Futures 134 (2021) 102848

Contents lists available at ScienceDirect

Futures

journal homepage: www.elsevier.com/locate/futures

The future of unmanned combat aerial vehicles: An analysis using the Three Horizons framework

Javier Jordan

Department of Political Science, Faculty of Political Science and Sociology, University of Granada, Calle Rector Lopez Argueta, 4, 18071 Granada, Spain

ARTICLE INFO

Keywords:
Unmanned combat aerial vehicles
Military technology
Air power

ABSTRACT

This article examines the future of unmanned combat aerial vehicles (UCAVs). As a foresight tool it uses the Three Horizons framework, which helps understand the process of change underway at present in combat aviation as a result of the advances in technology associated with the fourth industrial revolution. According to this framework, the first horizon corresponds to manned combat aviation, the strategic effectiveness of which is beginning to be called into question. The second horizon comprises different strategic innovations currently in progress which can be viewed as support for the first horizon but also as disruptive innovations that may bring about a change in the dominant model. The article then explores a third hypothetical horizon in which UCAVs take centre stage in combat missions and identifies potential drivers of this alternative and disruptive future.

1. Introduction

A number of air forces and defence companies are investing in the development of sixth-generation fighter aircraft with a view to entry into service in approximately 2035–40. Two such projects are underway in Europe: the BAE Systems Tempest (United Kingdom, Italy and Sweden) and the Future Air Combat System (France, Germany and Spain). The distinct feature of the new programmes with respect to previous generations of jet fighters is the lead role of the 'system of systems' over the aerial platform. An assumption of all the programmes is that the sixth generation will feature a manned combat platform, which will operate as a team with various unmanned combat aerial vehicles (UCAVs), including some with a high degree of autonomy. However, the progress achieved by the technology prompts the following questions. Will the crewed platform be an actual fighter plane or an advanced command centre for the UCAVs? Will UCAVs replace manned fighter aircraft in main air-to-air and air-to-ground combat missions?

The present article seeks to address the above questions using the Three Horizons framework. This foresight tool has been selected as it is helpful for structuring reflections on disruptive innovation processes. The article takes as a case study the United States Air Force (USAF) which, like some of its European counterparts, is developing a sixth-generation air combat system through its Next Generation Air Dominance Program (NGAD). The USAF has been chosen on account of the wealth of information available on its technology programmes and associated debates. Furthermore, given the United States' leadership in technology it is logical to assume that its programme implications will affect the two European sixth-generation air combat systems. The article is based on a detailed examination of documents on the future of combat aviation in the USAF. The documents include official papers, public statements by senior military and civilian figures, articles published in professional journals, and specialist websites.

E-mail address: jjordan@ugr.es.

https://doi.org/10.1016/j.futures.2021.102848
Received 21 April 2021; Received in revised form 19 July 2021; Accepted 15 September 2021

The topic of UCAVs generally, and lethal autonomous weapons systems (LAWS) in particular, has been addressed in numerous works from the legal, ethical and arms control perspectives (Aaron & Axinn, 2013; Bhuta et al., 2016; Scharre, 2016). It has also given rise to social and political concerns, as reflected in the open letter by NGO The Future of Life Institute (2015) –endorsed by, among others, Elon Musk and Stephen Hawking—which called for LAWS to be banned and in the European Parliament's call for a European strategy to prohibit such weapons systems (News European Parliament, 2021). It is worth noting from the outset that present-day UCAVs are not LAWS. Fewer works investigate the topic from the future studies perspective. Based on the information collated and the Three Horizons foresight approach, the present article seeks to identify the main factors that will condition the future role of UCAVs in air combat and air-to-ground missions.

The article is structured as follows: it begins by outlining the Three Horizons foresight framework and then applies this to the evolution of combat aviation, to current programmes and to intuitions concerning the future of UCAVs. It sets out the (non-testable) hypothesis that the third horizon corresponds to a future in which unmanned systems will take on the lead role as air platforms in air-to-ground and air combat missions, forming part of a 'system of systems' based on human-machine teaming. Lastly, the article identifies the main drivers that will condition the materialisation of this hypothetical third horizon.

2. The Three Horizons framework

The Three Horizons framework is a qualitative foresight tool for structuring reflection on processes of profound long-term change. It is premised on the idea that many organisations, technologies and political policies exhibit life cycles of initiation, growth, success and decline. The cycles can be viewed as waves of change that displace each other successively, an analogy which underlies representations of the three horizons.

As Fig. 1 shows, the three horizons do not refer simply to the short, medium and long term but rather to the processes of change required to maintain strategic effectiveness in a context of change. Depending on the specific case, the timescale of each horizon may range from a few years to several decades. The important aspect from the strategic perspective is not the timescale but the qualitative difference of the structural change in each horizon. The Three Horizons framework focuses on the strategic effectiveness of the system (vertical axis) as the environment evolves over time (horizontal axis). The approach contemplates the simultaneous existence of the three horizons from the present time onwards. This allows alternative futures to be visualised and opinions concerning continuity, innovation and transformative visions to be articulated.

The figure illustrates the gradual erosion of a dominant system (H1) which coexists with processes of innovation (H2) and transformation that culminate in a new dominant system (H3) which better harnesses the opportunities offered by the changing environment. Thus, the Three Horizons framework helps us understand the development of processes of profound change by identifying structural patterns underlying surface events.

Having set out the above preliminary considerations, the three horizons are as follows:

Horizon 1 (H1) denotes a dominant system in a given environment at the present time. It has high strategic effectiveness and may even have reached its peak. The system is largely coherent with the environment's dominant values and other dominant systems and institutions. Some H1 systems become so crucial for the functioning of society that they acquire 'critical infrastructure' or 'strategic undertaking' status and receive special attention from government, as is the case of energy companies, for example (Curry & Hodgson, 2008). In other cases, a system is part of a given public policy (for example, the military use of air power, the focus of this article). Its apparent robustness depends on different types of anchor which favour the status quo and it benefits from past successes that confirm its strategic fit. This is not in itself negative: daily life is possible thanks to the continuity of public policies and organisations which interact with the people and drastic changes to their mode of operation are thus inappropriate.

At the same time, Horizon 1 systems are open to sustained innovations, that is, those that offer improvement using ways and means tried and tested by the habitual actors and which do not represent any major risk. Indeed, the resources and consolidated experience of the systems enable this incremental growth to be embraced. However, as the environment changes over time this adaptation

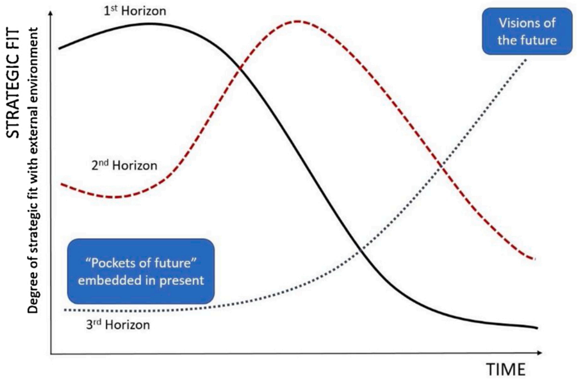

Fig. 1. Schematic of the futures-oriented Three Horizons framework.
Source: Curry & Hodgson, 2008: 2.

occasionally becomes self-confirmatory and is owed more to inertia than to true effectiveness. ‘Regulatory capture’ thus sets in: management of change is subordinated to certain specific interests and other change options that would bring wider gain are curtailed. In such cases the H1 system gradually falls short of expectations, proves incapable of dealing with new threats and fails to harness the opportunities afforded by the context. In short, it gradually loses its fitness for purpose. At the same time, its dominant position hampers the emergence of new systems better suited to the context. In these circumstances, the dominant position of the H1 (itself once an H3 reflecting a particular vision of positive change) becomes a problem (Sharpe, 2013). If incremental adaptations fail to improve its strategic fit, the system will enter decline. Although not disappearing entirely, it will be relegated to a secondary position.

Horizon 2 (H2) is a transition phase characterised by innovation and situated between two paradigms. The changing environment generates new challenges and opportunities, triggering the dilemma whether it is better to respond with known means or to opt for radically different approaches that overcome the limitations of the H1. In this ambiguous period, elements of the dominant system coexist with H3 proposals, which are often hypotheses that have yet to be tested. Creativity, experimentation, negotiation, and debates among coalitions for and against the change are all in abundance. Innovations are set in motion that pave the way for Horizon 3 although they are presented in a manner which is confusing and difficult to articulate.

H2 is often a turbulent phase in which both directions are contemplated simultaneously. It is consistent with what Clayton Christensen (2016) terms the ‘innovator’s dilemma’, namely, whether to continue supporting the old dominant system which appears to be in decline or invest more substantial resources in a new road, the true effectiveness of which has yet to be demonstrated. This dilemma may be constrained by attempted co-option by the H1 system which, if successful, will absorb the potential of the innovations and prolong its own lifespan. In such cases, the outcome would be a ‘Horizon 2 minus (H2-)’.

In the opposite case, however, as the effectiveness of the disruptive innovations gradually becomes clear these are likely to become consolidated and attract further support and resources, gaining a competitive advantage over other options, including those from H1. This is known as ‘Horizon 2 plus (H2+)’, which paves the way for H3.

H3 is the transformative vision. If it is to prevail, it must not only demonstrate superior effectiveness to H1 but also overcome any resistance to abandoning the latter. Viewed from the current perspective, where the H1 system is dominant, H3 is a very remote possibility and may even be ruled out entirely. Some of its elements remain in hibernation until the new system is fully developed, while others begin to manifest themselves in the present as glimpses of the future. This new paradigm remains in the background but slowly takes shape as an alternative which remedies the shortcomings of the dominant system. New actors gradually emerge and H2 innovations become consolidated. In the long run the Horizon 3 eventually becomes the dominant system, the result of a far-reaching transformation incorporating successful innovations from Horizon 2 (Sharpe, 2013).

The simplicity of the Three Horizons Framework makes it useful for structuring thinking around the major long-term challenges faced by the current dominant system (H1). It broadens the perspective by contemplating changes as potentially transformative, rather than merely adaptive. The framework considers emerging forces and seeds of innovation that might potentially generate a new system (H3) but would go unnoticed if the search for solutions were confined to the H1 level. The technique also helps differentiate between sustained innovations which improve and strengthen the current system from disruptive ones that pave the way to new models. Both types of innovation coexist in periods of transition (H2).

At the same time, the inherent ambiguity of the transformation process encourages flexible thinking and helps avoid simplistic debates (conservative/progressive, good/bad changes). The framework aids discussion of the positive contribution of all three horizons. All processes of change entail loss and gain; moreover, the step change from one horizon to another is often accompanied by transitions of power. H1 was in its day an H3 and it is quite possible that, despite the changes to the environment, there are things to be retained and from which lessons can be learnt. Moreover, some apparently promising disruptive innovations may turn out to be failures. The technique presupposes the simultaneous existence of the three horizons, each with different degrees of strategic effectiveness over time, and any exploration of the future must therefore consider the potential contribution of each.

3. The future of combat aviation in the USAF viewed through the Three Horizon framework

A detailed study of the available documentation shows that combat aviation is undergoing a profound transition even if there is no clear and agreed view on the exact direction of the innovations in progress. Given this lack of clarity, the Three Horizons technique can help articulate our exploration of the future.

In order to contribute to the debate this article takes as its hypothesis the most disruptive vision: under the third horizon, manned combat aviation will be displaced as the main platform and replaced by unmanned air combat systems operating as platforms within a system of systems in which human-machine teaming will occupy centre stage. The article examines the far-reaching factors which could result in the current H1 (main platform: manned combat aviation) being replaced by the hypothetical H3 (main platform: unmanned combat aviation). The sections which follow will discuss the patterns underlying each of the three horizons.

3.1. First horizon: lead role of manned combat aviation and secondary role of unmanned air systems

Manned aviation has been the predominant air combat system since World War 1, a conflict which witnessed the development of the primary missions of aerial military power: reconnaissance, air-to-air combat, close air support, interdiction operations, and strategic bombing. Technological advances during the inter-war period and World War 2 significantly improved the performance, range and weaponry capabilities of the platforms. At the same time, a series of innovations in navigation, remote sensing, communications, and command and control were introduced both in aircraft and ground support systems (Van Creveld, 2011).

The latter part of World War 2 and early years of the post-war period saw the first jet fighters, beginning with the German Me-262.

These fighters were used extensively in the Korean War (1950–1953), with the American F-86 and Soviet MIG-15 the best-known examples. Advances in technology and the experience gained in Korea led to a second generation of jet fighters featuring improved avionics, generalised use of radar and missiles, and the ability to fly continuously above the speed of sound, etc. A third generation which emerged in the Vietnam War brought further improvements and versatility to fighter planes. The advances continued in a sustained manner and gave rise to a fourth generation at the end of the 1970s. Modernised fourth and fourth-plus generation aircraft form the backbone of most European air forces today. The last two decades have witnessed the arrival of fifth-generation fighters, essentially the American F-22 and F-35, the latter replacing fourth-generation planes in several European countries. Other fifth-generation models such as the Russian Su-57 and Chinese J-20 have yet to become fully operational.

The fourth-plus and fifth generations of fighters owe much to technological advances in computation, high sensorisation, and connectivity with other air, naval and ground platforms. Like their advanced civil aviation counterparts, the latest generations of fighter planes use advanced (fly-by-wire) flight control systems which keep the aircraft stable irrespective of the manoeuvres ordered by the pilot. In fighter planes such as the Eurofighter, for example, fly-by-wire not only reduces pilot workload (carefree handling) but is indispensable for controlling the aircraft given that some avionics that provide combat agility make flying in normal conditions extremely difficult. In other words, manned combat aviation is viable thanks to the assistance provided by the aircraft's artificial intelligence (AI). The same is true of assistance with decision-making. Increased aircraft sensorisation and network operation, with data received from other manned and unmanned platforms, make AI increasingly necessary to process all the information and recommend options, thereby avoiding pilot overload. All these are sustained innovations which strengthen the H1 system.

Throughout its century-long history, combat aviation has always been manned. However, it is less well known that the development of unmanned aerial vehicles (UAV) commenced almost in parallel, with early prototypes dating back to World War 1. In World War 2, planes laden with explosives were guided by remote control for high-precision bombing. The Cold War period saw limited development of UAVs, which were used for secondary roles in support of manned aerial combat vehicles. These uses mainly comprised actions against aerial targets although they were used occasionally also for high-risk intelligence, surveillance, target acquisition and reconnaissance (ISTAR) (Singer, 2009).

The development of UAVs for military purposes has been stepped up in the last two decades, spurred largely by their use in the fight against terrorism and insurgency in conflicts that followed the September 11 attacks. Armed drones offer advantages such as persistence over the theatre of operations, a shorter sensor-to-shooter chain, and lower political costs compared to manned aircraft. However, their use by the United States in its controversial targeted killings campaign has raised ethical questions concerning armed drones generally. Major political differences have arisen among European countries, some of which (United Kingdom, France, Italy) have armed their drones, while in others (Germany, for instance) the political debate continues (Sprenger, 2021).

Outside Europe, the acquisition of armed drones is becoming more common due to the diversification of manufacturers (Israeli, Chinese and Turkish in particular). Their use in combat is no longer the sole preserve of the United States, as the recent conflicts in Syria, Libya and Nagorno-Karabakh show. Still, experience in these conflicts has been limited and has served to highlight the limitations of the technology in terms of a potential conflict between advanced armies where both sides would probably neutralise enemy drones using electronic warfare, conventional air-to-air systems or specific anti-drone systems (Bryen, 2020).

With the exception of armed drones (UCAVs), there have been relatively few problems in accepting the use of unmanned systems for other military purposes, particularly intelligence, surveillance and reconnaissance (ISR) missions, a field in which continuing developments in technology have led to drones coexisting increasingly with manned aviation. In fact, UAVs have practically replaced crewed aircraft in reconnaissance missions deep inside contested air space (Iran, for example). However, these roles and others such as inflight refuelling are largely support missions for the core mission of all air forces: combat and attack. As such, they are innovations that do not challenge H1.

Nonetheless, serious question marks against the long-term strategic effectiveness of H1 have arisen for three reasons.

Firstly, the increasing cost of the development, acquisition, operation and sustainment of manned aerial platforms. Step ups in the level of technology and effectiveness from one generation of combat aircraft to another require massive investment, ultimately leading to a reduction in fleet sizes and to opportunity costs for other areas of the defence budget given that the accounts cannot be balanced. In the current climate, the multiplication of costs will also affect the next generation of fighters. The Congressional Budget Office warned back in December 2018 that the next air dominance fighter (the Penetrating Counter Air programme, which subsequently became the current NGAD) would cost 300 million dollars apiece, more than twice the cost of an F-22 and over three times that of any of the F-35 variants (Insinna, 2018). This cost increase is giving rise to paradoxical situations such the USAF's acquisition of the F-15X (an upgrade to a platform initially designed over forty years ago) as an economically sustainable solution to complement the more expensive and slower to acquire fifth-generation F-35A (Insinna, 2020).

The rising costs and subsequent reduction in units purchased lead to uncertainty concerning the effectiveness of the H1 system in a high-intensity armed conflict between advanced armed forces. As the saying goes, “quantity has a quality all its own”. Bearing in mind that actual availability is always lower than the number of aircraft, and that air forces are likely to suffer attrition in a matter of days, one might reasonably question whether the improved effectiveness associated with advances in technology compensates the reduction in absolute terms in the number of manned aerial platforms.

Secondly, improved air defence systems continue to pose a threat to combat aviation. This is not an insurmountable barrier given that a constant feature of the history of armaments is the competition between weaponries to counteract each other. Air defence systems have represented a challenge since the earliest days of combat aviation and one of the features of fifth-generation aircraft (radar stealth) is designed to allow the planes to operate inside the range of advanced air defence systems. Despite improved doctrines and technologies for the suppression of enemy air defences (SEAD), such operations are currently difficult for fourth-generation aircraft without heavy losses in terms both of pilot lives and also planes that cost tens of millions of dollars each and are limited in number. The technology race continues, meanwhile, and Russia and China are developing increasingly sophisticated and longer range integrated air defences in which various systems work together against high-altitude targets up to a distance of 400 km. Detection methods (passive radars combined with infrared search and track systems, and in future quantum radars) are also improving in an attempt to reduce the stealth of current fifth-generation planes. Improved air defence systems are part of a broader strategy to create anti-access/air denial bubbles (A2/AD) to deprive the air forces of the United States and its European allies of the superiority they have enjoyed since the 1991 Gulf War.

The third reason is the gradual expansion of UAVs, which is interpreted in this article as the hypothetical third horizon. Technological advances associated with AI, the Internet of Things and 3D printing are already making their presence felt in the improved capabilities of UAVs generally and UCAVS in particular. This aspect will be discussed in the following section, which examines the second horizon.

3.2. Second horizon: innovations and synergies between manned and unmanned combat aviation

The second horizon is already clearly observable. The past decade has brought more intense exploration of new concepts and experimentation with different technologies associated with combat aviation and UCAVs. Some can be interpreted as sustained innovations to improve the H1 of manned combat aviation. However, the period can also be viewed as a transition towards a new combat aviation model in which the lead role is played by unmanned platforms (H3). The following section will outline some of the innovations and projects underway that illustrate the inherent ambiguity and lack of clarity of H2.

To begin with, the usefulness demonstrated by military UAVs has prompted further investment and developments which have strengthened their technological readiness. Major advances in autonomy have been achieved in areas such as take-off, compliance with predetermined flight parameters, in-flight refuelling (by another UAV) and landing, including on aircraft carriers –something achieved for the first time in 2013 by the X-47B (Freedberg, 2014). As noted above, these advances have helped UAVs assume increasingly important roles in ISR missions, where they have gradually replaced crewed aircraft. The stealth technology and full flight autonomy of the RQ-170 have, for over a decade, allowed it to operate in contested air spaces such as Iran and Pakistan. One wonders, therefore, why this specific model –or an improved variant– has not been armed to become a UCAV: in the same way that it can be launched to take aerial footage of an Iranian nuclear facility, it could also be used to launch a GPS-guided bomb from an internal weapons bay (Rogoway, 2016b).

One possible explanation is that cultural and bureaucratic resistance on the part of USAF –there is no evidence of a veto at political level– has prevented such use until recently. This would explain the suspension of the X-45 programme led by the Defense Advanced Research Projects Agency (DARPA) and Boeing. The first flight of the X-45 demonstrator took place in 2002. This was a UCAV demonstrator whose AI system afforded it a high degree of autonomy not just in terms of flying but also to decide on and execute tactical options. In 2005 a pair of X-45 s successfully completed a test mission in which they acted entirely autonomously and as a team to attack pop-up targets. However, when the X-45 programme was transferred from DARPA to the USAF, it was suspended by the latter for no clear reason. Another possible explanation is that stealth drones such as the RQ-170 are, in fact, being armed under classified USAF programmes. Prior to the publication of the first images taken in operations in Afghanistan in 2007, the RQ-170 was a UAV developed under a classified programme. The USAF may well have continued the development of a classified UCAV programme to retain a competitive advantage over rival foreign powers and also to prevent suspension of the programme due to internal political and social factors (Rogoway, 2016b).

Whatever the reason, since the late 2010s the USAF has publicly stated its renewed interest in leveraging UCAVs through a range of programmes, most of them led by the Air Force Research Laboratory (AFRL). One of the most important of these is Skyborg, an AI system capable of piloting UCAVs fully autonomously, even if it is usually presented as operating in tandem with crewed fighter aircraft. Skyborg is open architecture so that new complex autonomous behaviours can gradually be added. A Skyborg-directed UCAV will not do anything a manned fighter cannot do. However, it will do it more quickly thanks to its ability to process and exploit the enormous amount of information provided by advanced combat aircraft sensors and, in particular, the information received from the other platforms and sensors of the network of which the UCAV forms part (Trevithick, 2020). A human would take much longer to process all this situational data. AFRL hopes to produce a first autonomous UCAV capable of executing a specific mission and then use this as the basis for iterations with more complex AI (Trevithick, 2019).

In parallel to the above, the concept of 'loyal wingman', used to denote teamwork between manned and unmanned combat aircraft, is gradually gaining acceptance. The USAF is already trialling the concept with the XQ-58A Valkyrie, as is the Royal Australian Air Force (RAAF) through a similar programme developed with Boeing (Lee, 2020). The concept is also part of the two European sixth-generation systems –Tempest and FCAS (Newdick, 2021; Stevenson, 2019). The aim is for manned platforms to be accompanied on different missions by one or more UAVs/UCAVs (advanced sensors, electronic warfare, attack, decoy), which would act as a force multiplier to increase the range and number of sensors and weapons systems. Unlike current single-use cruise missiles or decoys, the accompanying UAVs would be 'attritable'. Although the idea is to reuse them for various missions, given their relatively low cost and the fact that they are unmanned they could be sacrificed, if necessary, in high-risk activities, thus avoiding the need to expose manned aircraft.

Associated with the 'loyal wingman' is the concept of low cost, single-flight accompanying drones. This blurs the borderline between UCAVs and intelligent munition, such as the US Air Force's 'Golden Horde' swarming munitions programme. In turn, this concept complements DARPA's 'flying missile rail' concept whereby a manned host aircraft would launch various UCAVs, each of which carries intelligent munitions and missiles, thus considerably extending both range and tactical flexibility (Rogoway, 2017). In January 2021, DARPA contracted several companies to commence design work on the LongShot programme to develop a fighter-launched stealth drone capable of firing long-range air-to-air missiles (Trevithick & Rogoway, 2021). Here too the concept might be interpreted as a sustained innovation that extends the capabilities of the H1 system, although it can also be viewed as a further step in the direction of the H3 hypothesis suggested in the present article. In fact, the USAF has said it intends to include Skyborg in its loyal wingman drones, which opens the door to the possibility that the computer brain will control autonomous UCAVs in the future. It also plans to introduce loyal wingmen in large-scale military exercises –including in the role of adversaries– in order to improve the Skyborg AI algorithms before deployment in actual missions (The War Zone Staff, 2021).

Experiments are also underway with UCAVs that operate semi-autonomously in swarms, receiving instructions remotely from a human operator midway through a mission. Since 2014 at least, DARPA (2019) has been developing its Collaborative Operations in Denied Environment (CODE) which allows, for example, a team of UCAVs to seek out and attack targets according to parameters determined by human controllers. Although in principle they would require authorisation to attack, they could also do this completely autonomously.

The issue of different degrees of autonomy requires brief explanation. Non-autonomous UAVs still exist: these are drones whose entire functions are controlled remotely by a human operator. Above this lowest rung, three levels of autonomy can be distinguished (Scharre, 2016: 9). The first is human-in-the-loop or semi-autonomous operation. Here the human operator assigns one or more tasks to the UAV for automatic execution, whereas others are controlled by the human operator. The MQ-9 Reaper UCAV falls into this category. The second is human-on-the-loop or supervised autonomous operation, where the UAV follows mission parameters which have been predetermined or are updated mid-flight by human operators and consults the controllers who then take the key decisions. The RQ-170 Sentinel UAV falls into this second category. This level of autonomy allows a single operator to supervise several UAVs at the same time and it will gradually become the norm for various types of drones. The third level is human-out-of-the-loop or fully autonomous operation. Here, the UCAV has full operational autonomy and can seek and select targets and take tactical decisions based on pre-programmed parameters. This third possibility raises the greatest ethical, legal and political concerns as it transforms a UCAV into a LAWS. With the exception of munition such as the Harpy loitering and anti-radiation missile, aerial LAWS are still a concept under development in experimental programmes within the H2 framework. No UCAV that might be considered a LAWS exists today. In fact, there is no public record of any UCAV (C standing for combat) with second-level autonomy (human-on-the-loop) being operational at the present time.

Another H2 innovation is DARPA’s Air Combat Evolution (ACE) programme to develop AI for close air-to-air combat. Alpha-Dogfight trials held as part of ACE include one in late 2020 when an AI agent defeated a highly experienced pilot 5−0 in F-16 simulated dogfights. The USAF’s ARLF hopes to stage a duel between an AI system and a human pilot with real aircraft in 2024 (The War Zone Staff, 2021). According to DARPA, ACE aims to foster human operator trust in human-machine teaming and create a hierarchical system in which the highest-level cognitive functions (for example, combat strategy design, target selection and prioritisation, selection of the most appropriate weaponry, etc) would be the responsibility of humans, while less demanding cognitive functions (execution of tactical manoeuvres during combat) would be left to the UCAVs. The UCAVs would therefore have human-on-the-loop autonomy.

The USAF is also experimenting with AI co-pilots in crewed fighter aircraft. December 2020 saw the first actual flight of an ISR U-2 which used an algorithm known as ARTUµ as its co-pilot. The AI looked after sensor control and tactical navigation, prioritising the search for enemy missile launchers, while the pilot dealt with possible aerial threats. According to Air Force Chief of Staff Gen. Charles Q. Brown Jr, the USAF aims to export the innovation to other aircraft to maintain its technological advantage over potential adversaries (Secretary of the Air Force Public Affairs, 2020).

Using the framework adopted in the present article, all these innovations come under H2. The inherent ambiguity of the horizon means we cannot be certain as to their future direction. One possibility is that they will serve as mere enhancers of the current H1. Indeed, the vision of sixth-generation systems is an H3 whose cornerstone is not a manned fighter but a ‘system of systems’ consisting of a network of manned aerial platforms, different types of unmanned platforms (accompanying; fully autonomous systems; UAVs for ISR), intelligent munitions acting in swarms, satellites, and ground systems. Manned aircraft would continue to perform direct combat missions along with support and control missions, but they would be supported by an array of unmanned systems possessing varying degrees of autonomy (Trevithick, Joseph, Rogoway, 2019). This H3 represents a transformation with respect to the current H1 but is less disruptive from the institutional, political, cultural and even ethical standpoints.

Plausible also, however, is an even more disruptive H3 in which the system of systems and network centric warfare remain the cornerstone but the lead role in combat and attack mission execution would rest primarily with UCAVs. Official USAF plans concerning the future use of UCAVs explicitly acknowledge their revolutionary impact on the role of humans in aerial combat in the long term, although they do not specify what that impact will be (United States Air Force, 2009). In this H3, the system of systems would be characterised by human-machine teaming in which humans would have responsibility for general planning and supervision, while information processing and execution would essentially rest with the AI via unmanned platforms. This alternative H3 is outlined as a hypothesis in the following section.

3.3. *Third horizon (exploratory): lead role of unmanned systems in combat and attack missions*

A change as far-reaching as the replacement of manned combat aircraft by autonomous systems needs to offer significant improvement compared to the previous situation or be an unavoidable requirement of the changing environment. The mere availability of the technology would not suffice to overcome the institutional, cultural and political barriers which would likely be erected against such a disruptive innovation. For this H3 to be plausible, relevant drivers of change need to be identified. This article identifies three such drivers: operational advantages, lower acquisition and sustainment costs, and balance of power.

The first set of change-facilitating forces are the advantages that autonomous aerial combat systems would offer once they attain a level of technological readiness that places them on a par with manned combat aircraft in terms of performance.

One obvious advantage is the processing speed and elimination of tiredness offered by AI compared to a human when processing the vast amount of information generated by the multiple connected sensors in the 'systems of systems' of sixth-generation and subsequent generation platforms. This greater speed is important to defeat the enemy decision cycle and to succeed in the increasingly populated and dynamic battlefield of the future, for which projects already under development include hypersonic weapons, intelligent munitions swarms, swarms of real decoys or decoys generated by electronic warfare. It will also be crucial to deal with the UCAVs of an enemy air force situated at the forefront of this H3 (Byrne, 2014: 56–57; Singer, 2009: 64). Consequently, it is plausible to think that autonomy will become both a cause and effect of the increased speed, in decision-making terms, of combat for air dominance (Leys, 2018: 51).

Other operational advantages are already evident in existing UCAVs. By not placing pilot lives in danger, UCAVs offer greater tactical flexibility and are suitable for higher-risk missions such as actions against, or inside the range of, an advanced enemy A2/AD bubble. UCAVs would allow strikes to be launched against otherwise inaccessible targets. Unmanned systems also avoid the need for dangerous Combat Search and Rescue missions for pilots downed over enemy territory, with added savings in terms of the availability and preparation of air and human resources required for such missions.

Moreover, as they do not carry humans and do not require cockpit space or pilot life support systems, UCAVs can operate for longer periods and their range and persistence in the theatre of operations can therefore be extended significantly. Range is a particular advantage against A2/AD bubbles, which can be attacked through launches from safer distances and with support from (also probably unmanned) inflight fuelling aircraft operating outside enemy range. The lack of a pilot also allows UCAVs to perform extreme manoeuvres given that the aircraft's structure can withstand greater G force than a pilot (Rogoway, 2016b). To all these advantages one should add also the technological advances achieved in intelligent munitions. In this way, air combat maneuvering –an area in which humans currently hold the advantage over UCAVs– can be matched through the use of highly maneuverable short-range missiles such as the AIM-9X Sidewinder.

Furthermore, all the aforementioned operational advantages are compatible with human-in-the-loop and human-on-the-loop UCAVs, which request authorisation from a human decision-maker prior to attacking opportunity targets. Clearly, a factor that militates in favour of full autonomy is the vulnerability of the link between the UCAV and its command centre to interferences from a technologically advanced enemy. Russia, for example, has successfully interfered with various types of drones in Ukraine and Syria using advanced electronic warfare systems (Trevithick, 2018). Full autonomy as protection against interference is a pragmatic criterion used already in cruise and anti-ship missiles and will be difficult to avoid in very specific tactical situations and in a context of rivalry between major powers in which Russia and China are developing and trialling their own UCAV programmes and countermeasures to neutralise unmanned enemy systems (Mayer, 2015: 771). It should be noted, however, that enemy interference is less of a problem against robust line-of-sight data links between, for example, components of a swarm or between a UCAV and an advanced command post on board a manned aircraft (Rogoway, 2016b; Stillion, 2015: 43–44).

At first sight, a further pragmatic criterion in favour of full autonomy is discretion, given the risk that data link emissions could facilitate detection and subsequent destruction by the enemy of one's own stealth UCAVs. However, again this is not a valid objection considering the progress being made in Low Probability of Detection/Low Probability of Interception (LPD/LPI) communications such as those currently used by the F-22 and F-35 (Freedberg, 2019).

A final pragmatic criterion in favour of full autonomy is that the major advances achieved in AI, swarming, hypersonic weapons, directed-energy weapons, etc, could see battlefields become so complex and astonishingly fast that they will surpass human capacity to manage them effectively, thus leading the bulk of decisions to be taken by AI. However, many disruptive changes will still be required for such a scenario to come about. In any event, this would be a hypothetical H3, to be considered if the H3 outlined here were eventually to become the H1.

Consequently, full autonomy (human-out-of-the-loop) would be the exception in the H3 posited in this article. It would most likely be limited to certain tactical contexts which genuinely require it and to minimise very high risk. A plausible exception would be SEAD missions against anti-air systems protected by advanced electronic warfare systems capable of neutralising external UCAV communications. From the political standpoint, it would be much easier to justify the use of fully autonomous systems due to the danger such missions pose for strike packages with human-machine teaming and also because the SEAD is a prerequisite for other missions involving manned systems and non-fully autonomous manned systems.

The most normal scenario, however, will be human machine-teaming in which critical decisions are subject to human approval and tactical execution is largely delegated to autonomous human-in-the-loop or human-on-the-loop systems. The autonomy already ceded to various types of air-to-air missiles and air-surface missiles will be granted to some extent also to the platforms that fire them, albeit within strictly defined parameters. Accordingly, the H3 system of systems would be a human-machine hybrid offering synergies between human intelligence and AI, leading to greater operational advantages than those offered by the current H1.

The second driver of change is economic. To begin with, the costs of developing and manufacturing air platforms will be lowered thanks to the elimination of all pilot operation and survival systems. Depending on the degree of sophistication of the UCAV, the cost ratio of the autonomous system versus the manned system could be as much as four, or even six, to one. Moreover, since they will work in a swarm, not all the UCAVs will require the same sensors (for example, advanced radars or powerful electronic warfare systems). Connection via Data Link means that the shared AI can receive and process information, take decisions and distribute tasks among the different UCAVs. All this will allow resources to be optimised (Rogoway, 2016b). As for research and development costs, a substantial portion of the technologies needed for UCAVs are being developed by the civil sector, leading to cost reductions and economies of scale very different to those found in traditional high-tech military programmes (Altmann & Sauer, 2017: 125).

Meanwhile, the lead role of UCAVs would also eliminate the need for the vast majority of pilot training flying hours. Although it is difficult to determine the true cost per hour and estimates vary depending on the source consulted, the figure is approximately $36,000 for the F-35A (Relm, 2021). According to NATO, a pilot requires a minimum of 180 h per year (over and above the hours required for initial pilot training) although not all member states meet this figure due to the cost.

A further factor is the wear and tear that flying hours cause to current manned platforms. The platform lifespan of the Eurofighter is approximately 6000 h and the maximum estimated lifespan of the F-35 is 8000 h. If these were piloted by AI, training would be virtual and sustainment costs would be considerably lower, with major savings achieved also on manufacturing costs as the platform would be designed to fly for significantly fewer hours (Rogoway, 2016a). As noted earlier, a current challenge faced by H1 are the growing acquisition, operation and sustainment costs of the successive generations of combat aircraft. These are forcing the United States and, in particular, European air forces to reduce fleet sizes, thus jeopardising their ability to have sufficient combat fighters available in the event of actual conflict with a rival military power.

In addition, the lower platform acquisition costs would allow more frequent iterations. Depending on the air force, current manned combat platforms have an average lifespan of three to four decades and they undergo regular small-scale updates and more extensive mid-life upgrades, which add considerably to the cost. Switching to an autonomous combat force would facilitate the goal expressed by Will Roper –the then Assistant Secretary of the Air Force for Acquisition, Technology and Logistics– to replicate a “new Century Series”, a reference to the rapid design and acquisition of various fighter aircraft by the USAF (with designations between F-100 and F-106) during the 1950s and 1960s. Repeating that approach today would allow new and more advanced models to be produced more affordably and more frequently (Tirpak, 2019).

A third driver of change relates to the balance of power. Competition between countries capable of developing truly effective autonomous UCAVs would generate structural incentives for the adoption of the technology. This dynamic would be in line with the structural realism perspective and previous experience in other processes of military diffusion (Horowitz, 2010: 23–60; Mearsheimer, 2003: 32–36; Van Creveld, 1991: 311–320). The race affects the United States and China in particular today, in anticipation of a high-intensity armed conflict between the two. Given the economic and technological resources which both countries devote to defence, this would provide considerable impetus for innovations such as those indicated under H2 above.

If H3 is adopted by some countries, other countries that retain H1 will find themselves at a disadvantage in terms of air dominion for two reasons. Firstly, the qualitative superiority of UCAVs over manned aircraft in air-to-air combat. Secondly, the numerical advantage of UCAVs –thanks to their lower acquisition and sustainment costs– compared to manned platforms, which would be fewer in number due to their high costs.

This imbalance could also affect trade. The combination of military effectiveness and lower acquisition and sustainment costs will make UCAVs a very attractive product. As a result, aeronautical industries that continue to focus on producing manned fighter aircraft rather than more capable and cheaper unmanned systems will put their market position at risk. A precedent for this dynamic can already be seen: the United States’ policy not to export UCAVs to the Middle East has not prevented Iraq, Egypt, Iran and the United Arab Emirates from obtaining them via Chinese UCAV exports (Milan & Tabrizi, 2020: 734–735).

In this context of global competition, social, political and institutional barriers to the emergence of H3 will come under great pressure. The establishment of a legal regime to restrict or even ban the development and acquisition of UCAVs, thus reducing the leverage of the balance of power driver, will depend on the goodwill of all countries. If one or more states develop UCAVs that perform significantly better than manned combat aircraft, their competitors will have a powerful incentive to equip themselves with similar capabilities. Given the difficulties in verifying and enforcing international law on past UCAV-related issues, the United States’ targeted killings campaign for example, the prospects in this regard are far from encouraging (Bieri & Dickow, 2014).

This does not mean that the aforementioned social, political and institutional barriers will become meaningless. Rather, they will become intervening variables that will affect to varying degrees the ultimate configuration of H3, in particular limiting the possible deviation of UCAVs towards LAWS. In view of the disruptive nature of the transfer of lethal decisions to an AI in certain missions (even if in accordance with mission and targeting parameters determined by human decision-makers), current resistance will increasingly focus on the control mechanisms and accountability of future aerial LAWS. Without human control of any kind, a wholly autonomous UCAV could cause much more serious harm than a human-in/on-the-loop UCAV (Scharre, 2016: 23). Moreover, the more complex the operating environment of an autonomous UCAV, the more complex its AI will need to be, which will make full understanding of its behaviour and predictability more difficult from the human perspective. In a (dystopic) H3 characterised by generalised use of fully autonomous UCAVs, errors will be inevitable sooner or later. Multiple tests, training of associated personnel, software verification and validation will reduce but not prevent entirely the likelihood of errors in such complex systems. In addition, enemies will seek to hack and spoof the systems (Scharre, 2016: 23–24).

It is plausible, therefore, that ensuring ultimate effective control of UCAVs to prevent their generalised use with human-out-of-the-loop autonomy will be a key intervening variable to arrive at the H3 proposed here. In fact, in the United States a human decision maker is ultimately responsible for all decisions on lethality (Roff, 2014: 214). Similarly, it will be important to retain the capacity to abort a LAWS-initiated mission (U.S. Department of Defense, 2012). It is logical to assume that human veto will remain a condition of the emergence of H3 and will be used as a mitigating argument by those advocating the change. Put another way, for the H3 to materialise assurances will be required that humans will remain the moral agent and fail-safe, and that, as a general rule, human-on-the-loop will be set as the upper limit of autonomy.

However, a blanket prohibition on UCAVs with autonomy below the human-out-of-the-loop level is not very plausible bearing in mind the operational and economic advantages noted earlier and, above all, for the balance of power reason indicated. A foretaste of the influence of systemic pressures on internal political resistance can be observed in the broader issue of armed drones. Opposition to armed drones in some European countries stems from their association with the United States’ targeted killings campaign in countries such as Pakistan, Yemen and Somalia (where the main problems are not the drones themselves but the legality of the actions) and also from ethical reservations surrounding concepts such as killer robots and remote control warfare (Horowitz, 2016: 26). However, despite the ongoing debates in Germany and elsewhere, an assumption of sixth-generation aerial combat systems such as the Future Combat Air System led by France, Germany and Spain is that accompanying armed drones will form a natural part of the system of systems. Not to include them would reduce the capabilities of these systems compared to their sixth-generation rivals (Wachs, 2020).

Lastly, it is appropriate to mention the assumptions underlying the three drivers of change and their respective vulnerabilities, following an analogous (albeit simplified) approach to the Assumptions Based Planning method (Dewar, 2004).

Two main assumptions underlie the operational advantages: firstly, the technological advances that will afford unmanned systems an advantage over their manned counterparts will materialise; secondly, systems to counter unmanned systems will not prove sufficiently effective to neutralise these or undermine confidence in them. In reality, both assumptions could be combined into a single one, namely, the existence of technological advances that protect UCAVs against sophisticated countermeasures, while also giving them a competitive advantage over manned combat aircraft. This is the big unknown, which also affects the timeframe of the scenario posited. Barring the delays habitually suffered by major programmes, American and European sixth-generation air combat systems will begin to be introduced as of 2035, attaining readiness during the 2040s. It is very difficult to make specific predictions regarding the extent of the development of AI and other UCAV-associated technologies. Hence, the hypothetical H3 lacks a clearly defined timeframe. The innovations outlined for H2 point to gradual technological improvements in UCAVs, but any significant impediment to these advances due to technological, political, economic or legal obstacles would be a signpost that would negatively impact on the plausibility of the scenario discussed here.

Turning to the economic advantages driver, in addition to the twin assumption referred to above (technological advances), a further one must be considered: such advances must not entail an exponential increase in acquisition and life cycle costs that would ultimately vastly exceed the cost of manned systems. If having effective UCAVs to combat advanced enemies proves much more expensive than manned systems, it would be a further signpost as to the plausibility of the scenario.

In the case of the balance of power driver, three assumptions can be identified: competition between major powers will continue; institutional resistance within air forces will not suffice to block change; and political, legal and social changes will be insufficient to prevent the proposed scenario completely. In this regard, an evolution in major power relations towards more cooperative and peaceful positions would be a disincentive to the investment of resources in new, large-scale programmes. It would not halt them entirely but would slow them down and reduce their size. A case in point is the F-22 Acquisition Programme: the USAF initially intended to purchase 750 aircraft but the end of the Cold War and the strategic changes of subsequent decades ultimately saw production capped at 187 (Niemi, 2012: 54). Moreover, military innovation studies highlight the impact of bureaucratic in-fighting within military institutions on the likelihood of far-reaching changes gaining traction (Grissom, 2006; Rosen, 1991). Hence, an aspect to play close attention to is the degree of influence of pro-H3 coalitions, in which high-ranking officers with careers closely tied to UCAVs will clearly play a major role. Conversely, a predominance of senior officers whose careers are linked to manned combat aircraft and who are opposed to the H3 would be a signpost of the vulnerability of the scenario posited. Lastly, strategic studies literature warns of the underbalancing of power (Schweller, 2004) resulting from the lack of consensus among elites and the different political actors when seeking to counterbalance a hostile power effectively. This phenomenon represents a vulnerability for the third assumption set out above. In the case of the United States, if political positions opposed to the H3 were to hold sway in government, Congress or among the heads of the major technology firms associated with developing the horizon, the viability of the scenario proposed for the USAF would also be undermined.

4. Conclusion

Advances in technology in unmanned aerial systems fuel speculation concerning the future of manned combat aviation. This article has situated different advances in the field of UCAVs using the Three Horizons framework and acknowledges the ambivalent nature of numerous innovations that can be categorised as H2. Many of these can be interpreted as sustained innovations consistent with H1 or as disruptive innovations coherent with H3. The article has also identified the challenges faced by the current manned combat aviation system (H1). The main challenge is that maintaining a qualitative advantage necessarily entails increasingly high acquisition and sustainment costs which jeopardise the strategic utility of the system as they lead to a deficit in the actual numbers of aerial platforms available.

As an alternative to the current H1, the article explores a hypothetical H3 in which advances in technology result in UCAVs which are equal or superior to manned combat aircraft and will replace them as front-line combat platforms as part of a system of systems characterised by human-machine collaboration.

In this H3, advances in technology that afford UCAVs superiority over manned combat platforms are a necessary but insufficient variable. As added independent variables the article identifies three sets of drivers of change: operational advantages, economic advantages and systemic pressure derived from balances of power. Acting in combination, these drivers will exert pressure on institutional resistance (within air forces) as well as on the understandable political, social, ethical and legal resistance to such a disruptive H3 which will arise in some countries.

The extent to which the balance will tip in favour or against change in specific countries warrants attention in future studies. As a further avenue of research, it would be interesting to know how European air forces are adapting their doctrine to the opportunities and challenges generated by innovations in the ambivalent context of H2. Lastly, the article invites reflection in future works on the potential consequences of the proposed H3 for strategic stability in times of crisis, the credibility of deterrence, and the extent to which governments are likely to resort to military force.

Acknowledgment

This article has been funded by the Spanish Agencia Estatal de Investigación project PID2019-108036GB-100/AEI/10.1339/501100011033.

The open access charge of this article has been funded by: Universidad de Granada / CBUA].

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Javier Jordan is Associate Professor of Political Science at the University of Granada, Spain.