipped with.[392] These are significant ranges, underlining that these platforms can have wide area effects. Further, the Orbiter 1K is explicitly designed for "missions against soft-shell and human targets" in infantry and special operations contexts.[393]

Orbiter 1-K in air.
Source: Wikimedia Commons

There are different reports about the degree to which automated and autonomous technologies are integrated into the Orbiter 1K's and the SkyStriker's targeting. Like the IAI Harop, these suggest that, via the use of target recognition software, these platforms could possibly be technically capable of striking targets without human assessment but, in practice, are currently operated in line with "human-in-the-loop" principles. Elbit Systems, the SkyStriker's manufacturer describes the platform as a "fully autonomous LM [loitering munition] that can locate, acquire and strike operator-designated targets".[394] A human operator reportedly visually inspects targets before the SkyStriker conducts attacks in a process that is described as "really just dragging an icon on the screen".[395] Human operators can also "abort a strike up to two seconds to impact".[396] The Orbiter 1K is described as a "[human]-in-the-loop guidance system whereby the operator is either actively flying or otherwise monitoring the video feeds from the drone and they can see what it sees throughout the mission".[397] Early media coverage given to the Orbiter 1K noted that the platform as being capable of "independently scanning [a given area], detecting a target and then destroying it".[398]

In sum, the 2020 Nagorno-Karabakh War saw the widespread deployment of different types of loitering munitions. Fighting in the war also extended to populated areas,[399] but it is uncertain whether loitering munitions were used in these environments. The precise quality of human control exercised in these scenarios is, once again, uncertain. The manufacturers of the Harop, Orbiter 1K,

388 Neelam Mathews, "Threatened India Issues Flurry of UAV Orders," Shephard, September 9, 2021, https://www.shephardmedia.com/news/air-warfare/threatened-india-issues-flurry-uav-orders/.

389 Snehesh Alex Philip, "Army Orders over 100 Indo-Israeli Kamikaze Drones amid Active LAC and Precarious LoC," ThePrint, September 3, 2021, https://theprint.in/defence/army-orders-over-100-indo-israeli-kamikaze-drones-amid-active-lac-and-precarious-loc/727508/.

390 Oryx, "The Fight for Nagorno-Karabakh: Documenting Losses on the Sides of Armenia and Azerbaijan."

391 Aeronautics, "Orbiter 1K MUAS" (Aeronautics, November 2019), https://cp-aeronautics.com/wp-content/uploads/2019/11/Orbiter-1k.pdf.

392 Elbit Systems, "Sky-Striker. Tactical Loitering Munitions for Covert and Precise Airstrikes."

393 Aeronautics, "Orbiter 1K Loitering Munition UAS" (Aeronautics), accessed February 1, 2023, https://aeronautics-sys.com/wp-content/themes/aeronautics/pdf/Orbiter_1K_Brochure_EN_web1.pdf.

394 Elbit Systems, "Sky-Striker. Tactical Loitering Munitions for Covert and Precise Airstrikes."

395 Elbit Systems official quoted in Sebastian Sprenger, "Elbit Systems Pitches SkyStriker Drone in Emerging Market of Loitering Munitions," DefenseNews, June 21, 2017, https://www.defensenews.com/digital-show-dailies/paris-air-show/2017/06/21/elbit-systems-pitches-skystriker-drone-in-emerging-market-of-loitering-munitions/.

396 Elbit Systems, "Elbit Systems at Farnborough 2018: COTS for Military Platforms, VR Tour of IAF's MTC and Airborne Self Protection," Elbit Systems, July 4, 2018, https://elbitsystems.com/pr-new/elbit-systems-at-farnborough-2018-cots-for-military-platforms-vr-tour-of-iafs-mtc-and-airborne-self-protection/.

397 Joseph Trevithick, "Israeli Company Allegedly Flew a Suicide Drone on a Real Combat Mission in Azerbaijan," The Warzone, August 30, 2018, https://www.thedrive.com/the-war-zone/23270/israeli-company-allegedly-flew-a-suicide-drone-on-a-real-combat-mission-in-azerbaijan.

398 Arie Egozi, "Aeronautics Introduces Orbiter 1K Loitering Munition," FlightGlobal, May 21, 2015, https://www.flightglobal.com/civil-uavs/aeronautics-introduces-orbiter-1k-loitering-munition/116974.article.

399 Amnesty International, "In the Line of Fire: Civilian Casualties from Unlawful Strikes in the Armenian-Azerbaijani Conflict over Nagorno-Karabakh," January 14, 2021, https://www.amnesty.org/en/documents/eur55/3502/2021/en/.

and SkyStriker describe these systems as being operated in line with "human in-the-loop" principles. Nevertheless, there are possible indications that these systems are technologically capable of engaging targets without human assessment.[400] The range (max. 100 km, SkyStriker; max. 100 km, Orbiter 1K; max 200km, Harop) and operational endurance of these systems (max. 2 hours, SkyStriker; max. 2.5 hours, Orbiter 1K; max. 9 hours, Harop) underline trends towards greater system mobility. Given that one of the systems used, the Orbiter 1K, is specifically designed for anti-personnel missions, these long radiuses indicate that objects and personnel in a wide area could be identified as targets.

Table 6: Nagorno-Karabakh in 2016 – The first use of loitering munitions in combat?

The first combat use of a loitering munition is suspected to have occurred in April 2016 during a flare-up of the unresolved territorial dispute between Azerbaijan and Armenia over Nagorno-Karabakh.[401] Footage published online appears to show an Azerbaijani Harop operating over Nagorno-Karabakh.[402] Artsrun Hovhannisyan, then spokesman for Armenia's Defence Ministry, reported in a media interview that the Azerbaijani military had used the Harop to strike a bus carrying Armenian military volunteers, killing seven.[403] The Harop is capable of autonomous flight to its loitering area at which point the operator manually selects a target for the platform to strike.[404] But there are question marks about the quality of human control exercised in this instance. Without knowing the particularities of the strike, it is difficult to assess whether the seven Armenian military volunteers constitute "[...] the first ever to be killed by a killer robot".[405]

5.3 Russia's War in Ukraine (Feb 2022-)[406]

Loitering munitions have been used on both sides of the ongoing War in Ukraine. The Russian military has deployed its domestically manufactured KUB-BLA and Lancet-3, as well as a modified version of the Iranian-manufactured Shahed-136 (renamed Geranium-2), while Ukraine has reportedly used Polish-manufactured Warmates, Australian-manufactured Drone40s, as well as Switchblades (both 300 and 600) and Phoenix Ghosts received from the US.

Russian Operated Loitering Munitions

Manufactured by ZALA Aero, the unmanned aircraft systems (UAS) division of the Kalashnikov Group, KUB-BLA systems have been operational since 2019,[407] after having reportedly been tested by the Russian military in Syria between 2015-2018.[408] When ZALA Aero received permission to export this platform,[409] marketing

400 Watts and Bode, "Automation and Autonomy in Loitering Munitions Catalogue (v.1)", 12, 25, 50.

401 Thomas Gibbons-Neff, "Israeli-Made Kamikaze Drone Spotted in Nagorno-Karabkh Conflict," The Washington Post, April 5, 2016, https://www.washingtonpost.com/news/checkpoint/wp/2016/04/05/israeli-made-kamikaze-drone-spotted-in-nagorno-karabakh-conflict/.

402 Mike Eckel, "Nagorno-Karabakh Witnesses Debut Of 'Kamikaze Drone,'" RadioFreeEurope, April 6, 2016, https://www.rferl.org/a/nagorno-karabakh-kamikaze-drone-debut/27658645.html.

403 Eckel; David Hambling, "Frontline Tech: How Could Loitering Munitions Change The Battlefield?," Forces Net, April 6, 2016, https://www.forces.net/technology/frontline-tech-how-could-loitering-munitions-change-battlefield; Haaertz, "Report: Israeli-Made Suicide Drone Used in Nagorno-Karabakh Conflict," Haaertz, April 6, 2016, https://www.haaretz.com/israel-news/report-israeli-made-suicide-drone-spotted-in-nagorno-karabakh-conflict-1.5428051.

404 IAI, 'Harop Loitering Munition System'.

405 Billy Perrigo, "A Global Arms Race for Killer Robots Is Transforming the Battlefield," Time, April 9, 2018, https://time.com/5230567/killer-robots/.

406 This section includes information up until January 2023. The authors want to thank Anna Nadibaidze for research assistance provided on this section, in particular via accessing Russian-language sources.

407 ZALA Aero, 'New Unmanned Combat Aerial System by ZALA Aero', 17 February 2019, https://en.kalashnikovgroup.ru/media/bespilotnye-letatelnye-apparaty/kontsern-kalashnikov-razrabotal-vysokotochnyy-udarnyy-bespilotnyy-kompleks-kub-bla.

408 Deagel.com, "KUB-BLA," Deagel.com, 2022, https://www.deagel.com/Defensive%20Weapons/KUB-BLA/a003856; Avia, "Российский Дрон-Камикадзе 'Куб-БЛА' Уничтожил Лидера Сирийских Террористов?," AVIA-PRO News, October 23, 2021, https://avia.pro/news/rossiyskiy-dron-kamikadze-kub-bla-unichtozhil-lidera-siriyskih-terroristov.

409 Potential customers of the KYB at USD 160,00 per unit could be "any CSTO members (e.g. Armenia), Belarus, Syria, and Russia's typical Middle Eastern and North African partners such as Egypt, Iraq, and Algeria", Elisabeth Gosselin-Malo, "KUB Loitering Munition May Find Role in Future Ukraine Conflict," Shephard, February 11, 2022, https://www.shephardmedia.com/news/air-warfare/kub-loitering-munition-may-find-role-in-future-ukr/?msclkid=6b662911b00311ec9bb97769c2a1d332.

material noted that “this drone already has a successful experience of combat use, confirmed in real conditions”.[410] In December 2021, reports by Russian state-owned news agencies claimed that KUB systems had been used to strike militants fighting in the Syrian province of Idlib.[411] The KUB has a range of 40km and an operational endurance of 30 minutes.[412] The platform is designed “to defeat remote ground targets”,[413] including infrastructure facilities.[414] The KUB can reportedly “only be used against static targets”.[415]

KUB system downed in Ukraine.
Source: armyinform.com.ua

In the War in Ukraine, photos of unexploded KUB platforms captured in Kyiv began circulating on social media sites such as Telegram[416] and Twitter[417] in March 2022.[418] In all photos circulated, the KUB is clearly recognisable, indicating that the system either malfunctioned or was downed by Ukrainian electronic warfare systems. These images showed that the KUB was armed with a fragmentation warhead.[419] Fragmentation warheads are “anti-personnel metal spheres [used] to maim and kill victims”[420] that disperse “pieces of the weapon or surrounding material around the point of detonation”.[421] In what is possibly the first reported sighting of a KUB in Ukraine on 12 March 2022, Ukrainian officials reported that the KUB “carried a kilogram of explosives with metal ball bearings” and “dropped over a tall building in Kyiv’s Podil area, setting the roof on fire”.[422] The historical Podil neighbourhood is in Kyiv’s city centre surrounded by many civilian sites including churches, monuments, museums, the oldest Ukrainian university, and apartment buildings.[423] Later footage released by the Russian Ministry of Defence shows the KUB in a strike on an Ukrainian-operated M777 howitzer.[424] Further, in June 2022, the state-run Russian news agency TASS reported that the KUB had been widely used by the Russian military in Ukraine.[425]

410 Kalashnikov press release quoted in UAS Vision, “Russia’s Loitering Ammunition KUB-E Cleared for Export,” UAS Vision, February 2, 2022, https://easy.telodig.com/content-https-www.uasvision.com/2022/02/02/russias-loitering-ammunition-kub-e-cleared-for-export/.

411 The New Arab Staff, “Russia Says Kamikaze Drone Tests in Norther Syria Complete amid Reports of Civilian Deaths,” The New Arab, December 17, 2021, https://english.alaraby.co.uk/news/russia-completes-kamikaze-drone-testing-northern-syria.

412 Army Technology, “Zala KYB Strike Drone, Russia,” Army Technology, January 12, 2023, https://www.army-technology.com/projects/zala-kyb-strike-drone-russia/.

413 ZALA Aero, “ZALA KYB-UAV,” Kalashnikov, 2022, https://zala-aero.com/en/production/bvs/kyb-uav/.

414 Svetlana Tsygankova, “Беспилотник-Камикадзе ‘КУБ-БЛА’ Рекомендовали к Принятию На Вооружение,” RGRU, August 30, 2022, https://rg.ru/2022/08/30/bespilotnik-kamikadze-kub-bla-rekomendovali-k-priniatiiu-na-vooruzhenie.html.

415 Quoted in Thomas Harding, “Russia’s KUB-BLA Kamikaze Drone Intercepted in Ukraine,” N UK, March 14, 2022, https://www.thenationalnews.com/world/uk-news/2022/03/14/russias-kub-bla-kamikaze-drone-intercepted-in-ukraine/?msclkid=2ed40b59b00611ecb3785642537186cc.

416 Pravda Gerashchenko, “На Подолі в Києві Відбувся Вибух, в Результаті Якого Сталося Загорання Приміщення Ощадбанку.,” Telegram, March 12, 2022, https://t.me/Pravda_Gerashchenko/3674.

417 Ukraine Weapons Tracker, “#Ukraine: The First Proof of Loitering Munitions Combat Use by the Russian Army.,” Twitter, March 12, 2022, https://twitter.com/UAWeapons/status/1502613919222976516?cxt=HHwWiMC-nb_ZrdopAAAA.

418 Ukraine Weapons Tracker, “#Ukraine: It Seems That Russian ZALA KYB ‘Kamikaze’ Drones Have Serious Problems with Detonation.,” Twitter, March 14, 2022, https://twitter.com/UAWeapons/status/1503437049596157961?cxt=HHwWkoC5tf6BpN0pAAAA; Ukraine Weapons Tracker, “#Ukraine: Another ZALA KYB ‘Kamikaze’ UAV (Loitering Munition) Crashed Today, Apparently Failing to Detonate Again.,” Twitter, March 20, 2022, https://twitter.com/UAWeapons/status/1505551250712059904?cxt=HHwWglCzndi45eQpAAAA; Ukraine Weapons Tracker, “#Ukraine: Another Russian ZALA KYB ‘Kamikaze’ UAV Fell down in #Kyiv Yesterday.,” Twitter, March 23, 2022, https://twitter.com/UAWeapons/status/1506587380232425478?cxt=HHwWjMC43a7PvOgpAAAA.

419 Ukraine Weapons Tracker, “#Ukraine: The First Proof of Loitering Munitions Combat Use by the Russian Army.”; Stefano D’Urso, “Russia Is Now Using Loitering Munitions in Ukraine,” The Aviationist, March 17, 2022, https://easy.telodig.com/content-https-theaviationist.com/2022/03/17/russia-loitering-munitions-in-ukraine/.

420 Brent M. Eastwood, “Putin’s Kamikaze Drones Are Going to War in Ukraine,” 1945, March 15, 2022, https://www.19fortyfive.com/2022/03/putins-kamikaze-drones-are-going-to-war-in-ukraine/?msclkid=b9af71e4b00b11ecbb35e4fae89675a7.

421 Simon Bagshaw, “Implementing the Future Declaration on Explosive Weapons in Populated Areas: Informing Changes to Military Policy and Practice” (London: Article 36, October 2021), 3, https://article36.org/wp-content/uploads/2021/10/explosive_weapons_28.10.21.pdf.

422 Fatima Shakeel, “Proof Has Emerged of Russia Using Suicide Drones in the Invasion of Ukraine,” Wonderful Engineering, March 14, 2022, https://wonderfulengineering.com/proof-has-emerged-of-russia-using-suicide-drones-in-the-invasion-of-ukraine/?msclkid=1757c5c1b00511ecaa8f1007032c67cc.

423 Harding, “Russia’s KUB-BLA Kamikaze Drone Intercepted in Ukraine.”

424 Varvara Koshechkina, “Минобороны Показало Уничтожение Американских Гаубиц На Украине Российским Дроном,” Lenta.ru, May 18, 2022, https://lenta.ru/news/2022/05/18/dron_kamikadze/.

425 TASS, “Kamikaze Drones Successfully Used in Russia’s Special Operation in Ukraine - Defense Firm,” TASS Russian News Agency, June 8, 2022, https://tass.com/defense/1462311.

Much of the discussion about the KUB in (English-language) news media and analysis asserts that the KUB "incorporates artificial intelligence visual identification (AIVI) technology for real-time recognition and classification of targets".[426] The source for these claims is a particular fact sheet by the Kalashnikov Group that speaks of AIVI as a system that ZALA Aero is developing.[427] But that fact sheet does not mention the KUB.[428] It is therefore unclear whether the KUB features AI technology in targeting. ZALA Aero has claimed that the KUB is "high precision" in nature, "intelligent" and "most effective" against air defence systems.[429] The Kalashnikov Group notes that the KUB strikes targets "based on target coordinates, which are set manually or based on an image from a target guidance payload".[430] These are important insights into human operators' role in the KUB's targeting process. The latter appears to include two modes: either the operators enter target coordinates that the system then strikes; or the operators preload images of target profiles that the KUB then searches for.[431] If used in the second mode, it is unclear, however, whether human operators assess a target object that has been identified as matching the pre-programmed target profile before the system launches a strike.

Russia has also deployed a second ZALA Aero Group manufactured loitering munition to Ukraine: weighing 12kg, the Lancet-3, a system with a range of 40 km and an operational endurance of 40 minutes.[432] According to open-source analysis, this platform can strike various objects including trucks, troop carriers, tanks, armoured fighting vehicles, air defence systems, and radar units.[433] The Lancet-3's targeting software appears to be primarily designed to strike stationary objects,[434] making entrenched Ukrainian troops potential targets.[435] Russian state-owned news agency RIA Novosti reports that the Lancet "[...] drones are used against Ukrainian troops entrenched in open-type fortifications, hiding in forest plantations or houses, according to howitzers' estimates".[436] The source goes on to explicitly mention that "drones with high-explosive or thermobaric warheads are used to hit manpower".[437] The Russian military appears to have primarily used the Lancet-3 to strike "high-value targets at long range".[438]

Lancet.
Source: Wikimedia Commons

As with the KUB, the Russian military appears to have rarely deployed the Lancet-3 during the invasion's early months, most likely due to "operational shortcomings or a lack of inventory".[439] The Lancet-3 has only been used in large numbers from

426 Army Technology, "Zala KYB Strike Drone, Russia."

427 Kalashnikov Media, "ZALA AERO Представила Новую Технологию На Основе Искусственного Интеллекта," Kalashnikov Media, August 27, 2019, https://kalashnikov.media/article/technology/zala-aero-predstavila-novuyu-tekhnologiyu-na-osnove-iskusstvennogo-intellekta.

428 See also Allen, "Russia Probably Has Not Used AI-Enabled Weapons in Ukraine, but That Could Change."

429 ZALA Aero, "New Unmanned Combat Aerial System by ZALA Aero," Kalashnikov, February 17, 2019, https://en.kalashnikovgroup.ru/media/bespilotnye-letatelnye-apparaty/kontsern-kalashnikov-razrabotal-vysokotochnyy-udarnyy-bespilotnyy-kompleks-kub-bla.

430 ZALA Aero, "ZALA KYB-UAV"; Kalashnikov Group, "KUB-BLA," Telegram, May 19, 2022, https://t.me/kalashnikovnews/747.

431 Global Security, "Kub-UAV Guided Munition," GlobalSecurity.org, 2023, https://www.globalsecurity.org/military/world/russia/kub-uav.htm; Kyle Mizokami, "Kalashnikov Is Getting into the Business of Self-Destructing Drones," Popular Mechanics, February 20, 2019, https://www.popularmechanics.com/military/aviation/a26414352/kalashnikov-kub-bla-drone/; Frank-Stefan Gady, "KUB Loitering Munitions Can Likely Be Operated with a Human-in-the-Loop," Twitter, March 18, 2022, https://twitter.com/HoansSolo/status/1504750094310064129.

432 Watts and Bode, "Automation and Autonomy in Loitering Munitions Catalogue (v.1)", 19.

433 Oryx, "Hit or Miss: The Russian Loitering Munition Kill List," Oryx, November 25, 2022, https://www.oryxspioenkop.com/2022/11/hit-or-miss-russian-loitering-munition.html.

434 Oryx, "Hit or Miss".

435 Stetson Payne, "Ukraine Situation Report: Russia Launches Rocket Attack on Kherson," The Warzone, December 24, 2022, https://www.thedrive.com/the-war-zone/ukraine-situation-report-russian-grad-rocket-attack-strikes-kherson.

436 RIA Novosti, "Источник: Против Украинской Армии Начали Применять Усиленные 'Ланцеты,'" RIA Novosti, July 21, 2022, https://ria.ru/20220721/lantset-1803923300.html.

437 RIA Novosti.

438 David Hambling, "Russian Loitering Munition Racks up Kills but Shows Limitations," Forbes, December 1, 2022, www.forbes.com/sites/davidhambling/2022/12/01/russian-loitering-munition-racks-up-kills-but-shows-limitations/?sh=58ce7f655d58.

439 Vijainder K. Thakur, "Russian Army Steps Up Use of 'Cuba' Kamikaze UAVs Along Entire Frontline as Russia-Ukraine 'Drone War' Intensifies," The EurAsian Times, October 29, 2022, https://eurasiantimes.com/russian-troops-step-up-use-of-kamikaze-cuba-drones-frontline/.

October 2022 onwards, chiefly in eastern and southern Ukraine.[440] The numbers of systems used have varied. In January 2023, Ukrainian Air Force Spokesman Yurii Ihnat claimed that the Ukrainian military had "shot down almost 500 drones" since September 2022,[441] a figure which includes platforms beyond loitering munitions. There is also uncertainty over how many remain in Russia's arsenal or can be produced in the future, as the sanctions' regime affects electronical components and processors used in Lancets.[442]

In October 2022, Russian media outlets claimed that the Russian military had "used several hundred domestic loitering munitions", especially KUBs and Lancets, to target "Ukrainian anti-aircraft missile systems as well as radar stations".[443] Open-source analysis conducted by *Oryx* found that the Lancet-3 had been used to strike various Ukrainian targets with varying degrees of accuracy.[444] In several videos depicting Lancet strikes, soldiers are shown to flee the area seconds before impact, suggesting that the platform is "highly audible or visible or both", allowing Ukrainian soldiers, reportedly, to also bring it down with small arms fire.[445]

Zala Aero report that the Lancet-3 can transmit video, allowing it to confirm successful target engagement.[446] The system is characterised as being "capable of autonomously locating and striking a given target"[447] and being designed to "autonomously conduct reconnaissance and attack targets".[448] Rostec similarly describe the Lancet-3 as a "high precision" weapon.[449] Equipped with an optical-electronic guidance unit and communication module, the Lancet-3 has a "human-in-the-loop" functionality which allows human operators to visually inspect targets before force is used.[450] The system reportedly also features "combined technology" allowing it to fly to a holding area and "use its camera to locate a target without human guidance".[451] In addition, reports about the use of "modernized" Lancet systems, the Lancet-3(M),[452] with an operational endurance of 60 rather than 40 minutes, appeared in Russian state media in July 2022.[453]

In mid-September 2022, reports began circulating about the Russian military's use of the Iranian designed uncrewed aerial platforms Shahed-131 and -136 (Russian names: Geran'-1 and Geran'-2).[454] Whether these systems should be classified as loitering munitions is debated. The Shaheds do not display design features that

440 Parth Satam, "'Impossible to Intercept,' Russia Claims Its Lancet Kamikaze UAVs Can Beat Laser Weapons That 'Fry' Drone Electronics," The EurAsian Times, November 3, 2022, https://eurasiantimes.com/impossible-to-intercept-russia-claims-its-lancet-kamikaze-drones/.

441 Felipe Dana, "Russia, Shaken by Ukrainian Strike, Could Step up Drone Use," AP News, January 3, 2023, https://apnews.com/article/putin-zelenskyy-politics-russia-government-ukraine-war-f57d7f47ca38d6b4ff57f8f382cec919.

442 Hambling, "Russian Loitering Munition Racks up Kills but Shows Limitations"; Allen, "Russia Probably Has Not Used AI-Enabled Weapons in Ukraine, but That Could Change."

443 RIA Novosti, "Источник Раскрыл Данные о Применении Российских Дронов-Камикадзе На Украине," RIA Novosti, October 20, 2022, https://ria.ru/20221020/svo-1825258182.html.

444 Oryx, "Hit or Miss: The Russian Loitering Munition Kill List."

445 David Hambling, "Russian Videos Reveal New Details of Its Loitering Munitions," Forbes, November 4, 2022, https://www.forbes.com/sites/davidhambling/2022/11/04/russian-videos-reveal-new-details-of-loitering-munitions/?ss=aerospace-defense&sh=3f20ab415dbc.

446 Kalashnikov Media, "Kalashnikov Presented Precision UAV Weapon Systems - ZALA LANCET," Kalashnikov, June 24, 2019, https://en.kalashnikovgroup.ru/media/bespilotnye-letatelnye-apparaty/kalashnikov-predstavil-vysokotochnyy-udarnyy-bespilotnyy-kompleks-zala-lantset.

447 ZALA Aero, "ZALA Lancet-3," Kalashnikov, 2022, https://zala-aero.com/en/production/bvs/zala-lancet-3/.

448 TASS, "Kamikaze Drones Successfully Used in Russia's Special Operation in Ukraine - Defense Firm."

449 Rostec, "Ударный Беспилотник «Ланцет»: Копье XXI Века," Rostec, August 30, 2019, https://rostec.ru/news/udarnyy-bespilotnik-lantset-kope-xxi-veka/.

450 Watts and Bode, "Automation and Autonomy in Loitering Munitions Catalogue (v.1)", 21-22.

451 David Hambling, "Russia Steps Up Kamikaze Drone Strikes As It Targets Ukraine's American Artillery (Updated)," Forbes, July 21, 2022, https://www.forbes.com/sites/davidhambling/2022/07/21/russia-steps-up-kamikaze-drone-strikes/?sh=11cae4684626.

452 Watts and Bode, "Automation and Autonomy in Loitering Munitions Catalogue (v.1)", 21.

453 RIA Novosti, "Источник: Против Украинской Армии Начали Применять Усиленные 'Ланцеты.'"

454 Nikita Sologub, "За Русь Взорвусь. Что Известно Об Иранских Дронах-камикадзе «Шахед», Которые Использует Российская Армия в Украине," Mediazona, October 19, 2022, https://zona.media/article/2022/10/19/shahed-geran.

are typical for most loitering munitions: the systems navigate using a preloaded set of GNSS coordinates.[455] When used in conjunction with ISR capable platforms, some suggest that the Shahed-136s can receive updated GNSS coordinates during flight.[456] As the Shaheds are not designed to loiter, we do not classify them as loitering munitions but as a "direct attack munition".[457] These systems are consequently not included in our catalogue. The use of Shaheds systems is still discussed here in order to provide a more complete empirical picture about Russian military operations using loitering munitions and similar systems in Ukraine.

Due to the lack of reliable information about the Iranian development of armed drones, very little was known about the Shaheds-131 and -136 systems before their purported use in Ukraine. For example, the *Jane's Unmanned Yearbook 2022-2023*, "often seen as the authoritative source on unmanned systems",[458] only includes the Shahed-129,[459] a system that is not a loitering munition but an armed drone resembling the Bayraktar-TB2. Nonetheless, the recovery and inspection of several systems in Ukraine has allowed more information about technical specifications to be reported.

The Shahed-131 is an earlier version of the Shahed-136: both are similar long-distance systems, they are both propeller-powered, equipped with a warhead weighing approximately 30-50kgs, have a simple auto-pilot system, and use GNSS-based guidance to hit fixed rather than moving targets via satellite coordinates.[460] The system's payload may include camera equipment.[461] The systems differ in their range, with 900km for the Shahed-131,[462] and up to 2,500 km for the Shahed-136.[463] The Shahed-136 is designed to strike various ground targets.[464]

The first visual confirmation of the Shahed-136s (designated in Russian military service as "Geran'-2") deployment to Ukraine was made on 13 September 2022.[465] Reports discussing the use of these platforms increased in October 2022, often to strike critical Ukrainian electricity infrastructure and other civilian but also military objects at a long distance.[466] On 17 October, Shahed-136s were used as part of a strike against a civilian apartment building in Kyiv, killing three people, including a pregnant woman.[467]

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455 Military Today, "Shahed 136," Military Today, 2023, http://www.military-today.com/aircraft/shahed_136.htm.

456 Sebastien Roblin, "Iran's Shahed-136 Kamikaze Drone: Everything You Need to Know," 1945, October 21, 2022, https://www.19fortyfive.com/2022/10/irans-shahed-136-kamikaze-drone-everything-you-need-to-know/.

457 Eric Sof, "HESA Shahed 136: A Cheap and Deadly Iranian Kamikaze Drone," Spec Ops Magazine, December 16, 2022, https://special-ops.org/hesa-shahed-136-kamikaze-drone/.

458 Joanna Frew, "Drone Wars. The Next Generation. An Overview of New Armed Drone Operators" (Oxford: Drone Wars UK, 2018), 11, https://dronewarsuk.files.wordpress.com/2018/05/dw-nextgeneration-web.pdf.

459 Janes, *Janes All the World's Aircraft: Unmanned* (S.L.: Jane's Information Group, 2022), 103–4.

460 Bronk, Reynolds, and Watling, "The Russian Air War and Ukrainian Requirements for Air Defence," 34; John Ismay, "'Loitering Munitions' from Iran Add to Skies Teeming with Drones," The New York Times, October 20, 2022, https://advance-lexis-com.proxy1-bib.sdu.dk/api/document?collection=news&id=urn:contentItem:66ND-CM41-JBG3-63T0-00000-00&context=1516831.; Leonid Nersisyan, "Iran and Russia Weigh Risks and Rewards from Potential UAV Deal," Shephard News, August 31, 2022, https://www.shephardmedia.com/news/uv-online/iran-and-russia-weigh-risks-and-rewards-from-potential-uav-deal/.

461 Defence Monitor Worldwide, "Russia Would Have Ordered from Iran around 2,000 Drones Including Loitering Munitions," Defence Monitor Worldwide, November 19, 2022, https://advance-lexis-com.proxy1-bib.sdu.dk/api/document?collection=news&id=urn:contentItem:66W6-S071-JDJN-6235-00000-00&context=1516831.

462 Seth G. Jones et al., "Combined Arms Warfare and Unmanned Aircraft Systems. A New Era of Strategic Competition" (Washington, DC: Center for Strategic & International Studies, November 2022), 47, https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/221110_Jones_CombinedArms_UASs.pdf?2xC7tI7AtaEEaNOG0AEKAOdjDsvYwHMn.

463 Army Recognition, "Shahed-136. Loitering Munition," Army Recognition, November 15, 2022, https://www.armyrecognition.com/iran_unmanned_ground_aerial_vehicles_systems/shahed-136_loitering_munition_kamikaze-suicide_drone_iran_data.html.

464 Sof, "HESA Shahed 136: A Cheap and Deadly Iranian Kamikaze Drone."

465 osint_east, "The Earliest Documented Use of the Shahed-136 in Ukraine Is Supposed to Have Occurred in Mid-August. Initial Visual Confirmation Was Made on September 13.," Twitter, n.d., https://twitter.com/osint_east/status/1586387498799751169?s=20&t=lZzcl9CBE8-eNDFyTIIXgA.

466 Bronk, Reynolds, and Watling, "The Russian Air War and Ukrainian Requirements for Air Defence," 32; Jeremy Binnie, "Ukraine Conflict: Details of Iranian Attack UAV Released," Janes, September 29, 2022, https://www.janes.com/defence-news/news-detail/ukraine-conflict-details-of-iranian-attack-uav-released.

467 John Ismay, "The Iranian Drones in Ukraine's Already Crowded Skies," The New York Times, October 19, 2022, https://www.nytimes.com/2022/10/19/us/politics/ukraine-drones-iran-russia.html.

Kyiv after Russian attack using Shahed-136 drones. **Source:** National Police of Ukraine

Russian forces are reported to have received 2,400 Shahed-136s from Iran[468] and the systems have since been widely used in Ukraine.[469] Open-source intelligence analysis suggests that a large proportion of Geran'-2 strikes were intercepted by Ukrainian air defences.[470]Another important difference between many of the loitering munitions included in our catalogue and the Shahed-131 and -136 is that the latter platforms are rarely used alone, but instead launched in groups of 10.[471] This, combined with their flight at low altitude,[472] makes it more challenging for air defence systems to destroy all of these platforms, and has led to multiple civilian casualties.[473] These (comparatively) cheap and expendable platforms (as of October 2022, more than 400 Shahed-136 have reportedly been used already)[474] are used in groups in the hope that such systems saturate Ukrainian air defence systems,[475] meaning that at least some of them will reach their target. By being used in groups while making a loud motor-like noise, they also take a psychological toll on Ukrainian civilians.[476] These patterns of use and the way they appear to be integrated into Russian strategy departs from the more sporadic uses of armed aerial systems and loitering munitions earlier in the war.[477]

Ukrainian Operated Loitering Munitions

Switchblades are manufactured in the US by AeroVironment and exist in two variants that differ in size and target type. The smaller variant, the Switchblade 300, first appeared in a tech demonstration in 2011,[478] while the development of the larger Switchblade 600 started in December 2020 in an effort to present a "new category of extended range loitering munitions".[479] The two variants differ in terms of their weight, size, and payload. Although both can be carried by one person, the Switchblade 600 and its components are significantly heavier.[480] Both systems are designed to strike both stationary and moving targets.[481] The variants also differ in their payload: the Switchblade 300 carries an Orbital ATK high-

468 Mark Didenko, "Russia Ordered 2,400 Iranian Suicide Drones, Zelenskyy Says," The New Voice of Ukraine, October 11, 2022, https://english.nv.ua/nation/zelensky-says-russia-ordered-2-400-iranian-suicide-drones-ukraine-news-50276038.html.

469 Military Today, "Shahed 136."

470 Roblin, "Iran's Shahed-136 Kamikaze Drone: Everything You Need to Know."

471 Bronk, Reynolds, and Watling, "The Russian Air War and Ukrainian Requirements for Air Defence," 35.

472 Jones et al., "Combined Arms Warfare and Unmanned Aircraft Systems. A New Era of Strategic Competition," 21.

473 UK Ministry of Defence, "Latest Defence Intelligence Update on the Situation in Ukraine - 12 October 2022," Twitter, October 12, 2022, https://twitter.com/DefenceHQ/status/1580055920351924224; Bronk, Reynolds, and Watling, "The Russian Air War and Ukrainian Requirements for Air Defence," 35.

474 Bronk, Reynolds, and Watling, "The Russian Air War and Ukrainian Requirements for Air Defence," 36.

475 John Hardie and Ryan Brobst, "Iranian Shahed-136 Drones Increase Russian Strike Capacity and Lethality in Ukraine," FDD's Long War Journal, October 18, 2022, https://www.longwarjournal.org/archives/2022/10/iranian-shahed-136-drones-increase-russian-strike-capacity-and-lethality-in-ukraine.php.

476 Sologub, "За Русь Взорвусь. Что Известно Об Иранских Дронах-камикадзе «Шахед», Которые Использует Российская Армия в Украине"; Morgan Meaker, "Ukraine Enters a Dark New Era of Drone Warfare," WIRED, October 21, 2022, https://www.wired.com/story/russia-ukraine-drones-shahed-136-iran/.

477 Bronk, Reynolds, and Watling, "The Russian Air War and Ukrainian Requirements for Air Defence," 33–34.

478 Army Technology, "Switchblade Tactical Missile System," Army Technology, April 8, 2022, https://www.army-technology.com/projects/switchblade-tactical-missile-system/.

479 Makayla Thomas, "AeroVironment Introduces Family of Loitering Missile Systems," AeroVironment, October 1, 2020, https://www.avinc.com/resources/press-releases/view/aerovironment-introduces-family-of-loitering-missile-systems-featuring-new.

480 Army Technology, "Switchblade Tactical Missile System."

481 AeroVironment, "Switchblade 300 Loitering Missile Data Sheet," AeroVironment, 2021, https://www.avinc.com/images/uploads/product_docs/Switchblade_300_FutureState_Datasheet_03312021.pdf.

explosive fragmentation warhead[482] that "relies on inert projectiles placed inside the warhead"[483] to primarily target personnel.[484] On 6 May 2022, the Ukrainian military released footage of what is supposedly the first use of a Switchblade 300 to strike a Russian position.[485] The Switchblade 600 is equipped with an anti-armour warhead designed to strike military vehicles.[486] The Switchblade 300 and -600 have an operational endurance of 15 and 40 minutes, respectively.[487] In July 2022, the US announced that it will supply a total of 700 Switchblade 300s and 10 Switchblade 600s to Ukraine,[488] commenting that Ukraine had specifically requested these platforms.[489] The delivery of the Switchblade 600s was delayed to the end of 2022.[490] In April 2023, news media reported the first use of Switchblade 600s in Ukraine.[491]

Soldier launches Switchblade-300 during a training exercise.
Source: U.S. Marine Corps

Switchblades have reportedly been used by US special operations forces in Afghanistan, Iraq, and Syria, but the extent of their usage in combat is unclear because it has not been made public.[492] However, in 2015, an US acquisition personnel was honoured for "the successful delivery of more than 4,000 Switchblade All Up Rounds," thereby providing accidental insights into the scale of their operation in Afghanistan.[493] The US trained some Ukrainian military personnel who were in the US when the Russian invasion of Ukraine began. While the extent of the training provided is unclear, a US defence official noted that "some minimal training for knowledgeable UAS operators" was needed to operate these systems and that "we're going to be working through those training requirements directly with the Ukrainian Armed Forces".[494]

The Switchblade 300 can be guided manually through remote piloting via a camera feed[495] but is also capable of autonomous flight via a type of GPS waypoint

482 Janes, "AeroVironment Switchblade," in *Janes All The World's Aircraft: Unmanned* (S.L.: Jane's Information Group, 2022), 279.

483 Northrop Grumman News, "Oribtal ATK's LEO Warhead - the Alternative to Cluster Munitions," Northrop Grumman, March 16, 2016, https://news.northropgrumman.com/news/features/orbital-atks-leo-warhead-the-alternative-to-cluster-munitions.

484 Kelsey D. Atherton, "Everything to Know about Switchblades, the Attack Drones the US Is Giving Ukraine," Task & Purpose, March 24, 2022, https://taskandpurpose.com/analysis/switchblade-attack-drone-ukraine/.

485 The Shephard News Team, "Ukraine Strikes with Switchblade," Shephard News, May 9, 2022, https://www.shephardmedia.com/news/uv-online/ukraine-strikes-with-switchblade/.

486 Army Technology, "Switchblade Tactical Missile System."

487 Janes, "AeroVironment Switchblade," 281.

488 Gosselin-Malo, "Loitering Munitions in Ukraine: Not Game-Changing, but Headache-Inducing."

489 Amanda Macias, "US Send 100 Killer Drones Called Switchblades to Ukraine," CNBC, March 30, 2022, https://www.cnbc.com/2022/03/30/us-sends-100-killer-drones-called-switchblades-to-ukraine.html.

490 Stephen Losey, "Switchblade Kamikaze Drone Production to Ramp up Following Ukraine Use," Defense News, October 11, 2022, https://www.defensenews.com/digital-show-dailies/ausa/2022/10/11/switchblade-kamikaze-drone-production-to-ramp-up-following-ukraine-use/.

491 Sebastien Roblin, "Watch the First Confirmed Use of a Tank-Busting Switchblade-600 Drone in Ukraine," Popular Mechanics, April 21, 2023, https://www.popularmechanics.com/military/weapons/a43660797/first-confirmed-use-tank-busting-switchblade-600-drone-in-ukraine-video/.

492 Slav Kandyba, "New Drone-Missile Hybrid Deployed in Afghanistan," iTech Post, December 3, 2013, https://www.itechpost.com/articles/6481/20130312/new-drone-missile-hybrid-deployed-afghanistan.htm; Hambling quoted in Giulia Carbonaro, "How Switchblade Drones Could Turn the Tide of Ukraine War," Newsweek, March 17, 2022, https://www.newsweek.com/switchblade-drones-ukraine-war-russia-1688906.

493 Sofia Bledsoe, "PEO Workers Receive Army Acquisition Awards," US Army, May 11, 2015, https://www.army.mil/article/148323/PEO_workers_receive_Army_acquisition_awards.

494 John Kirby quoted in Tara Copp, "Kyiv Asked for a New Kamikaze Drone to Fight Russia. The Air Force Delivered Phoenix Ghost," Defense One, April 21, 2022, https://www.defenseone.com/technology/2022/04/kyiv-asked-new-kamikaze-drone-fight-russia-air-force-delivered-phoenix-ghost/365945/.

495 David Hambling, "Drones on Their Way to Ukraine: Here's What We Know about Them," Forbes, March 17, 2022, https://www.forbes.com/sites/davidhambling/2022/03/17/shadowy-switchblade-munition-on-its-way-to-ukraine/?sh=6b8e6eb85e13.

navigation.[496] When operated manually, the system "provides the operator with real-time video and Cursor-on-Target GPS coordinates for information gathering, targeting, or feature/object recognition".[497] The Switchblade is equipped with ISR sensors (including cameras) and image processing, i.e. software designed for feature and object recognition.[498] AeroVironment describes the Switchblades as "human-in-the-loop" systems as the platforms require "positive target confirmation" before a strike.[499] Moving forward, AeroVironment's President & CEO, Wahid Nawabi, suggested that the system may be capable of "select[ing] targets autonomously with minimal support by human-in-the-loop'".[500] As the technology reporter Hambling remarks, "the operator may do little more than confirm a target located by the smart weapon, requiring only a brief burst of communication rather than continuous control".[501]

Soldier prepares Switchblade-300 for launch.
Source: U.S. Marine Corps

In addition to the Switchblade 300, the US has supplied Ukraine with newly developed Phoenix Ghost loitering munitions.[502] The first 121 of these platforms were delivered in April 2022 and the US has since reportedly provided Ukraine with a steady supply.[503] The US Air Force had been jointly developing this platform in collaboration with Aevex Aerospace before the invasion.[504] The Phoenix Ghosts has been described as having a similar tactical role and set of targets as the Switchblades.[505] Such platforms have therefore been used to strike Russian mortar positions and "medium-armoured targets".[506] Yet, the Phoenix Ghost has a long-endurance loitering capability of up to six hours, while the Switchblade 600 can loiter for up to one hour.[507] There is still very little information available about the extent to which automated and autonomous technologies are part of the Phoenix Ghost's targeting system. The Phoenix Ghost operates via infrared guidance.[508] Ukrainian operators of the Phoenix Ghost appear to have done a week-long training course.[509]

496 AeroVironment, "Switchblade 300," AeroVironment, 2022, https://www.avinc.com/tms/switchblade.

497 AeroVironment, "Switchblade 300 Loitering Missile Data Sheet."

498 Janes, "AeroVironment Switchblade," 279.

499 Mike Ball, "AeroVironment Unveils New Loitering Missile System," Defense Advancement, October 7, 2020, https://www.defenseadvancement.com/news/aerovironment-unveils-new-loitering-missile-system/.

500 David Hambling, "AeroVironment Aims to Disrupt Industry with New Loitering Missile," Forbes, October 1, 2020, https://www.forbes.com/sites/davidhambling/2020/10/01/new-loitering-missile-aims-to-destroy-targets-and-disrupt-industry/?sh=1aef95d5390f.

501 David Hambling, "AeroVironment Aims to Disrupt Industry with New Loitering Missile".

502 Flavia Camargos Pereira, "US Military Assistance to Ukraine Approaches USD 10 Billion," Shephard News, August 11, 2022, https://www.shephardmedia.com/news/landwarfareintl/us-military-assistance-to-ukraine-approaches-10-billion/.

503 US Department of Defense, "Senior Defense Official Holds a Background Briefing," US Department of Defense, July 22, 2022, https://www.defense.gov/News/Transcripts/Transcript/Article/3103383/senior-defense-official-holds-a-background-briefing/.

504 Jon Harper, "New Phoenix Ghost Drone Was 'Big Safari' Project," FedScoop, May 6, 2022, https://www.fedscoop.com/new-phoenix-ghost-drone-was-big-safari-project/.

505 US Department of Defense, "Senior Defense Official Holds a Background Briefing."

506 David Hambling, "Has Elusive 'Phoenix Ghost' Loitering Munition Broken Cover at Last?," Forbes, August 2, 2022, https://www.forbes.com/sites/davidhambling/2022/08/02/has-elusive-phoenix-ghost-loitering-munition-broken-cover-at-last/.

507 Hannah Fuchs, "How Drones Are Changing the Way of War," Deutsche Welle, May 9, 2022, https://www.lrt.lt/en/news-in-english/19/1688905/how-drones-are-changing-the-way-of-war; Jones et al., "Combined Arms Warfare and Unmanned Aircraft Systems. A New Era of Strategic Competition," 20.

508 Ashley Roque and Gillian Rose, "Ukraine Conflict: Pentagon Sending New 'Suicide' Drone, Additional Artillery," *Janes Defence Weekly*, April 22, 2022.

509 Max Hauptman, "What Is Phoenix Ghost, the Secretive Loitering Munition the Pentagon Is Sending to Ukraine," Task & Purpose, May 2, 2022, https://taskandpurpose.com/news/phoenix-ghost-secretive-loitering-munition-pentagon-sending-ukraine/.

Finally, Australia has supplied Ukraine with another type of loitering munition, 300 Drone40s, in August 2022.[510] Weighing 0.2kg, the Drone40 has a range of 20km and an operational endurance of 60 minutes.[511] Equipped with a fragmentation warhead, the Drone40 is designed to both strike personnel and armoured military objects.[512] Analysts note the Drone40's potential use in populated areas.[513] The Drone40 includes autonomous technology to support targeting allowing the system, for example, to identify and track the radar profiles of objects such as T-72 tanks.[514] The system has been characterised as "human-in-the-loop" when equipped with ISR sensors allowing human operators to follow the platform's video feed.[515] Further, DefendTex CEO Travis Reddy has stated that the "weapon system will never be autonomous, fully acquire and prosecute target without authorisation and confirmation from the human".[516] Given the growing range of loitering munitions already used by Ukraine and the fact that the Pentagon has invited companies "making or considering making" weapons similar to the Switchblade "to see if their new weapon can prove useful in the hands of Ukraine's military", more loitering munitions of similar types are likely to be used in the war in Ukraine.[517]

Both sides have used loitering munitions much more pervasively and frequently in the war in Ukraine, featuring at least six different platforms designed to strike personnel and a wide range of objects

In sum, compared to the previous cases discussed, both sides have used loitering munitions much more pervasively and frequently in the war in Ukraine, featuring at least six different platforms designed to strike personnel and a wide range of objects: the Drone40, the KUB-BLA, the Lancet-3, the Phoenix Ghost, the Switchblade 300, and the Warmate. The loitering munitions used in Ukraine have different ranges and operational endurance. To illustrate, the Switchblade 300 has a range of about 10km and can remain airborne for about 15 minutes, the Lancet-3 can remain airborne for 40 minutes, and the Phoenix Ghost for up to six hours. Again, this underlines trends towards greater system mobility. The (comparatively) large combat radius of some of these systems (particularly the Lancet-3 and the Phoenix Ghost) indicates that objects and personnel in a wide geographical area could become targets.

The manufacturers of these systems report that they are operated in line with "human in-the-loop" principles.[518] Nevertheless, the ability of human operators to exercise control over these systems is contingent on first, whether the human operator can watch the system's video feed[519] and second, whether they have sufficient situational awareness to make properly informed targeting decisions.[520] Military personnel launching these systems through pneumatic launch canisters comparable to mortars[521] are likely to be in close proximity to frontline fighting.

510 MilitaryLeak, "Australia to Deliver 300 DefendTex D40 Kamikaze Drones to Ukraine," MilitaryLeak - Breaking Military News and Defense Technology, August 26, 2022, https://militaryleak.com/2022/08/26/australia-to-deliver-300-defendtex-d40-kamikaze-drones-to-ukrainia/.

511 Technology.org, "Flying Mines DefendTex D40 Small, but Capable of Destroying Anything, Even Tanks," Technology.org Science and Technology News, August 23, 2022, https://www.technology.org/2022/08/23/flying-mines-defendtex-d40-small-but-capable-of-destroying-anything-even-tanks/.

512 Technology.org, "Flying Mines DefendTex D40".

513 Joseph Trevithick, "British Troops Get Small Swarming Drones They Can Fire from 40mm Grenade Launchers," The War Zone, February 3, 2021, https://www.thedrive.com/the-war-zone/38909/British-troops-get-small-swarming-drones-they-can-fire-from-40mm-grenade-launchers.

514 Atherton, "A Drone with a Can-Doom Attitude."

515 Atherton, "A Drone with a Can-Doom Attitude".

516 Quoted in Atherton, "A Drone with a Can-Doom Attitude".

517 Kelsey D. Atherton, "What We Know about the Phoenix Ghost Drones Going to Ukraine," Popular Science, April 28, 2022, https://www.popsci.com/technology/phoenix-ghost-drone-explained/?msclkid=36ad0832d0ff11ec9abe0e7726bf7fe8.

518 Observations made in this and the following paragraph are not singularly problematic for the use of loitering munitions but also apply to other types of crewed/uncrewed systems. The authors wish to thank Dan Gettinger for this observation.

519 Atherton, "Everything to Know about Switchblades, the Attack Drones the US Is Giving Ukraine."

520 Arthur Holland Michel, "Tweet With Reports That Kamikaze Drones Are Entering the Fray in Ukraine…," Twitter, March 18, 2022, https://twitter.com/WriteArthur/status/1504834614833127427.

521 Stavros Atlamazoglou, "The Lastest US Weapon Heading to Ukraine: A 2-Foot Long, 5-Pound Drone Designed for One-Way Missions," Business Insider, March 21, 2022, https://www.businessinsider.com/us-sends-ukraine-loitering-drones-for-kamikaze-attacks-on-russia-2022-3?r=US&IR=T.

Soldier retrieves Drone40 during a training exercise. **Source:** U.S. Marine Corps

This proximity could significantly impact their capacity to critically scrutinise targets suggested to them by the platform's target recognition software.

Whether human operators have the requisite mental space to question machine-prompted targets in time constrained environments is a major concern of previous research on air defence systems. Failures such as the Patriot fratricides in the 2003 Iraq War underline that high-pressure combat situations can exacerbate the challenges inherent to human-machine interaction.[522] In pressured combat situations where human operators are close to frontline fighting, a lack of time for deliberation may combine with automation bias, leading human operators to uncritically trust target prompts without questioning or scrutinising them in sufficient detail.[523]

In addition, it is significant that KUB and Lancet platforms have been found in populated areas. Some military analysts have actively called for providing more close-range loitering munitions such as the Switchblade to Ukraine because these are particularly "valuable" for urban warfare operations. They are said to "blend the ability to manoeuvre, conduct surveillance, and strike targets into a single platform, reducing the time between detection and engagement of a target".[524] US military sources also argue that they are "a good option for urban warfare because they can be very precise and avoid collateral damage".[525] The Switchblade originates in the 2004 Defense Advanced Research Projects Agency's programme called Confirmatory Hunter Killer[526] that was specifically developed for urban combat operations.[527] Two other systems whose manufacturers mention their application in populated areas, the Australian Drone40 and the Polish Warmate, have also been used in Ukraine.[528]

Further, like policy discourse after the 2020 Nagorno-Karabakh War, we are seeing a 'hype' around the greater usage of loitering munitions in Ukraine. Security analyst Samuel Bendett refers to the Switchblade as "a key mission multiplier by having every Russian tank, armoured vehicle, or personnel position as a potential target".[529] Other voices go even further in highlighting the (perceivably) transformative effects of these weapons: "the tank – which used to be the king of the battlefield – is now playing second [fiddle] to missile systems that did not exist a couple of years ago".[530] Such claims often draw significant criticism.[531] However, the discourse that "future conflicts are going to rely heavily

522 Bode and Watts, "Meaning-Less Human Control. The Consequences of Automation and Autonomy in Air Defence Systems," 56–58.

523 Bode and Watts, "Meaning-Less Human Control," 59.

524 Ryan Brobst and Bradley Bowman, "Ukraine Is Getting Switchblade. It Should Be Just the First Wave of Loitering Munitions for Kyiv," Breaking Defense, March 18, 2022, https://breakingdefense.com/2022/03/ukraine-is-getting-switchblade-it-should-be-just-the-first-wave-of-loitering-munitions-for-kyiv/.

525 Green Beret quoted in Atlamazoglou, "The Lastest US Weapon Heading to Ukraine: A 2-Foot Long, 5-Pound Drone Designed for One-Way Missions."

526 US Department of Defense, "Department of Defense Fiscal Year 2008/2009 Budget. Volume 1 Defense Advanced Research Projects Agency," February 2007, 382, https://www.darpa.mil/attachments/(2G9)%20Global%20Nav%20-%20About%20Us%20-%20Budget%20-%20Budget%20Entries%20-%20FY2008%20(Approved).pdf.

527 Hambling, "Drones on Their Way to Ukraine: Here's What We Know about Them."

528 Watts and Bode, "Automation and Autonomy in Loitering Munitions Catalogue (v.1)", 37, 61.

529 Quoted in Gosselin-Malo, "Loitering Munitions in Ukraine: Not Game-Changing, but Headache-Inducing."

530 AeroVironment spokesperson quoted in Gosselin-Malo; see also Phillips Payson O'Brien, "War Will Never Be This Bulky Again," The Atlantic, May 26, 2022.

531 Rob Lee, "Tweet @RALee85: Thread: I Completely Disagree with This Article's Conclusions," Twitter, June 1, 2022, https://twitter.com/RALee85/status/1531749210923704320.

on unmanned assets for battlefield engagement"[532] appears to be getting 'stickier' and more pervasive over time – with potentially significant consequences for the proliferation of loitering munitions.

These consequences could extend to changing the "human-in-the-loop" principle: many of the platforms used in Ukraine already appear to have the latent technological capability to apply force without prior human assessment. Ukrainian civilian and military officials have also made statements pointing in this direction. In January 2023, Ukraine's digital transformation minister, Mykhailo Fedorov, held that using loitering munitions without a "human-in-the-loop" is "a logical and inevitable next step", and that there has been "a lot of R&D [research and development] in this direction".[533] Ukrainian Lt. Col. Yaroslav Honchar further underlined the operational demand for processing information and making decisions at machine speed, which may lead to loitering munitions applying force without human assessment. Honchar noted, "We have not crossed this line yet – and I say 'yet' because I don't know what will happen in the future".[534]

Many of the platforms used in Ukraine already appear to have the latent technological capability to apply force without prior human assessment

In these ways, the war in Ukraine has continued the trend regarding the widespread use of different types of loitering munitions demonstrated in the 2020 Nagorno-Karabakh War. The three areas of concern we have identified are clearly seen in Ukraine. First, both conflict parties have used at least six different types of loitering munition, the patterns of use are more extensive than in previous cases, and loitering munitions were used for diverse purposes, including targeting military objects but, in the Russian case, personnel and in populated areas. Second, our analysis suggests that there could be significant uncertainties around the situational and decision-making dimensions of human control. Along the decision-making dimension, the systems used in Ukraine appear to be operated with a "human-in-the-loop" but may integrate the latent technological capability to apply force without immediate human assessment. Therefore, the actual quality of human control exercised by operators in specific targeting decisions is uncertain. Loitering munitions' use in urban warfare and other high-pressure combat situations suggests that established findings from problems inherent to human-machine interaction hold. Human operators may over-trust the system's prompts, they may lack the time for critically deliberating the system's prompts and they may have had inadequate training to guarantee their understanding of the system. Along the situational dimension of human control, the systems' operational range (max. 20km, Drone 40; max. 40km, KUB and Lancet-3; 10km, Switchblade 300; 40km, Switchblade 600) and endurance (max. 30 mins KUB; 40 mins, Lancet-3; max. 15 mins, Switchblade 300; max. 40 mins, Switchblade-400; max. 60 mins, Drone 40; max. six hours, Phoenix Ghost) extends the systems' potential target area both geographically and temporally, thereby possibly making the use of force more unpredictable.

532 Quoted in Gosselin-Malo, "Loitering Munitions in Ukraine: Not Game-Changing, but Headache-Inducing."

533 Bajak and Arhirova, "Drone Advances in Ukraine Could Bring Dawn of Killer Robots."

534 Bajak and Arhirova; see also David Hambling, "Will Ukraine Deploy Lethal Autonomous Drones against Russia?," New Scientist, November 1, 2022, https://www.newscientist.com/article/2344966-will-ukraine-deploy-lethal-autonomous-drones-against-russia/.

6 Conclusion

As the recent wars in Libya, Nagorno-Karabakh, and Ukraine demonstrate, loitering munitions are becoming an increasingly prominent feature of modern battlefields. These weapons have been designed to strike a range of target profiles, including in some cases human beings, and they have been deployed in various operational contexts, including populated areas. Our analysis of the global trends in the development, acquisition and fielding of these technologies' points to their growing proliferation. This trend will likely intensify as the practices of developing and operating these weapons become more widespread, and the framework of great power competition deepens its hold on strategic thinking. Loitering munitions matter for the ongoing international debates on autonomous weapon systems (AWS). The developments examined in this report are therefore deserving of detailed empirical scrutiny because of how these weapons integrate automated, autonomous and, potentially, AI technologies to support targeting and mobility functions.

Some currently fielded loitering munitions appear to be capable of using a combination of sensors, algorithms, and target profiles to identify, track, select, and strike targets. Most existing types of loitering munitions, however, are advertised as operating with a "human-in-the-loop". This means that, in principle, human operators are needed to evaluate and authorise strikes. Whilst these systems may not qualify as AWS in the strictest technical sense, their development points to wider global trends towards the integration of greater levels of autonomy into various types of weapon systems. However, our catalogue of the integration of automated, autonomous, and AI technologies into 24 loitering munitions, as well as three investigations into patterns of use (Libya, Nagorno-Karabakh, Ukraine), suggests that the precise quality and form of control exercised by human operators is uncertain both along the decision-making and the situational components of human control. In terms of the decision-making dimension, practices surrounding loitering munitions underline problems inherent to human-machine interaction, such as automation bias, a lack of time for deliberation, and a possible lack of system understanding. Along the situational dimension of human control, certain types of loitering munitions have significant operational ranges which extends the temporal and geographical limits of where force may be used. In populated areas, these patterns of use create new sets of unpredictability regarding the use of force that may result in loitering munitions having indiscriminate and wide area effects.

The proliferation and fielding of loitering munitions has, in our assessment, contributed toward a, perhaps inadvertent, normalization of integrating automated, autonomous, and AI technologies into the targeting processes of existing weapon systems which, in some cases, are operated under uncertain conditions of human control. Our survey of loitering munitions demonstrates that for many platforms there already is ambiguity in manufacturer communications about the extent to which systems can apply force without prior human assessment. The conflict dynamics involved with the War in Ukraine – a key site for the testing and prototyping of new loitering munitions– may result in the further reduction or removal of human operators from the decision-making loop. Both parties to this conflict have already claimed to have access to loitering munitions with autonomous targeting capabilities and have implied an intention to field these platforms "autonomously".

These moves are politically significant and are happening concurrently to the stalling of the international discussion about the potential regulation of AWS at the UN CCW.[535] Both the 2021 and the 2022 series of GGE meetings ended with a failure to progress its mandate. There have been regulatory efforts outside of the GGE. In February 2023, 33 states from Latin America and the Caribbean agreed in the 2023 Belén Communiqué on "the urgent need to negotiate a legally binding instrument".[536] The 2023 "Responsible AI in the Military Domain" (REAIM) Summit also saw 57 states agreeing on a joint Call to Action structured around the responsible use of AI technologies in warfare. These political declarations are not legally binding, remain "relatively unspecific regarding concrete measures",[537] and are detached from a truly global process of norm-setting in this domain.[538] This leaves open the space around AWS void of specific binding legal regulations which, we believe, are required to address the various challenges posed by such systems. Our detailed study of loitering munitions illustrates that developing and operating increasingly mobile systems with sensor-based targeting do not offer guides to "good practices", as highlighted by some states parties to the CCW. To the contrary, our analysis demonstrates the problems and challenges such practices create, and thereby highlights areas in need of new legally binding rules.

On this basis, **we urge states to develop and adopt legally binding international rules on autonomy in weapon systems**,[539] including loitering munitions as a category therein. **We recommend that states**:

- **Affirm, retain, and strengthen the current standard of real-time, direct human assessment of, and control over, specific targeting decisions when using loitering munitions and other weapons integrating automated, autonomous, and AI technologies as a firewall for ensuring compliance with legal and ethical norms.** This should include agreeing on substantive qualifications of what a meaningful quality and form of human control entails. A key prerequisite for meaningful human control is for human operators to have a form of *digital literacy*. Based on our previous research, this should entail: (1) a functional understanding of how the sensor-based targeting system operates and produces outputs, including its known weaknesses; (2) sufficient situational understanding; and (3) a capacity to scrutinise sensor-based targeting rather than over-trusting the system.[540]

535 For more on this, see Ingvild Bode, Hendrik Huelss, Anna Nadibaidze, Guangyu Qiao-Franco, and Tom FA Watts. "Prospects for the global governance of autonomous weapons: comparing Chinese, Russian, and US practices." *Ethics and Information Technology* 25, no. 1 (2023): 1-15.

536 Costa Rica Ministry of Foreign Affairs, "América Latina y El Caribe Acuerdan En Costa Rica La Urgente Necesidad de Negociar Un Instrumento Internacional Para Regular La Autonomía En Los Sistemas de Armas (English Version at the End)," Costa Rica Ministry of Foreign Affairs, February 24, 2023, https://www.rree.go.cr/?sec=servicios&cat=prensa&cont=593&id=7136.

537 Tobias Vestner and Juliette Francois-Blouin, "Globalizing Responsible AI in the Military Domain by the REAIM Summit," Just Security, March 13, 2023, https://www.justsecurity.org/85440/globalizing-responsible-ai-in-the-military-domain-by-the-reaim-summit/.

538 Ingvild Bode et al., "Prospects for the Global Governance of Autonomous Weapons: Comparing Chinese, Russian, and US Practices," *Ethics and Information Technology* 25, no. 1 (March 2023): 5, https://doi.org/10.1007/s10676-023-09678-x.

539 ICRC, "ICRC Position on Autonomous Weapon Systems and Background Paper," 2.

540 Bode and Watts, "Meaning-Less Human Control: Lessons from Air Defence Systems for Lethal Autonomous Weapons."

- **Establish controls over the duration and geographical area within which weapons like loitering munitions that can use automated, autonomous, and AI technologies to identify, select, track, and apply force can operate.** This should include the development of self-deactivation or self-destruction measures for situations in which connection with the system's operator is broken and/or the design of control measures which prevent anti-personnel strikes without operator authorisation.
- **Prohibit the integration of machine learning and other forms of unpredictable AI algorithms into the targeting functions of loitering munitions because of how this may fundamentally alter the predictability, explainability, and accountability of specific targeting decisions and their outcomes.**
- **Establish controls over the types of environments in which sensor-based weapons like loitering munitions that can use automated, autonomous, and AI technologies to identify, select, track, and apply force to targets can operate. Loitering munitions functioning as AWS should not be used in populated areas.** To minimise the inadvertent risks associated with possible indiscriminate and wide-area effects caused by the fielding of these weapons, states should introduce "limits on situations of use, such as constraining them to situations where civilians or civilian objects are not present".[541]
- **Prohibit the use of certain target profiles for sensor-based weapons which use automated and autonomous technologies to support targeting functions. This should include prohibiting the design, testing, and use of autonomy in weapon systems, including loitering munitions, to "target human beings" as well as limiting the use of such weapons "to objects that are military objectives by nature".**[542]
- **Be more forthcoming in releasing technical details relating to the quality and form of human control exercised in operating loitering munitions in specific targeting decisions.** Such measures should be viewed as integral to verification, certification, and trust building efforts. They also function as a mechanism for providing constructive scrutiny of the precise level of human control exercised over the targeting functions involved with both loitering munitions and other categories of weapon systems integrating autonomy.
- **Share, where appropriate, details regarding the level and character of the training that human operators of loitering munitions receive.** States developing and using weapon systems integrating automated, autonomous, and AI technologies in targeting should, to the greatest extent possible, publish details about the training provided to loitering munition operators. These measures should be intended to help ensure that those operating these systems are not inadvertently set up to fail and can overcome the risks associated with automation bias and/or a lack of sufficient situational awareness when tasked with making targeting decisions. This measure would have the added benefit of aiding the circulation of current "practices" in this area, including amongst states which may otherwise be considered "adversaries", and allowing for them to be subject of public scrutiny.

541 ICRC, "ICRC Position on Autonomous Weapon Systems and Background Paper," 2.
542 ICRC, "ICRC Position on Autonomous Weapon Systems and Background Paper," 2.

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