Glimpses of Tomorrow: the Coming Age of Autonomous Air Warfare

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Abstract
Although future cannot be predicted, it is imperative to exercise a long term prospective view aiming to capture important trends in the security environment, which can improve the understanding of the nature and character of future war, thus assisting the definition of strategy, defence and operational planning. Throughout the short history of Air Power, we have witnessed a change of the relationship of man with the machine. This essay will describe the current state of play regarding these changes, exploring competing arguments, in order to demonstrate the potential shift to a new military paradigm. The analysis of autonomy and the main drivers towards autonomous systems will be confronted by the challenges and implications of Lethal Autonomous Weapon Systems. This will highlight the implications of specific mission tailored autonomous systems, thus aiming to regulate its development and employment. The main thesis presented emphasizes the need to leverage the human-machine interface, which can provide the best immediate benefits, while further consideration should be given before embracing full autonomous operational templates.

Resumo
Reflexos do Amanhã: a Ascensão da Guerra Aérea Autónoma

Embora o futuro não possa ser previsto, é obrigatório exercer uma visão prospetiva de longo prazo com o objetivo de capturar as tendências importantes no ambiente de segurança, por forma a melhorar a compreensão da natureza e do caráter da guerra futura, ajudando assim, na definição da estratégia, no planeamento de defesa e operacional. Ao longo da curta história do Poder Aéreo temos assistido a uma mudança da relação do homem com a máquina. Este ensaio irá debruçar-se sobre o estado atual destas tendências, explorando argumentos concorrentes, a fim de demonstrar o potencial de mudança para um novo paradigma militar. A análise da autonomia e dos principais fatores potenciadores do desenvolvimento e emprego de sistemas autónomos será confrontada com os desafios e as implicações dos sistemas autónomos letais. Isso irá destacar as implicações de sistemas autónomos em tipologias de missão específicas, permitindo assim antecipar a regulação do seu desenvolvimento e emprego. A principal tese apresentada enfatiza a necessidade de aproveitar os benefícios imediatos proporcionados pela colaboração homem-máquina, enquanto uma análise mais aprofundada deve ser iniciada antes de abraçar por completo os modelos operacionais autónomos.

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Introduction

It is always important to identify, describe and understand future military implications of strategic and operational change. These dynamic and volatile changes will dictate the way military forces adapt and innovate, shaping the contours and establishing the trends of future military transformation. Although future cannot be predicted, it is imperative to exercise a long term prospective view aiming to capture important trends in the security environment, which can improve the understanding of the nature and character of future war, thus assisting the definition of strategy, defence and operational planning.

Within these important trends, and focusing our analysis on capability development driven by technology evolution, we may foresee drastic changes in the character of future war and a potential shift to a new military paradigm. Throughout the short history of Air power, we have witnessed a change of the relationship of man with the machine. First, man was the machine, using his motor skills to propel a heavier than air object. Then, man started controlling the machine, gaining a basic understanding of its capabilities. Soon after, begun exploring the qualities of the machine and employing it in combat. As technology progresses, man observes the machine executing tasks in an increasingly automated way. Therefore, throughout the last century of aviation, we have witnessed extraordinary evolutions regarding the human-machine relationship. Slowly, the human value within this equation has been qualitatively changing from the physical dimension to the cognitive and ethical domains.

Considering the drivers of technology, the strategic environment and the operational advantages of autonomous systems, it is not difficult to foresee a future where a drone might "fire a weapon based solely on its own sensors, or shared information, and without recourse to higher, human authority" (MoD, 2011, pp. 5-4). Therefore, this study sets as an underlying assumption that autonomous air warfare will begin to emerge, introducing profound challenges to war as a human endeavour. Furthermore, the degree of human input into machines' actions will continue to decrease, influenced by diverging international approaches and interests. In order to avoid repeating past mistakes, we are at the right time to question the nature of this revolution, addressing its concerns, and purposefully choosing the most tolerable future.

Within this overarching framework, we will try to describe the current state of play by exploring the competing arguments, in order to demonstrate the potential shift to a new military paradigm. This main objective can be achieved by answering three fundamental questions: What do we mean by "*Autonomy*"? What are the main drivers towards autonomous systems? What are the challenges and implications of Lethal Autonomous Weapon Systems (LAWS)?

Our perspective is that we need to move away from the "*all or nothing*" discussion about autonomous systems and spend more time addressing the implications of specific mission tailored autonomous systems, aiming to regulate its development and employment. Therefore, the emphasis should be on leveraging the human-machine interface, which can provide the best immediate benefits, while further consideration should be given before embracing full autonomous operational templates.

In order to narrow the scope of the discussion, this essay will focus on airborne autonomous systems, adopting a western perspective to the problem, namely the United States of America (USA), as the major researcher, developer and user of this technology, and as such, setting the trends for future warfare innovations.

Autonomy

Currently, there is no international consensus regarding the definition of an "*autonomous weapon*", which increases the complexity of the analysis[1]. This brings some confusion between terms like "*autonomy*" and "*automation*". From a semantics perspective "*Autonomy*" is derived from the Greek terms "*Auto*" (himself) and "*Nomos*" (rules or laws). That is, the one that dictates the rules of conduct independently from others. Within the framework of the decision cycle, it means that the machine is able to observe, orient, decide and act without external human assistance. Thus, the term predictability distinguishes both concepts. An automated system follows a set of instructions to complete a task in a predictable way, while a stand-alone system can adaptively react to unexpected events, having its response options only limited by a set of basic rules, pre-installed in its operating system.

So, for the purpose of this discussion we can define the concept of autonomy as the system's ability to perform a sequence of actions, seeking the best solution for a given situation, without human interference. However, to capture its essence we must look at autonomy as a spectrum influenced by several factors such as the complexity of the mission, the adaptability to the operating environment, and the level of collaboration with the human element. Doing so, it will be possible to identify dramatic changes on the output of the machine. Therefore, several scales and taxonomies can be used to take into account those factors and outputs[2]. Within this framework we can differentiate four basic levels of autonomy (US DoD, 2011, p. 46).

1 The United States Department of Defense, the International Committee of the Red Cross, and the United Nations Special Rapporteur for extrajudicial, summary or arbitrary executions all use similar definitions, but there is no standard definition that is universally embraced. In order to help clarify, as a prerequisite to examining legal, moral, ethical and policy issues, what an autonomous weapon is, how autonomy is already used, and what might be different about increased autonomy in the future see (Scharre and Horowitz, 2015).

2 See Melzer (2013, p. 6); US DoD (2011, p. 46); MoD (2011, pp. 2-2/2-3); and Ramage *et al.* (2009, p. 2-1).

Level 1, or Human Operated (i.e. Remote Control), wherein a human operator makes all the decisions and the system reaction depends on input from the operator. Therefore, the system has no autonomous control of its environment although it may have information-only responses to sensed data. For example, the remotely controlled Predator drone fits under this category.

Level 2, or Human Delegated, in which certain autonomous reactions rely on pre-programmed functionalities. Still, the system cannot adaptively react to new situations. The vehicle can perform many functions independently of human control when delegated to do so. This level encompasses automatic controls, engine controls, and other low-level automation that must be activated or deactivated by human input and must act in mutual exclusion of human operation. A typical example is an auto-pilot system existing in commercial aircraft.

Level 3, or Human Supervised, where the behaviour of the system depends on a set of pre-defined rules, enabling definition and implementation of new procedures. The system can perform a wide variety of activities when given top-level permissions or direction by human. Both the human and the system can initiate behaviours based on sensed data, but the system can do so only if within the scope of its currently directed tasks. The surveillance drone Global Hawk has autonomy levels between Level 2 and Level 3 and can perform a selection of tasks without human interference, such as altitude and route control and adjust its mission in accordance with changes in the environment, like weather conditions or traffic avoidance.

And finally, the Level 4, of Fully Autonomous, where the system receives goals from humans and translates them into tasks to be performed without human interaction, but where the machine behaviour is bounded by a set of inviolable rules. A human could still enter the loop in an emergency or change the goals, although in practice there may be significant time delays before human intervention occurs.

By translating these levels of autonomy into the ability to employ lethal force, that is, select and engage targets, we can better understand the impact of the human interference in the process. From a decision making perspective, when we refer to the paradigm of "*man-in-the-loop*", it ultimately means that the final decision to use lethal force resides in the human decision maker. Within this control type, the machine may provide the target list but a human selects which target will be attacked. In the "*man-on-the-loop*" control type, man supervises several machines that select targets which will be approved by a human before being engaged by machines. This targeting process may only allow for a limited decision time. Passing the threshold of full autonomy, the system has the authority to use lethal force, while the human factor is relegated to an "*out-of-the-loop*" function. Under this framework, the human interference in the use of lethal force will be restricted to the definition of governing laws of the autonomous systems (or Rules of Engagement – ROE) which could bound machines' behaviour.

Drivers for Autonomy

The employment of drones capable of applying lethal force, under human remote control, is a known fact of modern conflict[3]. Additionally, if we consider the taxonomy presented, there are already several examples of automatic weapon systems, including the decision-making capability to employ lethal force. For example, a Tomahawk missile makes its flight and hits the target without human intervention. The Patriot missile system is capable of automatically intercept an approaching missile more than 50 km away (McDaniel, 2008, p. 40). The Phalanx close-in weapon system installed on board of frigates, for ship's close protection against missile attacks, performs an automatic decision, according to a criteria defined by the human element, on which targets to attack (Olsthoorn and Royakkers, 2011). Also, the USA Navy Aegis combat system is capable of autonomously tracking and attacking enemy aircraft.

Therefore, at the present moment, at least 30 countries have in their portfolios several systems with autonomous modes capable of engaging targets at machine's speed, but under human-supervision, and in relatively limited contexts (Scharre and Horowitz, 2015, p. 18). These are mostly human-supervised autonomous weapons to defend against short-warning saturation attacks from incoming missiles and rockets (CNAS, 2016, p. 4). The level of autonomy is still low because they are supervised in real time by human operators who can manually disable the system in the event of a malfunction, communications failure or cyber-attack.

However, an increasing number of countries including China, Russia[4], France, Germany, Israel, the United Kingdom and the USA are currently developing systems for greater autonomy in combat situations[5]. In a recent survey, Roff and Moyes (2016a), identified 256 weapon systems with varying degrees of autonomy, ranging from independent movement ("*Self-Mobility*"), employment of weapons ("*Self-Direction*"), and the ability to autonomously modify or set goals ("*Self-Determination*").

3 The contemporary political preference for Remote Air Warfare can be verified in practice, noting that in late 2011 the USA employed armed drones, simultaneously and continuously in six different theaters: Libya, Iraq, Afghanistan, Pakistan, Yemen, and Somalia.

4 The Russian chief of General Staff, Gerasimov, was recently quoted as saying that, "in the near future it is possible a fully robotized unit will be created capable of independently conducting military operations." (Freedberg, 2015).

5 Besides Nations, also International Organizations such as NATO are recognizing the nature and magnitude of this revolution and have already started assessing the potential legal, ethical and strategic impacts of LAWS. As an example, see Kuptel and Williams (2014) and JAPCC (2016).

As the global trendsetter, the USA, with its ambitious Third Offset Strategy[6], offers some glimpses about future autonomous warfare. As an operational template, it is centred in human-machine collaborative networked environments, aiming to obtain military advantages against likely adversaries (Work, 2015)[7]. Therefore, it postulates that advances in artificial intelligence and autonomy are going to enhance a new era of human-machine collaboration and combat teaming (Work, 2016). This aims to merge the tactical acuity of a computer to enhance human decisions with the employment of manned and unmanned systems. Confronted with anti-access and area denial (A2AD)[8] adversary weapons, the USA seeks to develop the means to offset the proliferation of advanced technologies.

Driven by the political direction of travel, research continues to accelerate the development and fielding of weapon systems with growing autonomy levels. Some of the publicly disclosed examples include the prototypes for future combat drones such as the USA Navy X-47[9] or the UK Taranis (Heyns, 2013, p. 45), which will have the capability to autonomously search, identify and locate enemies, but can only engage with a target when authorized by mission command. They will also have the capability to defend itself against enemy aircraft. Other innovations include autonomous ammunitions (US DoD, 2013, p. 78) and drones[10] which can loiter over the battlefield covering a wide area while waiting to take out high-priority targets

6 The Third Offset Strategy intends to replicate the military-technical advantage, against a peer competitor, of the two previous offset strategies – nuclear deterrence in the 1950s and the guided munitions regime in the 1970s. The first offset strategy leveraged US nuclear superiority to compensate for the numerical inferiority of ground forces in Europe. As Soviet Union reached nuclear parity, the second offset strategy leveraged USA monopoly of advanced technologies to develop long-range precision strike weapons (Jackson, 2015).

7 Judging by FY2017 budget outlook, this reform is starting to take shape (Mehta, 2016).

8 Anti-access strategies aim to prevent USA forces entry into a theater of operations, while Area-denial operations aim to prevent their freedom of action in the confines of the area under an enemy's direct control. Prospective adversaries are developing and fielding military capabilities that will place USA forces operating from large, fixed forward bases, and in the littoral regions, at increasing risk. These threats include actions by an adversary in the air, on land, and on and under the sea to contest and prevent USA joint operations within their defended battlespace (Krepinevich *et al.,* 2003).

9 The X-47B is a tailless, strike fighter-sized unmanned aircraft developed by Northrop Grumman as part of the USA Navy's Unmanned Combat Air System Carrier Demonstration program. Under a contract awarded in 2007, the company designed, produced and is currently flight testing two X-47B aircraft. In 2013, these aircraft were used to demonstrate the first ever carrier-based launches and recoveries by an autonomous, low-observable relevant unmanned aircraft. In April of 2015, the X-47B once again made aviation history by successfully conducting the first ever Autonomous Aerial Refueling of an unmanned aircraft (Northrop Grumman, 2016).

10 For example, Israel´s Harpy is a "*Fire-and-Forget*" autonomous weapon system designed to detect, attack and destroy radar emitters (Israeli-weapons.com, 2016).

such as mobile air defences, mobile surface/surface missile launchers and long-range rocket systems.

It is possible to assume that current technological trends point towards a qualitative shift beyond autonomous mission *execution* to autonomous mission *performance* (US DoD, 2013, pp. 66-67). The difference lies on the ability of a machine to go beyond a pre-programmed activity and allow the system to self-decide how to operate itself to accomplish the human directed mission goals. That means the capability to optimize their behaviour in unforeseen situations in order to find the optimal solution. And of course, with the development of the autonomy levels, several new mission sets and operational concepts can emerge which will open the way for a shift in the air warfare paradigm.

These new operational templates include, for example, the "*loyal wingman*" concept, where fully automated drones fly alongside a manned aircraft to perform several tasks. Under this scenario, we can imagine an F-35 orchestrating an attack with 20 drones that are weapons-equipped and that the F-35, with all its sensors and communications, is essentially an orchestrator (Clark, 2014). This example can also be applied to a Special Operations Aircraft that will use drones as scouts in order improve its survivability (Swarts, 2016). The testing of the robot wingmen will begin as early as 2018 in order to introduce it as a validated operational template in the 2020s timeframe (Axe, 2016).

In a more disturbing, but promising perspective, drones with fully autonomous capabilities work in collaboration within a "*swarm*". Although we are still on the early stages of development, we can forecast the operational implications of such concepts. For example, the USA Navy Low-Cost UAV Swarming Technology (LOCUST) is intended to launch up to 30 small swarming drones, that once airborne, start sharing information with each other, enabling autonomous collaborative behaviour in either defensive or offensive missions (Smalley, 2015). The resilience of the swarm allows it to self-reconfigure and autonomously change its behaviour to complete the mission. Thus, the operational concept of "*swarming*" can fulfil a multitude of tasks, such as monitoring large areas through multi-sensor information integration, search, identification and tracking of several targets, search and rescue missions, identification of enemy threats and convoy protection, or the saturation of opposing anti-aircraft threats with multiple targets. Ultimately, it may serve as an asymmetric technology against advanced air defence systems, in which hundreds of drones deny the effectiveness of unmanned weapons systems and batteries of surface to air missiles. As scheduled, the LOCUST proof of concept was achieved in the summer of 2016 with a demonstration by the USA Navy (Matthews, 2016, pp. 38-41).

Similar advances of Artificial Intelligence promise to unveil dramatic changes to the human interference in the tactical domain, introducing new and unmatched lethality to air-to-air combat. For example, within the context of air-to-air combat, the time delays associated with the use of remote operation of unmanned platforms constrain critical decisions (Byrnes, 2014, p. 49). However, focusing on the improvement of real-time decision making capabilities, recent experiments have demonstrated an Artificial Intelligence algorithm that controls flights of Unmanned Combat Aerial Vehicles in aerial combat missions within an extreme-fidelity simulation environment (Ernest *et al*., 2016). This simulation allowed drones to repeatedly and convincingly "*defeat*" a human pilot during several Beyond Visual Range engagements (Reilly, 2016).

Although still in the research phase, this technology can have great implications, for example, in providing inputs/advice to manned operators or acting as the basic decision tools for drones when faced with a new situation and unable to communicate, as well as, allow a single operator to coordinate swarms of unmanned combat platforms. "Within this operational template, a human can give general inputs and guidance to the swarm, and be confident that in general, relying on advanced computational capability, the swarm will behave as required" (Deptula quoted by Clarke, 2016).

Judging by other initiatives that have been reported by the media, revealing the operational interest on "*swarming*", it is reasonable to expect that covert projects are being developed and that further capabilities will start to emerge and be employed in near future conflicts (Lamothe, 2016).

After discussing the meaning of autonomy and having a look at current and future capabilities and operational templates, it is possible to summarize some of the arguments in favour of increasing autonomy, in particular regarding LAWS.

The drivers for autonomy have to do mainly with operational efficiency. That is, the need to perform increasingly complex and risky military missions with lower costs (human and economic) determines the growing interest in autonomous weapons systems. From an operational perspective, the human interference over the machine has some disadvantages on the machine's efficiency. Also, remote control of drones requires constant communication between the platform and the control station, as well as an increasing volume of information and bandwidth. Thus, information volume and the dynamics of the battle space will require faster reaction times, beyond man's capability. This vulnerability can be minimized, either resorting to internal processing in flight, partially or completely autonomously or acting cooperatively with other platforms. In most ambitious visions, such machines are able to identify friend from foe, in static or dynamic scenarios. Additionally, drones have aerodynamic advantages that theoretically give them a higher degree of survival as a result of their manoeuvrability and stealth capability. Moreover, the proliferation of vehicles in the battle space favours the autonomous option because there are not enough operators to control the existing platforms. Some would even argue (Arkin, 2009) that LAWS can be more human in battle than the soldier himself, contributing to an increase of ethics on the battlefield, where human limitations on combat effectiveness do not limit the performance of the machines (e.g. physiological aspects, cognitive exhaustion, emotions or fatigue, including susceptibility to error). Furthermore, we must also think about the preservation of the scarce friendly human resources in war.

In summary, within this technophile benign perspective, by extracting man from the decision cycle, we are improving its efficiency. We are standing before an operational template, conducted in a networked environment, which emphasizes the importance of the speed of the decision cycle; the ability to maximize the power and lethality of combat through the use of interoperable, joint and combined forces; the ability to collect and analyse information, acting quickly, accurately, and in a discriminate fashion, preserving civilian casualties and infrastructure. This "Western Way of War" has exposed several challenges such as the prevention of fratricide and collateral damage; information sharing; the scarcity of bandwidth and the integration of the common operating picture. Considering these requirements and operational challenges, it is apparent that a greater autonomy of air platforms could be an appropriate solution for increasingly complex operating environments (Ramage *et al.,* 2009, pp. 2-12). Within this framework, long-range autonomous systems capable of independently navigate, identify and attack mobile targets will offer a major conventional deterrence, particularly if considering future scenarios dominated by opposing A2AD strategies.

Challenges and Implications of Lethal Autonomous Weapon Systems

The USA Department of Defense Directive on Autonomy in Weapon Systems (2012) is the first publicly disclosed policy, by any country, regarding the use of lethal autonomous systems which lays the guidelines and assigns responsibilities for the development and employment of these weapons. Additionally, it recognizes and establishes guidelines to minimize the probability and consequences of failures in autonomous and semi-autonomous weapon systems that could lead to unintended engagements, as well as, unacceptable levels of collateral damage beyond those consistent with the Laws of War, ROE, and commander's intent. However, this raises some questions regarding the ability to fully test these systems against adaptive, unpredictable enemies, as well as minimizing the risk of unanticipated situations on the battlefield (Sharkey, 2013, pp. 8-11). Although it restricts autonomous weapon systems to apply non-lethal, non-kinetic force, such as some forms of electronic attack against materiel targets; however, it allows the waiver of restrictions by high level approval in cases of urgent military operational need.

History has taught us, sometimes in a cruel manner, that the introduction of a new weapon system in the battlefield, whose impact had not previously been evaluated, can transform war and humanity itself. Given this perspective we may anticipate that the gradual transition to autonomous systems will be conditioned by two key factors: technological capability and human acceptance for machines to make lethal decisions. Assuming that technology will continue to evolve and that operational necessity will follow, then we will have to discuss in greater depth the reasons that influence human acceptance for such a change.

International Humanitarian Law was created to ensure that there are limitations on the methods and means used to wage war. Influenced by this framework, the main objections to the use of autonomous systems in war come from the inability to fulfil the universal ethical and legal standards, particularly that LAWS miss the inherent human qualities of intuition, compassion, common sense, and judgement. Although rather effective when performing quantitative assessments, they have limited qualitative abilities, which are crucial when dealing with human life (Heyns, 2013, p. 10). This will be most important in the ability to distinguish between combatants and illegitimate targets[11], in particular in complex urban environments, as well as, in meeting the requirements of proportionality, or even addressing other key aspects of the International Humanitarian Law such as "*superfluous injury*" or "*unnecessary suffering*"[12]. Judging by the "*unintended*" consequences of the recent employment of remote operated drones under the operational template of "*targeted killings*" (Davis , 2016), it is reasonable to expect that those challenges could be significantly higher if we consider complex systems that run without human supervision. This means that, no matter how robust the Artificial Intelligence may be, it is impossible to predict how swarms of systems will behave when confronted with each other. Therefore, currently, and in the near future, it is reasonable to say that the subjective nature of morality seems difficult to codify in software (Asaro, 2014, p. 219).

In a semi-autonomous system, currently more common, the process of "*man-in-the-loop*" is nothing more than the requirement for a human to authorize weapon engagements. In this way, the human element can be held liable for eventual errors, as in the case of collateral damage or breach of ROE. In the case of an autonomous system how can we ensure the compliance with this principle? Who will be responsible for any error? The commander, the engineer, or the programmer? Therefore,

11 Some critics highlight the insufficient discrimination between combatants and non-combatants and the lack of proportionality of the response, as main dissociative factors to the emergence of LAWS (Sharkey, 2013, pp. 8-11).

12 Rule 70 of customary international humanitarian law: The use of means and methods of warfare which are of a nature to cause superfluous injury or unnecessary suffering is prohibited (ICRC, n.d.).

accountability becomes more difficult to determine as man moves away from the decision cycle[13].

In order to address this accountability gap, along with the moral responsibility and controllability challenges, many argue for the need to submit the LAWS to the requirement of "*meaningful human control*", before, during and after employment in conflict.[14] This concept has three essential components, or "*minimum necessary standards*", that could ensure better informed decisions and actions, as well as, reducing the potential for mistakes (Horowitz and Scharre, 2015, p. 4; Garcia, 2014).

First, human operators are making informed, conscious decisions about the use of weapons. Thus, they must have full contextual and situational awareness of the target area and be able to perceive and react to any change or unanticipated situations that may have arisen since planning the attack. Second, human operators have sufficient information to ensure the lawfulness of the action they are taking, given what they know about the target, the weapon, and the context for action. That means that there must be active cognitive participation in the attack and sufficient time for deliberation on the nature of the target, its significance in terms of the necessity and appropriateness of attack, and likely incidental and possible accidental effects of the attack. Third, the weapon is designed and tested, and human operators are properly trained, to ensure effective control over the use of the weapon. In reality, there must be means for the rapid suspension or abortion of the attack.

Therefore, assessing LAWS´ compliance against such cumulative principles – confidence in the information that is guiding the human judgements being made; clarity of human action and potential for timely intervention; predictability, reliability and transparency in the technology – could ensure legitimate target selection and proportionate response, while guaranteeing a sufficient framework of human accountability throughout the use of lethal force (Roff and Moyes, 2016b).

Although the concept of "*meaningful human control*" may be useful, since it deals with the theme of informed action by a human, the real challenge is to determine what constitutes appropriate human control over autonomous systems and what level of information will be required to make a decision. However, the level of information required is scenario driven and as such, is influenced by multiple

13 For a detailed study about the challenges of accountability see (Human Rights Watch, 2015).

14 Topic first addressed by the non-governmental organization "Article 36" in a 2013 report on how the United Kingdom is thinking about autonomous weapon systems. For a comprehensive discussion about the "*meaningful human control*" concept, its strengths and weaknesses, as well as, other conceptual and policy-oriented approaches that address these concerns see UNIDR (2014), Horowitz and Scharre (2015), Roff and Moyes (2016b).

variables like weapons used, targets engaged, ROE, etc. Therefore, the context in which a weapon is employed changes how the control of that weapon is exercised by humans. For example, it is not possible to compare the degrees of "*meaningful human control*" between an air-to-air engagement, where computer systems play a significant role both in helping the pilot find a target and in guiding weapons to their targets, with an infantry soldier engaging an enemy combatant (Horowitz and Scharre, 2015, p. 12).

Currently, whether one uses the term meaningful, adequate, effective, or some other term, there seems to be a consensus about the requirement for some level of human qualitative control over the use of force by LAWS (Scharre, 2015). However, assuring human control of LAWS, thus reducing the operational efficiency, may be seen as a constrain to some countries with lower ethical and moral thresholds. Therefore, further discussion will be required in order to reach an agreement about the universal principles which may govern the development and employment of LAWS.

Furthermore, viewing war as the utmost political choice, one may conclude that the proliferation of autonomous systems may contribute to reduce, even further, the threshold for waging it, to the extent that it lowers the operational and social costs of employing the military instrument. Therefore, by lowering the costs to achieve national objectives it will further contribute to disengage society from the employment of autonomous systems. This will in turn create an erosion of the accountability of political action, thus favouring the political willingness to use force as first resort and increasing preventive military postures. Additionally, it may promote further breaches of state sovereignty, and with it, an increased risk of a less secure world. Hence, by increasing the frequency of war, so will the potential danger to civilians.

Moreover, controlling the proliferation of autonomous systems will be a challenge. Given the advances of commercial off the shelf technologies, it is reasonable to expect the proliferation of small, smart, cheap, and long-range drones capable of carrying lethal payloads (Hammes, 2014). Therefore, this tri-dimensional proliferation will develop horizontally between States and vertically, from states to non-state actors, adding a new portfolio of effects to warfare. Considering that the Western higher standards for targeting could inhibit the fielding of cheap LAWS, it is possible that, given the proliferation of technology, less technological advanced actors, with fewer ethical constrains, will have an initial advantage and motivation to field those systems, allowing them to affect a wide range of targets. So, the perspective of employment of these systems by rogue nations, non-state actors or even single individuals, heightens the possibility of producing massive effects, including terrorist attacks. Consequently, the use of LAWS could become a future alternative, free of sacrifice, to the suicide bomber[15]. Hence, the West will be confronted with an emergent paradigm shift, from the exquisite and very few to the cheap and very many, thus creating additional incentives for the most advanced states to adopt the preventive development of LAWS, while they can maintain an asymmetric advantage.

Having those challenges in mind, public perception will be the key factor for the acceptance of autonomous systems. As technology matures and more civilian and military artificial intelligence applications are being introduced, so will the trust increase and the acceptance of increasing levels of autonomy. The public acceptance will start on the civilian domain technologies and it will gradually expand to the military applications arena. Any urgent operational requirements, like the ones seen during the Afghanistan and Iraq conflicts which have catapulted armed drones, may accelerate the development of LAWS to a point of no return.

As the trajectory toward autonomy and complexity accelerates, so does the risk that autonomous weapon systems will, eventually fail. Considering the employment of LAWS in a defensive role, such as the interception of ballistic missiles, it will be easier to accept the risk of possible failures. However, the legal and ethical concerns will increase if employing such systems in complex, rapidly changing and inherently difficult urban environments, under an offensive role posture (Boothby, 2014, p. 207). Under the latter scenario, and within the current framework which requires all states legally to evaluate weapons before fielding them, offensive LAWS should be rejected (Idem). Thus, rather than a revolution towards the development of fully autonomous systems, we will see initially, an evolution thru the introduction of limited versions of the technology, which will in turn require a readjustment of the policy. Eventually, as technology matures, allowing for the full compliance of war's legal principles, we will witness a spread towards more complex environments and functions, making the proliferation of LAWS unavoidable.

Conclusion

Although revolutionary in its magnitude and effects, the emergence of autonomous air warfare will be rather evolutionary, developing in an insidious way. For the moment, despite current systems possessing advanced sensors, they still lack the ability to process the information in real time and act according to its outcome. Likewise, testing autonomous systems continues to be a problem, insofar as there is no way to submit the system to all possible situations found in the real world.

15 On 2 October 2016, in Irbil, Iraq, a drone flown by ISIS killed two Kurdish soldiers and two French paratroopers. The attack is possibly the first where a drone fitted with an improvised explosive device has inflicted casualties on troops from a Western nation (Atherton, 2016).

Additionally, interoperability is a complex challenge when attempting to interact with different systems without existing common protocols. Thus, the technological challenges of operating groups of autonomous vehicles with similar decision-making capability to humans are still unresolved. After all, and from the military perspective, so that a system can be called truly autonomous, it must be able to achieve the same level of situational awareness as the human being. Despite numerous developments in order to provide greater autonomy levels, these technological constraints still impede their full development to all air power activities, including the most complex and dynamic functions like air combat. However, given the exponential progression of technological change that we are living in, it is reasonable to assume that these limitations will be overcome in the future, as some were in the past, as the operational requirements arise.

So, in a probable future, as technology matures, and aiming to ensure greater political and public acceptance, we may envision the employment of rudimentary LAWS in attack missions with non-lethal weapons, and in areas where there are only confirmed military adversaries. Additionally, parallel control systems that guarantee "*meaningful human control*" requirements must be developed. As commanders establish their command intent and the ROE to frame the actions of combatants, in the future, the same will apply to LAWS. Hence, systems will be programmed based on the commander's intent, while commanders retain the ability to set the desired level of autonomy depending on the various stages of a mission. Accordingly, the autonomous operation will take place within previously established levels, while man will supervise the execution of operations and retain the ability to change or cancel any unwanted behaviour.

Considering that automation is at the heart of the Pentagon's ambitious Third Offset Strategy, and that both Russia and China, amongst others, are investing heavily in robotics and autonomy, one may expect that this, for now, probable future, will insidiously transform itself into a possible future.

The emergence of LAWS will be driven first and foremost by political endorsement rather than by purely technological achievements. Currently, states don´t publicly support the removal of humans from life and death decisions, citing, at a minimum, the need to ensure accountability on the battlefield. Additionally, it is generally agreed that LAWS should be governed by International Humanitarian Law and that commanders would also have command responsibility for their robots, as they do for their soldiers. Therefore, the emphasis, for now, is on the enhancement of human-machine collaboration. However, as the technological equalization emerges between adversaries, so will the drivers increase to develop fully autonomous systems. Sooner or later, the proliferation of advanced technologies will increase the social and political appetite for removal of the moral constrains of autonomous air warfare. Some may even consider that keeping man within the decision cycle could become a strategic disadvantage against a military-technical superior adversary.

From a pessimist perspective, after briefly assessing the opportunities but also the challenges, and having history as a guide, one may conclude that as technological maturity increases, so will the public confidence, thus encouraging politicians to allow the development of a new range of applications with direct impact on war. When, and if, this happens, we will be faced with a fundamental transformation of war.

In addition to changing the way we fight, expressed in capacity, lethality and operational efficiency, also changes the fighter prototype, the human interference and the experience of war itself, both individually and as a political instrument, thereby altering the relationship with society. Ultimately, this revolution will bring with it a redefinition of the human role in air war: from a doer, to a supervisor, and ultimately to an observer, hopefully reserving for himself the final authorization to use lethal force.

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