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Autonomy in Air Defence Systems

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1 Introduction

The American historian Melvin Kransberg stated that *"invention is the mother of necessity."* This quote is proven to be true in the context of hypersonic missiles. These missiles pair immense speed with unseen manoeuvrability to establish their supremacy in airborne ranged weapons. In 2021, The European Defence Agency identified hypersonic missiles as an Emerging Disruptive Technology. Russia has confirmed this concern by launching an attack on Ukraine with the hypersonic Kh-47M2 Kinzhal in March 2022. This novel invention highlights the necessity of a highly responsive air defence system to keep Europe's airspace safe.

The time critical factor is the dominant consideration when determining the performance needs of an air defence system that could potentially fend off hypersonic missiles. This paper analyses the problematic characteristics of hypersonic missiles and how these missiles manage to evade air defence systems in Chapter 2. It will then build on these findings to suggest innovations needed to counter hypersonic missiles in Chapter 3. More specifically, this paper will evaluate to what extent autonomy can assist in missile defence. Chapter 4 will analyse the relationship between the suggested technological innovation and ethics, law, military structure, and the current security environment. This interplay between the hard and soft sciences is needed to enable a sustainable implementation of new technology in a multidimensional environment. At the core of this paper is the following research question:

"How and to what extent can autonomy help in countering the threat of hypersonic missiles?"

2 Setting the Scene

Speed is the essence of war.

— *Sun Tzu*

2.1 Autonomy

Autonomy can be interpreted in many ways, but in general, the following definition is accepted: *"The ability of a machine to perform an intended task without human intervention using interaction of its sensors and computer programming with the environment."*[1] Since the concept of autonomy is the core of this essay, it is worthwhile to explore the definition in two ways: the sophistication of the machine's decision-making process and the level of human-machine interaction.

Firstly, the sophistication of the machine's decision-making process must be defined as it remains a controversial topic in legal and ethical discussions [2, 3]. An autonomous system is considered to be capable of understanding higher-level intent and direction. Using its perception of the environment, an autonomous system can choose a course of action from a number of prepared reactions, but can also suggest an innovative solution [4–6].

Secondly, we will only consider autonomous machines where a human is still on the loop and practices a supervisory role over the machine. While many weapon system functions can be outsourced to a machine, meaningful human interaction will be required. The explicit definition of meaningful human interaction in the context of autonomous air defence systems will be discussed in further chapters.

2.2 Hypersonic Missiles

A hypersonic missile is a guided airborne ranged weapon that can reach speeds exceeding five times the speed of sound. High-speed missiles are not revolutionary in warfare; ICBM's such as the Minuteman III can accelerate up to Mach 23 [7] in their terminal phase. Hypersonic missiles currently under development outshine the competition by pairing high speeds with manoeuvrability, making tracking and interception nearly impossible by a modern Air Defence System (ADS) [8]. While multiple types of hypersonic missiles are currently under development [9], we will only consider Hypersonic Glide Vehicles (HGVs) in this essay. Other hypersonic missiles, such as hypersonic cruise missiles, still face significant technological challenges in development [10].

HGVs gain initial energy from a powered launch vehicle. The launch vehicle injects the HGV into the atmosphere at high speed from space. After the HGV is released, the initial energy is recycled to enable a high-speed glide to the target [11]. The unusual trajectory of HGVs, as seen in Figure 1, poses additional problems for the defender because it maintains a degree of ambiguity as to what is the actual target. This prevents the defender from activating any active or passive defence measures [12].

The strategic implications of hypersonic missiles can destabilise the doctrine of 'Mutual Assured Destruction' which kept two nuclear states in a Nash equilibrium. This doctrine depended on neither state being able to launch a successful first strike. The European Defence Agency has identified hypersonic weapon systems as an emerging disruptive technology that will significantly change the rules of conduct of conflict within one or two generations [13]. To gain insight on how to counter HGVs, we must first understand the mechanism behind a modern ADS and its shortcomings.

2.3 Air Defence Systems

Distancing oneself from a dangerous situation is human nature. Humanity went from fighting with sticks and stones to throwing spears, shooting arrows, firing bullets, and now launching missiles. Countries rely on modern integrated ADS (composed of a complicated network of structures, equipment, personnel, procedures, and weapons) to counter the enemy's airborne penetration of one's own claimed territory.

Despite being a convoluted network of sophisticated technologies, the effectiveness of an ADS can be expressed in a series of consecutive probabilities that result in the probability of killing an incoming missile P_K:

$$P_K = P_{Kill|Engaged} \cdot P_{Engaged|Tracked} \cdot P_{Tracked|Detected} \cdot P_{Detected|Active} \cdot P_{Active} \tag{1}$$

where:

P_{Active}	Probability of the ADS being active. Shortened as P_A.
$P_{Detected\|Active}$	Probability of detecting, and correctly identifying, an incoming missile. Shortened as $P_{D\|A}$.
$P_{Tracked\|Detected}$	Probability of tracking the incoming threat in order to compose a firing plan. Shortened as $P_{T\|D}$.
$P_{Engaged\|Tracked}$	Probability of formulating, and executing, a firing plan by firing an interceptor missile. Shortened as $P_{E\|T}$.
$P_{Kill\|Engaged}$	Probability of the interceptor destroying the incoming missile. Shortened as $P_{K\|E}$.

Hypersonic missiles evade modern ADS by lowering its P_K in different ways:

1. Current sensor architecture is insufficient when detecting hypersonic missiles that fly at much lower altitudes than traditional ballistic missiles. As seen in Figure 1, the curvature of the earth offers additional shielding to HGVs from ground-based radars [14–16]. These two factors significantly reduce the probability of detection $P_{D|A}$ until it is too late.

2. The HGV's novel trajectory, taken together with its ability to change course after being released into the atmosphere, complicates the detection, tracking, and engaging of an incoming missile [12, 14, 15, 17, 18]. These factors reduce all the probabilities mentioned in equation 1 except for P_A.

3. The high speed of an HGV reduces the time available to respond to a threat [12, 14]. Human error occurs in a disproportionate amount in stressful and time-sensitive situations, often with fatal consequences. This human shortcoming was the case with the downing of Iran Air Flight 655 in 1988 [19]. The reduced time to compose an effective firing plan is detrimental to the probability of engagement $P_{E|T}$.

Hypersonic defence is thus not an adjunct of ballistic defence but a new category of its own. Figure 1 below summarises the differences between ballistic missiles and HGVs.

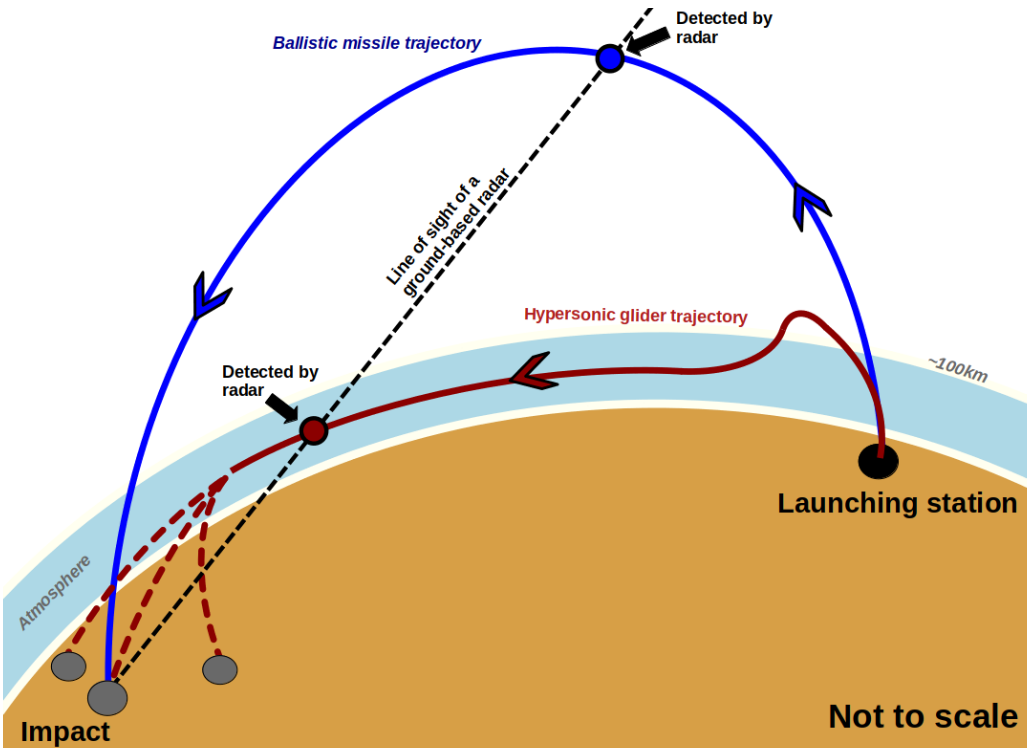

Figure 1: Detection of ballistic missiles vs hypersonic glide vehicles.

The need for advanced air defence capabilities suggests consideration of alternative systems capable of meeting the high standards set by hypersonic missiles. Human bandwidth forms the main bottleneck in a rapid response. A necessary but challenging innovation is therefore greater autonomy.

3 Necessary Innovations

If you can't see it, you can't shoot it.

— *U.S. Air Force Gen. John E. Hyten*

As stated in the previous chapter, a modern ADS cannot thwart HGVs. Hypersonic speed complements the missiles' manoeuvrability to increase effectiveness considerably. Given the short timelines, only very responsive and highly capable ADS could stand a chance in defeating an incoming HGV [9]. This chapter analyses the necessary upgrades in present air defence capabilities and the crucial role artificial intelligence will play in the future of ADS.

3.1 Sensors

The importance of sensors cannot be overstated. Sensors are essential throughout the entire intercept cycle and form the backbone of missile defence operations. Improvements in detection, identification, and tracking of aerial threats are a part of the first step in building a robust ADS. Therefore, we will review the most promising sensor technologies capable of helping an ADS to meet the hypersonic standard. We should note that the topics discussed in this section should serve as a supplement to existing air defence systems (ground-based radars, IFF[1], Command and Control (C2) networks, interconnected subnets,..). Terrestrial sensors will remain the backbone for air and missile defence architectures, but supplementary systems must be considered due to their inherent limitations. We have identified two sensor technologies that could upgrade an ADS' sensory capabilities to a level sufficient enough to defend against HGVs: space-based sensors and hyperspectral sensors.

The use of space-based sensors (SBS) would address a crucial capability gap in ground-based sensors: detecting threats further than 500 km away (as discussed in 2.3). The construction of an interconnected network of low earth orbit satellites could provide a permanent, global sensing capacity [20]. Pairing this range benefit with a low-latency communications network would greatly extend the effective range of current ADS. Early detection of HGVs would alleviate the time pressure and allow us to develop a more effective firing plan, increasing the P_K of an ADS. The integrated use of ground- and space-based sensors would further enable a "birth-to-death" tracking capability [21]. In the context of hypersonic defence, this addition would open more time windows that an ADS can leverage to engage an HGV. The U.S. has recognised the advantage of SBS and is currently developing a fleet of satellites that include a 'Tracking Layer' to detect and track missiles and a 'Transport Layer' to transfer the data [22, 23]. The EU is investing in TWISTER[2], a PESCO project, to construct their own space-based network [24].

Distinguishing a fast-moving threat from the warm and irregular surface of the earth still poses a significant problem in detecting HGVs [25]. The field of hyperspectral imaging could offer a solution to this problem. An ordinary camera evaluates incoming reflected light in three colours: red, green, and blue. A combination of these three values is given to each pixel to represent the collected data. In comparison, hyperspectral image pixels are composed of data collected in hundreds of narrow wavelength ranges that are far outside the visual electromagnetic spectrum [26]. The images are visualised as a three-dimensional (3D) cube - called a 'data cube' - composed of data of the same scene from different wavelengths [27]. By using unique 'fingerprints' in the electromagnetic spectrum, known as spectral signatures, hyperspectral sensors can detect a wide range of (camouflaged) targets [28]. If the spectral signature of an HGV is known, hyperspectral sensors can be integrated with SBS to provide a far-reaching and reliable early warning system. Once an aerial threat is detected, the wide coverage of SBS provide a highly effective tracking system.

3.2 Role of Autonomy

Modern ADS generate terabytes of data in small- to medium-sized controlled missile tests. The vast majority of this data is not used because of the lack of workforce [29]. The expansion of missile defence with SBS and hyperspectral sensors will exponentially increase the amount of data to process. Even worse, developments in aerial threats only shorten the time available to draw life-saving conclusions from this data. The field of machine learning offers us a potential solution to these problems.

Machine Learning (ML) is an evolving branch of computational algorithms designed to emulate human

[1] Identification Friend or Foe

[2] Timely Warning and Interception with Space-based TheatER

intelligence by learning from the surrounding environment [30]. Algorithms in the field of ML revolve around enabling a machine to process large amounts of data. The goal is to develop the necessary skills to draw correct conclusions from new data and, ideally, autonomously improve their performance over time. Once a system proves it has a thorough understanding of the data, it can be used in practical applications. These practical applications have proven to be very successful in numerous fields such as crime investigation, finance, epidemiology, and marketing [31–34]. An important subclass of ML is deep learning. Deep learning algorithms mimic the complex neural networks of the human brain. The technical details of deep learning neural networks go beyond the scope of this essay and will thus be simplified as a form of ML. Nonetheless, the advantage of these neural networks is the reduced need for human interaction. However, much larger datasets are needed to effectively train a deep learning algorithm. Leveraging these capabilities for military operations will be vital in building an adaptive and highly resilient ADS. In the following sections, we will assume a situation in which an ADS has been successfully supplemented with the technologies discussed in 3.1. We will evaluate the different roles in which an intelligent, ML-driven system can assist with (or automate) an ADS.

3.2.1 Detection and Identification

The first step in an interception cycle is detecting and identifying an incoming threat. In-flight HGVs give off strong infrared radiation signatures due to frictional heating [35]. HGVs generate their strongest radiations in early flight, at maximal speed. In these early stages, they exhibit identifiable spectral signatures in various segments of the electromagnetic spectrum [36]. The proposed space-based architecture, equipped with hyperspectral sensors, could generate the necessary data to detect and identify HGVs. With global surveillance satellites, the launch of a ballistic missile needed to boost an HGV into the atmosphere can also be detected and serve as an initial alarm. The problem here is the volume of useful and non-useful data generated by the sensory network.

Therefore, we propose gradually delegating this task to a fully autonomous system based on advanced deep learning algorithms. We suggest integrating higher autonomy into an ADS in three phases. A slow and steady evolution will not only allow the identification of technological errors, but will give time to resolve additional challenges (cfr. Chapter 4). In a first phase, the feeding of data to the machine must be automated. The machine will learn from this data and from the reaction of the human operator. We suggest experience both in prefabricated test scenarios and 'hands-on' experience to maximally develop the machine's capacities. In a second phase, once the machine's performance is satisfactory in simulations, the machine can be implemented into the sensory network of an ADS. The operator will consider the machine's suggestions, but it will remain a strict *'human-in-the-loop'* system. The classification of an identified threat must be an exclusive right of the human operator in this phase. In a third phase, we suggest letting the machine take over the detection and identification steps of an interception cycle. A *'human-on-the-loop'* system, where the machine works autonomously but the human maintains veto right, would fit best in this situation. The transition between different phases does not solely depend on technological developments. Ethical, juridical, and political considerations must be made when transitioning from these phases. These considerations will be discussed in Chapter 4.

3.2.2 Tracking

A network of geographically overlapping SBS could constantly monitor a flying threat. To maximise tracking potential of this space-architecture, we suggest an autonomous *'Internet of Things'* configuration. The different satellites would be able to communicate with one another without the need to send the data to earth first. We suggest that the communication between satellites happens in parallel to the communication to earth.

3.2.3 Engaging

Proficient ML algorithms can automate data processing to detect anomalies, spot complex patterns, and improve their performance autonomously. However, the manoeuvrability of HGVs still poses a significant problem. A firing plan using advanced endo-atmospheric interceptors (still in development) is necessary to counter HGVs [37]. Guiding these advanced interceptors requires a constant, low latency influx of high quality data [38]. In this stage, the human decision-maker will need to work with the autonomous machine, in the same way a general works with his staff. Humans and machines have complementary capabilities that could potentially cancel out each other's shortcomings. Therefore, we do not suggest *'meaningful human **control**'*, as many papers on the topic of AI formulate it, but *'meaningful human **interaction**'*.

Autonomous systems are emotionless, relying purely on raw data and statistical methods to predict outcomes and decide how to react to these outcomes. Machines do not get tired, nor do they stress, removing significant sources of human error. Furthermore, machines are capable of performing complex *'what-if analyses'*, where the effect of actions on future performance is evaluated. The main advantage is that all of this happens in mere milliseconds. However, the thought process behind an advanced ML algorithm remains a black box. Despite having enormous potential, a machine cannot provide information on how results are obtained. Furthermore, the same input will not guarantee the same output [39]. These factors hamper the user's trust in the model and the system.

Humans are on the opposite side of the spectrum. We lack the raw computing power of machines, and let emotions and irrational biases influence our view of data. More than once, this has caused the engaging of illegitimate targets [40, 41]. However, humans can understand higher-level intent and analyse a situation in a broader manner. A classic example is the Cold War close call of October 5, 1960. A U.S. early warning radar had mistaken a moonrise for a large-scale missile launch. Operators quickly figured out this was a sensor error, as the Soviet leader Nikita Khruschev was in New York at the time [42].

We suggest a semi-autonomous, joint system where humans and intelligent technology work together in a collaborative and coordinated fashion. The two systems must be aware of each other's tendencies and aware of each other's capabilities and defects. A scenario with mutual control, where the AI could verify the human is not making irrational decisions fuelled by emotions, would make an AI a valuable team member.

3.3 Overview

A series of sensory upgrades are needed to bring a modern ADS to the hypersonic standard. A space-based sensor architecture would offer a permanent, global monitoring capability. To increase the chance of a correct identification, we suggest integrating hyperspectral sensors in the proposed space-based network. This would increase the probability of detection (and identification) $P_{D|A}$. With an interconnected network of overlapping SBS, the probability of tracking once detected $P_{T|D}$ increases significantly. An overview of our proposal is seen in Figure 2.

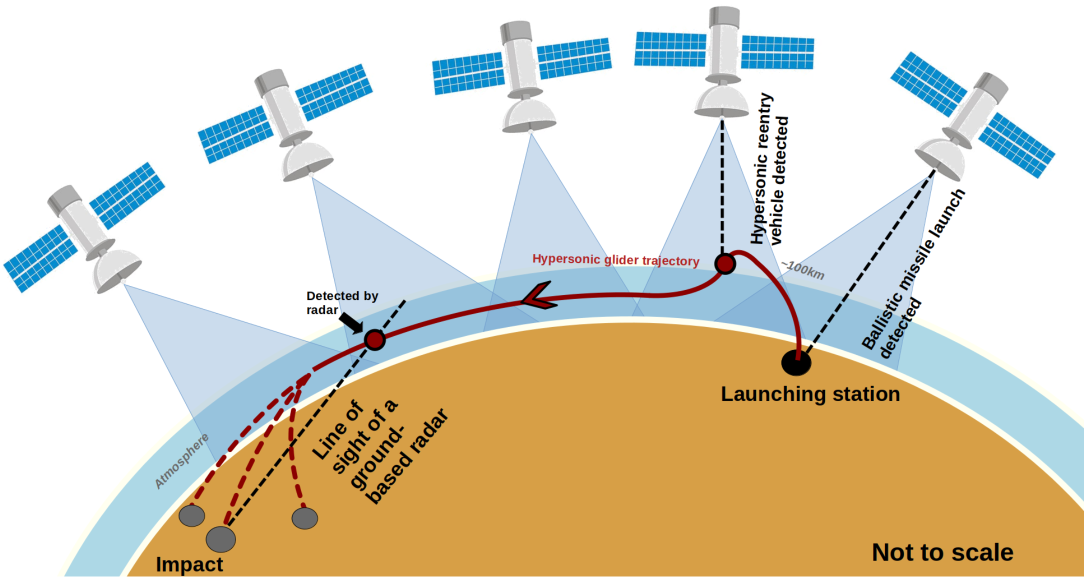

Figure 2: Overview of the suggested improvements and its effects on hypersonic missile defence.

The massive influx of data requires autonomous subsystems in order to effectively process it in a timely manner and formulate a suitable plan of action, thus raising $P_{E|T}$. The integration of machine learning algorithms into this novel ADS is crucial to maximise the ADS' P_K. We suggest not only a layered sensory network - composed of various ground- and space-based sensors - but also 'layered autonomy'. Tasks such as detection, identification and tracking can be fully delegated to a machine. The engagement cannot be delegated, but must be assisted in a cooperative manner by an AI. This however raises additional questions outside the technological realm.

4 Challenges

Technology alone is not enough.

—*Steve Jobs*

Technological advances are not made in a vacuum but in a multidimensional context. The technical challenge of heightened autonomy is just one of the many aspects worth reviewing. Moreover, according to the Martens Clause, mentioned in the Geneva Conventions, and the preamble of the Convention on Certain Conventional Weapons (CCW), a ratifying State is obliged to consider the moral implications of new technology [43]. The following sections will discuss the interaction with ethics, international law, military structure, and the peace-and- security paradigm.

4.1 Ethical - Juridical

The debate surrounding ever-increasing autonomy in weapon systems is influenced and complicated by emotional messages from the Campaign to Stop Killer Robots, such as *"Less Autonomy, More Humanity!"* Although killer robots are offensive, the same ethical-legal concerns apply to defensive systems [44].

Self-defence is an innate reflex and therefore inherently human [45]. The legality of a defensive system, such as an ADS, is based on Art. 51 of the UN Charter. In the event of an armed attack, a state may invoke the right to self-defence [46]. Although it is a just cause, it is bound by ethical Ius In Bello principles laid down in the Law of Armed Conflicts (LOAC) or International Humanitarian Law (IHL).

The technological development of autonomous weapons systems is overshadowed by ethical-legal concerns regarding the compliance with IHL and the accountability gap.

4.1.1 International Humanitarian Law

The principles of distinction and proportionality are based on what Thomas Aquinas described as just intent. He stated that *"one must intend to promote the good and avoid evil."* [47] These Ius In Bello principles were not embodied in the Geneva conventions until the Additional Protocol I codified them in 1977 [48]. The latter is not ratified by notable countries such as the U.S., Israel, Iran, Pakistan, Turkey, and Iraq [49].

The principle of distinction concerns, on the one hand, the division of the population into combatants and non-combatants and, on the other hand, the granting of special protection status to certain objects. Ignoring the absolute protection of non-combatants and protected objects (e.g., world heritage sites or nuclear power plants) is considered a war crime [50]. Since an incoming hypersonic missile is an unmanned object with no protected status, it is a legitimate target for an ADS. An extensively tested autonomous sensor system and analytical AI body should be able to detect, identify and track this target (see Section 3.1).

A hypersonic missile is a legitimate target for an autonomous ADS. The principle of proportionality may be questioned however. This principle limits potential harm to civilians; it requires that civilians be harmed as little as possible, and that when harm cannot be avoided, it is in proportion to the military gain [51]. It is a complex utilitarian calculation. Assuming a successful interception of an ADS over a densely populated city, the collateral damage caused by crashing debris must be taken into account. If the target of the hypersonic missile is a weapons depot in an unguarded rural area, the human cost caused by the debris may be much higher than the one caused by impact on target. Consequently, the intervention of an autonomous ADS is unethical and legally questionable. However, because of the short reaction time and the ambiguity of a hypersonic missile's impact (see Section 2.3), an autonomous response is necessary. The AI model must take population density into account when determining a firing plan. This way, the interception point can be more adequately "chosen" and collateral damage minimised.

4.1.2 Accountability Gap

The International Court of Justice punishes human agents who violate the above principles, but it cannot impose sanctions on systems. Anti-autonomy lobbyists try to create the impression that autonomous weapon systems operate completely independently, which results in impunity in case of violations [52]. However, the system must be programmed in order to work within specific parameters; autonomous weapons will never be totally human-free [2].

The legal problem is that there is no consensus on the definition of autonomous weapon systems. Moreover, the debates for it are influenced by emotional messages [52]. A definition must form the basis of an ethical-legal framework that makes impunity impossible and provides a cascading solution to the accountability problem. Furthermore, a legal answer for this accountability gap will result in better performance and accuracy of the human operators on the loop because they are held responsible for the human-system outcome performance [53]. By suggesting a cooperative workflow in the engaging phase of an ADS, we have attempted to minimise this accountability gap.

4.2 Peace-and-security Paradigm

4.2.1 Road to war

The competition between hypersonic missiles and ADS was initiated when China and Russia conducted their first hypersonic missile test, respectively in 2014 and 2016 [54]. As a reaction, Europe launched a new PESCO initiative, called TWISTER, to counter the emerging threat.

Sir Edward Grey, Britain's foreign secretary at the start of World War I stated that *"The moral is obvious; it is that great armaments lead inevitably to war* Sun Tzu, an ancient war philosopher, also emphasised the ambiguous relationship between technology and war. *"One probably drives the other. Wars have pushed technology to advance and at the same time advanced technology has also pushed people towards war."* This may be true for ADS and hypersonic missiles. Integrating advanced autonomy in our ADS would offset the offence-defence balance. This could trigger hostile states to further upgrade their offensive capabilities, setting the first steps on the road to war. Therefore, it is important to use soft power diplomacy to break the vicious arms race cycle and to establish an ethical-legal framework (cfr. Section 4.1).

4.2.2 Five Operational Domains

The character of war is changing, but the nature of war is not [55]. In the 20th century, technological advancements pushed the boundaries of lethality, range, and speed in all four domains: land, sea, air, and space. It also introduced cyberspace as the fifth operational domain in the 21st century [56]. An efficient ADS operates in all five domains. Information is gathered by ground- and space-based sensors and processed by an AI-assisted decision-making body that defines and eventually counters the threat. A sea, land, or air platform will launch an interceptor when necessary.

The interdependency of the operational domains emphasizes the importance of cyberspace. First, cyberspace enables the performance of Network Centric Operations by integrating the sensor, shooter, and C2 grids into a tightly integrated Detect-Identify-Track-Engage cycle. Secondly, because the other four domains are becoming increasingly reliant on cyberspace to function efficiently, cyberattacks may be used to weaken air defence capabilities. This would contribute significantly to reducing enemy fighting potential in a multi-domain battle [57]. Enhanced cybersecurity capabilities will play a big role in securing the proposed sensory architecture and the resulting stream of data.

4.2.3 Mutual Assured Destruction

The doctrine of 'Mutual Assured Destruction', illustrated by the Cuban missile crisis in 1962 [58], keeps nuclear powers in a Nash equilibrium. A contemporary example is NATO's reluctance to support Ukraine in their fight against Russia, for fear of nuclear escalation [59]. Both are counterexamples to the argument that great armaments lead inevitably to war (see 4.2.1). The introduction of HGVs may lead to an imbalance and unintended escalation in the conflict. Because the missiles' short flight lengths give countries little time to decide how to respond, the target nation may reply with an impulsive response, not knowing whether the incoming missile is carrying a nuclear payload [60]. Furthermore, HGVs are an ideal weapon for a preemptive surprise attack because of their current superiority over ADS. In several minutes, an attacking nation could destroy a nation's nuclear arsenal, nullifying the doctrine of Mutual Assured Destruction. We suggest that hypersonic missiles should be included in nuclear arms control negotiations.

4.3 Military

4.3.1 Military Sociology

Military organisations are unique; they use legitimate lethal force. Armed forces strive to implement standardisation and uniformity to deal with life-threatening environments in a controllable and predictable manner. Therefore, a rigid, centralised, and hierarchical structure characterises a military. Today, armed forces do not operate in a vacuum but in a competitive VUCA[3] environment characterised by rapid multidimensional change. In order to survive, it is of prime importance to be a learning organisation that responds to the changing environment through sustainable change management. The next step is more autonomy. However, the bureaucratic structure impedes change [61]. Moreover: *"military personnel often lack trust in the safety and reliability of autonomous systems. Some military professionals see the development of autonomous capabilities as a direct threat to their professional ethos or incompatible with the operational paradigms they are used to."* [1] Our suggestion for the gradual implementation of autonomy is described in 3.2. This must be paired with a training and coaching framework for the military operators to achieve trust in their AI colleague and prevent dependency.

4.3.2 Military Psychology

Automation bias is defined as the decreased performance of a machine-human system due to humans interacting with autonomous systems [53]. A higher level of autonomy in weapon systems results in an increased performance and better decisions. At the same time, a higher level of autonomy may result in a loss of skills and a sense of agency. Therefore, it is important that human operators remain trained to take over the system in case of a system failure. In that training, they need to be confronted with the deadly nature of an ADS to increase the moral sense of agency and avoid collateral damage.

4.4 Need for European Cooperation

Several EU countries are already evaluating the use of advanced air defence as a response to complex aerial threats in a PESCO project [62]. The U.S. is already in the process of constructing an advanced ADS with elements mentioned in this essay. The Pentagon has recently awarded a contract for more than $342 million for the construction of a network of space sensors [63]. The sheer size and cost of such a project poses a challenge that can only be overcome by a European cooperation.

In March of 2022, Russia has used a hypersonic missile on Ukraine. This marks the first time such weapons were used on the European continent [64]. This resulted in a certain psychological and propaganda effect, [65] which was presumably Russia's goal. In our opinion, this must serve as a wake-up call. Hypersonic weapons are not a myth anymore, and they are far more capable than any defensive system Europe has. To properly protect ourselves against advanced aerial threats, cooperation between EU member states is necessary. This must be paired with increased cooperation between military and civilian industry. For example, the protection of a space-based network could be aided by civilian cybersecurity specialists.

4.5 Conclusion

Increased autonomy in weapon systems is a sensitive subject in many fields. The technological challenge of designing a capable AI that would serve as a helpful teammate to a human operator is just one piece of the puzzle. Technology will always interplay with ethics, law, social structures, and economics. This chapter has evaluated some of these additional challenges and proposed measures to tackle them. A complete analysis of the different challenges is out of the scope of this paper. Nonetheless, a unified Europe is necessary to overcome the critical challenges to guarantee a safer Europe.

[3]Volatile, Uncertain, Complex, and Ambiguous

5 Conclusion

Modern air defence systems are no match for complex aerial threats, such as the hypersonic missile. In order to bring modern air defence systems to the hypersonic standard, hardware and software upgrades must be made. Autonomy will play a crucial role in maximising the effect of these upgrades.

To answer the central research question, *"How and to what extent can autonomy help in countering the threat of hypersonic missiles?"* we specifically investigated the necessary upgrades to the sensory architecture. As sensors form the backbone of missile defence operations, these upgrades are necessary to support any future endeavours.

We suggest upgrading our current ground based sensor network with space based sensors to increase the geographical range. To enhance identification capabilities, we also suggest the use of hyperspectral sensors that increase the sensory range in the electromagnetic spectrum. The combination of space based sensors and hyperspectral sensors would aid in the detection, identification, tracking, and finally engaging of an aerial threat. However, the massive influx of data exceeds human bandwidth.

Autonomous subsystems will be necessary to process the massive influx of data and maximise the upgrades' effectiveness. We suggest a layered approach to this autonomy. Detecting, identifying, and tracking an incoming threat can be delegated to the machine with a human operator remaining on the loop as an overseer. The limits of autonomy-assisted air defence become clear in the engagement phase. This phase requires a different approach. We suggest a human-machine collaboration, supposing that an AI-assisted ADS and the human operator are complementary colleagues.

Autonomy integration in air defence systems is a multidisciplinary task that necessitates a holistic approach. All five operational domains - land, air, sea, space, and cyber - must be considered. As a result, the pursuit of more autonomy in air defence systems requires a harmonious integration with ethical concepts, International Humanitarian Law, military psychology and -sociology. It is also worth considering the implications for the global security culture, which is currently defined by the Mutual Assured Destruction doctrine. A parallel soft power approach, in addition to technological hard power growth, is absolutely essential. The goal is to provide an ethical-legal framework for autonomy in air defence systems while also limiting the vicious arms race cycle through enforceable agreements.

The integration of autonomous subsystems will be an essential step to counter hypersonic missiles and the complex aerial threats of today. The potential cost of this step will be high, as challenges are presented in various fields as discussed in Chapter 4. The potential cost of doing nothing will be much higher.

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