The Path to 5th Generation Electronic Warfare

The Rising Impact of Electromagnetic Spectrum Operations

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Preface

In a world of interconnected systems, electronic warfare (EW) is vital. Surprisingly, EW is a field that is still not well understood by most warfighting professionals because of the technical nature of EW and the complexity of its integration into different fields of warfighting. Also, the need for secrecy associated with EW can unintentionally make it difficult for outsiders to appreciate its importance.

Everyone engaging in the field of EW encounters security classifications. Unfortunately, they can build walls that impede the development of knowledge and tactics. Secrecy in EW is certainly necessary and important, and restraint is appropriate when talking about the technical capabilities, performance and applications of EW systems. However, the hesitancy of some experts to, even superficially, talk about EW with those outside the inner-circle of EW warfighters, creates challenges in promoting its importance to the wider community. A lack of broader understanding results in EW being under-appreciated and in danger of insufficient resources being provided to develop and integrate EW across the armed forces.

Many were sceptical that an unclassified paper discussing EW was feasible, especially one that accounts for aspects of 5th-generation systems, such as the F-35 Lightning II. Although the topic certainly narrowed the breadth and depth of this paper, it nonetheless shows that much can be said about EW that can remain "unclassified". For example, many warfighters can be effectively informed about the importance of EW within air power at an unclassified level. Informing warfighters can, in turn, promote the necessary discussions that lead to developing ideas on integrating and implementing EW into a wider force structure. More should be said about EW; it matters now more than ever.

Because armed forces rely increasingly on data communications, often using satellite and other remote systems, the role EW has is broadening. A modern force lacking EW capabilities can be weakened greatly because its ability to communicate is inadequate.

This paper shows that EW is continually and increasingly important to air power. Also crucial is to discuss some EW areas that air forces may consider when transitioning to a 5th-generation status. This paper uses historical and current trends in EW to discuss potential opportunities and future designs. Although this study focuses more on the strategic impact of 5th-generation systems on EW, it also emphasises the increased need and relevance of EW assets in modern and future warfare. EW is critical in supporting joint-forces operations, however, EW now has the potential to achieve significant effects on the battlefield beyond the traditional enabler role. As such, EW is essential to air power.[1]

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1 Sanu Kainikara, *Essays on Air Power* (Canberra: Air Power Development Centre, 2012), 50-51.

Abbreviations

AAR	Air-to-Air Refuelling
AD	Air Defence
ADF	Australian Defence Force
AEW	Airborne Electronic Warfare
AESA	Active Electronically Scanned Array
AI	Artificial Intelligence
AF	Air Force
APAR	Active Phased Array Radar
APDC	(Australian) Air Power Development Centre
ARM	Anti-Radiation Missile
ASPI	Australian Strategic Policy Institute
AWACS	Airborne Warning and Control Systems
CASEVAC	Casualty Evacuation
C2	Command and Control
CoG	Centre of Gravity
COMINT	Communications Intelligence
db	Decibel
DE	Directed Energy
DEAD	Destruction of Enemy Air Defence
DIRCM	Directional Infrared Countermeasures
DRFM	Digital Radio Frequency Memory
EA	Electronic Attack
ECCM	Electronic Counter-Counter-Measure
ECM	Electronic Counter-Measure
EM	Electromagnetic
EMS	Electromagnetic Spectrum
EP	Electronic Protection
ES	Electronic Warfare Support
EW	Electronic Warfare
FCR	Fire Control Radar
FLIR	Forward Looking Infrared
GNSS	Global Navigation System Satellite
GPS	Global Positioning System
HARM	High-Speed Anti-Radiation Missile

IAD(S)	Integrated Air Defence (System)
IED	Improvised Explosive Device
IFF	Identification Friend or Foe
IR	Infra-Red
IRST	Infra-Red Search and Track
IW	Irregular Warfare
ISR	Intelligence, Surveillance and Reconnaissance
JEMSO	Joint Electromagnetic Spectrum Management Operations
MANPAD	Man Portable Air Defence System
MEDEVAC	Medical Evacuation
MPA	Maritime Patrol Aircraft
NATO	North Atlantic Treaty Organisation
NCO	Network Centric Operations
PLA	People's Liberation Army
PGM	Precision Guided Munition
RAAF	Royal Australian Air Force
RADAR	Radio Detection and Ranging
RCS	Radar Cross Section
RF	Radio Frequency
RNLAF	Royal Netherlands Air Force
RPA	Remotely Piloted Aircraft
RPAS	Remotely Piloted Aircraft System
RPV	Remotely Piloted Vehicle
SAM	Surface-to-Air Missile
SEAD	Suppression of Enemy Air Defence
SIGINT	Signals Intelligence
UAV	Unmanned (or Uninhabited) Aerial Vehicle
US	United States
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy

Contents

Glossary of Terms

To establish a baseline for this document, it is first necessary to define a few widely used terms in current doctrine and the literature regarding Electronic Warfare (EW). Where possible, current military open-source definitions are used throughout the paper. The EW definitions are from the US Joint Publication on Electronic Warfare of 2012.[2]

Electronic Warfare (EW) is defined as 'military action involving the use of electromagnetic (EM) energy and directed energy (DE) to control the EMS or to attack the enemy. EW consists of three divisions: electronic attack (EA), electronic protection (EP), and electronic warfare support (ES).'

Directed Energy (DE) 'is an umbrella term covering technologies that produce concentrated EM energy and atomic or subatomic particles. A DE weapon is a system using DE primarily as a means to incapacitate, damage, disable, or destroy enemy equipment, facilities, and/or personnel.'

Electronic Attack (EA) 'refers to the division of EW involving the use of EM energy, DE, or anti-radiation weapons to attack personnel, facilities, or equipment with the intent of degrading, neutralizing, or destroying enemy combat capability and is considered a form of fires.' Examples are using HARM weapons to engage radar, jamming radar and communications signals, and electronic deception.[3]

Electronic Protection (EP) 'refers to the division of EW involving actions taken to protect personnel, facilities, and equipment from any effects of friendly, neutral, or enemy use of the EMS, as well as naturally occurring phenomena that degrade, neutralize, or destroy friendly combat capability.' Examples are using flare and chaff to counter infra-red guided missiles, stealth features, spread spectrum communications, emissions control, DIRCM (Directed Infra-Red Counter Measures), decoys, EM hardening, interference, masking, spectrum management, wartime reserve modes, and EM compatibility.

Electronic (Warfare) Support (ES) 'refers to the division of EW involving actions tasked by, or under direct control of, an operational commander to search for, intercept, identify, and locate or localize sources of intentional and unintentional radiated EM energy for the purpose of immediate threat recognition, targeting, planning, and conduct of future operations.' Examples are signals intelligence (SIGINT) (although not all SIGINT is EW), and threat warning & direction finding. Important to note is an increasingly grey area

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2 United States Chairman of the Joint Chiefs of Staff, "Joint Publication 3-13.1 Electronic Warfare," (2012): viii.

3 Not all countries include the use of anti-radiation weapons in their definition of EA.

between the EW and the intelligence world, especially regarding ES. This grey area is not always easily defined because sensors can often contribute to both worlds; the difference is in the analysis and way the gained information is used. Because of the increased tempo of operations, a subject discussed in Chapter 3, the sharp distinction between EW and intel is increasingly blurred.

Spectricide refers to unintended negative consequences of using the EMS. It is a relatively new term and, as such, not (yet) integrated in existing doctrinal documents. The word spectricide is a neologism combining the words spectrum and fratricide, the latter describing the unintended killing or wounding of friendly forces. Spectricide is increasingly important because the military and civilians increasingly dual-use the EMS. The congestion, contestation and competition of the EMS means that unintended adverse effects on friendly forces and civilians are highly likely.

1.
Introduction

Air forces worldwide are developing 5th-generation fighter capabilities with the introduction of the Lockheed Martin F-35 Lightning II fighter aircraft in western forces. The F-35 introduces advanced technologies including sensor fusing, stealth, and advanced networking capabilities. To optimally make use of the new capabilities, air forces need to adapt many elements of their organisation including technology, culture, and the approach to air warfare. This movement is referred to by some air forces as moving to a '5th-generation air force'.

In the history of warfare, while using the electromagnetic spectrum (EMS), which 'is the entire range of electromagnetic (EM) radiation', is relatively new, the use has quickly changed the way warfare is approached.[4] A consequence of military using the EMS, is the rise of electronic warfare (EW), which focuses on enabling and countering uses of EMS. For thousands of years, the effective control of armies over long distances and with large forces was restricted by the limitations of communicating, because doing it successfully is a key to winning wars. As armies grew larger and more difficult to control, better communication was increasingly needed. While pigeons, sound, light and smoke signals were all used to relay information over longer distances rapidly, these methods were restricted, and it was impossible for commanders to communicate orders to groups of soldiers instantaneously beyond the horizon.[5] With the telegraph being invented and implemented, followed by wireless technology, military communication started projecting itself rapidly over long distances. These events made communications increasingly efficient. It is not surprising that the first implementation of what we now call EW took the form of countermeasures employed against long-range communications. With the progress of beyond-line-of-sight communications, armies could not only increase in size, but also became more manoeuvrable and able to react to the enemy faster and from further away. This led the

4 United States Chairman of the Joint Chiefs of Staff, "Electronic Warfare," I-1.

5 Christopher H Sterling, *Military Communications: From Ancient Times to the 21st Century* (California, USA: ABC-CLIO, 2008), xxiii-xxvi.

way to increasingly complicated tactics. Since long-distance communication started, military have sought ways to intercept and influence communications to their advantage.[6]

Military forces have always sought ways to exceed adversaries and, at times, technology played a major role in delivering the advantage. The renowned theorist, Clausewitz, identified that warfare has two distinct elements: nature and character. The nature of warfare is unchanging, and includes the use of violence, with war being a continuation of policy; both elements that are certain to manifest themselves during a conflict. But the character of war evolves, always adapting, and being adapted to, the changes taking place in technology, society, culture, and many other areas that touch the realm of war. The exploitation of EMS in war, and specifically its ability to project information instantly over long distances, has certainly changed the character of warfare.

The advent of science and commercialisation has made EW particularly prone to rapid changes and improvements in technology. These changes are especially evident during larger conflicts and global wars. Despite its relative novelty in warfare, EW already has a long history in counter-developments. Recent history shows that winning the battle in the EMS confers a significant advantage. However, some nuance is appropriate when advocating new ways by which EW can influence wars, since its advantage may be significant but is not absolute. Several conflicts have demonstrated that technology alone cannot win a war; the Vietnam War being a well-known example. Other elements, such as the will of the people to fight, can more greatly influence the outcome of wars than advances in technology. Because using the EMS has become crucial though, it can further influence the course of wars and conflicts.

Like warfare itself, EW is not a static art. With technology innovation and implementation of new technology, EW continues to evolve so that its applications and the doctrine informing it expands. EW now incorporates a wide range of measures that are 'essential for protecting friendly operations and denying adversary operations within the EMS throughout the operating environment.'[7] In most countries, EW doctrine currently uses three separate categories to represent how EW systems apply differently: electronic attack (EA), electronic protection (EP), and electronic warfare support (ES).[8] Although countries explain them differently, they approach them similarly.

Despite similarities, air power has no globally accepted definition. How a country does define it depends on its air force's capabilities. A recent trend in defining air power is that military now expand the scope to include space and even cyberspace. The USA currently

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6 M. T. Thurbon, "The Origins of Electronic Warfare," *The RUSI Journal* 122, no. 3 (1977): 60-61.

7 United States Chairman of the Joint Chiefs of Staff, "Electronic Warfare," vii.

8 Ibid., viii.

defines air power as 'the ability to project military power or influence through the control and exploitation of air, space, and cyberspace to achieve strategic, operational, or tactical objectives.'[9] In contrast, Australia's definition is limited to 'the ability of a nation to assert its will by projecting military power in, through and from the air domain.'[10] Finally, once translated, the Dutch define air power 'the ability to realise, or help realise, political and military goals through and within the third dimension above the surface of the earth.'[11] Because a military such as that of the USA dedicates considerable resources towards space and cyberspace, it would be realistic for it to include space and cyberspace into its air power definition. However, for many smaller air forces, space and cyberspace are assets that are, for now, often under-resourced. Space and cyberspace are terms not yet found in the air power definitions of many countries, although that may change in the near future. However, this does not mean that these air forces disregard space and cyberspace. How air power, space and cyberspace, relate to each other and to EW, will be detailed later in this paper.

Air power and EW have always mutually benefitted from each other to the extent that changes in air power and EW often correspond: when air power shows a spurt of growth, EW nearly always follows the same trend. Consequently, resistance by leadership in embracing air power translates itself into resistance in embracing airborne EW. Air forces mainly use airborne EW to enable air power to better deliver its effects and to support joint warfighting assets.

Airborne EW and its missions cannot be understood without taking current and historical movements of air power development into account. With the current advances in technology leading to sensors being miniaturised, expanding communications, and spreading EW systems, air power and EW mutually benefitting from each other is more apparent. Furthermore, much of the technology that accompanies 5th-generation aircraft is, in some way, related to the EMS and thus to EW, more than in the past. This paper focuses on the increased interaction between 5th-generation air power and EW.

Reason for the Paper

This paper results from the Royal Australian Air Force (RAAF) and the Royal Netherlands Air Force (RNLAF) cooperating because they are both modern air forces. They were

9 United States Department of the Air Force, *Basic Doctrine: Volume 1*, vol. 1 (Curtis E. LeMay Center for Doctrine Development and Education, 2015), 25.

10 Royal Australian Air Force, "Australian Air Publication Aap 1000-D: The Air Power Manual," (Canberra: Air Power Development Centre, 2013), 121.

11 Air and Space Warfare Centre, *Dp-3.3 Nederlandse Doctrine Voor Air & Space Operations*, ed. Commando Luchtstrijdkrachten (The Hague: OBT bv, 2014), 13.

also adding a 5th-generation fighter, the F-35 Lightning II, to their inventory. Both Air Forces investigate ways to adapt force design to maximum employment of 5th-generation capabilities; 5th-generation systems rely heavily on the EMS. Introducing 5th-generation systems into air forces can influence EW at many levels. This paper examines the implications of this adaptation to EW by considering past and present developments in air power and EW, and examining future 5th-generation focused developments. Importantly, 5th-generation capability is not only about technology; effort is required to adapt procedures, tactics, infrastructure, people, culture, and many other elements, to optimally transform the organisations into 5th-generation air forces.

All small and middle-sized air forces will likely go through a similar process to the RAAF and the RNLAF when transitioning to a 5th-generation Air Force and adapting their force design accordingly. Although this paper is a result of cooperation between the RAAF and RNLAF, the paper is relevant to other small and middle-sized air forces planning a 5th-generation transition.

Outline

This paper investigates several aspects of air power and EW that are, or should be, evolving with the transition to 5th generation enabled air forces. Understanding the changes occurring in EW requires knowing air power and how it relates to the EMS and EW. Chapter 2 overviews how air power and EW originated, became reliant, how they changed and what motivated them.

This history relates to understanding the effects of current and future developments on airborne EW. Chapter 3 describes present day air power roles and characteristics. Chapter 4 considers present day EW and its role in air power and concludes with changes that currently influence both. Chapter 5 investigates what a 5th-generation air force is and what this says about air power and EW. Chapter 6 examines how EW interacts with 5th-generation air power. Chapter 7 explores some other subjects that are closely related to the developments in EW such as space and cyberspace. The paper concludes by offering recommendations about EW within 5th-generation air forces.

Disclaimer

This paper does not claim to officially stand for either the RAAF or RNLAF, nor the APDC, nor be a comprehensive beginner's guide to EW. Some EW basics are defined in the section preceding Chapter 1. While EW has been defined and categorised varyingly, this paper uses the US DOD terminology.

2.
A Brief History of Air Power & Electronic Warfare

Study the past if you would predict the future.

- Confucius

This chapter explores the background of EW and highlights how it continues to inform capability. This history describes how the current situation came to exist and identifies areas within EW and air power that are adjusting to contemporary situations and will adjust their future.

EW has adapted constantly to changes in the battlespace and in technology to influence the character of wars, how they are fought, and how forces are designed to fight wars. Certain parts of EW history, particularly during major conflicts and wars of the previous century, show periods of more rapid change than others. In a relatively short time, EW has progressed in developing technology, and implementing and applying that technology in warfare. This increased use indicates the significance of controlling the EMS.

Technology using the EMS initially focussed on communications, but its use has expanded. Communications, radar, guidance and navigation, sensors, and weapons are just some of the ways that the EMS is now used. The following history of air power and EW focuses primarily on the Western perspective and concentrates on conflicts preceding Operation *Desert Storm* that saw rapid advances in these fields.

Pre-World War II

The history of air power and EW being integrated into joint force design is relatively new. Fighting wars on land and at sea had occurred for millennia, while, until recently, the air, as an operating environment, was relatively unexploited. One of the reasons why air power differs significantly from other domains is because its history is relatively short as it began after land and sea doctrine had been well established.

EW preceded the military use of aircraft. It played a part on land and sea, for example, during the Russo-Japanese war where Russian ships jammed Japanese transmissions. Military aircraft first entered service in 1908,[12] and during World War I, radios became small enough to enable wireless air-to-air and air-to-ground communications from the cockpit. As soon as aircraft gained the ability to transmit messages using the EMS though, their adversaries found ways to exploit vulnerabilities in such communications. Transmitting messages by wireless led to opponents attempting to block or intercept them. Thus, was born EW in the air domain.[13] The later arrival of powered flight, but at much the same time as radios were fit into aircraft, meant that air power and EW have been linked from the start of their use in warfare.

Underestimating just how quickly air power grew in importance is easy. About 15 years after the first powered and controlled flight of the Kitty Hawk by the Wright Brothers in North Carolina, World War I ended. By then, air power became a permanent and indispensable presence in large scale wars.[14] Developing air power and using its altitude to extend range and reach of systems affecting the EMS, is important to EW.

Although air power quickly became a force that could no longer be ignored, aircraft as an essential part of a military took longer to be accepted. Air power advocates fought an uphill battle to gain the attention they believe it deserved; this is partly due to the army and navy already being well established services by the time air power became relevant. Embracing air power by the other services was considerably resisted for two reasons: people in power were unfamiliar with aviation, and the cost of aviation equipment was high. Surprisingly, some classical air power theorists and advocates were court-martialled or, in the case of the Russians just prior to World War II, shot.[15]

A topic repeated throughout this paper is the high cost of air power, which appears to have become higher as the years have passed. Unfortunately, this high cost also relates to the constant challenge to developing airborne EW further. The greater diversity of systems using the EMS widens the range and sophistication of EW systems needed; this, in turn, increases the cost.

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12 Richard P. Hallion, "Air and Space Power: Climbing and Accelerating," in *A History of Air Warfare*, ed. John Andreas Olsen (Washington, D.C.: Potomac Books, Inc., 2010), 371-72.

13 Thurbon, "The Origins of Electronic Warfare," 57-59.

14 Hallion, "Air and Space Power: Climbing and Accelerating," 372-73.

15 Martin van Creveld, *The Age of Airpower* (New York: PublicAffairs, 2011), 57.

World War II

World War II saw many developments in both air power and EW. Some changes can be attributed to evolving air power theory, and some to improving technology. Air power theory adapted to developing circumstances and technology. It was the progress in technology coupled with conceptual innovation that saw EW emerge in World War II as a strategic military capability.

Airborne EW emerged as an exclusive field during World War II because it played a significant role.[16] The rapid developments in EW during World War II exemplify that EW adapts quickly in times of conflict. Just before World War II, simultaneous advances in electronics in several countries motivated major developments. An example is implementing radar technology that measures the return of electromagnetic signals to determine where objects are located. As is often the case in war, technological development gained momentum as World War II intensified. Air power increasingly relied upon developments in radar, communications, and other uses of the EMS. Radar on land, air and sea, sonar, long-range communications, Identification Friend or Foe (IFF) systems, navigation aids, and landing aids became widely used in World War II. To counter these advances, chaff, a wide range of noise jammers, and the occasional deception jamming were used, eventually leading to more sophisticated systems and techniques to counter them.

Simultaneous developments, to varying degrees of sophistication, were seen in countries worldwide, particularly Britain, Germany, the USA and Japan. It became quickly apparent that inferior equipment, or the unavailability of EW equipment, had an enormous impact on controlling the air and guiding bombers to the locations. Developing and implementing EW influenced the outcome of battles and consequently the eventual outcome of the war.

The primary reason that EW initially earned so much attention was both using and fearing bombers during wartime. Interwar air power theorists, notably, Italian, Giulio Douhet, and American, William 'Billy' Mitchell, focused largely on the capacity of the bomber to destroy. They correctly identified that air power had much potential. Writing about civilian targets, especially Douhet, heightened the sense of fear that air power instilled in governments and their populations. An oft-quoted phrase of British parliamentarian, Stanley Baldwin, in 1932 says: 'The bomber will always get through.'[17] This attitude was typical of how the British felt at that time and clearly shows the imagined terror of bombers as an unstoppable force of destruction. Baldwin's speech resulted from terror

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16 Mario de Arcangelis, *Electronic Warfare : From the Battle of Tsushima to the Falklands and Lebanon Conflicts* (Poole, Dorset: Blandford, 1985), 11-18.

17 The Times, "Mr Baldwin on Aerial Warfare - a Fear for the Future," *The Times* 1932.

to reality after London was bombed during World War I. However, talking in absolutes is dangerous, and history shows various successful developments aimed at preventing bombers from getting through.

The first large-scale use of the EMS occurred during the Battle of Britain. Although many factors combined to ensure a British victory in that battle, two important aspects of EMS operations influenced the Battle of Britain. The first was using an operational radar network. Successfully implementing radar technology, coupled with a network to report enemy movements and direct friendly aircraft to the enemy, gave the British a much-needed upper hand. Second, the British implemented EW measures to interfere with German navigation and bombing-aids that were guiding German bombers to British cities. These measures were critical in reducing British civilian casualties.

British radar was effectively part of the first comprehensive Integrated Air Defence System (IADS). While the Germans were well-aware of both the radar and, at times, countermeasures to their navigation aids, they were unable to counter these successfully. The Germans' navigation of their raids was hampered, thus reducing the effect. The Germans underestimated the importance of the British radar system and failed to allocate adequate resources to counter it. The British were better able to respond to German attacks by efficiently guiding British aircraft towards the opposing forces to reduce the number of British aircraft required to counter German bombing raids. Developments in EW contributed considerably to the British ability to hold their own against a numerically larger German force.

The smart use of the EMS became crucial. If done well, it could ensure victory; if done poorly, it could quicken defeat. Owing to the size of EW equipment, most of the airborne EW development focused on bomber aircraft. Because miniaturising electronics had just started, the bombers allowed enough room for the still bulky and heavy EW systems and their accompanying operators. EW focused on many areas vital to air power assets' operation, namely, navigation, communication, and radar systems. Because their continued availability denied German forces successfully using their systems, they contributed greatly to the war effort.

The Korean War

The Korean war showed how too much focus on nuclear and conventional all-out warfare reduced the options available to air power in limited wars. Once World War II ended, Douhet's radical ideas about the unlimited potential to destroy were somewhat validated by the successful use of the atomic bomb. The potential terror that air power brings to the minds and hearts of the people was emphasised and thus shaped the military and politics globally. The atomic age had arrived, and nuclear strategy, with its emphasis on mutually assured destruction, dominated US and USSR policies. This strategy in turn influenced the direction of air power for many years. Nuclear strategy was to build large strategic bombers capable of intercontinental flight and delivering nuclear weapons. The rise of the intercontinental nuclear bomber led to interceptor fighters capable of countering those bombers. Concentrating on such air force assets and methods to counter them negatively influenced the development of tactical aircraft and their supporting mission systems.

The direction that air power took within the Cold War strategy also influenced EW's development. While progress nonetheless remained, it applied particularly to areas such as the maturing of strategic signal intelligence (SIGINT). Navies provided the impetus for developing EW, with most from the West becoming gatherers of military information during fleet operations. However, owing to the closed nature of the Soviet Union, navies became services that gathered all-purpose intelligence.[18] This shifting focus led to SIGINT—which includes communications intelligence (COMINT) and electronic intelligence (ELINT)—being better resourced. In airborne EW, similar shifts in emphasis were seen so that efforts to defeat radars and radar guided weapons decreased.

The reduced focus on radar and radar guided weapons was also a reaction to the less advanced Soviet radars. Chaff was an effective countermeasure in reducing the need for expensive and complex EW systems.[19] Reconnaissance aircraft used altitude to stay clear of Soviet missiles and aircraft threats, and it was not until the downing of a U-2 Dragon Lady over Russia by an SA-2 SAM system in 1960, that the need for other countermeasures was properly identified. This downing of the U-2 demonstrated that the Soviets had equipment capable of defeating American aircraft flying at very high altitudes.[20] For several years after the Korean war, EW developments were driven primarily by the necessity to protect strategic bombers and reconnaissance aircraft against increasingly sophisticated Soviet radar and surface-to-air missile (SAM) systems.

The battle for the EMS played a large role in Korea as North Korea had an efficient air defence network supported by radar, SAM and Radar-controlled anti-aircraft artillery. This network increased aircrew casualties because the network was able to locate and engage incoming coalition aircraft with both SAM and MiG-15 fighters. The US bombers were particularly vulnerable targets, and consequently, the USA quickly reintroduced jamming equipment that it had not used since World War II. After adjusting the equipment to cope with the North Korean radar systems, the USA effectively countered the systems and

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18 Martin Streetly, *Airborne Electronic Warfare : History, Techniques and Tactics* (London: Jane's Publishing, 1988), 54-55.

19 Ibid., 15-16.

20 Alfred Price, *Instruments of Darkness: The History of Electronic Warfare* (London: Macdonald and Jane's, 1977), 251-58.

considerably reduced losses to the American bombers. Without the ability to suppress Korean air defences, the losses could not have been endured. The reintroduced equipment and accompanying tactics used against the North Korean radar threats were remarkably like those used in World War II. That is, the laying of chaff corridors and using large-scale electronic jamming to protect the bomber packages.

While the EW measures employed during the Korean conflict focused mainly on the strategic aircraft, they were not the sole users of the airspace. Smaller aircraft were also deployed from the start. The gradual increase in capabilities of tactical aircraft, allowed them to conduct more accurate bombing than could strategic bombers. An interesting side effect of the improved accuracy is that pilots could sometimes use it to increase their standoff.[21] Although the use of tactical aircraft in Korea increased, EW was not often used on these smaller aircraft.

Initially, Cold War nuclear strategy restricted EW being developed because SIGINT and COMINT were emphasised. At the start of the Korean War, allied EW equipment was not adequate to counter North Korean air defences. However, during the War, while EW was adapted to correct this inadequacy, it did not progress extensively. The tactics and further developments were based largely on the type of equipment used during World War II but were adequate for the situations encountered in Korea. The next section discussing the war in Vietnam shows that this approach of simply adapting procedures and equipment was not maintained.

The Vietnam War

The war in Vietnam saw American aircraft increasingly engaged by SAM and AAA systems that were integrated in an advanced IADS. Although the greatest loss to air power assets resulted from small arms fire, radar threats were a close second; they impacted greatly upon operations. The radar threat led to the development of additional EW systems such as jamming pods to accompany strike packages.[22] Initially, tactics like those used in World War II and Korea returned to the battlefield. Large formations of aircraft, designed particularly to maximise the coverage of individual jamming systems, re-emerged. The large-scale use of chaff, remarkably like the tactics applied in World War II and Korea, was also re-introduced, with chaff corridors being laid to mask the approach of strike packages.[23]

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21 van Creveld, *The Age of Airpower*, 318.

22 Dan Hampton, *The Hunter Killers* (New York: HarperCollins, 2015), 366.

23 Price, *Instruments of Darkness: The History of Electronic Warfare*, 270-71.

Vietnam saw many new EW developments, a prominent one being the wide-scale use of dedicated standoff Airborne Electronic Warfare (AEW) platforms. Also, in Vietnam, the now iconic EW aircraft, the EA-6B Prowler, was first used operationally.[24] Some aircraft were dedicated to the 'wild-weasel' role, named after a project aimed at detecting and engaging missile threats. These aircraft used specialised equipment that enabled them to conduct the new mission role of suppression of enemy air defence (SEAD). As the Vietnam War continued, more advanced and complicated EW systems were brought into service.

In addition to dedicated aircraft, the Shrike missile was introduced. It preceded the high-speed anti-radiation missile (HARM) still used today and indispensable when fighting an opponent with modern radar-based equipment. Both missiles are anti-radiation missiles (ARM) designed specifically to lock onto and destroy targets radiating specific signals in the EMS.[25]

An important difference between Korea the war in Vietnam, was that chaff was not only used by large bombers. After introducing jamming pods and chaff dispensers on smaller aircraft, despite some initial resistance to them, tactical aircraft gained capabilities of defending themselves against radar threats.[26] These measures countering radar threats reaped results; for example, in 1965, 8.4 SA-2 missiles were fired per downed aircraft. However, the number of missiles required was increased quickly so that the average used throughout the war rose to 26 missiles fired per downed aircraft.[27]

EW in Vietnam not only focused on radar threats, although they did receive the most attention. Infrared guided missiles that were targeted using the large heat signature of aircraft were operationalised in Vietnam. These missiles motivated the development and fielding of a countermeasure in the form of flares: a projectile that creates a large heat signature when dropped by an aircraft.[28] The large-scale and diverse use of the EMS by systems engaging friendly aircraft led to the quick growth and implementation of capable EW equipment on aircraft.

Air power relates to more than fixed-wing aircraft. Expanding on experiences in Korea and, slightly later French operations in Algeria, rotary wing aircraft were used extensively in Vietnam. This influenced the need for EP measures on helicopters.[29] The Vietnam War

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24 Streetly, *Airborne Electronic Warfare*, 15-16, 41-43.

25 Sanjay Poduval, *Electronic Warfare : War in the Fourth Dimension*, ed. Centre for Air Power Studies (New Delhi: KW Publishers, 2009), 12-13.

26 Hampton, *The Hunter Killers*, 169-74.

27 Ibid., 368.

28 Price, *Instruments of Darkness: The History of Electronic Warfare*, 268.

29 John Everett-Heath, *Helicopter in Combat. The First Fifty Years* (London: Arms and Armour Press, 1992), 20-21, 60.

used helicopters immensely in the attack and air-assault role, which often brought them in close to the enemy and made them susceptible to enemy fires. Although helicopters were not equipped with EW systems during the Vietnam War, the lessons identified during the conflict led to EP equipment being appreciated and thus acquired for helicopters. Experiences in Vietnam were important to the future use of helicopters, as the wars following Vietnam saw helicopters profiting from the increased survivability that EW equipment provided.

In many ways, Vietnam was to EW what World War I was to air power. All the basic air power roles seen in World War I are still taken today, and all the basic EW roles seen in Vietnam also remain. The Vietnam war was a true catalyst for EW and it added the remaining EW roles not seen during World War II. The Vietnam war inspired the development of most contemporary equipment types and concepts of operation; also established was an approach towards EW that remains basically unchanged.

Although posing a great danger, Vietnam defences consisting of Soviet systems were limited in diversity. The only radar-guided SAM system was the SA-2, which was by then an older Soviet system, as were the AAA guns and fire control radar (FCR).[30] Since allied aircraft faced only a few types of threat systems, American engineers were able to focus their resources on combating this collection of older systems and consequently rapidly develop EW countermeasures that stayed effective throughout the war.

Nevertheless, as the radar-guided SAM and AAA systems were increasingly used, the Vietnam war was significant in ensuring EW developed rapidly because it was brought to the tactical aircraft, whereas it had previously been the sole domain of strategic bombers and reconnaissance aircraft.

Other Cold War Era Developments

Aircraft operated over Vietnam for over a decade and, during this time, they gained additional capabilities. However, the basic air power roles did not change, even though the tactics did. The air war in Vietnam thus reaffirmed that the main air-power roles were complete to the extent that how air power is applied remains stable. There is little reason to assume that new roles will be necessary soon. Much the same can be said for EW whose central roles are addressed further in the next chapter. They have not significantly changed, even though important technological advances have occurred since Vietnam.

The wars in Korea and Vietnam are not universally regarded as unbridled successes of air power because, with all its destructive potential, it did not play a decisive role in defeating

30 Price, *Instruments of Darkness: The History of Electronic Warfare*, 271.

the enemy. One of the reasons was that substantial political interference during Vietnam limited the efficient use of aircraft. For example, the situation evolved to a point where the US President decided personally which targets to attack. Smart as a President may or may not be, he was not the right person to make tactical decisions. Air power lost the ascendancy it gained during World War II and fell into a relative decline that it did not necessarily deserve. The decline however, had its effect on airborne EW.

The post-Vietnam Cold War era saw EW systems trying to keep pace with the systems they were designed to counter; progress being more evolutionary than revolutionary. However, although digital components were introduced to EW systems, as opposed to larger and slower analogue ones, they allowed for systems that were more capable of operating automatically.

EP measures were installed on helicopters. The systems differed from those on fixed-wing aircraft because they sought to identify and defeat short-range guided weapon systems.[31] Not only western helicopters adapted. Russian helicopters started adopting EP in the 1980s, when they were frequently engaged by SA-7 and, later, Stinger missiles, during the Afghanistan war. Although EP is by far the most seen form of EW on helicopters, some countries also equipped helicopters with dedicated EW equipment in the EA and ES role.[32]

While major EW systems developed in Korea and Vietnam, other conflicts also provided valuable lessons to the West. For example, EW was used extensively in the Arab-Israeli conflicts. Towards the end of the Vietnam era, the 1973 Yom Kippur War saw the Arab states employ a range of modern, often mobile, radar guided and infrared systems against Israeli air assets. The inability of the Israeli systems to counter these new threats resulted in Israel losing many aircraft in the first week of the conflict.[33]

Wars in the Middle-East highlighted the importance of SIGINT to wage effective EW. EW systems will not be prepared for emerging threats if users are unaware that an adversary is exploiting the EMS. Failing to collect information about enemy systems in peacetime and thus allocate resources can result in being unprepared against specific threats during a conflict.[34]

In the post-Vietnam period, the cost of developing and fielding systems increased rapidly. Because of the rising cost of military equipment, fewer countries have the resources to develop and manufacture EW equipment. Interestingly, pushed by their unique situation,

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31 Everett-Heath, *Helicopters in Combat*, 20-21, 103.

32 Ibid., 174-75.

33 Price, *Instruments of Darkness: The History of Electronic Warfare*, 271-72.

34 Poduval, *Electronic Warfare*, 13-14.

Israel is one of the few small countries that invested heavily to develop EW capabilities, albeit often with assistance from the USA.

By the end of the Vietnam era, under some influence of smaller wars like Yom Kippur, the dedicated roles and methods of countering enemy radar signals in the EMS were well developed. Many EW techniques and equipment such as chaff and jamming seen in World War II, and later in Korea and Vietnam, remain relevant and useful in situations, even today.

What this brief history highlights is that, in times of conflict, the fast-paced cyclical nature of developing technology ensures constant reactions and counter-reactions. EW is an area prone to such developments. From Vietnam onward, such development responded to broad technological advances and those used specifically by opposing weapon systems by focusing largely on updating the technology on aircraft.

Conclusion

Air power and airborne EW are complicated and frequently misunderstood. Both are expensive and often battle to gain funding needed to advance them and thus stay relevant. After World War I, because many nations needed to rebuild, they allocated less finance to their armed forces and thus did not develop air power. However, in further time after World War I, air power capabilities were significantly better resourced as governments identified the increasing role that aircraft could play in wars.

World War I established most of the air power roles and capabilities matured during World War II that emphasised the importance of aircraft in strategic and tactical operations. This significant role, and the quick increase in technological capabilities of aircraft, led to rapid developments in air power. Many responded after the nuclear bomb was introduced because aircraft were initially the sole means of delivery, leaving EW focusing largely on these aircraft. The nuclear era motivated resource allocation for strategic air power and methods to counter strategic bombers.

Air power has won an uphill battle to secure a place within the military; a battle that EW continues to face in some areas. From this brief history of air power and EW, four important lessons follow. First, incorporating leading-edge technology is essential in keeping operational systems relevant. This technology is expensive and can limit the progress in both fields. Second, both fields often see quick developments in times of conflict, because of the obvious parallel and cyclical nature of developing air power and EW. Third, since initially being applied during World War I, the importance of EW in air power has been increasing. Fourth, apart from the select warfighters that are directly connected to either air power or EW, knowledge of air power and EW is insufficient, especially regarding EW. In many wars, the development of EW only started after significant losses occured. The limited appreciation of the role of EW in air power hampers inter-service cooperation and development, and its adequate funding. Both air power and EW are specialised areas and properly explaining the position and importance of air power and EW within the military and the government is vital to an air force's success.

The role of EW within air power should not to be understated. Without proper EW measures in World War II, Korea, Vietnam, and other wars in the Middle-East, air power would have been challenged to achieve its goals; history shows that EW systems are often crucial when facing capable opponents.

3. EW, Air Power Roles & Characteristics

The preceding history of air power and EW highlighted that the two subjects are closely linked. This chapter shifts focus to examine the roles and characteristics of air power, especially how it relates to EW and the importance of how they interact.

EW is relevant to all the air power roles. Furthermore, airborne capabilities benefit EW and vice versa. Certain high-threat environments are impenetrable without the significant support of EW systems and this can limit the number of nations that can operate in higher threat environments. EW certainly plays a critical role because it is necessary to accomplishing certain air power missions. EW can also increase mission effectiveness by gaining valuable intelligence on systems emitting signals in the EMS.

While EW can also be used from the land and sea domains, the third dimension brings a number of unique capabilities and limits to EW. Its use from land and sea can often not match the performance increase and capabilities gained when employing EW from the air.

Air power can be distinguished by its characteristics that best suit the different missions and tasks for which it is used. These characteristics relate to air power's strengths and weaknesses and explain why it has acquired a unique place within the military establishment. The characteristics also emphasise the areas requiring attention when air operations are planned. Distinguishing air power's characteristics simplifies its advantages: they are remarkably stable and thus provide an excellent basis upon which to understand airborne EW.[35] By the end of World War I, the main air power roles were established and most of the characteristics remaining today were identified.

The first part of this chapter explains the capabilities and limitations of airborne EW from the perspective of the unique air power roles. I now focus on air power characteristics and EW. Although the roles and characteristics differ slightly between air forces, a trend is easy

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35 van Creveld, *The Age of Airpower*, Chapter 2.

to detect. This chapter uses the air power roles and characteristics as defined by the RAAF in the Air Power Manual.[36]

EW & the Air Power Roles

Control of the air: *The ability to conduct operations in the air, land and maritime domains without effective interference from adversary air power and air defence capabilities.* An effective way to counter an aircraft is to engage it by another, preferably, more capable, aircraft. Although now often multi-role aircraft, fighter aircraft were developed to gain and maintain control of the air. Initially, three conditions applied to ensuring that aircraft flew at relatively low altitudes, but which made them vulnerable to ground fire: 1) the technical limitations of aircraft, 2) the need for detailed intelligence, and 3) the influence of the weather.

Control of the air needs EW support in many situations. While the most obvious is so an aircraft can protect itself, other areas are important. For example, radar influences EW as it relies on sending active signals that then bounce back from objects so that the echoes alert operators to the presence of other entities. Aircraft are gaining stealth attributes that make them harder to detect by radar, but stealth can challenge their traditional reliance upon radar systems to detect opposing aircraft.

However, EW can assist in detecting opposing forces by other means. Aircraft are becoming more networked in that they send and receive large amounts of information. Because signals sent by aircraft are susceptible to interception, they can be found passively without assistance needed by friendly radar systems. The gain is thus two-fold because an extra layer of detection of the enemy is added and friendly aircraft using passive detection systems are less likely to be detected by the enemy. When the enemy has effective EW systems, control of the air can be hindered by a reduced ability to communicate, either being reduced by jamming, or self-induced by the need to stay undetected.

Strike: *The ability to attack with the intention of damaging, neutralising or destroying a target.* Some aircraft are designed specifically to attack ground positions in a strike role. A trend is that aircraft are often multi-role, in that they can execute multiple types of missions, or swing-role because they can execute multiple roles quickly or even during the same mission. In addition to ground strike, maritime strike can be executed by aircraft such as the P-3 Orion, P-8 Poseidon, and certain types of helicopters.

Strike missions often require the aircraft to operate relatively closely to enemy systems. In a heavily contested environment, EW systems are a prerequisite for survival. Here again,

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36 Royal Australian Air Force, "Australian Air Publication AAP 1000-D: The Air Power Manual," 45-76.

the most obvious use of EW is so aircraft can protect themselves. Many combat aircraft have extensive EP features to for surviving in contested environments, including electronic hardening of the systems, and various measures such as flares, chaff, and other decoys to protect them from incoming missiles. Stealth attributes are also a form of EP by enabling aircraft to fly closer to opposing radar systems. Dedicated EW assets, with their more potent and advanced methods to win the battle for the EMS, assist friendly strike aircraft to accomplish their mission. For example, dedicated jammer aircraft, from a distance, can help to jam enemy radar and communication systems. Jamming can occur from various locations, by using stand-off jamming from long distances outside the reach of enemy systems, or escort jamming involving dedicated EW aircraft accompanying packages for fighters or bombers. Jamming is also possible as a form of self-protection by fighters and bombers equipped with these systems.

Dedicated EW aircraft are also capable of detecting enemy systems and, in this way, contribute considerably to planning insertion and extraction routes, finding possible targets, and determining which assets will be used for the missions.

Air mobility: *The ability to move personnel, material or forces using airborne platforms.* Increasing the ability of aircraft to carry large amounts of troops and equipment into, between, and within, theatres worldwide has increased the reliance on air mobility assets. Aircraft in the air mobility role are not limited to landing at and taking off from safe airfields; they sometimes find themselves operating in hostile environments. This is particularly true of tactical transport aircraft such as the C-27 Spartan, C-130 Hercules, and aircraft like the C-17 Globemaster III, strategic transport aircraft capable of landing on unimproved airstrips. These aircraft can be faced with capable threats making use of the EMS. Air mobility mainly uses EW in self-protection role, although not all strategic level aircraft have EW assets installed.

To be more intelligence-focused than EW, another way of using aircraft in the air mobility role is to outfit them with sensors that can passively record information in the EMS. This information can later be used to analyse capabilities of opposing forces. Systems emitting in the EMS often have long ranges that put air mobility aircraft out of range of enemy weapon systems, but in the range of enemy EMS signals.

Intelligence, surveillance and reconnaissance: *ISR synchronises and integrates the planning and operation of sensors, assets, and processing, exploitation and dissemination of systems in direct support of current and future operations.* ISR gains much by using the third dimension. This involves using the unique air power characteristic of perspective derived from increased height, combined with the characteristics reach and speed. Aircraft can thus quickly gain intelligence on relatively large portions of the battlefield. ISR can gain information from some of the sensors used for EW.

A drawback of using air power for ISR is the impermanence of air power. Aircraft have restricted endurance, which is a complicating factor in planning and executing. However, the situation is improving with contemporary developments that considerably increase the endurance of many airborne platforms, especially the medium and high-altitude long-endurance RPAS.

EW & Air Power Characteristics

Air power developed exponentially as the advantages of exploiting the characteristics of air power became apparent to forces worldwide. Aircraft became more common in civilian society, and commercial initiatives started to influence military developments. All air-power theorists acknowledge the advantage of speed, reach and access that air power has. Air power is fast, and aircraft can largely overcome geographical boundaries that restrict movement within systems that use the land and sea domain.

This section examines how air power's unique characteristics influence EW.

1. **Perspective**: Height gives airborne EW assets some advantages compared to systems on land and at sea. Because of their altitude, aircraft can influence the air, sea and ground domains. An advantage of such elevation contributing to EW is that airborne systems can look over the horizon as compared to systems lower to earth. This gives them height and also increases the ease of accurately detecting the distances of enemy systems by detecting the angle of the beams reaching the EW aircraft. With the EW systems being able to reach long distances, aircraft can build situational awareness of crews by supplying information about hostile systems using the EMS.

   However, two drawbacks of height need to be considered: first, it exposes an aircraft to hostile detection from larger distances; and second, it does not necessarily allow for clear visibility when certain terrains mask enemy actions.

   This chapter now outlines eight important characteristics relating to air power and EW:

2. **Speed**: The speed of aircraft is useful for both reaching places, and for extracting EW assets, quickly, when in harm's way, increasing survivability. Speed contributes to the flexibility of the platform and helps achieve quicker and more precise position fixes for EW assets. Speed gives platforms a level of unpredictability because they can show up in unexpected places.

3. **Reach**: Because distance matters when coupled with height, which increases the distances that EW can operate at, reach is a powerful characteristic. In uncontested airspace, reach enables EW to target locations far from the friendly troops by

bypassing the enemy's ground forces and concentrating on other CoG (Centre of Gravity) that are difficult to reach with other assets. The combination of aircraft reach and the added reach of the EW sensors provided by altitude is an important characteristic of airborne EW.

4. **Flexibility**: Air power is characterised by flexibility, which has both advantages and disadvantages. An advantage is that aircraft can quickly reposition within an environment to gain more detailed information and can thus often fly away when threatened. Another advantage of flexibility is that aircraft are, at least in theory, capable of passively collecting large amounts of diverse information about an operating environment.

   A disadvantage of air power's flexibility is that aircraft can find themselves in many different operating environments and situations. Because of this, combat aircraft need to be equipped with capable EW systems to protect themselves against the wide range of threats that might be encountered in various theatres of operation.

5. **Precision**: The relatively high speed of aircraft with EW systems results in their being able to locate positions easier than similar EW systems with a fixed location. By using multiple locations to record the direction that related signals are coming from, an aircraft can accurately establish the direction of these signals. Although newer techniques are in service to achieve this effect in other ways, the quick movement of aircraft makes airborne EW a simple method for fixing emitters.

   In some ways, airborne EW is at a disadvantage when it comes to precision. Signals in the EMS are sometimes more capable of penetrating hard surfaces than physical weapon systems. There is a danger that jamming and other signals sent from an aircraft can create collateral damage due to unrestricted views as compared to units on the ground with their limited horizon. Effort needs to be taken to create proportionate, discriminate and accurate responses from EA assets.

6. **Dependency**: Aircraft require significant support from, for example, ground crew, other personnel, education, and training. A drawback of aircraft is that they are often difficult to hide when near an airfield. This, in turn, makes it difficult to hide EW capabilities used when flying in the theatre, thus allowing the opposition to take precautions.

   The quick nature of air operations means that air power is highly dependent on accurate and adequate information. Here, EW can play a role, since the intelligence gathering capabilities of EW can be used to further the information dominance and shape the planning and execution of operations.

7. **Fragility**: Fragility of aircraft as complicated machines was evident from the start and is the curse of aviation. For an aeroplane to fly, nearly all the components that it consists of must keep working. The specialised domain in which aircraft operate demands high-quality equipment since they need to meet higher standards than most ground and sea-based systems. This increases equipment costs and extends their development time.

   Fragility also means a certain level of redundancy is to be expected in the EW realm, but due to the already very high cost of this equipment, reality does not often mirror this expectation.

8. **Payload**: An aircraft payload is limited. Some EW equipment, especially that dedicated to EA and ES, is large and heavy, limiting the capability of smaller aircraft to do certain EW missions.

   Some EW equipment is mounted in pods, which limits the number of pylons available on aircraft; a problem when there is a competing need to install weapons. Newer aircraft often do not have the option of installing equipment under pylons if they must retain their low observability; EW equipment must therefore be integrated in the frame.

   Installation options that are limited by size and weight means that choices must be made about what type of EW suits an aircraft uses based on the type of mission to be flown and what opposition is likely to be encountered. Recent developments in miniaturisation and antennas partially reduce this disadvantage.

9. **Impermanence**: Currently, air power presence is relatively fleeting, although improvements in systems such as UAV (Uninhabited Aerial Vehicle) that have longer endurances are now available. An aircraft cannot stay airborne forever and it either needs to be replaced in time, or a capability gap must be accepted.

   This impermanence means that air operations involving EW need to be planned carefully since the assets devoted specifically to EW are always scarce. Impermanence is also a reason that UAV, having a longer endurance, could increasingly become the preferred EW aircraft in lower threat scenarios where EW is required.

To conclude, air power roles and characteristics are stable in time with EW influencing air power as much as air power influences EW. The air power roles make it easier to understand the different types of missions and tasks that air power can accomplish. The support given to air power by EW equipment has developed with the technical capabilities current at the time. In contested environments, EW is essential in ensuring aircraft survivability. In less-hostile environments, EW is still an important means of detecting and classifying threats. Air power characteristics influence EW, having both advantages and disadvantages to operations in the third domain. While air power gives EW a flexibility that other domains cannot, it also increases the vulnerability of EW assets. Air power and EW are now two areas that are linked in many ways, including technical innovation that allows for an increasing use of systems associated with the EMS, and an increased proliferation of EW equipment in aircraft. As will be seen in the following two chapters, this link only becomes stronger as time passes.

4.
Influences of Modern Air Power on EW

Changing global dynamics and increasing technology in civilian and military environments are influencing air power and EW in the modern age. History shows that successfully using air power, which involves implementing and using technology correctly, can be a deciding factor in wars. Also important to its success are increasingly advanced EW systems. For modern combat aircraft, a considerable amount of technological capacity, resources and investment go into EW systems that improve aircraft situational awareness and survivability.

To identify change drivers and disruptors in EW and air power, the operating environment must be considered by noting how it was and how it is expected to operate. While Force designers can never be sure what future environment will exist, recent conflicts provide clues. Air power and EW was applied substantially differently during Operation *Desert Storm* in 1991. During that campaign, using and controlling the EMS

was critical to the success of operations within enemy

airspace. Operation Deliberate Force in Bosnia, operations conducted by Israel, and the campaign in Afghanistan, all show an increasing trend to rely on the EMS in air warfare. However, even though it is likely that the EMS will continually grow in importance in military operations, recent trends give no absolute guarantees about future operations and needs.

To identify important aspects of modern EW, this chapter examines its contemporary use and influences on air power. The chapter also focuses on changes in global politics that influence air power and EW. The influence of technology changes, especially those related to 5th Generation, is discussed in more detail in the later chapters. This chapter begins with Operation *Desert Storm* because it marks the dawn of modern air power and the increased relevance of the EMS in warfare. Around the time as this campaign, the Soviet-Union collapsed, the Cold War ended, and air forces needed to reinvent themselves. The small wars in which Western forces increasingly intervened produced five effects: first was increasing irregular warfare; second were questions about traditional systems and forces;

third was an increasing desire for expeditionary assets and aircraft that could support the projection of power; fourth was the temporary reduced threat after the Soviet collapse that decreased defence budgets and significantly affected air power and EW; and fifth was the reduced threat to aircraft after the shift to irregular warfare produced a lower priority of certain EW equipment within many small and middle-sized air forces.

The post-Cold War period also coincided with increasing technology. That Operation *Desert Storm* saw a sharp increase in the importance of the EMS is not coincidental. The rise of digitisation and wireless technology made available advanced systems such as GPS and extensive use of highly accurate weapons. If forces cannot control the EMS in a conflict, they will struggle to control anything in the physical domain. The digitisation and overall integration of technology into aircraft resulted in a sharp increase in cost, a tendency of concern for air power. Since resources and the cost of air power are limited, force designers who need to make difficult choices face challenges. Airborne EW was one of the areas that was negatively affected by certain design choices made.

Aircraft and associated systems are not only becoming more expensive, the development and production times have increased significantly. These increases influence the amount of new systems designed. Instead of regularly seeing new aircraft designs, the approach is to continue updating aircraft. The high level of complexity, coupled with fewer aircraft being manufactured, leads to the force being vulnerable because of quantity. Such vulnerability is crucial when a country is being invaded, because its available forces need to resist till more equipment is produced. The deficiency in number and production times may result in failure when an imminent invasion is realised.

One trend is to increasingly form coalitions when intervening in emerging geo-political challenges. Although coalitions allow asset capabilities to be shared, this remains particularly challenging for EW. Its classified nature leads nations often to be reluctant to share detailed EW information. Sharing information gained by EW assets in theatre risks giving away specific EW capabilities.

While the decades have seen reduced interest in some areas of EW, recent developments have renewed efforts in developing and purchasing capable and dedicated EW equipment. The EMS is critical for the efficacy of applying air power, and the increasing use of wireless technology is making it more important to both military and civilian developments.

Operation *Desert Storm*

Operation *Desert Storm* marks the starting point of modern air power and use of the EMS. That campaign saw a massive use of air power that shaped the situation on the ground in such a way that ground forces overwhelmed their opposition soon after the ground phase commenced.[37] The adopted approach to air power led to a quick and decisive victory for coalition forces. Behind this success were new theories applied to enabled air power to regain favour after its perceived inability to help bring victory to larger conflicts such as the Korean and Vietnam wars. Faith in air power was mostly restored. While air power has been increasingly used in small wars since Operation *Desert Storm*, the campaign prioritised air power as the preferred military option for governments.

Technology was significant in *Desert Storm* seeing the first wide-scale use of the EMS by systems not focused on radar and (voice) communications. The EMS was vital to the space-based Global Positioning System (GPS), ISR and communication satellites, tactical data links, and stealth operations. New air power theory, combined with new technologies related to the EMS, distinguished Operation *Desert Storm* from previous conflicts.

In the three decades following Vietnam, the US Air Force's approach to air power, and by extension most Western air forces, was particularly influenced by two theorists. The first is John Boyd, who is known for his concept of the OODA-loop (Observe-Orient-Decide-Act). The OODA loop focuses on the interaction between entities and emphasises the need to adjust to situations quicker than the opposition can. The relative speed between actors is crucial, as it can complicate an opponent's ability to adapt. Boyd affected the character of air operations and played a prominent role in promoting alternative approaches to target selection. Boyd's theories were already applied during the Vietnam War, and they continued to influence air-power thinking in the post-Vietnam period. He emphasised that practitioners of air power must 'maintain the ability to adapt, while denying the enemy the ability to adapt.'[38] The second theorist is John Warden who, at the end of the 1980s, wrote about modern air power theory in, *The Air Campaign: Planning for Combat*. Further referred to as the five-ring model, the book viewed the enemy as a system and created a more efficient approach to defeating the enemy by cleverly prioritising targets.[39] Although their approaches differed, both theorists offered the idea, strategic paralysis, as David Fadok explains,

'Strategic paralysis is a military option with physical, mental, and moral dimensions which intends to disable rather than destroy the enemy. It seeks maximum possible political effect or benefit with minimum necessary military effort or cost. It aims at rapid decision

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37 Department of Defense, "Conduct of the Persian Gulf War," (Washington, D.C.: United States of America,, 1992), i-v.

38 Frans P. B. Osinga, "The Enemy as a Complex Adaptive System: John Boyd and Airpower in the Postmodern Era," in *Airpower Reborn: The Strategic Concepts of John Warden and John Boyd*, ed. John Andreas Olsen (Annapolis: Naval Institute Press, 2015), 76-80.

39 John A. Warden, *The Air Campaign: Planning for Combat* (New York: Pergamon-Brassey, 1989), 128-40.

through a "maneuver-battle" directed against an adversary's physical and mental capability to sustain and control its war effort to diminish its moral will to resist.'[40]

It was through converging the smart application of air power theory with the use of new technologies that contributed to distinguishing *Desert Storm* from how air power was previously applied. The influence of Boyd and Warden was evident in planning and executing the air campaign.

While Boyd focused on the psychological aspects of strategic paralysis, Warden, arguably the most influential post-World War II air power theorist, dealt primarily with the physical effects that contributed to strategic paralysis.[41] Warden's theory was successfully put into practice in liberating Kuwait from Saddam Hussein's forces during Operation *Desert Storm*. The theory centred on a five-ring model that was essential for an enemies' system to keep working. In descending order of importance, the rings were leadership, processes (often referred to as organic or system essentials), infrastructure, population, and fielded forces.[42] Warden's approach to prioritising targets focused combat operations which enabled strategic results using conventional tactical methods. No longer were armed forces spending valuable time and resources engaging large amounts of tactical military and civilian targets; they could focus their strikes mainly on areas that generated the necessary effects to paralyse the enemies' system from within, such as attacking the leadership. Warden's approach aimed to make air power a more economically viable alternative to land power, paving the way for further developments in air power and consequently in airborne EW suited to enable his approach.

Warden's theory shows that striking the leadership is a valuable approach to paralysing the enemy. Leadership is not often found at the forward edge of the battlefield, and it takes assets that can penetrate deep behind enemy lines to reach critical personnel and infrastructure. The ability to bypass fielded forces and engage more important targets is where EW became highly relevant to Operation *Desert Storm*. It was the successful use of the EMS and developing and applying airborne EW that largely determined the ability to bypass the enemy. Because air power, supported by EW, can project itself beyond military and geographical boundaries, it can focus on the enemy's centre of gravity. Bypassing the enemy, in turn, allows a potentially quick victory to occur while using a minimal amount of violence. The combination of dedicated EA to neutralise AD, effective EP systems on the aircraft, and ES which ensured timely localisation of the systems allowed freedom of manoeuvre to coalition aircraft. The EMS was used by many systems. Part of successfully

40 David S. Fadok, "John Boyd and John Warden: Air Power's Quest for Strategic Paralysis" (Air University, 1995), 10.

41 Ibid., 13-19, 23-29.

42 Warden, *The Air Campaign*, 34-45.

implementing Warden's theories can also be attributed to aircraft and weapons being modernised to the extent of enabling air power to target more accurately while remaining out of reach of the enemy.

Iraq could not contest the intensive use of the EMS by the coalition. EMS superiority helped enable coalition forces to overwhelm Iraqi opposition and control the theatre. Finding enemy targets with advanced sensors, sending target locations remotely to other assets, navigating in desert terrain with the help of GPS, de-conflicting friendly assets using digital position updates, guiding weapons to target, and ensuring coalition forces did not become targets, all heavily depended on using the EMS. Stealth aircraft used many aspects of the EMS; stealth features enables aircraft to bypass enemy systems that would previously need to be destroyed or heavily jammed for extensive periods.[43] Stealth aircraft also used GPS for navigation, infra-red imaging for finding and tracking targets, and laser for guiding its bombs.

An example of the importance of EW in *Desert Storm* is the use of SEAD. The HARM missile played a crucial role in the initial operations against Iraq's Integrated Air Defence (IAD).[44] Two effects on the enemy emphasised the utility of the HARM. First, the weapons ability to home on signal enabled it to destroy Iraqi air defence radars that remained active after launch of the HARM. Second, after a few days, Iraq's air defence caught on to the trend of being attacked while emitting radar signals and decided to keep them off, effectively disabling the Iraqi IADs.

Operation *Desert Storm* shows the importance of keeping technology up-to-date. Developing EW between Vietnam and Iraq was more than adequate to counter the diverse, but second-tier systems encountered in Iraq. Because they were adequate, the coalition was prepared and won the battle for the EMS in Iraq, which enabled them to initiate the plan according to Warden's design. EW developments and uses of stealth, HARM, and SIGINT, allowed coalition aircraft to locate and bypass the enemy and engage the targets where the effect on the enemy was most substantial, in turn enabling a quick end to Operation *Desert Storm*. The available EW technology also allowed the coalition to target civilian infrastructures such as communications networks used by the opposing military and government.

The success of Operation *Desert Storm* does not mean that a similar approach will be successful in every theatre. Iraq was a perfect situation for the coalition. First, critical resources, such as oil, were already in-theatre, and enough time was available to build up a large force. Second, in contrast to World War II, where Britain and Germany both had a

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43 Osinga, "The Enemy as a Complex Adaptive System," 83.

44 Note: Not all countries include SEAD in their definition of EW or EA.

force that was advanced technologically, the coalition was superior so that the battle for the EMS was won with little resistance. Third, the desert environment was ideally suited for aircraft to target Iraqi ground forces who had little place to hide.[45] The flat terrain allowed EW and ISR assets an unrestricted view of the battlefield, thus increasing the already large disparity in capabilities.

Operation *Desert Storm* restored the politician's faith in air power, thanks partially to Warden's theory and its practice during the campaign. Besides a new theoretical approach to air warfare, technology played was significant to Operation *Desert Storm*. The wide-scale use of the EMS by the coalition was enabled by military systems making use of a broad range of new technologies. Furthermore, EW systems, having been modernised sufficiently between Vietnam and *Desert Storm* to control the systems operated by opposing forces, were able to contribute to the value of air power demonstrated in Iraq. Operation *Desert Storm* shows that air power can be substantially influence the outcome of a conflict if a rational air power theory underlies the use of advanced technology supported by sufficient assets controlling the EMS.

Cold War Influences - Defence to Expeditionary

> *'Nations that aspire to influence the geo-political landscape positively, will per force have to maintain robust air power capabilities that can be innovatively employed across the entire spectrum of conflict and can contribute in the broadest sense possible to national security.'*[46]
>
> *- Kainikara*

While every country assesses its own security environment when choosing which capabilities their air forces will acquire, changes in the world order can shift each assessment quickly.[47] Their decisions are shaped by their geopolitical situation, but also the economy that determines the available resources. Large economies with sufficient military industry and funding are more capable of investing in specific air power assets that project power. However, because of their increased global interests, these countries often benefit more than most from doing so. The type of military investments made by large, and small to middle-sized economies, differs considerably related to specialised assets

45 van Creveld, *The Age of Airpower*, 320-25.

46 Sanu Kainikara, *The Cassandra Effect: Future Perceptions on Air Power* (New Delhi: Vij Books India PVt Ltd, 2016), 22.

47 John Andreas Olsen, *Airpower Reborn : The Strategic Concepts of John Warden and John Boyd*, History of Military Aviation Series (2015), 177.

such as dedicated airborne EW equipment. During the Cold War, the lesser resources of smaller economies were traditionally used for air power for defence. Times have changed and achieving success in air power is increasingly dependent upon enablers including dedicated EW assets, transport, ISR, and refuelling.

The end of the Cold War changed the world order and reduced, at least temporarily, the need for extensive defensive air forces that Western nations needed in case the Soviet Union decided to invade Western Europe.[48] This change challenged Western military in the post-Cold War era because a defensive role required a different force structure to meet the demands of deployment. Military often focused on assets that supported Air Defence and systems that searched for opposing aircraft. The Cold War shaped air forces in a way that limited their ability to project air power over vast distances. Emerging from the Cold War, forces were not designed to be expeditionary since the geographical threat was nearby.[49] For this reason, ISR and EW assets often remained limited to relatively short-range systems. These limits were particularly true of European countries that worried about countering a Soviet invasion.[50] Without needing long-range EW assets, most air forces did not own many dedicated EW systems, leaving EW to the army and navy. Although army EW systems can operate well, their range is limited, and they are relatively static. The shortcomings of Cold War air forces became clear when NATO conducted Operation *Deliberate Force* in 1995, an air campaign by NATO against the Bosnian Serb Army which was also based upon Warden's theories as previously seen in Operation *Desert Storm*.

This force instigated a transition point for the air forces involved, but also influenced other Western air forces not directly participating.[51] Performance in that conflict showed that focusing solely on air power as a means of defence lessened the ability to project power and thus lessened the value of air power to project national power. However, additional capabilities, particularly those supporting expeditionary warfare, were needed to project and sustain forces over even moderate distances. Many European air forces missed important capabilities in EW, Command and Control (C2) and information systems, support systems and personnel, strategic airlift, ISR, tactical mobility, and air-to-air refuelling; this made them highly reliant on American assets.[52]

Experiences such as the operations in former Yugoslavia and the Australian intervention in East Timor increased investment in non-kinetic assets to ensure deployment, sustainment

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48 van Creveld, *The Age of Airpower*, 317-19.

49 Michael S. Erickson, *European Airpower in a New Age of Air Policing* (Milton Keynes: Biblioscholar Dissertations, 2012), 12.

50 van Creveld, *The Age of Airpower*, 78.

51 Erickson, *European Airpower in a New Age of Air Policing*, 1-3.

52 Ibid., iii.

and support of forces. For example, to support the operations, small and medium-sized air forces focused more on Air-to-Air Refuelling (AAR), not an asset that smaller countries needed when the prominent task was to defend the state's territory. Air transport was also often expanded to adapt to the needs of expeditionary operations. Rather surprising was that, although support by EW assets contributed significantly to Operation *Deliberate Force* succeeding after the war, most European countries did not spend more on dedicated EW systems.

Because the global order changes quickly, armed forces must remain flexible when designing their assets to remain useful to national power. With conflicts far from home being the standard, air power needs dedicated assets, including transport, aerial refuelling, and EW, to support them. With the balance shifting between the United States, Russia, and China, governments might be enticed to focus more on defending their own territories. This focus can mean re-allocating resources and thus a diminishing capacity to project power. However, armed forces have grown accustomed to benefitting from air assets. Although, since the future capability to defend the nation should not be ignored, air forces must be capable of supporting operations occurring far from home.

Irregular Warfare

Although the identified air power roles and characteristics are stable over time, the changes to air power are substantial. The idea of war as an act of violence is untarnished by time, yet, the classical view of conflict in the form of two large opposing armies is not always seen these days.[53] Events on the ground, such as increasing irregular warfare (IW), are transforming air power as air power influences how events unfold on the ground.

The rise of IW has marked warfare in the recent decades and has significantly affected EW. The US Department of Defence defines IW as 'A violent struggle among state and non-state actors for legitimacy and influence over the relevant populations. IW favours indirect and asymmetric approaches, though it may employ the full range of military and other capabilities, in order to erode an adversary's power, influence, and will.'[54] IW is not a new way of war; it has been around for thousands of years. The high incidents of IW questions the role of air power within this type of warfare. Answering this is important to understand some of the developments in airborne EW.

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53 Carl von Clausewitz et al., *On War*, Index edition ed. (Princeton, N.J.: Princeton University Press, 1984), 90.

54 US Special Operations Command; US Marine Corps, "Joint Operating Concept (Joc) - Irregular Warfare," ed. Department of Defense (Washington, D.C.: Department of Defense, 2007), 1.

IW influences air power at different levels. IW changes the importance of certain air assets, including increasing the need for ISR dus to an increase in relatively hard to find targets. IW often sees intense cooperation with special forces.[55] IW changes situations related to targeting, often needing more detailed information and analysis when the situations encountered are dynamic. In addition, IW can shift the primary threat to air assets, for example the push to EW developments to counter IR missiles during conflicts in Iraq and Afghanistan.

Threats to aircraft come from many different systems, and that non-state actors have capable systems is worrying. The greatest threat to aircraft in IW often comes from infrared-guided Man Portable Air Defence systems (MANPAD), such as, the US Stinger and the Russian SA-7 family of missiles,[56] rather than radar-guided systems. Newer versions of MANPAD systems are becoming more lethal, with better ranges and guidance systems, and other capabilities to engage low flying targets from all angles.[57] The technical capacities of these systems can challenge the worth of some standard IR countermeasures, such as, traditional flares that equip many aircraft. The relatively low price and wide availability of some of these systems increase the threat towards aircraft, especially low-flying systems such as helicopters and some RPAS. The increased threat has prompted research, development, and acquisition of systems to counter them. Efforts are being made to expand the range of missile detection systems, improve flare efficiency, and equip aircraft with DIRCM (Directional Infrared Countermeasures). Also being developed are similar systems that work by using directed energy focused on damaging the sensor of the incoming missiles.[58] Owing to limited funding, small and middle-sized air forces feel compelled to make choices in protective EW systems.

Some air forces focus on systems capable of countering the IR missiles that are quickly evolving with improved capabilities, instead of equipping aircraft with systems to counter radar-guided missiles. Although this is understandable in the light of the threat, such as seen in Afghanistan, the change has led to some Western air forces not having sufficient EW systems to counter radar-guided missiles. Countries' focusing on IR threats alone is understandable when they have low budget and fly in theatres such as Afghanistan. However, we need to understand that these choices result in a nation's air force not being suitably equipped and capable of committing itself to full spectrum warfare. Aircraft without sufficient EW equipment and support cannot be expected to survive in an

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55 Air Power Development Centre, "The Reality of Air Power and Irregular Warfare: What's in a Name? 'Irregular Warfare and Counterinsurgency'," *Pathfinder Collections* 4 (2010): 23-27.

56 Poduval, *Electronic Warfare*, 156-57.

57 Adamy, *Ew 104*, 344-49.

58 Ibid., 373.

environment with modern radar threats. The increased attention to threats by MANPAD systems that potentially reduce attention to systems capable of combating radar threats, exemplifies how IW influences EW development.

The Rising Cost

> *'In the year 2054, the entire defense budget will purchase just one aircraft. This aircraft will have to be shared by the Air Force and Navy 3-1/2 days each per week except for leap year, when it will be made available to the Marines for the extra day.'*
>
> *- Augustine's Law Number XVI*[59]

Air power is costly and adding EW systems makes it more so.[60] What follows discusses the rising cost of air power and its influence on airborne EW. The military is only one of many organisations competing for resources, and governments are astutely aware of the high cost of air power. This cost has increased over the years and continues to thwart innovation and expansion in both quantity and quality of air forces worldwide. While increasingly using civilian technology may positively impact the cost of military technology, the need to pay more to keep combat aircraft and EW systems on the leading edge can limit this effect.

In "The Age of Airpower", van Creveld criticises the smaller number of aircraft owned by the USAF than in the decades following World War II. Many Western air forces take issue with this situation even though this reduction was partly due to overall budget cuts. However, the rising cost of aircraft is certainly significant. Even considering inflation, fighter aircraft are many times more expensive to purchase and sustain than they were after World War II.[61] Research by the Australian Strategic Policy Institute (ASPI) identifies factors that influence the cost of jet aircraft that the ADF acquired since the 1940s. In 2015, on a per aircraft basis, the F-35 was the second most expensive fighter aircraft, surpassed only by the F-22.[62] Owing to the rising cost of the aircraft and reductions in budget, considerably fewer F-35s and F-22s will be produced than initially planned. For example, the USAF's purchase of the F-22 shrank from an expected 750 aircraft to 187. The F-35 is about 50 per cent more expensive than the F/A-18 was. Even though the F-35

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59 Norman R Augustine, *Augustine's Laws*, Sixth ed. (Reston, Virginia: AIAA, 1997), 107.

60 Michael; Ryan Frater, Michael, *Electronic Warfare for the Digitized Battlefield* (MA, USA: Artech House, 2001), 213-14.

61 van Creveld, *The Age of Airpower*, 425-28.

62 James Mugg, "Jet Fighter Costs - a Complex Problem," (2015).

houses impressive technology, the limited number to be purchased because of high cost, is concerning. With examples of comparable cost rises being common in the past decades, the projected high cost of aircraft is also concerning. The decreased number of aircraft purchased may prove critical in future wars.

Rising costs are varyingly caused by increasing labour and materials costs, and the complex systems behind programming aircraft, weapon and EW systems. The need to integrate a growing number of EW measures and systems into aircraft continues to increase the cost of airframes and other related systems. The rapid current advances in EW technology can further increase costs. The increasing availability of technology will likely not decrease the cost of 5th-generation air power, particularly regarding leading edge systems, anytime soon.

Because of its increased complexity, developing military aircraft is increasingly lengthy so that this combined with a need for advanced technology make aircraft costly. The high cost is a challenge for military trying to fund the purchase of aircraft and a grave threat to the preparedness of many armed forces. Nearly everything related to developing and acquiring air power needs a long-term outlook, but this long term increases how armed forces are challenged in gaining government approval of projects.[63] For example, with the F-35, countries had to buy early into the program or risk forgoing receiving the F-35 later or at all. However, the earlier the necessary commitment is required, the less likely governments are to spend the large cost it takes to join a development program, as was sometimes the case with the F-35.

While the cost of air power is undeniable, increasing costs must be moderated since even the world's largest economies are struggling to sustain large numbers of combat aircraft. Rising cost also causes some countries to choose cheaper, less capable fighters for their air force. Although such cheaper fighters can still be capable if, for example, EW pods are added, the lack of stealth features may restrict them regarding high-end scenarios. Countries may even choose to quit the expensive business of operating fighter aircraft altogether; New Zealand took this step recently.[64]

Often questioned is whether the Western world over-complicates aircraft to the extent of believing that they need to be sufficiently advanced to combat the threats likely to be faced in the next two decades. Maybe the obsession with leading and cutting-edge technology has lowered Western powers in the world balance.[65] One possible solution emanates from

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63 Olsen, *Airpower Reborn*, 178.

64 Government of New Zealand, "Royal New Zealand Air Force," Government of New Zealand, https://nzhistory.govt.nz/war/rnzaf.

65 Mugg, "Jet Fighter Costs".

the USA that lowers the cost of some combat capabilities by assessing the potential of substantially cheaper off-the-shelf aircraft for environments that do not require high-end aircraft. In other words, these aircraft can reach a similar effect but with lower initial and on-going costs.[66] The low-cost approach is exciting and thus worth exploring, but the obvious danger is that a country will eventually focus too much on these aircraft, to the detriment of those needed in higher threat environments or during state-on-state conflicts. Low-cost aircraft will have a hard time surviving in a hostile EMS environment.

Choices regarding airborne EW are based on the direction that air power takes. Constrained Western defence budgets and the commensurate small numbers of EW systems in many air forces, challenge Western military forces. Small and middle-sized air forces, having limited EW assets, focus mainly on EP and some ES; EA capabilities are often missing or severely restricted.

Restricted budgets force difficult choices when acquiring military equipment, and airborne EW is not always a preferred contender. Lacking EW capabilities has causes that differ between countries:

1. When it comes to aircraft, everything is expensive and land and sea-based systems are more economic than aerial. Airborne equipment must be relatively light and meet stringent airworthiness regulations. Sensors must be upgraded/replaced quickly to combat newly developed radar and communication, which conflicts with the long development in aviation.
2. The extensive range of EW capabilities is not entirely needed or used in some stages of the conflicts of the past few decades.
3. That few countries are developing their own EW equipment creates a challenge. To develop EW equipment, a country needs an advanced electronics industry and sufficient knowledge about the electronic systems to be countered. However, having an advanced electronics industry does not guarantee development.

The difficulties of developing and producing EW equipment means most countries are limited to purchasing equipment from a handful of countries who manufacture them. Because EW assets are sensitive, it is likely that the equipment classified for export will be less capable than the original systems. Although purchasing countries will thus pay the full price, the products may be inferior. Only countries that have strong political-military ties to the country of origin are likely to receive original systems. An example is when the Australian Government purchased the EA-18G Growler and accompanying EW equipment from the USA. Because they are strongly linked politically and militarily,

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66 Senate Armed Services Committee, *Presentation to the Senate Armed Services Committee Subcommittee on Airland Forces United States Senate.*, 2017, 11-12.

Australia was expected to receive capabilities equal or similar to those originally produced.[67]

The Influence of Civilian Developments

Civilian developments can influence military developments and their cost. Military aircraft costs are not all rising at the same rate. An aircraft such as the F-35, which is on the leading edge of technology, is costly, but advanced technology is becoming more widely available, a phenomenon that reduces some technology costs at a level down from that of the F-35.[68] The increased diversity of modern expeditionary air forces has increased the variety of aircraft and has emphasised support aircraft. Although they are certainly not always cheap, their advantage lies in fewer of them often being sufficient to support operations. This lower need contrasts with top-of-the-line fighters that tend to need many to perform sufficiently.[69]

Besides their initial purchase, the cost of sustaining the various types of support aircraft is substantial to the extent that sustaining them costs considerably more than combat aircraft.[70] Although a military may need dedicated EW assets, the cost may deter it from purchasing them. Everything that lowers the cost of EW assets can assist to lower their purchase price. One influence of civilian developments is to reduce the purchase and operating costs of military support aircraft by using civilian aircraft as a base design as opposed to designing completely new aircraft. Adapting existing designs remains complicated and thus much more expensive than civilian aircraft. Yet, designing anew can increase the development time and the price to an unacceptable level. Examples of modified airframes are the P-8 Orion and the E-7A Wedgetail, both based on a, heavily modified, Boeing 737 design, and the Israeli ELI-3360 MPA based on a Bombardier Global 5000 business-jet platform. Similar examples are found with refuelling and transport aircraft, such as the Airbus A-330 used as a tanker aircraft. The possibility of lowering the purchase as well as operating costs of dedicated EW assets that use civilian airframes can positively influence the number of dedicated EW aircraft. Many developments are taking place in this area, a recent example being the RAAF purchasing Gulfstream G550 aircraft for EW.

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67 Glen Braz, "The Ea-18g 'Growler': Force Level Electronic Warfare (Flew) in the Adf," in *Air Power Seminar* (Canberra2014).

68 Royal Netherlands Air Force, "5th Generation Air Force," (Breda: RNLAF, 2017), 4-5.

69 van Creveld, *The Age of Airpower*, 428-31.

70 Congressional Budget Office, "Paying for Military Readiness and Upkeep: Trends in Operation and Maintenance Spending," ed. The Congress of the United States (Washington, D.C.1997), 36.

Civilian research in EP measures may also decrease the cost of EW systems. Sometimes, unmodified civilian aircraft undertake military operations, which that can influence EW development. Civilian aircraft are used in theatres, such as Afghanistan and Iraq, that threaten aircraft to some degree. Unmodified civilian aircraft are not equipped to handle threats such as those posed by MANPAD systems. A DHL aircraft hit by an SA-14 missile while climbing out of Baghdad airport in 2003 shows that not only military aircraft are targeted. Fortunately, even after considerable damage to the Airbus's left wing, the pilots could, with remarkable skill, still land the aircraft.[71] An increased threat to civilian aircraft tends to increase investments in EW systems that can counter the threat. Modular EW systems are increasingly available to the civilian market, such as the Civil Aircraft Missile Protection System (CAMPS) manufactured by SAAB.[72] As seen in many other markets, some civilian developments technology can probably increase the quality and worth of, but eventually decrease the cost, of military EW technology.

Acquisition in Times of War

> *An air force is always verging on obsolescence and, in times of peace, its size and replacement rate will always be inadequate to meet the full demands of war. Military air power should, therefore, be measured to a large extent by the ability of the existing air force to absorb in time of emergency the increase required by war together with new ideas and techniques.*[73]
>
> *- Kainikara*

Historically, for air forces, peacetime expenditure differs significantly from wartime; Kainikara's words pose intriguing questions. Armed forces are costly, and it is not viable for democratic governments to sustain wartime armed forces numbers in peacetime. In times of peace, defence forces are often built and tailored to resist the most likely enemy until more equipment or reinforcements arrive. The idea is to increase the armed forces when large wars occur. After wars, armed forces quickly adjust numbers to peace-time.

71 Aviation Safety Network, "Criminal Occurrence Description Oo-Dll," Aviation Safety Network, http://aviation-safety.net/database/record.php?id=20031122-0.

72 SAAB, "Civil Aircraft Missile Protection System," SAAB, http://saab.com/air/electronic-warfare/self-protection-systems/camps/.

73 Kainikara, *The Cassandra Effect*, 85.

For example, just over a year after World War II ended, the Royal Australian Air Force reduced from 173622 personnel to 13238 personnel.[74]

It is unclear if increasing the size of the military after a large-scale war is still a viable approach. Will a modern force always be prepared when threatened by a non-democratic government that maintains larger armed forces? While some personnel can be trained remarkably quickly when the need arises, faster training often introduces more risk during training and subsequently on operations. Aircraft and EW equipment are needed to train personnel but insufficient training equipment being available because of what is needed in conflict is challenging. As well as training individuals, units need time to learn teamwork, training that preferably does not start on the battlefield. That specialised equipment now prevalent in modern forces may take too long to produce to be useful is conceivable. Production lines are cumbersome because many rare materials, which are hard to acquire in times of conflict, are used in modern equipment. That enough time is available to manufacture sufficient new equipment from the beginning of hostilities is highly unlikely. Countries face uncertainty about period that lies between the likely outset of a war and probable defeat. All solutions either require enormous investments in equipment and additional personnel, or broadly adjusting current development and production approaches.

Whereas like many systems involved in air power, acquiring equipment for EW often takes long, yet 5th-generation aircraft have one advantage. The next section asks if, instead of purchasing EW as an add-on, aircraft being equipped with EW systems from the start is popular. Such a trend would allow aircraft to be directly capable of protecting themselves against high-end threats in the EMS. But EW applies to more than the systems on aircraft that focus on EP and some limited EA. Precariously few dedicated EA aircraft exist in Western military. In high-end warfare, these aircraft are invaluable, but it is unlikely that they are available in large numbers on short notice when the need arises. Because it can take a long time to produce, dedicated EW assets should be taken into account when planning the force structure.

Update Frequency

> *From an air force perspective, staying static in any aspect is indeed a recipe for failure.*[75]
>
> *- Kainikara*

74 Alan Stephens, *Going Solo: The Royal Australian Air Force, 1946-1971* (Canberra: Australian Government Publishing Service, 1994), 10-20.

75 Kainikara, *The Cassandra Effect*, 85.

The technology life cycle is shortening while the life cycle of aircraft increases. A solution is to update aircraft more often, thus keeping them relevant and capable of defeating enemy systems. Modern aircraft have a system of incremental improvement, sometimes referred to as spiral development.[76] Practically, this approach to implies that developing an aircraft is only finished when it is eventually taken out of service. As figure 2 depicts, in the past, large updates were the standard, and they took aircraft off-line for extended periods. Although updates brought considerable improvements, development and implementation took too long, and the new technology was sometimes outdated by the time it was installed on the aircraft. Large updates are still seen occasionally, especially when fielding completely new systems on an aircraft, but updates are increasingly incremental. In a world of incremental updates, an aircraft's initial capabilities barely compare to the same aircraft many years and updates later.

Modular and incremental or spiral updates are packaged smaller and often target a specific area of the aircraft. One of the reasons that updates can occur rapidly is that much is achieved by improving and tweaking software. Besides fixing software bugs, these types of updates can greatly increase capabilities. When the hardware is updated, a system is not necessarily replaced entirely. The modern approach is to push technology when it is available, so air power can use the capability sooner. The trend is that updates target only part of the system relating to software or small hardware, such as sensors or processors of a specific system. The increased update rate challenges industry and air force regulations as both software and hardware aircraft changes need to be validated extensively before being released to the aircraft. Although a necessary evil, these procedures add to the time. Because the update frequency is increasing, the procedures must be flexible enough to allow air forces to keep advantaged technologically, while ensuring an acceptable safety margin. In the future, more computer-based validation will occur than currently and the increased software-intensive updates might simplify capability updates somewhat.[77]

Figure 2 displays the changes to how frequently aircraft have been updated. Introducing new aircraft types has decreased since the aircraft first began military service. While after world War II, new aircraft designs initially kept being introduced every few years, the increasing cost of air power caused the frequency to reduce steadily. To compensate, aircraft were kept competitive by occasionally introducing large updates to the airframe. The approach to 5th-generation aircraft will be more flexible and timelier than previously

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76 Jacques S. ;Lucyshyn Gansler, William; Spiers, Adam "Using Spiral Development to Reduce Acquisition Cycle Times" (University of Maryland, 2008), iv-v.

77 Malcolm G. Tutty, "The Profession of Arms in the Information Age: Operational Joint Fires Capability Preparedness in a Small-World" (University of South Australia, 2016).

with continual small updates and new features ensuring air forces have consistent competitive advantage.

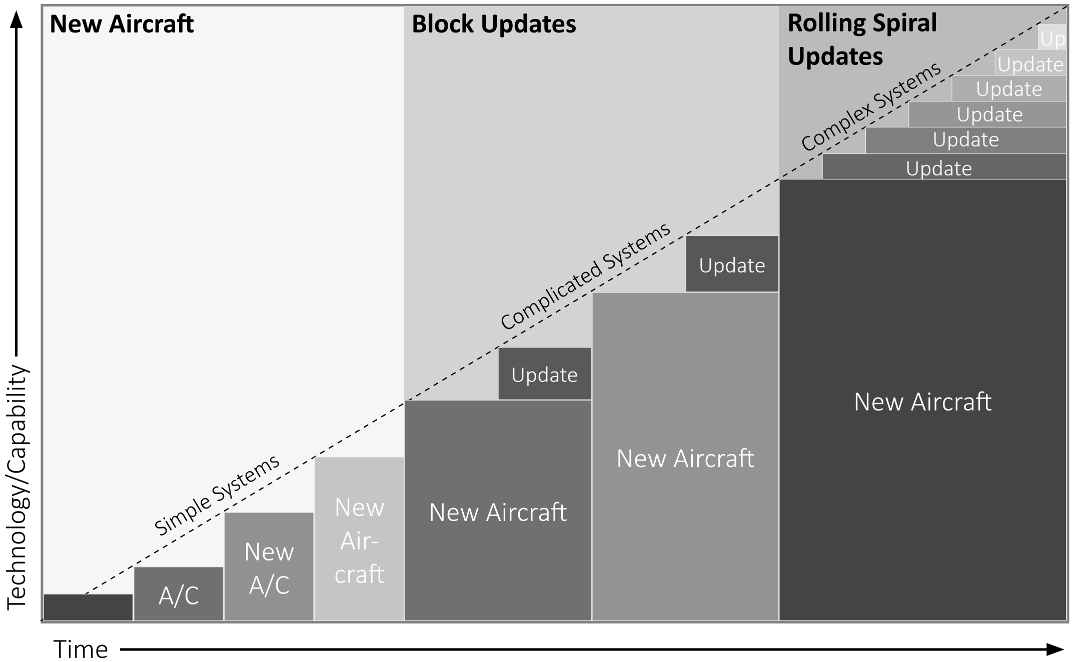

Figure 1 - New Aircraft versus updates frequency

Moving to incremental updates influences funding when we remember that equipment upgrades were historically time consuming with funding sometimes taking many years to release. Approaching updates incrementally means that funding is continually evaluated and that introducing modular updates on the airframe is quicker.[78] The incremental change means that sometimes lengthy legislative procedures can be adapted to ensure updates are fast.[79] Fortunately for defence, military technology is only one area in which increased, but smaller updates, are occurring. Because such updates are a global trend in many areas of government and industry, there is hope that legislation will keep pace to ensure that equipment in air forces can stay relevant.

78 Robert Chipman, "Ew, C4i and Enablers" (paper presented at the Seminar: A New Approach, and Attitude, to Electronic Warfare In Australia, Canberra, 2017).

79 Air Power Development Centre, "Air Power and the Information Domain," *Pathfinder Collections* 7 (2016): 28.

For airborne EW, the increased update frequency can have positive effects, but is also extremely challenging. EW needs to adapt continually, and a high tempo of updates contributes to this. Software upgrades can evolve EW systems, increasing capabilities and allowing equipment to adapt quickly to current and changing threats. Various EW components do not always follow the same technological development cycles buthave a modular approach. For example, a new processor or software can make the same sensor many times more useful. As such, EW equipment appears a perfect target for spiral developments. Currently the update frequency has a dark side as aviation is challenged by regulations that limit the speed of change. Comprehensive regulations demand much time and are expensive and it is difficult for many air forces to keep up with the update frequency of EW systems. If regulations can be adapted to effectively incorporate a faster rate of change, aircraft using EW can benefit from an increased update frequency.

EW in Coalitions

Creating coalitions combines the assets of multiple nations and increases combat power. Joining coalitions is preferred in politics in that coalitions have become the *de facto* approach to stabilisation operations. Coalitions build international credibility by increasing the number of countries politically supporting operations. Joining coalitions, in turn, can increase the security of the country joining among other countries in the region. Strength through combined numbers and capabilities is a powerful deterrent. However, working in coalitions can increase the complexity of EW.

While sharing information gained with EW assets, giving away EW capabilities can be unavoidable. EW's high sensitivity often leads countries not, or maybe not, to show the full extent of their EW capabilities to other nations. This applies even to countries that share diplomatic trust and are used to cooperating. Thus, in coalitions, certain EW systems are not used, or the information or advantages gained from them are not available to the whole coalition. These restrictions can be partially re-mediated by using procedures to ensure information is filtered, by removing or adjusting information to hide the method of data collection.

Unfortunately, filtering is not always possible, and the sensitivity of EW can mean that, even when working in a coalition with ample EW assets, nations without appropriate EW equipment may face increased risk. Nations cannot always rely on the full range of coalition EW systems, including the latest software iterations of these systems, to support them.

Because choices about EW support to coalition members will likely be made on a day-to-day basis, procedures must be flexible enough to incorporate quick changes to allow survival of coalition aircraft when risks increase. While no warfighter enjoys restricting coalition members access to information that may influence decision making and operations, such restrictions are somewhat understandable given the enormous impact that EW has upon warfare. This dilemma remains a delicate subject, with few solutions.

The Continued Relevance of EW to Modern Governments

> *A simple and basic truth, which no one debates or doubts, is that all military capabilities have to be oriented towards achieving the requirements of national security.*
>
> *- Kainikara*[80]

John Warden states that 'Advocates should begin with "the nonlimits of airpower" in mind: the presumption that airpower can accomplish any military task.'[81] Although this view may be somewhat extreme, Warden's statement does emphasise that air power is adjustable to different situations. However, to be adjustable, air forces need a wide range of tools. One of the toolboxes is EW, and its tools are needed across-the-board to ensure modern air forces can operate in environments and situations that they are likely to encounter.

Enabled by sufficient and capable EW systems, air power is the most flexible military tool available to a government. The relative safety and ease at which air power missions can be executed within the current theatres such as Iraq and Afghanistan add to its popularity within politics.[82] Although not a trivial process, air power is relatively easy to deploy, and equally importantly, to re-deploy. Air power has been used consistently and on a large scale over the past decades, and that is unsurprising. An air campaign is often the first visible use of violence by a country or coalition, and this is not expected to change soon.[83]

So, what does EW mean to air power? The scale of situations that air power can adjust to is largely shaped by EW assets. The past chapters have shown many examples of EW playing a significant role in conflicts. EW helped shape victory in World War II and enabled the coalition in Iraq and Bosnia to apply air power most efficiently. In the simplest terms, EW can support all the roles of air power. It is relevant to many differing threat levels; a higher threat means more dedicated and specialised EW assets are needed to support operations.

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80 Kainikara, *The Cassandra Effect*, 16.

81 Olsen, *Airpower Reborn*, 126.

82 Merrick E. Krause, "Airpower in Modern War," *Air and Space Power Journal* May-June 2015 (2015): 51-52.

83 Kainikara, *The Cassandra Effect*, 42.

Depending on the degree of threat, missions can sometimes be executed without EW assistance. However, doing this in the many conflicts of limited violence means accepting a certain amount of risk. Threats are changing. Threat systems are becoming increasingly dangerous to aircraft and are more widespread so that EW will become more important.

EW is difficult to explain to outsiders. Unfamiliarity results from misinterpreting how EW can vitally impact on the progress and outcome of conflicts. This unfamiliarity, combined with the costs of developing, purchasing and maintaining EW assets, can result in their being underfunded, thus limiting the environments that armed forces can operate in. Underfunding can increase the reliance of Western military on US systems for delivering essential dedicated EW support. This reliance can overburden a US system that is already challenged for EW capacity.

In the short time that EW has existed, much development has occurred after being shaped by major conflicts. Developing EW continues with increased digitisation, miniaturisation, and additional focus on contemporary and emerging technologies. Some large countries outside the West's influence allocate considerable resources to developing and implementing EW systems and weapons that use the EMS. In this fast-moving world of electronics, it is important to keep developing EW to keep pace with the opposition.

Considerable effort must be made to identify new systems that can threaten friendly troops, so equipment can be adjusted to combat them.[84] EW becomes dangerous when it gives a false sense of security and thus produces wrong procedures and decisions. If EW does not keep pace with technology developments, the influence that EW has will degrade to the point of being unreliable, and consequently dangerous to the troops it is meant to support. Since radio was introduced to aeroplanes of World War I, airborne EW has remained. In an increasingly digitised world, Western democracies will disregard EW at their peril.

84 Price, *Instruments of Darkness: The History of Electronic Warfare*, 254.

5.
The Origin of 5th Generation

There are two approaches to waging war, asymmetric and stupid. Every belligerent looks for an edge over its adversary.

- Conrad Crane[85]

The transition to 5th-generation air power by western air forces is needed to maximise their collective capability to ensure continued relevance to national power. This approach does not involve being superior in numbers but in technology that asymmetrically advantages a force against potential adversaries. A 5th-generation air force fits well within developments such as the US third offset strategy which is based on asymmetric advantages.[86] Staying relevant in a world of accelerating technology challenges Western military to use leading-edge systemic technologies while simultaneously adapting the organisation able to exploit these systems. Many of these developments are related to EW, making EW highly relevant to 5th-generations air forces. Because the EMS is increasingly used by both military and civilians, EW not only supports warfighting, it also develops from it.[87] Gaining or keeping asymmetric advantage with a 5th-generation air force challenges EW to play an important role.

While referring to 5th generation tends to focus on fighter aircraft, it says more despite being a somewhat ill-defined term depending on who uses it. Some commentators refer to 5th generation as an evolution, some as a revolution. Furthermore, some question whether 5th generation refers to technological change only or more. Confusion emerges from the questions, does it apply to fighters, aircraft, air forces, or is it broader? Even a 5th-generation fighter is not easily defined, probably because 5th generation has no real history because it was only recently introduced to the West by Lockheed-Martin after probably

85 Conrad C. Crane, "The Lure of Strike," *Parameters* 43, no. 2 (2013): 5.

86 K. Lange, "3rd Offset Strategy 101: What It Is, What the Tech Focuses Are.," DoDLive, http://www.dodlive.mil/2016/03/30/3rd-offset-strategy-101-what-it-is-what-the-tech-focuses-are/.

87 Robbin F. Larid, *A New Approach and Attitude to Electronic Warfare in Australia* (Canberra2017), 3.

borrowing it from the Russians.[88] Originally, a marketing term, '5th generation' has fit the bill particularly when discussing the new generation of aircraft such as the F-35 and the leading and cutting edge technology of the latest generation of fighters. Increasingly, 5th generation describes the whole approach to modern systems of air forces, warfare, and power.

Figure 5 displays the various 5th generation terminology that enables 5th-generation systems. To become a 5th-generation organisation, it needs to adapt to this technology and how it is used in air warfare. When they are aligned, 5th-generation air power results. The term 5th generation warfare refers to warfare that incorporates the effective application of technologies and concepts that are seen as (supporting) 5th generation systems. Examples are 'network-centric thinking, the combat cloud operational construct, multi-domain battle and fusion warfare.'[89] Peter Layton writes about this topic in more detail.[90] Part of the 5th-generation air force are various members, who themselves become enhanced by cooperation, such as with an army and air force. They have linked their information technology, adjusted their forces to the increased information density, and improved their warfare procedures to handle such changes. Then they can fully use the new capabilities gained with 5th-generation systems.

This chapter examines how 5th generation emerged as a term to explain how 5th-generation technology relates to EW. Because EW is highly technical, 5th-generation technology changes are used to discuss the influence of 5th-generation systems on EW. The chapter starts by glancing at the technical capabilities of the various generations of fighters, followed by describing what are 5th-generation characteristics. The chapter then examines why 5th-generation fighters can influence the whole military organisation, and why they are ranked above changes from the past. The chapter then shifts to 5th-generation air forces and air power to describe the breadth of their approach and the change it necessitates.

Although both the RAAF and the RNLAF are changing to become 5th-generation, in many ways, it remains an aspiration. Introducing 5th-generation aircraft into service does not transform an air force into a 5th-generation. Sharing information requires an extensive backbone because the huge amounts of it produced are too much to leave to human analysis alone. Personnel must be supported by systems that are able to analyse the information, and procedures should be developed that allow information to be quickly

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88 Bill Sweetman, "Is Saab's New Gripen the Future of Fighters?," http://aviationweek.com/defense/saab-s-new-gripen-future-fighters.

89 Peter Layton, "Fifth Generation Air Warfare," (2017), http://airpower.airforce.gov.au/Publications/Working-Paper-43-Fifth-Generation-Air-Warfare.

90 Ibid.

exploited. To fully support 5th-generation system capabilities, technology still needs to advance considerably. The following chapters take a decade-long view of this.

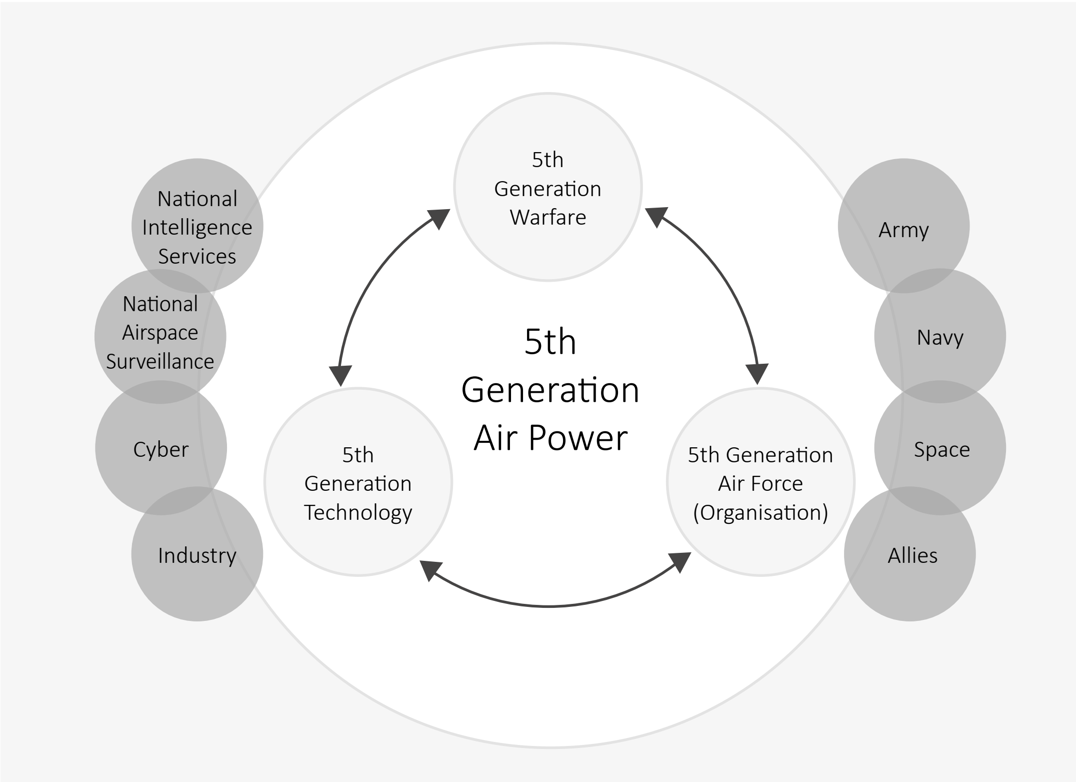

Figure 2 - Fifth Generation Air Power

5th-generation Aircraft

> *There is a belief, however, that fifth generation is fundamentally different, that it represents a step over the previous rate of progress. That belief is attributable to the impact of three technologies: low-observability (stealth)...a quantum advance in the fusion of systems that provide knowledge dominance; and a similar advance in the ability to detect, identify, track, and prosecute air and surface targets at substantial distances.*[91]
>
> *- Alan Stephens*

91 Alan Stephens, "Fifth-Generation Strategy," in *Airpower Reborn: The Strategic Concepts of John Warden and John Boyd*, ed. John Andreas Olsen (Annapolis: Naval Institute Press, 2015), 135.

Because 5th generation is a new term describing the next generation of aircraft, some attempt to describe the previous generation of fighter aircraft. The advance of aircraft systems is enabled by technology that enabled an increasing amount of equipment to be fitted to relatively small fighter aircraft. Table 1 briefly describes the characteristics of previous generation fighter aircraft and shows technology and systems gradually but steadily increased as fighters were developed.[92]

GEN	TIMEFRAME	EXAMPLES	CHARACTERISTICS
1	Post WWII - Mid 1950s	F-86, MiG-15, MiG-17	EW: None Armarment: Machine gun/cannon, Unguided rockets Other: Mostly subsonic, Basic Avionics
2	Mid 1950s - Early 1960s	F-104, F-5, MiG-19, MiG-21	EW: RWR Armament: IR & semi-active guided missiles Other: Supersonic, Air-to-Air Radar
3	Early1960s - 1970	MiG-23, F-4, Mirage-III	EW: Enhanced RWR Armament: Enhanced missile capabilities Other: Multi-role, Enhanced avionics, Enhanced radar (look-down), Beyond Visual Range (BVR) missiles
4	1970 - Late 1980s	F-16, F/A-18, F-15, MiG-29, Su-27	EW: Chaff & Flares now common component, LWR, jamming (via pods) Armament: IR & semi-active guided missiles Other: Fly-by-wire, HUD, Swing-role
4.5	Late 1980s - Into the 90s	F/A-18E/F, JAS-39, Typhoon, Rafale, Su-30	EW: Missiles approach warning systems, Jamming capabilities often autonomous Armament: Increased weapon capacity Other: Reduced RCS, Increased weapon capacity, extended ranges, AESA radars, Network centric datalinks

Table 1 - Previous Generation Aircraft

A few common characteristics describe 5th-generation aircraft. Not all these characteristics are necessarily new technologies, but it is a combination of a number of these characteristics that makes an aircraft 5th generation. First is stealth, or low-observability, which emphasises reduced visibility in the EMS. Radically increased situational awareness is also a defining feature that results from higher quality information from improved autonomous sensors, EW systems, and increased information received from other assets. Assets operating in other domains share information through

92 Air Power Development Centre, "Five Generations of Jet Fighter Aircraft," *Pathfinder Collections* 5 (2012): 47-49.

networks. The shared information is fused with the information generated by the aircraft's own sensors. Fusing from automated systems enables a high level of networking that distinguishes 5th-generation systems from their predecessors. A not often mentioned characteristic of 5th-generation fighters are new weapon systems.

These 5th-generation advances increase decision superiority which in turn allows forces to locate and destroy enemies before they detect friendly elements.[93] It is a significant advantage to be able to move undetected, while collecting a comprehensive real-time picture of the battlefield, and sharing that with other systems supporting the mission. If the opposition is unaware that information is being collected, they are less likely to adjust their behaviour. This makes collected information more valuable, since there is less potential for a situation to change from the time of collection. The combination of decision superiority leading to unpredictability and the deadliness and accuracy of the weapons enables 5th-generation fighters to hit targets previously thought unreachable and safe from attacks by aircraft.[94]The 5th-generation capabilities enhance the tempo and quality of decision-making compared to systems without these capabilities.

Another not-immediately-obvious advantage to 5th-generation aircraft is that they can share information and thus improve the preceding two generations of aircraft. The large amounts of data that 5th-generation aircraft collect can increase the situational awareness of less advanced aircraft than possible when flying independently.[95] Older aircraft still have the disadvantage of the pilot having to fuse the various information sources themselves rather than the aircraft. However, that more detailed information is available provides pilots operating older aircraft to better appreciate events unfolding within their battlespace.[96] Currently, information sharing is not fully developed because it is sometimes incompatible with digital communications between various types of fighters. Yet, efforts are being made to improve this situation.[97] Also, sharing may deliberately be limited due to the sensitivity of new 5th-generation technology or the need to limit active transmissions by an aircraft. The advantage of sharing information need not stop with aircraft but can be used to enhance other systems in all domains.

Figure 4 displays 5th-generation fighters' characteristics. Besides those previously discussed, they include adaptive organisation and improved tempo, which I examine later.

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93 Air Power Development Centre, "Five Generations of Jet Fighter Aircraft."

94 Royal Danish Air Force, "Royal Danish Air Force - Next Generation," *The Journal of the JAPCC* 24, no. Spring/Summer 2017 (2017): 6-9.

95 Robbin Laird, "Airpower and the Hybrid Threat," *Frontline Defence*, no. 6, 2015 (2016).

96 Aaron Mehta, "The Difference between 4th and 5th Gen Ew," Defence News.

97 William A.; Presa-Diaz Perkin, Carlos; Speed, Joseph, "Air Warfare Communication in a Networked Environment," *The Journal of the JAPCC* 24, no. Spring/Summer 2017 (2017).

The next section explores why the term 5th generation is now broadly used to define more than just the fighter aircraft it initially referred to.

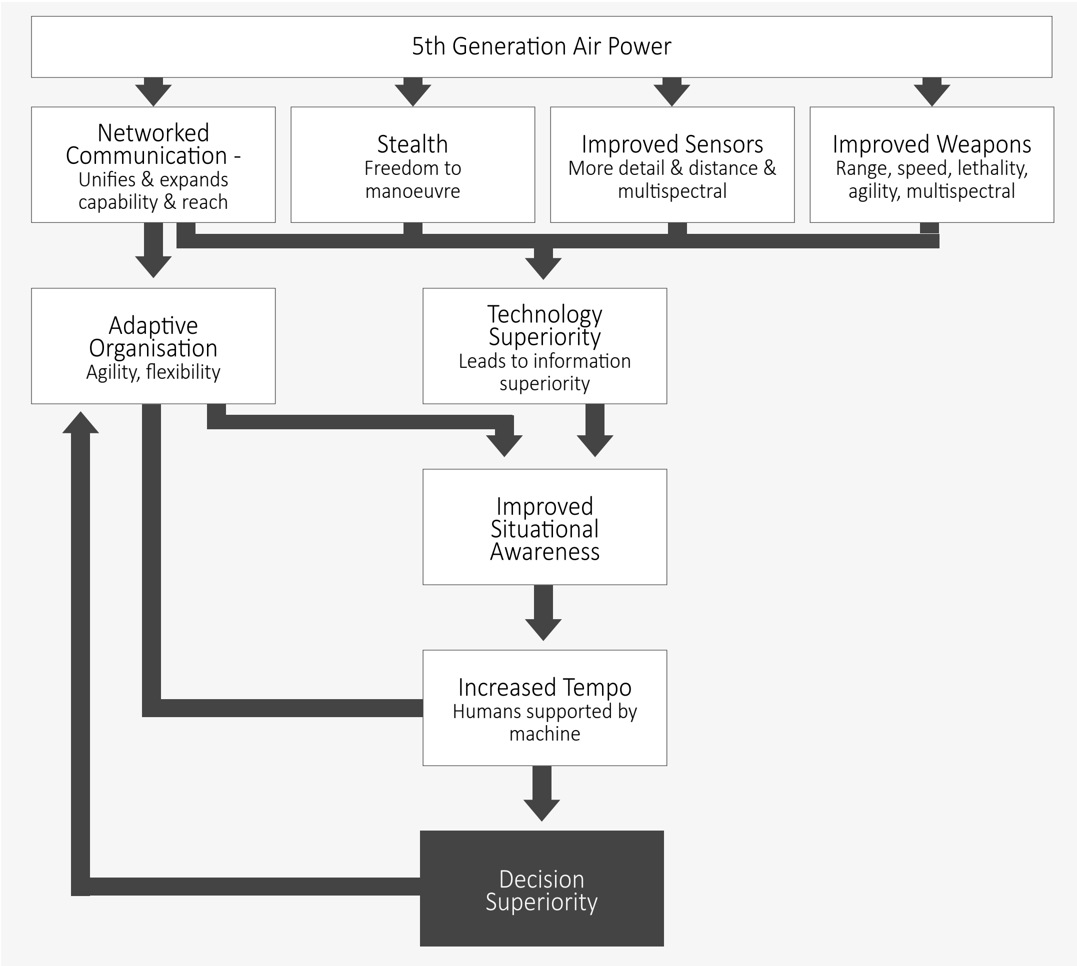

Figure 3 - Generation Systems

5th-generation Air Power

> *Fifth-generation refers to the latest technological evolution of aircraft. While the different aircraft generations traditionally refer to fighter jets, Air Force needs our people, working with all aircraft, capabilities and systems to achieve a fifth-generation force.*

> *A fifth-generation Air Force is a fully-networked force that exploits the combat multiplier effects of a readily available, integrated and shared battlespace picture to deliver lethal and non-lethal air power.*
>
> *A fifth-generation Air Force will provide the joint and networked effects necessary to prevail against the increasingly complex and lethal threats of warfare in the Information Age.*
>
> *- Royal Australian Air Force*[98]

The RAAF approach to 5th generation described above is like that seen within the RNLAF and implies that 5th generation not only brings but also needs major change to the organisation. While previous generations refer specifically to fighter aircraft, the interconnectivity of 5th generation fighters results in the term 5th generation evolving to encompass more.

Constant technological change is an integral part of any effective air force because vast technological change is needed to incorporate the new system-of-system data-rich capabilities. Technology that increases the information flow and density also requires the organisation to adapt to best use all the extra capabilities gained. Only by adapting the organisation can it handle the information flow and increase the speed of decision-making.

The 5th-generation capabilities require a new way of 'thinking, working, directing, supporting and fighting'[99]. This all needs to be achieved despite the uncertainty about the operating environment of the future and how to prepare for non-traditional situations. Organisations must be able to operate in the small-scale warfare of the past decades, and large-scale conflicts which, for a while, seemed a thing of the past.[100] The level of flexibility and agility in an organisation is important to success or failure in the transition to a 5th-generation force. These needs partially determine if a modern air force can best use its 5th-generation capabilities. Most airmen are familiar with the term 'flexibility is the key to air power', stemming from the Italian air power theorist, Giulio Douhet, who was one of the first to emphasise that flexibility is vital.[101] Even though Douhet could not have foreseen

98 Royal Australian Air Force, "Fifth Generation Explained," https://www.airforce.gov.au/Fifth-Generation-Explained/?RAAF-whY8eFJkE4+5GBF5e9dj+IO+IHd42mda.

99 Royal Netherlands Air Force, "5th Generation Air Force."

100 Royal Netherlands Air Force, "5th Generation Air Force."

101 Giulio Douhet, *The Command of the Air* (Alabama: University of Alabama Press, 2009). In this book, the emphasis on flexibility is obvious in all aspects related to successful implementation of air power.

how air power would evolve, flexibility remains important to air forces so they adapt quickly to be effective. Fortunately, air forces have often been highly flexible and agile.

Although the larger conflicts and wars of the 20th century importantly motivated EW innovation, they are not the sole drivers of change. For example, while EW increased dramatically in World War II, it was preceded by how military systems learned from civilian innovative technology at the start of the war.[102] The rate of technological innovation is increasing, which is largely due to digitisation and often related to gathering, sharing and analysing information using computers. While this increase restricts our predicting the future, it influences air forces' transitioning to the 5th generation.

Information Dominance

> *'The capacity of organisation and support systems to collect, process, distribute and protect data must match those of our major platforms.'*
>
> *- Plan Jericho*[103]

Many air forces have identified that new technology of 5th-generation fighters bring far-reaching implications for, and challenges to, organisations. Two reasons for this significant change both relate to information. First, a 5th-generation air force will be fully-networked and therefore will be capable of sending and receiving vast amounts of information that enhance the situational awareness of the platform and those around it to new levels. Second, receiving and updating this new order of volume and high tempo requires air forces and the whole armed force to adapt quickly to make quick decisions.[104] Quick and well-informed decisions support organisational decision superiority and make information a so-called combat multiplier to allow forces to deliver lethal and non-lethal air power faster than the opposition. Organisations with 5th generation capabilities are investigating ways to share, analyse, and use vast amounts of information. The capacity for sharing information forces organisations transitioning to 5th generation to adapt to make best use of the new capabilities.

> *Advanced communications, computing, and intelligence systems have dramatically increased the speed with which information can be collected and assessed, and with which decisions can be made and, ultimately, actions taken,*

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102 Reginald Victor Jones, *Most Secret War* (London: Penguin UK, 1978), 13-20.

103 Royal Australian Air Force, "Jericho: Connected, Integrated," ed. Royal Australian Air Force (2016).

104 "Air Force Strategy: 2017-2027," ed. Royal Australian Air Force (Canberra2017), 11.

> *to the extent that tempo has become a strategic quality as fundamental as firepower and maneuver.*[105]
>
> *- Alan Stephens*

Knowledge dominance can be a relative term. It is not enough to know many things; it is better to know more than the enemy. Knowing more means that the information used to decide is more comprehensive so that, even if organisations analyse and make decisions similarly to the opposition, it is possible to reach better conclusions that help gain the upper hand. If knowledge suffices, an organisation that is agile enough to adapt to the 5th-generation systems can increase the decision-making cycle and tempo of operations. The advantage gained by being able to quickly adapt to new information fits well within Boyd's OODA loop. The information allows an agile organisation to adjust to new situations quickly and to rapidly change the direction of operations in response to the opposition.

It is not yet clear which changes 5th-generation systems will ultimately bring, but they will influence more than just air forces and air power. The systems compel air forces to look more than previously outside the traditional physical domains of air, ground and sea, and invest in the space and cyber domains. This results from modern systems being interconnected, which increasingly influences actions in the air domain. The challenge is that air forces cannot adapt alone. They need to cooperate with other organisations specialising in handling and tracking of advances in the non-traditional domains. To stay relevant, other parts of the armed forces, and arguably some departments within the wider government, must adapt to changes that 5th-generation systems bring so that 'Defence and non-Defence stakeholders, including global industry and academia,' must collaborate.[106] Cooperation with Army, Navy and other governmental organisations that face similar challenges needs to be intensified to ensure unified effort. To suitably incorporate changes, the organisation must increasingly be flexible and agile in culture, structure and process.[107] Far-reaching cooperation with other organisations may challenge the flexibility and agility of many. Yet, only this integrated approach allows those in and outside the air force to fully benefit from the capabilities that 5th-generation systems bring, while also supporting and improving these systems by sharing information of their own.

Because information sharing is important to 5th-generation organisations, considerable effort is being put in ensuring equipment compatibility with contemporary and future systems. But compatibility relates to more than just technology. Operating procedures

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105 Olsen, *Airpower Reborn*, 137.

106 Royal Australian Air Force, "Air Force Strategy: 2017-2027," 15.

107 Richard A Poisel, *Information Warfare and Electronic Warfare Systems* (London: Artech House, 2013), 6.

must also be made compatible to achieve synergy in information flow. Compatible systems and procedures are vital to communicate broadly the right amount and type of information to advantage the forces.[108]

Conclusion

Fifth generation air power keeps air forces operable by allowing them to stay relevant as an important element to the national power. This effectiveness is not reached with superior numbers, but with technology. It allows 5th-generation aircraft to be increasingly networked systems that gather massive amounts of information. To effectuate this information, a 5th-generation air force needs to adapt at many levels. Both the technology and the organisation need to adapt and adjust respectively to be able to handle the large amounts of highly detailed data. The adaption must be flexible and agile, which fortunately describes the culture within many air forces.

The fifth generation deals in information, the quality and amount shared being much larger than in the past. With the advanced sensors collecting and sharing information, 5th-generation systems influence increase tempos of operations and heighten the decision superiority. Because of the increased interconnectivity of systems, EW is important to 5th-generation air power. Other developments such as those in cyber, space, and AI influence 5th-generation air forces. A 5th-generation force can benefit considerably from 5th-generation developments, but this is only possible when it has sufficient technical infrastructure, adequate procedures to support the information flow, and trained personnel to handle the information and make decisions based on the information.

108 Royal Australian Air Force, “Air Force Strategy: 2017-2027,” 17.

6. Interaction Between EW & 5th-Generation Air Power

'Victory smiles upon those who anticipate the changes in the character of war, not upon those who wait to adapt themselves after the changes occur.'

- Giulio Douhet[109]

Never has EW had more potential to influence events than in this time of increasingly interconnected forces. Most of the technology that accompanies 5th-generation systems is somehow more related to the EMS, and thus to EW, than in the past. Fifth-generation air forces rely heavily on the EMS to detect and identify, share information using communication, and target and guide weapons. The EMS is crucial to a 5th-generation air force, because all elements that are sharing information via non-physical means can be targeted in the EMS domain. If the battle for the EMS is lost, the interconnectivity is disabled. Losing the battle for the EMS can debilitate air forces that transition to, and rely on, 5th generation systems.

The key to approaching EW in a 5th-generation environment is to correctly balance EW assets. Every aircraft finding itself in hostile territory is in a hostile EMS environment, which can influence an aircraft's practical capability. All EW missions are important; EA, EP, and ES need to support each other to enable friendly forces to achieve their mission objectives. The future of air forces lies in operating aircraft with capabilities in all three EW categories. Many forces nonetheless invest their EW in EP, less on ES, but to date, little on EA. Technological improvement in many military systems, such as sophisticated networked air defence systems creates a need for EW assets that can enable the mission, not only protect the aircraft. Engagements often start with the battle in the electronic domain. Losing the battle for the EMS can result in losing the conflict; the EMS has become that important. The modern battlefield calls for improvements and a build-up in additional

109 Douhet, *The Command of the Air*, 30.

EW assets beyond the traditional EP systems. An example is the previously mentioned F/A-18G Growler platform, a specialised EW platform with jamming capabilities that can influence voice, data, GPS, surveillance and fire control systems. It can protect combat packages from many threats in the EMS.[110] Without balance in a force's EW assets that can cut a path through the EMS, an aircraft will not be able to safely traverse the battlefield in a high threat environment. If control of the air is needed to win the battle, that outcome involves winning the battle for, and control of the EMS.

To operate 5th-generation fighters, air forces need a strong technological infrastructure to support expanded capabilities and characteristics of next generation of fighters. The fighter is only part of a system within a cooperation of many systems; a system-of-systems. In a 5th generation force, interconnectivity enables EW to take a major role in assuring the continued stream of information is shared between all systems.

This chapter discusses uses important characteristics of 5th-generation air force fighters, to examine the ramifications on EW. They entail introducing stealth into mainstream fighter aircraft, improving sensor technology, intensifying networks so most systems interconnect, and advancing weapon technology. Closely related to these four ramifications are air defence as it relates to stealth, and big data as it relates to sensors.

Stealth

Stealth contribute to how well 5th-generation aircraft perform and survive, and is also part of EW as it relates to EP. While to some, stealth means that aircraft are unseen by opposing sensors, stealth does not necessarily suggest this. Stealth aircraft reduce their visibility in the frequencies that apply to a reduced radar cross section, a smaller IR signature, a reduced acoustic signature, visual aspects that decrease the change of detection by the 'mark I eyeball', and harder-to-intercept communications systems. Adding passive sensors to minimise transmissions necessary in the EMS is also a feature of the stealthy nature of 5th-generation aircraft.

Stealth is particularly potent when supported by EW measures such as stand-off EA, which can degrade the effect of opposing radar. Combining stealth features and supporting EA well reduces the distance that stealth aircraft can be detected at. Reducing detection ranges can allow 5th-generation aircraft to engage targets before they are detected themselves.

Stealth was used extensively in Operation *Desert Storm* and thus provided for bombers options that had not been available for a long time. Back in the early 1990s, stealth aircraft

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110 Air Power Development Centre, "The Importance of the Growler to Australia's National Security," *Pathfinder Collections* 6 (2014): 9.

were new and radar systems were not yet capable of detecting them. Consequently, during *Desert Storm*, the stealth bomber 'always got through' and could be used as a wild card to engage targets anywhere on the battlefield, regardless of how well defended they were. Introducing stealth enabled the approach to air warfare to fundamentally shift; it allowed quick engagement of Warden's inner rings by bypassing enemy forces. This subsequently enabled parallel attacks on a range of targets that resulted in strategically paralysing the enemy. Stealth brings both challenges and opportunities to EW. Some of the challenges regarding stealth design influence EW. What follows covers these challenges and the few regarding the jamming of stealth aircraft. The section ends by broadly assessing the impact of improved modern air defence on stealth and other 5th-generation developments in air power.

Stealth Design Challenges

Although stealth increases survivability of an aircraft, the disadvantages to aircraft involved influence EW. Five of them are noted.

Adding stealth features influences most aspects of aircraft design and increases the difficulty of it. For example, as specific materials that enhance stealth features may not be the strongest and lightest options, their use challenges design. Aerodynamic design also challenges designers being restricted in where they can place control surfaces. Because compromise is needed when designing the airframe, adding stealth features can jeopardise the manoeuvrability of an aircraft. Such restrictions can also limit the available choices integrating EW and other mission equipment. Since design is difficult, time to develop stealth aircraft and the extra cost to designing and manufacturing them both increase.[111] Stealth accounted for some of the high cost of the F-22 and the F-35.

A second challenge is that needing stealth reduces the options available when tailoring aircraft for combat missions. For example, while EW jammers such as the ALQ-131 pod were often add-ons mounted underneath the aircraft, the growing attention to the stealth of aircraft makes it unlikely that future high-end fighters and bombers will use EW pods much. Integrating EW equipment into the airframe has another advantage other than maintaining the stealth features. Integrated EW systems are often tightly integrated with aircraft software and hardware systems, making them easier to use and potentially better. Although the trend is to integrate EW systems into the aircraft, external EW pods continue to offer advantages. EW systems can be acquired after the airframe is already purchased, enabling the costs to be scheduled. EW pods can also reduce the total cost of acquiring

111 Jeffrey Smith, J., "Beyond the Horizon: Developing Future Airpower Strategy," *Strategic Studies Quarterly* Summer 2014 (2014): 89-90.

aircraft because pods will not need to be bought for all aircraft since they will not all be used simultaneously during operations. Another advantage is that potentially more EW systems are available to choose from, as it can be easier to integrate an EW pod than to tailor EW systems to a specific aircraft design.

A third challenge with stealth designs is that the limits to airframe design restrict the amount of armament carried by stealth aircraft. Although 5th-generation aircraft are capable of finding and engaging targets, when operating in a stealth role, they carry their weapons in internal bays, which limits how many weapons can be carried. When the need for stealth is not a factor, modular pylons that allow more weapons to be carried can be added. When aircraft need to stay hidden, other options must be found, such as passing target information to standoff shooters that are outside the range of enemy systems.

The fourth challenge is that stealth appears particularly vulnerable to rapid advances in counter-technology, and it is conceivable that counter-stealth developments will eventually limit the advantage contemporary stealth features provide. When stealth technology was first used in the F-117 Nighthawk during Operation *Desert Storm*, they could virtually not be detected by radar. However, no technological advantage lasts. When Bosnian air defence adapted to the situation, and no dedicated EW supported the F-117 mission in 1999 during Operation Allied Force in former Yugoslavia, the limit was apparent when one was downed by a SAM system.[112] 5th generation aircraft are built to last decades, but the stealth characteristics capability will become less effective as radar and other systems improve. Although 5th-generation design plans its upgrading, adjusting aircraft to cope with counter stealth technology is complex because physical stealth attributes often exist within the airframe. Thus, the benefit from upgrading is likely to be limited.

A final challenge is that systems that reduce the effect of stealth capabilities already operate. Stealth aircraft are adjusted to reduce their signature to certain frequencies so that not all aspects of the aircraft have the same level of stealth. Currently, radars using other than traditional frequencies make it more difficult for stealth aircraft to stay hidden. Also, is growing concern about quantum radar technology being developed that might negate stealth.[113] Another trend is more diversity in systems to detect aircraft, such as by increasing IR detection methods rather than radar.

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112 Robert H Gregory, *Clean Bombs and Dirty Wars: Air Power in Kosovo and Libya* (Nebraska: Potomac Books, 2015), 64-68.

113 Marco Lanzagorta, Quantum Radar, (Williston: Morgan & Claypool Publishers, 2012). 1-4.

Jamming and Stealth

Because jamming operates better when the location in question is known, the difficulty of locating stealth aircraft makes them more difficult to jam than legacy aircraft. When jamming a system, the receiver is what needs to be jammed, because jamming the transmitter is futile.[114] While normal data involves two-way communication because error correction is necessary, one-way data transmission is possible, but less reliable. If an aircraft only receives information without transmitting, it will not reveal its position to ES systems. When the location of an aircraft is unknown, directional jamming cannot be used. Directional jamming allows jamming power to be focused thus improving its outcomes. While wide areas can still be jammed, this method is often less effective and can greatly impact upon our force and civilian infrastructure.

Jamming large areas can indirectly reduce the chances of remaining undetected. Modern aircraft nearby will likely communicate using low-power spread-spectrum transmissions that are hard to detect. Distance is important to jamming well: the closer the transmitter and receiver are, the harder it is to jam the communication. Jamming large areas reduces the jamming power compared with directional jamming and will probably not stop aircraft in close proximity from communicating with each other. However, when much background noise affects the frequencies used by the aircraft, as when those frequencies are jammed, transmission power may need to be increased to ensure communications are unhindered by the jamming. Increasing the power output of the communications between aircraft increases the chances of detecting stealth aircraft that are communicating. While jamming communications can greatly disrupt 5th-generation systems, stealth features can increase the difficulty of jamming them.

Improved Air Defence and Stealth

Air defence systems have steadily become more capable during the past decade and have influenced EW and air power. While stealth can reduce the value of newer such systems, even aircraft with improved stealth features will likely need other EW measures to counter the increased threat of high-end air defence systems.[115] Just as stealth is not only for reducing the radar signature radar, air defence is not limited to radar for finding and tracking aircraft. Various methods guide missiles to their target, including IR and laser systems. Four factors that increase the power of modern air defence systems are that sensors are increasingly sophisticated and miniaturised, technology is wider available, and the systems have increased range, and are more mobile. The discussion follows.

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114 Adamy, *Ew 104*, 47.

115 Paolo Quaranta, "Airborne Electronic Warfare," *Military Technology* 32, no. 4 (2008): 110.

Air defence is influenced by an increased sophistication of sensors, making air defence more capable and deadly than previously. Enhanced sensors on air defence weapons require different than traditional EW measures, such as chaff and flare. Increasing are new EP techniques including stealth attributes, advanced decoys, and directional infrared countermeasures (DIRCM). Additionally, 4.5- and 5th-generation aircraft often have active-phased array radars (APAR) with new advanced jamming capabilities. Interest in direct-energy weapons that can destroy incoming missiles also increases. All these EW developments react to the increased lethal effect of air defence systems.[116] Each country needs to decide their focus for air power capabilities.[117] Purchasing 5th-generation aircraft leaves the options open when capable air defence finds its way into a theatre, or when a situation deteriorates, and a conflict escalates.

A second factor is that capable air defence systems are now widely available, partly because technology is also more widespread. Proliferating technology increases the chance of encountering capable and deadly systems in theatres that are currently still accessible to less advanced aircraft. Fortunately, aircraft purchased by small and middle-sized countries are often suitable for full-scale warfare and have systems that can handle advanced threats.

A third factor is the increasing range of detection and engagement of modern air defence systems.[118] The increase results from radar systems gradually improving along with their ability to detect targets with small radar cross sections. Also improved is the quality of engines, electronics being miniaturised, explosives, and the accuracy and precision of missiles. This means that fewer explosives, and improved aerodynamic models, have all contributed to increasing the effective missile range, which has itself made air defence systems more capable. It increases the area that is denied to aircraft and the height at which aircraft can still be engaged by certain types of missiles. For example, an effective way to defeat IR-guided shoulder-launched missiles is flying above the altitude the missiles can reach. With the increasing range of missiles, it is likely that smaller missiles, such as shoulder-launched types, will influence the higher regions of airspace previously thought safe.[119] Aircraft such as tankers, that were previously deemed safe with their distance or altitude from the battlefield, may need more sophisticated self-protection systems to survive. This development can also largely affect civilian traffic, as it is common to fly over

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116 Kym Bergman, “Raaf Electronic Warfare Receiving a Boost,” *Asia Pacific Defence Reporter* March (2015).

117 Kainikara, *The Cassandra Effect*, 19-21.

118 Ibid., 65.

119 Adamy, *Ew 104*, 126-32.

Simon Bird, “6th Generation Counter-Air Missile Architecture” (Msc, Cranfield University, 2014), 12.

areas of conflict at safe altitudes. To be sufficiently warned of these improved AD systems, EW systems need increased detection ranges from more powerful sensors and processing equipment. Improving the software of digital EW systems may increase the sensitivity without increasing false warnings.

The final factor is mobility, an important characteristic of capable air defence. While air defence systems were initially static, these systems increasingly see 'improved hide, shoot, and scoot capabilities, reducing reaction times.'[120] Although mobility may force air defence system designers to compromise on range, mobility enables air defence systems to survive. While it may increase reliance on wireless networks, and thus make forces more vulnerable, improved mobility decreases the time that they can be countered. Accordingly, the decision cycle between detecting air defence and destroying it must be short. Capabilities need to be adequate to cope with the improved mobility of these modern air defence systems.

Recent developments in Russian air defence systems, some of which were used in the conflict in Ukraine, show that air defence is capable of influencing events strategically. Positioning highly capable and mobile air defence systems may reduce an enemy's eagerness to initiate hostilities. Some debate if capable modern air defence systems can make air forces obsolete in that it will soon be impossible to fly over areas that these systems influence. Accordingly, by adding other systems such as drones and cruise missiles, countries can create a 'poor man's air force.'[121] However, as noted by Kainikara, air defence is purely 'air denial' and remains a form of defence. Control of the air implies a more pro-active approach and is the only proven method of preventing enemy air operations. Others considerably doubt whether a poor man's air force can truly control the air against a well-equipped pro-active opponent.[122]

The increased range and lethal power of air defence systems is one reason that developments such as stealth pertain to all air forces, not only those focused on high-scale regular warfare. EW is an important capability for solving the increased power of air defence. Although its systems may be able to detect stealth aircraft, it will often be considerably harder than detecting more traditional aircraft. The most capable air defence systems will need to be countered by combining stealth aircraft and dedicated EW assets using EA to support these aircraft. Because modern air defence is lethal, it calls for many EW measures. The EP measures of stealth and decoys, combined with the EA measure of jamming of enemy radars, enable aircraft freedom to move in contested areas.

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120 Adamy, *Ew 104*, 86.

121 Mark Clodfelter, "Theory, Implementation, and the Future of Airpower," *Air and Space Power Journal* September-October (2014): 122.

122 Kainikara, *The Cassandra Effect*, 36-37.

The increased lethal range of air defence systems also mean that standoff jamming needs to work over longer distances. Measures have developed that counter the effects of standoff jamming using advanced EP measures: technically adapting to reduce side lobes that are vulnerable to EA; using digital processors that thwart certain forms of jamming; electronically steering arrays; and using variable power output that increases the effect of radiated power. Possible counter-counter measures are increasing the jamming output, using more focused beams for jamming, and RPAS that can be placed in higher threat areas. Missiles with home-on-jam capabilities combined with long ranges, such as the extended range version of the AGM-88 AARGM, would also be advantageous. Home-on-jam missiles can engage targets passively, although a capable radar is likely to detect an incoming missile before it reaches the target. The availability of these missiles alone can limit air defence systems in actively searching for targets. A home-on-jam can also make EW aircraft vulnerable, since integrating multiple sensors can make air defence missiles capable to lock on to aircraft that actively jam radar signals with EA systems.[123]

The increased capabilities of air defence systems limit aircraft lacking stealth features in approximating modern AD systems. Coupled with the proliferation of air defence systems, stealth becomes important.[124] For now, it importantly advantages 5th-generation aircraft to the extent that those with advanced stealth features will be distinguished from older aircraft that are restricted by where they can physically operate, even if supported by dedicated EW assets. One development that may limit the need for stealth is in longer range air-to-surface weapons. Having increasing stand-off distances, they may limit the future need to come within weapon ranges of the enemy air defence systems. The increasing range of weapons is discussed later in this chapter.

Stealth is an important advantage for forces, particularly in conflicts with an increasing level of threat but, for now, less so low-level conflicts. Stealth has disadvantages that limit aircraft because it complicates design and allows aircraft to carry fewer weapons. Despite some disadvantages, the stealth attributes can increase air power assets to survive at a level that governments expect. Stealth contributes to national power because it allows governments to reach out to hostile targets without the opposition being able to counter.

123 Adamy, *Ew 104*, 86, 126-32.

124 Rob Huebert, "The Future of Canadian Airpower and the F-35," *Canadian Foreign Policy Journal* 17, no. 3 (2011): 233-34.

Improved Sensors and Data Collection

EW uses a multitude of sensors to detect emissions in the EMS. Therefore, improving sensor technology influences the ongoing development of air power and EW. It is also used in many other areas influencing air power: ISR, air defence, and space-based assets that profit from increasing technology. For example, the decrease in cost and size of sensors allows ISR platforms, of which many are RPAS, to also become smaller, to be more widely available, and more capable. The increased sensitivity and sensors' resolution and fast processors allows detecting signals from longer distances and improves the chances of correctly classifying and localising. The improved sensor capabilities increase the success of EW systems and are essential in detecting aircraft and other systems used by modern adversaries. This especially occurs with the emphasis on stealth in 5th-generation systems that make aircraft harder to detect with traditional methods such as radar.

With active sensors such as radar increasing the probability of being detected, those that can passively detect objects are becoming more useful. Their increased sensitivity improves the capability to passively detect opponents. Aircraft acquire, with passive capabilities, the ability to shoot other aircraft without being detected. A renewed focus on such sensors is seen in integrating IRST (infra-red search and track) systems on new aircraft, and retro-fitting IRST on older generation aircraft.[125]

That modern advanced sensors have been miniaturised is crucial although the occurrence is not new; smaller sensors allowed EW to transition from large aircraft, like bombers and dedicated ISR and EW aircraft, to smaller combat aircraft. However, digitisation has enabled the size of sensors to be very much reduced so that they can be integrated in smaller systems such as RPAS. This reduction means that sensors equip more systems of greater numbers and more diversely.

Up to date sensors are crucial to effective EW, and technology in this field moves fast. As with many modern systems, updating applies to both the sensor hardware and the quality of the software used for analysing incoming data. Indeed, software updates can play a surprisingly important role in improving the quality of sensors. Detection that is both early and specifically earlier than the opposition, is significant to winning battles. The technology advantage in 5th-generation air forces is relative, because keeping an edge is not possible if sensors are not regularly updated, be it for hardware or software.

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125 Jane's International Defense Review, "Beyond the Raptor and Lightning Ii: World Plays Fifth-Generation Catch-Up".

Sensors, Data, and Big Data

> *'Even today, there is a greater volume of information collected on the battlefield than can be analysed.'*
>
> *- Peter Layton*[126]

Part of the challenge of transitioning to 5th-generation air power is handling the increased amounts of information. Fifth- generation EW will steadily increase generated data and thus contribute highly to the collective data pool. Traditionally, sensors in systems for EP used only the gained information for self-protection. EP sensors, which are already receiving more detailed information than previously, are now recording data that can be passed directly from machine-to-machine to the data pool. Sharing sensor information makes 5th-generation systems more versatile and potentially better than legacy aircraft because they enable quicker delivery.

Many of the sensors used in EW produce detailed information on EMS emissions and can contribute to situational awareness and merge with other information gained from radar and visual or IR observations. Because of its extra fidelity, dedicated SIGINT equipment is still likely to detail information even further.[127] With dedicated ES sensors contributing real-time information to the data pool, other systems using this derive conclusions that the EW system could not. If the technology is capable enough to handle it, enhancing the data pool with EW information gained from sensors can enable situational awareness to improve decision making.

However, with increased sensor numbers and more detailed information also comes threats. The increase of sensors blurs the line between ISR and EW, since sensors often can provide information for both purposes. Ultimately, at least in theory, more and better data leads to better situational awareness. However, with the increased data flow, such awareness becomes more difficult to handle and process. This challenge needs to be addressed, as it is quite possible for an organisation to become paralysed by too much data. It is forced to decide without being clear which data is relevant. Handling large amounts of data needs technical adaption and organisations to be agile.

With the increased capacity of networks, processing can be 'outsourced' to computers at other locations, although needing to handle highly classified information adds addition demands of the computer systems.[128] Large amounts of data but a lesser capacity to analyse

126 Layton, "Fifth Generation Air Warfare". 6.

127 Adamy, *Ew 104*, 423.

128 Poisel, *Information Warfare and Electronic Warfare Systems*, 143-45.

them currently challenges the armed forces. Nevertheless, within the near future, enabling technology will eventually allow more information to quickly be disseminated, correlated, and sent to human analysts who can make quick and informed decisions.

Since systems will be expected to correlate data from many different sources, data need to be stored. Technical advancement is an important aspect in coping with increased data, as current storage systems are often unable to manage the continual flow of large amounts of data. With this continual flow, even processed data uses large amounts of storage. Technology to store and quickly retrieve large amounts of data is expensive. Air forces need to carefully balance the benefits of storing all information against the costs associated with data storage and retrieval. Regarding data storage, the level of security, redundancy, and integrity can increase the cost considerably. The highly sensitive nature of some data also increases the cost of storage, even before forces consider the added complexity of sharing the information over networks. Data storage has the attention of most modern air forces, seeing all modern systems, especially those related to EW, produce even larger amounts of data.

Using the extensive data to reach the right decisions will be one of the keys to winning battles, especially because modern opposing forces will also have access to large amounts of data. With sides having equal access, the speed of analysing data and the resulting decision-making is what counts. This speed underlies forces transitioning to genuine 5th-generation capabilities. Data analysis will increasingly be handled by powerful computers instead of humans and thus must be able to present future analysed information so that humans can quickly make informed decisions.[129]

> *'Enormous generation of data, along with the adoption of new strategies to deal with the data, has caused the emergence of a new era of data management, commonly referred to as Big Data.'*
>
> *- Panneerselvam*[130]

Collecting the data is a challenge to the systems involved and storing the data consistently challenges the available capacity. However, current computer processors and algorithms cannot yet fully analyse the merged data in ways that accommodate all the information collected by a 5th-generation force. When data collection results in data sets becoming

129 Tutty, "The Profession of Arms in the Information Age," 59-61.

130 John Panneerselvam, Lu Liu, and Richard Hill, "Chapter 1 - an Introduction to Big Data," in *Application of Big Data for National Security* (Butterworth-Heinemann, 2015), 3.

too large for traditional systems, we start entering the world of big data.[131] It implies an approach to data where algorithms can draw conclusions from data that initially were not obvious. Instead of long and time-consuming analyses, the big data approach focuses on attaining quick results, important to situations that military encounter. Although numerous large civilian companies are challenged by data-driven systems, many are starting to gain advantage by adopting big data.[132] This adoption will be no easier for military than for civilian companies. However, to better use 5th-generation systems, air forces need to adopt big data.[133]

Once information is found in the data, it is useless if not presented well. The information needs to be prioritised to ensure the right people see it at the right time.[134] Visualising what emanates from big data is another area requiring considerable effort.[135] Because this information can produce surprising but relevant results, users need technology as well as be flexible and agile to use it.

In future warfare, with the added speed at which information can be automatically gathered from data, the tempo of decision-making will no doubt be high. The complex dynamic situations that occur in air warfare and the high tempo of information derived from within these situations needs change from traditional decision making within the Command and Control structure. Armed forces with traditional forms of hierarchy with multi-layered decision making and long planning cycles, need to cope with volumes of fast-moving data.

The wide availability of modern sensors allows data to be gathered by different systems in a vast range of frequencies. The newly develop miniaturisation, improved sensor variety and fidelity, and heightened sensor capabilities, as detailed earlier challenges a 5th-generation air force.[136] Although challenging, big data provides solutions.

Network Interconnectivity

The drive to digitally connect many systems on the battlefield significantly increases the existing important role of EW. Because modern systems and the way of warfare they enable rely heavily on sharing information, it is crucial to keep this information flow going

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131 Ibid.

132 Harvard Business Review, "To the Cloud and Beyond: Big Data in the Age of Machine Learning," ed. Google Cloud (Brighton: Harvard, 2017).

133 Royal Netherlands Air Force, "5th Generation Air Force."

134 Tutty, "The Profession of Arms in the Information Age," Section 5.4.2, Section 7.4-7.5, Annex B

135 Panneerselvam, Liu, and Hill, "Chapter 1 - an Introduction to Big Data," 9-10.

136 Royal Netherlands Air Force, "5th Generation Air Force," 9.

although it is critically vulnerable, as discussed earlier.[137] EW is concerned largely with wireless transmission, which can be detected, intercepted, analysed and exploited. The critical vulnerability that interconnectivity creates can be exploited to gain an advantage over the enemy. This also indicates that forces need to protect their own information against an adversary. In these two areas, EW is key. By disabling access to the EMS, EW can disable an enemy's networking capability and effectively degrade their war fighting ability.[138] The growth of wireless communication means that EW needs to be part of all military operations.

Information superiority is a primary aim of 5th-generation air power, as it contributes to decision superiority. While within air power there is potential for volumes of information to be gained by EW systems, this information contributes only to decision superiority if it is available quickly. Previously, whereas many EW systems were not designed for digitally sharing their information, the need for increased tempo of information and operations forces a new approach. It is wasteful for highly advanced sensors on the battlefield not to be adding their data to the pool of readily available information. It needs to be shared and integrated with information gained from other sources.[139] Using networks for this purpose can produce more comprehensive situational awareness, which in turn is needed to make suitable and time-critical decisions.

Fifth-generation systems will not be the only systems sharing information. Some other contemporary systems currently have only limited capabilities to share information. Transitioning to a 5th-generation air force means improving capabilities of older aircraft staying in the inventory. The wish to transmit information real-time occurs when legacy aircraft digitise by introducing advanced tactical datalinks. By receiving data, older generation aircraft can enhance their situational awareness. Increased networking capabilities allow for a faster confluence of information and better situational awareness of older systems.

Networks and interconnectivity are not new. What is new is the level of interconnectivity, and the type and detail of information able to be transmitted. Before 5th generation popularised interconnectivity, a concept already used was Network Centric Warfare (NCW). It laid the technological and doctrinal basis for the approach now seen in 5th-generation air systems. Within NCW, the goal was for military systems to interconnect

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137 Ibid.

138 Adamy, *Ew 104*, 41-42.

139 Poisel, *Information Warfare and Electronic Warfare Systems*, 10.

and fuse information that was made available to recipients at all levels within the organisation.[140]

With NCW, as with 5th-generation systems, came the risk of forgetting the humans in the loop. Fortunately, NCW applied this to the human factor as exemplified by, "NCW… involves the linkage of engagement systems to sensors through networks and the sharing of information between force elements…However, NCW is also based on the idea that information is only useful if it allows people to act more effectively: this makes the human dimension fundamental to NCW."[141] NCW promoted the idea that care must be taken not to focus only on technology but also the concepts associated with it.[142] The human are active in the system supporting interconnectivity and concepts supporting 5th-generation air power. Experiences with NCW shaped thinking on 5th-generation interconnectivity and assisted in emphasising on the human part. A focus on the human element means that technology can improve the output of products and human decisions.

Information has a joint character which should be reflected in the ability to exchange it. While little reason exists for information to stay within specific domains, current technology sometimes prevents it being shared between domains. How far the flow goes is questionable: do forces transmit information to nearby tactical systems operating or as far back as the static national headquarters. For now, technology may limit the amount of information that can be transmitted simultaneously, but with increased technology, the limit may be temporary.

Modern warfare requires forces to be joint and combined.[143] One of the biggest challenges to interconnectivity is security in the cooperation with international partners in combined or coalition operations. Because countries operate different systems, they can be incompatible, which makes interconnecting nearly impossible. Gateways able to access multiple systems are being developed so that information is available, although this raises challenges to security and classification. Tactical networks are often closed and companies and nations are not keen on sharing technical details of these networks. Few examples

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140 David L. Jr. Peeler and Michael P. Dahlstrom, "Network Centric Warfare: Advantages and Disadvantages," *Strategic Impact* 03/2013 (2013): 94-95.

141 Australian Department of Defence, *Enabling Future Warfare: Network Centric Warfare (Addp-D.3.1)*, ed. Directorate of Future Warfighting (Canberra: Defence Publishing Service, 2004). As cited in: T. McKenna, Moon, T., Davis, R., Warne, L., "Science and Technology for Australian Network-Centric Warfare: Function, Form and Fit," *Australian Defence Force Journal* 170 (2006): 62.

142 Peter Layton, *Network Centric Warfare: A Place in Our Future?* (Canberra: Royal Australian Air Force, 1999), 13-16.

143 Royal Australian Air Force, "Air Force Strategy: 2017-2027," 8-12.

of well-implemented gateways that allow sharing of information amongst international partners are thus apparent.

Enabling the information flow within different types of forces needs effort. Military are dedicating many resources to developing technology to enable an interconnected force. This involves creating strong network architecture, handling the competing frequencies needed that are used for civilian purposes, correcting communication errors, and reducing the use of the traditional omni-directional antennae. Within legal and ethical boundaries, communication can also be exploited, for example, by searching for transmission from the many interconnected systems and adapting technology to be compatible with civilian systems used by the enemy.

Spectrum Management

With many systems transmitting in the EMS, spectrum management is an increasingly complicated yet essential part of planning and executing EW.[144] Various documents are involved, notably, the US joint electromagnetic spectrum management operations (JEMSO), which delves into methods to manage situations where multiple assets are using the EMS.[145] Dangerous situations can occur when systems that transmits using the EMS do not adhere to their assigned frequencies. Forces can even disable their own systems by blocking out communications of other systems using the same frequencies. Transmissions on non-assigned frequencies can also interest those assigned to monitoring transmissions. Countries' own forces could thus be dedicating assets to analysing friendly transmissions, when they should be monitoring those of their enemy.

Because interconnected systems are vulnerable to jamming at the receiver side, reducing the need for communication hubs to control networks increases the ability for a network to keep partially operating in a contested environment. Systems that are connected to the networks need to find their own path there and not simply rely on point-to-point networking. The system needs to be self-healing by, when needed, opening new paths to transmit information, and able to withstand jamming of large portions of the network.

Another challenge that network designers face is the level of error correction. It is important to ensure that information sent is not corrupted, although error correction also uses a fair amount of bandwidth and thus limits the speed at which information

144 United States Marine Corps, "Mcrp 3-32d.1 Electronic Warfare," ed. Department of Defense (Washington, D.C.: Department of Defense, 2016), 1-2.

145 United States Chairman of the Joint Chiefs of Staff, "Joint Electromagnetic Spectrum Management Operations," ed. Department of Defense (Washington, D.C.: Department of Defense, 2012).

can be sent.[146] Ideally, a network can adjust its error correction according to the level of interference or jamming that it encounters.

Many technical improvements improve a system's capability to operate in an EMS contested environment.[147] One of the methods involves using unidirectional antennas as opposed to omni-directional. For transmissions that require high bandwidth, unidirectional antennas are needed. Unidirectional antennas also allow power output of communication systems to be reduced. The less power used in a transmission, the less probable that a transmission will be detected. Also, directional antennas limit the direction by which the energy is transmitted, again lowering the chances of detection. A unidirectional antenna lowers the chances of jamming the system if it is coming from a different direction in which the antenna is directed since an omni-directional antenna will be influenced by transmissions coming from any direction if they have the right frequency and polarisation.[148]

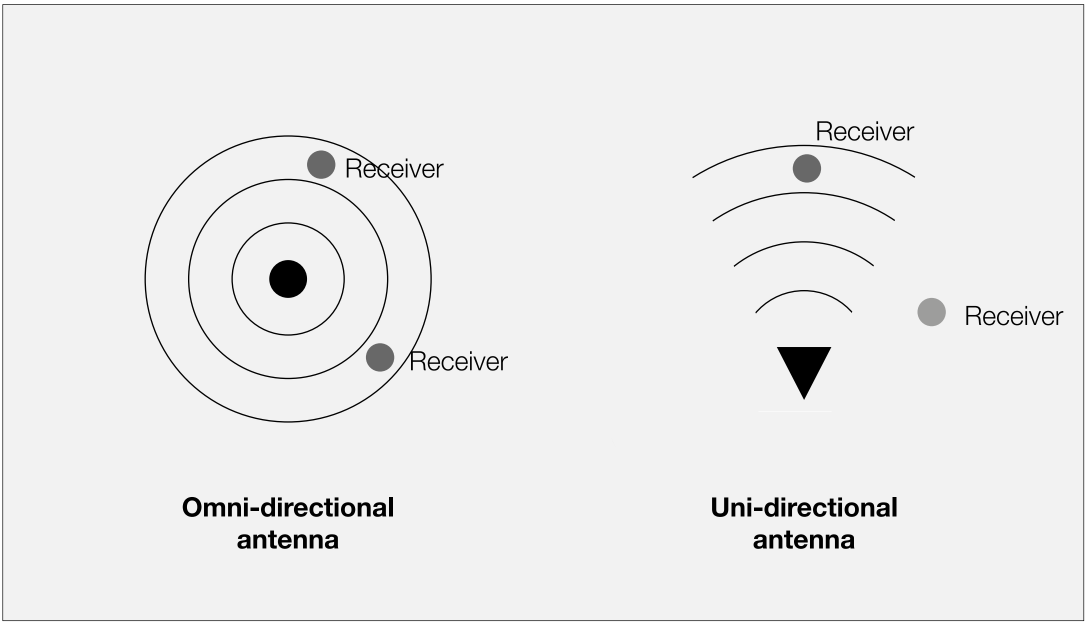

Figure 4: To receive transmissions at the same distance, more power is needed using an omni-directional antenna

146 Adamy, *Ew 104*, 39.

147 Ibid., 161-63.

148 Ibid., 50.

Because most opposing forces use digital communication in some form, intercepting signal is an important tool in exploiting information. This also applies to radar. Since 5th-generation systems share information, it would be wrong to sharply divide EW focused on radar systems from those using communication systems. While finding radar systems by listening for the signals can be successful, communication transmissions can also be part of the active EMS use of air defence as many can share in them. Specific communication patterns can be possibly found that enable these communication systems to be identified automatically and autonomously.[149] Those sensors locating communications and radar signals, and those jamming these signals must cooperate closely in real-time.

Although civilian systems are now capable of transmitting large amounts of data securely, they are not hardened to handle EW systems to the level of military systems. The proliferation of civilian systems on the battlefield has pushed military EW to regard these systems more. For example, EA-18G Growlers have been used extensively in Afghanistan to jam mobile phone signals.[150] As civilian systems become more capable, EW must focus increasingly on these systems. Civilian systems, especially for communication, are often improved and upgraded faster than military systems. The military will struggle to match the continued pace of developments. The interconnectedness of 5th-generation forces implies an increased EW focus on communications and calls for an increase in systems capable of enabling friendly communications and using, or otherwise disabling, the communications of the enemy, both military and civilian.

Important legal and ethical principles apply to jamming signals. With the increased use of the EMS by civilian equipment, some of which is critical to health and safety, the ethical opposition to jamming will increase and needs to be addressed. It is relatively easy to jam signals used by devices such as GPS and mobile phones. The implications of jamming civilian systems may not always be acceptable. It is often difficult to discern between communication used for military and civilian reasons.[151] Losing the GPS signal can disrupt banking, shipping, airlines, emergency services and other areas vital to civilian life. The loss of mobile phone communications also has far-reaching implications on the inability to reach medical services in life-threatening situations for example.

Interconnectivity is essential to 5th-generation systems. Sharing information can give 5th-generation aircraft the edge in combat, and improve other systems connected to the information flow. Despite these advantages, interconnectivity also brings the vulnerability of possibly severely degrading 5th-generation systems by separating them from others. The

149 Ibid., 257.

150 Bergman, "Raaf Electronic Warfare Receiving a Boost," 1.

151 Layton, "Fifth Generation Air Warfare". 19.

interconnectivity increases the importance of EW assets that can both enable and exploit the flow of information.

Weapons

As with ground-based air defence, air-launched weapons are developing that importantly allow 5th-generation aircraft to use new capabilities better. Western countries are developing their weapons but Russia and China are also investing in modern weapons capable of engaging targets quickly and at long distances.[152] Weapons are becoming more accurate, increasingly lethal, and more difficult to jam because of their advanced sensors and electronic guidance systems.[153] Weapons are increasingly gaining the capability to transmit via 2-way datalinks, giving them additional features, which can increase the performance of missiles and reduce an aircraft's chance of being detected. EW is also vulnerable because it can be detected and is possible to jam. Multispectral and improved sensors, and increased speed and range, are making weapons deadlier and motivating developments in EW equipment.

With smaller and more capable sensors, multiple sensors are being added to seeker heads, leading to modern seekers having more than one method of tracking targets.[154] Radar guided weapons are gaining additional capabilities such as being able to switch to some form of EO guidance if their radar guidance is jammed, and to accurately identify the correct target in the terminal phase. Multispectral sensors share their information with the missile guidance systems to validate the target information from multiple sources, including radar, infra-red, and ultraviolet. The increase in multiple tracking methods increases the difficulty of jamming these missiles because it needs to operate in multiple frequencies.[155]

Recent developments, especially in Russia and China, increase the speed of missiles. Some countries research hypersonic technology that enables long-range missiles to fly Mach 5 and faster.[156] This increase allows less time for detection of missiles thus giving opponents less time to react to the threat. Also, it makes missiles harder to intercept or evade. Early detection is important and increasing missile speeds will undoubtedly increase the

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152 Adamy, *Ew 104*, 118.

Bird, "6th Generation Counter-Air Missile Architecture," 19.

153 Adamy, *Ew 104*, 1.

154 Schleher, *Electronic Warfare in the Information Age*, 69.

155 Streetly, *Airborne Electronic Warfare*, 47.

156 Air Power Development Centre, "Hypersonic Air Power," in *Beyond the Planned Air Force* (Canberra: Air Power Development Centre, 2017), 2.

development of early detection methods for incoming missiles. Although developments in air power aim to destroy missiles, it may continue to prove difficult to destroy a missile reaching hypersonic speeds. EP measures originate from the targeted system, in that missiles will always need to defeat the EW measures to gain a hit. With newer missiles having vast amounts of energy left to manoeuvre in their terminal phase, that evasive manoeuvring can still help defeat a missile is doubtful. The last and only line of defence will likely be the EP systems that an aircraft is equipped with. With reduced time to react, faster missiles force EP measures to act autonomously. They need to detect, identify, classify and act quickly. The combination of systems that can react quickly yet reliably to high-speed missiles, will be difficult to design and costly to mass produce.

Increased missile range is important because it reduces the advantage that modern air-defence systems with long ranges have. They potentially allow targets to be engaged without the target being able to affect the shooter. Increased range also decreases the chances of detecting the shooter with active methods before being engaged. EW is used to detect guidance signals of long-range weapons. This feature of EP may become more important because stealth features make weapons harder to detect.

Development does not only apply to kinetic weapons. Another is the expected increase of directed energy (DE) weapons.[157] They blur the sharp divide between EP and weapons because they can be both. For now, development focuses largely on self-defence systems using laser, although weapons using acoustics and other methods are either being developed or available. DE laser weapons are developed to defend against both missile and RPAS threats and have advantages.[158] The energy is highly focused to increase effectiveness and accuracy and decrease collateral damage. There is no expenditure of ammunition which means that, if sufficient energy remains to power the system, and generated heat can be dissipated, the system can keep operating. Also, laser travels at the speed of light, which is an important advantage when attempting to defeat fast moving systems. While most practical applications of DE weapons are to defend, technology may expand the areas that DE weapons are used for.[159]

Although not as powerful as DE weapons, a trend in EW is the increased use of laser jammers for self-defence. While they are not designed to physically destroy targets, they still can focus their power in a small area and thus increase their effect as opposed to older

157 Kainikara, *The Cassandra Effect*, 65.

158 Morgan Cole, “Air Force Intensifies Testing of High Powered Electromagnetic Weapons,” Defense Systems, https://defensesystems.com/articles/2017/09/29/electromagnetic-weapons-air-force.aspx.

159 Asheesh Shrivastava, “Directed Energy Weapons: Safety of Airborne Platform,” *National Defence Aerospace Power* 119/17 (2017).

jamming systems which spread their energy. The increase of imagery trackers in weapons also calls for systems that can blind or confuse incoming missiles for longer periods of time. It is notable that, where IR weapons and jammers have a history of developments and counter-developments, laser jammers are relatively new, and have yet to see significant counter-developments.[160] Undoubtedly, proliferation of laser jammers will increase developments in home-on-jam missiles that look specifically for strong laser signals.

Protecting aircraft from modern IR-guided missiles is challenging. Improvements in missile guidance, is due to improved sensors, that enable missiles to differentiate between aircraft and the flares used for self-protection.[161] Steps to significantly enhance flare technology, and the increased attention to and prevalence of IR jamming technology, are the means to counter the improved seekers used by missiles. EP systems that use lasers or IR emitters to jam incoming missiles, often referred to as DIRCM, are useful in high-risk environments.[162] However, also come disadvantages.[163] Emitting on the right wavelengths is important when trying to defeat systems, and DIRCM have only limited capacity to emit on multiple wavelengths. DIRCM systems also actively emit energy directly on the incoming missile seeker. To do this, the incoming missiles must be detected and very accurately located: a complex and difficult task. Another disadvantage of DIRCM is the classification. DIRCM use specific patterns to jam incoming missiles and these jam codes vary with the type of missiles, meaning DIRCM systems go through many types of jamming and bases what is effectiveness on the behaviour of the missile. To do this, DIRCM is programmed with classified information on enemy systems and methods to defeat them. Because DIRCM technology remains relatively new, these systems will unlikely be available to all countries interesting in purchasing them.[164]

Fifth-generation fighters need 5th-generation weapons, which are capable of reliably engaging a target quickly from long distances, without giving away the position of the fighter. The increased use of modern sensors and the improved speeds, distances and lethality of missiles all influence the worth of the 5th-generation fighter. Fifth-generation weapons are pushing developments in EW to protect aircraft against these enhanced weapons. Using DE weapons to destroy missiles and drones, and more advanced jammers that precisely target incoming missiles are among the more recent developments taking place.

160 Adamy, *Ew 104*, 69, 374.

161 Ibid., 86.

162 Ibid., 370.

163 Ibid., 374.

164 Ibid., 375.

Conclusion

> *Successful military operations now greatly depend on control of the electromagnetic spectrum. The force that can deprive the enemy the use of the electromagnetic spectrum, exploit the enemy's use of the electromagnetic spectrum to obtain information for its own purposes, and control the electromagnetic spectrum will have an important advantage.*
>
> *- United States Marine Corps*[165]

With increasingly digitised and interconnected military and civilian systems, EW is again being seriously considered. The vast use of the EMS to search and identify opponents, transmit data, and guide weapon systems, means it is vital for air forces to allocate resources to EW if they wish to stay relevant on current and future battlefields. The changes are making EW a more potent weapon.

Fifth-generation fighters are much more advantaged than those of older generations and use EMS well in many ways. Stealth features are important to the 5th-generation fighter because they increase the aircraft's survival. However, this does not remove the need for dedicated EW assets when in conflict with advanced opponents. Stealth is a feature of EP, but it also influences EW in other ways. Since detecting stealth aircraft is difficult, jamming their incoming communications is more so. The potential for 5th-generation aircraft with advanced stealth features to have more freedom of manoeuvre increases the decision superiority of the force. Stealth opens options otherwise not available to forces. They can strike targets deep behind enemy lines, in accord with Warden's inner rings.

Fifth-generation aircraft are designed with a broad suite of integrated EW capabilities, and their sensor suites make use of the EMS in ways not previously seen. Miniature technology has allowed more increasingly capable sensors to be integrated into 5th-generation systems. The capabilities of older legacy sensors can also be improved with new processors or programming. Sensors are increasingly gaining capabilities to send their information to other systems in real time. The increase in information density and flow affects the analysis of information. Increased use of big data technologies may prove potent in disseminating the information gained from the many sensors in and around the battlefield. This increase in information is an important reason that 5th-generation air forces need to adapt their technology and organisation. The information gained allows forces faster updates and more detailed situational awareness. This awareness is both an advantage when all levels

165 United States Marine Corps, "Mcrp 3-32d.1 Electronic Warfare," 1-1.

within a force can make use of the information, and because forces can be flexible enough to adapt to change where and when needed.

EW initially focused on military communication technology and radar and navigation systems but is now much broader. Because 5th-generation systems use EMS extensively, especially to communicate, the systems of interest to EW and intelligence have grown. Military and civilian communications equipment differ, but the differences are narrowing.

Equipment such as cell phones and satellite phones are often opponents' main means of communication. Modern civilian communication equipment allows opponents to better establish command and control (C2) networks. They enable opponents in irregular warfare to share information rapidly, besides more traditional uses such as triggering IEDs.[166] One challenge facing modern EW is a quickly evolving civilian communication infrastructure, incorporating new technology and becoming more secure and hardened. This quick evolution brings a need for EW equipment to adapt fast to stay effective.

Not only combat aircraft gain from interconnectivity. Non-combat aircraft such as tankers can contribute more to air power by receiving stronger digital communications. This occurs when they are fitted with certain electronic support equipment. In effect, they are then used as forward antenna stations while they execute their main task but can send important information on the use of the EMS to others. More aircraft can support air, land, and sea operations while executing their primary tasks. Fifth-generation calls for most friendly assets to collect and send their information and integrate it into a common picture. A platform that is not collecting intelligence and immediately sharing it with other assets is partially wasted, and thus decreases the level of situational awareness and information dominance of a force.

Fifth-generation fighters are supported by a new range of weapon systems. They give fighters an increased strike range, more accuracy and lethality, and a lower probability of detection. Although some weapons can also be used by older generation aircraft, 5th-generation fighters have the capability to carry weapons internally, which improves their stealth characteristics. A disadvantage of 5th-generation stealth fighters is that they are limited in the number of weapons carried, which limits their ability to engage many targets without support from other assets. Improved weapons challenge current EA and EP equipment. Recent developments contribute to a continued effectiveness of EW systems against modern weapons that have improved range, guidance, and lethality.

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166 Tutty, "The Profession of Arms in the Information Age," Section 5.4.4.

7.
Other Contemporary Influences on EW

This final and diverse chapter investigates developments taking place that either can influence EW or show how it can influence other capabilities. The chapter investigates the two new domains of space and cyberspace and how they relate to EW, and then the rise of RPAS and its link to EW. The final chapter takes a practical approach and investigates the present-day culture of limiting destruction, and how EW may contribute to this.

Space

> *A truly responsive operationally responsive spacelift capability must be able to place a tactically significant payload into the orbit of choice at any time, from any accessible location and be able to conduct self-contained launch operations.*[167]
>
> *- Warren Frick*

Increased use of the space domain can influence air power significantly since it relies heavily on the space domain to support missions. Communications increasingly depend upon satellites, as does navigation. Timings needed to synchronise crypto equipment also gather data from satellites. Weather details, a crucial element in air power, is collected with the help of many satellites orbiting the earth. If things go wrong, emergency locater beacons use satellites to relay the position of crews in need of recovery. Missions are prepared with the help of imagery gained from satellites. The list goes on, but few areas within air power are not in one way or other linked to the use of satellites in the space domain.

167 Warren Frick, Joseph Guerci, and Brian Horais, "Responsive Air Launch" (paper presented at the 2nd Responsive Space Conference, Los Angeles, CA, 2004), 1.

Significant changes are expected in the space domain in the next decade and airborne EW cannot afford to disregard them. All satellites use the EMS extensively and EW is needed to secure continued use of space-based systems, while reducing the effectiveness of opposing systems in space or their making use of space assets. EW in space is not new but intensified use of the space domain implies that the influence between EW and the space domain is increasingly important.[168]

While better sensors and improved communications equipment enhance equipment used in the space domain, two other important developments are increasing the accessibility to space. Companies like *SpaceX*, *Virgin*, and *Blue Origin* are all investing significantly into making space more accessible, effectively lowering the cost of entering the domain.[169] Another development is miniaturisation, which can greatly reduce the size of some satellites. Only a few countries can produce and launch large satellites for military purposes. While smaller satellites may not have the capabilities that larger modern ones have, the small ones give small and middle-sized countries the capability of owning space-based assets. By making satellites smaller, while simultaneously gaining more options to launch satellites, the space domain is unfolding to many countries that previously had no resources to invest in space.

More countries can achieve effects from space that, until recently, only large countries could. Many of these capabilities will be linked to space-based ISR and autonomous space-based communication platforms. For technologically advanced countries, the question will not be if they can launch equipment into space. The questions will be how long it will take to launch a satellite into space, and into which orbit can one be launched. Countries that invest heavily in the space domain, and have the geography to support space launches, will gain the ability to quickly launch small satellites to areas where they are needed. If the threshold in complexity and cost for quickly launching and positioning satellites is lowered enough, it reduces the need for more traditional ISR assets such as RPAS, large satellites, and reconnaissance aircraft.

Three effects of increasingly used space-based assets on EW are as follows:

1. An increased use of space-based communication by both civilian and military interests, a trend likely to continue. An increase of space-based communication and EW are obviously connected because all communication from and between satellites occurs using the EMS methods like radio and laser. Satellites follow fixed orbital paths making their positions known and predictable, which is important

168 Poduval, *Electronic Warfare*, 166-67.

169 Brandon C. Halstead, "The Ultimate High Ground - U.S. Intersector Cooperation in Outer Space," *Journal of Air Law and Commerce* 81 (2016): 598-601, 04-07.

when trying to jam communications. Disabling satellite communications effectively renders it temporarily useless so that ground, sea and air-based systems are disabled and their ability to work as an interconnected force is severely hamper. Targeting satellites with EA measures is an effective temporary method of reducing the effectiveness of 5th-generation forces.

2. An increased proliferation of EW sensors in space. As noted, an advantage of airborne EW sensors is that they can have an increased range of detection. This is no different for the space domain, since the higher a system sits, the farther its horizon is. With space becoming more accessible and small satellites with more capabilities increasingly available, it is likely that many EW sensors will be established in small, relatively cheap, satellites. These EW sensors can monitor the EMS in locations deemed important, and merge the information gained with systems closer to earth. Although the distance limits satellites' ability to detect low power signals, many systems that use the EMS output considerable power levels and can be detected from orbital distances. Also, the increased sensitivity of sensors heightens the viability and usefulness of EW sensors in space.[170]
3. More attention to effective EP measures to protect satellites. With the increased importance and use of the space-domain, comes a need to better protect satellites from EA. Many will have some passive EP measures such as electronic hardening, and it is probable that expensive and critical satellites will have some form of active EW measures. Adding EP measures inhibits the development of cheap satellites for military purposes, and choices must be made by balancing cost with protection measures. If the threshold for launching satellites is low enough, the better option may be to launch more satellites as opposed to adding costly EP measures.

Space has become more accessible in the past decade, which is likely to continue. This increase and the reduced size of many types of satellites, provides options not previously available to many countries. Many countries are preparing space programs, often of limited size, but these developments open the way to wider uses, including military. The already strong space industries of some countries will become more flexible so that, for example, if they have their own facilities, they will be able to launch specialised satellites into orbit at short notice. Countries increasingly communicate using satellites, which can become a vulnerable point that can be exploited by EW assets. They thus need to be protected from EA, either passively or actively. Furthermore, more countries can be expected to use the space domain to place EW sensors capable of sensing transmission in the EMS on and close to earth.

170 For open source information on the possibility of detecting signals from earth in space, see the various articles on EW in space written by Adamy in The Journal of Electronic Defense.

Cyberspace

Cyberspace is strongly linked to EW to the extent that Cyber, EW, and military networks have already been integrated at different levels within armed forces.[171] Although modern classified military systems are generally not connected to the internet, they are nearly always networked and are thus vulnerable to cyber-attacks. Even if these classified systems were not networked, as occurs with stand-alone radar system, they still work with digital components that can be targeted with cyber-operations. Because 5th-generation systems are interconnected, and highly digitised, military systems can be particularly vulnerable to both EW and cyber operations. Both the EMS and cyberspace are part of the information domain.[172] There are some natural overlaps between EW and cyber as they both use electronics to create effects.[173] Because many devices using the EMS can be targeted by cyber warfare, and that it often takes place in the EMS, EW and cyber operations need to be closely coordinated.[174]

Cyberspace consists of physical networks, logical networks, and cyber-personnel and its operations refer to achieving objectives in or through cyberspace.[175] Information is moved between computers using the internet or other types of networks. By using it, either within computers as transmitted between them, or by interfering with information movement, it is possible to gain an advantage.[176] An example of systems having both EW and cyber vulnerability are the increasingly used software defined radios. EW can locate and jam the signals from them while other cyber operations can be used to target the internal workings of the radio. Technology will ensure that more systems are fielded that potentially have two-way vulnerability.[177]

Both EW and cyber focus on information so that finding and enabling it and disabling its transfer can be achieved by EW and cyber. Because they can both target the same areas, they are increasingly integrated. The strategic support force of the Chinese People's Liberation Army (PLA) is but one of many examples that 'brings together single service

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171 Jane's International Defense Review, "Us Army Seeks Rapid Fielding of Cyber Quest 2017 Systems," Jane's International Defence Review, http://www.janes.com/.

172 Air Power Development Centre, "Manned or Unmanned?," 59.

173 Department of Defense, "Cyberspace and Electronic Warfare Operations," ed. Department of the Army (Washington, D.C.: Army Publishing, 2014), 2-5.

174 United States Chairman of the Joint Chiefs of Staff, "Joint Electromagnetic Spectrum Management Operations," I-11.

175 "Joint Publication 3-12 Cyberspace Operations," ed. Department of Defense (Washington, D.C.: US DOD, 2013), v-vi.

176 Adamy, *Ew 104*, 30-31.

177 Brian Russell, "Cyberspace Operations and Electornic Warfare Convergence, Part I - Skating to Where the Puck Will Be," *Marine Corps Gazette* July 2017 (2017): 70.

and national-level space, cyber, and electronic warfare capabilities.'[178] Another example is the USMC, where merging is termed spectrum warfare, merging cyber, EW, and signals intelligence.[179] Russia takes an integrated approach to information warfare, where cyber and EW are used to gain advantages, even when not directly related to warfare.[180]

Although cyber warfare has been part of war for some years, in the last decade, modern small- and middle-sized armed forces have started resourcing the cyber domain. It is not possible to imagine a future war against a modern, or arguably any, opponent where the cyber domain is not in play. It affects all other domains and all services should integrate cyber in their operations. However, the level of integration needed with air power assets within cyber operations is something that is not yet clear.[181] While for large countries, much can be said for a separate cyber command, a detailed discussion on where cyber should occupy national structures is beyond the scope of this paper.[182] Some expect the growth of cyber commands to rival the growth of air forces starting from World War I.[183] The next few years will see developing national structures that place cyber and EW in the area most suited to the structure and resources of the country. Many air forces will be too small to have their own dedicated cyber-warfare units. It is imperative that they liaise extensively with national cyber security and warfare units. Less than even air power, cyber warfare is not bound to geographical locations. In theory, units can target any enemy location connected to a network. With the help of friendly aircraft, even remote and local networks can potentially be targeted, with considerable consequences to enemy systems.

Cyber is a fast evolving domain within warfare and the next large-scale war will show the depth of how vulnerable modern military systems are. Because of the similarities between EW and cyber, both systems need to cooperate intensively to gain the outcome that both worlds strive for. While cyber can complement EW operations, because 5th-generation systems are interconnected and digitisation, they are susceptible to cyber warfare.

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178 Layton, "Fifth Generation Air Warfare". 21.

179 Matthew E.; Schuette Poole, Jason, C., "Cyber Electronic Warfare - Closing the Operational Seams," *Marine Corps Gazette* Aug 2015 (2015).

180 Michael; Vogler Connell, Sarah, "Russia's Approach to Cyber Warfare," ed. CNA Analysis & Solutions (Arlington: CNA, 2017), 1-2.

181 John A. Warden, "Smart Strategy, Smart Airpower," in *Airpower Reborn: The Strategic Concepts of John Warden and John Boyd*, ed. John Andreas Olsen (Annapolis: Naval Institute Press, 2015), 124.

182 Colin S. Gray, "Airpower Theory," ibid., 177.

183 Clodfelter, "Theory, Implementation, and the Future of Airpower," 119-20.

Remotely Piloted Aerial Systems

Within air power, one of the dominant trends is progressively increasing the development and use of Remotely Piloted Aircraft Systems (RPASs). They are also abbreviated as unmanned or uninhabited aerial vehicles (UAVs) and remotely piloted vehicles (RPVs). Sometimes, the abbreviations are defined slightly differently but, to avoid confusion, this paper refers to these systems as RPAS. Although some RPASs have been used for EW purposes, their primary role to date is ISR. Compared to piloted systems, RPASs offer many advantages, but some disadvantages. EW can be important in both enabling and degrading RPAS.

RPAS Advantage

There are some advantages of using RPASs compared to using manned aircraft. First, being unmanned allows for cheaper and more efficient designs because no space and equipment is needed to house humans. Some space is lost to automation, and communication systems that control the RPAS. However, integrating cockpit instruments, ejection seats, pressurisation and oxygen, and many other systems built to support the human or humans in the aircraft are no longer necessary. Second, without the element of loss of human life, losing an RPAS is less vital than a traditional aircraft, although often still costly. Politically, it is easier to send an RPAS into harm's way, than a piloted vehicle. Third, the pilot is not physically in the same environment as the aircraft, potentially reducing the high levels of physical and mental stress. This is advantageous to performance. Fourth, by moving the control of aircraft from the cockpit to a building many kilometres away, it easier for control to be divided and for its sensors to be operated by various personnel. A fifth important advantage of RPASs is the capability to change crews during missions, especially since some RPASs have very long endurance.[184]

Miniaturisation

The amount and type of EW equipment carried by RPASs is limited unless their size is increased; in the past, EW is one reason for larger sized RPASs.[185] Because many are smaller than regular fighter aircraft, miniaturising EW equipment is an important development.

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184 Peter Layton, "A New Direction for Australian Air Power: Unmanned Armed Aircraft," no. CAF Papers (2016), http://airpower.airforce.gov.au/Publications/A-New-Direction-for-Australian-Air-Power-Armed-Unm.

185 Air Power Development Centre, "Pathfinder 107: Irregular Warfare and Air Power," ed. Royal Australian Air Force (Canberra2009), 25.

The size reduction will increase the capability for RPASs to mount EW equipment next to the existing sensors and systems.

RPAS Survivability and EP Measures

Conflicts in past decades show that RPASs are highly suitable to conducting ISR in uncontested environments. RPASs are expected to be prominent in conflicts involving air supremacy.

The next decades will be more uncertain than recent time so that RPASs may need to survive in hostile environments. When facing opposition, most RPASs find themselves in situations for which they are currently not well equipped.[186] Air defence systems being progressively more widely available dictates that all aircraft operating within range of the enemy will likely need EP measures. As there are few RPASs with EP systems, this prospect makes them vulnerable leaving doubt that current RPAS platforms can survive in contested airspace.

Theoretically, an RPAS is an ideal asset to use when there is a high risk to a crew. If technology can support it, RPAS development will logically focus on increasing their ability to survive hostile environments, even though this will make RPAS more expensive. There are already RPAS EW developments like the Light Spear Jammer developed by ELBIT and designed specifically for use on RPASs.[187] The advantages of using RPASs in dangerous environments pushes RPAS development towards more EW and strike capabilities.[188] More robust types of RPASs are certainly being developed.[189]

Enabling RPASs to better survive hostile environments by equipping them with EP measures can result in a considerable increase in cost. Unfortunately, the rising cost of RPAS is already challenging the military. Another approach being researched is to

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186 "Manned or Unmanned? The Future of Air Power Delivery," *Pathfinder Collections* 7 (2016): 11-14.

187 Elbit Systems, "Elbit Systems Launches at Farnborough 2016: Light Spear™," Elbit Systems, http://elbitsystems.com/pr-new/elbit-systems-launches-farnborough-2016-light-spear-self-protection-jamming-system-unmanned-aircraft-systems-uas/.

188 Air Power Development Centre, "Pathfinder 107: Irregular Warfare and Air Power," 9.

189 Center for Strategic and Budgetary Assessments, "Thinking About the U.S. Military's Next-Generation Uas Force:," (Washington, D.C.: Center for Strategic and Budgetary Assessments, 2013).

manufacture cheaper RPASs with little self-protection other than stealth features like low RCS and infra-red signature though it means accepting a higher loss rate.[190]

RPAS as an EW Platform

Besides using EW measures for protection, RPASs are themselves highly capable of being used as EW platforms.[191] While acting in an ES role and as signals intelligence are tasks already performed by some RPASs, other possibilities to push RPASs into an EA role exist. Depending on the type of RPAS, they have advantages such as being able to come closer to enemy systems that are radiating in the EMS and having endurance times longer than traditional EW aircraft. The viability of EA will depend on the EW capabilities of the opposition. With the reducing size and weight of sensors, RPASs may also be used in a combined ISR and EW role, and as a platform from which to conduct cyberspace operations.

RPAS as a Communications Hub

Besides dedicating RPASs for EW tasks, another use is in the C4 support role. They can be used as repeater stations for all types of transmissions to receive and re-transmit signals. By having multiple RPASs in this role, it is possible to create a network supporting 5th-generation interconnected systems that is flexible and has extensive survivability and robustness in the modern battlespace. Using RPASs as relays can also reduce the power output of aircraft along the front line by reducing the send distance. This increases survivability because the lower power output needed reduces the likelihood of detection. In this way, although not dedicated to EW, RPASs can still contribute to enabling operations in the EMS.

Measures Against RPASs

Until now, this section has talked mainly about EW in a support role. However, the sheer amount of RPASs and other unmanned systems means that EW must focus part of its development on defeating them. Two factors complicate this prospect: first, although air power uses unmanned systems, the land and sea domains are similarly increasingly using unmanned systems. Second, warfare changes with technology. As well as traditional state

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190 Jane's International Defense Review, "Bargain Hunt: Air Forces Move to Embrace Low-Cost Ucavs," Jane's International Defence Review, http://www.janes.com/images/assets/318/71318/Bargain_hunt_Air_forces_move_to_embrace_low-cost_UCAVs.pdf.

191 Richard A Poisel, *Introduction to Communication Electronic Warfare Systems* (London: Artech House, Inc., 2008), 26-27, 37-38.

actors using RPASs, the low cost and commercial availability of small unmanned systems has allowed non-state actors to use them in various roles including ISR and strike. They have been used in Gaza, Syria and elsewhere. No matter how small, any opponent can effectively be capable of producing air power. These two factors are complex because the first relates to technologically advanced military systems and the second relates to small, relatively simple commercial systems, possibly used in large numbers. The factors thus demand very different EW responses.

RPASs are controlled using signals within the EMS and this makes them vulnerable to EW systems. The continual real-time control of RPASs and sensors cannot be guaranteed in an environment that is contested by opposing systems controlling the EMS. Additionally, controlling RPASs makes them vulnerable to detection and location by ES systems searching the EMS for transmissions.

Although jamming appears an easy way to defeat RPASs, it is limited. It might divert an RPAS from its mission, however, the pre-defined mission might still be executed. Additionally, if an RPAS uses a robust network and communications structure, the information sent by the RPAS cannot be easily stopped. Since jamming only works by jamming receivers, short of destroying the RPAS, the only way to stop the data from the RPAS to a ground station or satellite, is by jamming the ground station or satellite. However, jamming is not useless and still has advantages since there is a certain dependence of RPASs on communications and datalinks. Besides disabling the possibilities of in-flight re-tasking, jamming degrades the communications because the RPASs have no way of correcting errors in the data they send.[192]

While advanced systems are harder to defeat because they are built to be more robust in a hostile environment, many smaller commercial systems can be used. Being small, they are often harder to locate and target. Commercial systems have more limited capabilities when communications signals are lost; often being programmed to simply return to the originator. This increases EW's value in protecting forces from commercial RPASs. With EW, it is possible to target large numbers of RPASs without any collateral damage to civilian infrastructure. Cyber capabilities add the possibility of taking control of the RPAS, as already developed systems do.

RPAS Autonomy & Ethics

The more autonomously an RPAS can operate, the harder it will be to use EW measures to affect its system. Even though it may be technically possible to make RPAS autonomous to a certain degree, it is resisted on moral and ethical grounds. This is especially true when

192 Adamy, *Ew 104*, 244, 57.

autonomy extends to autonomously applying kinetic effects. For now, while such effects are a bridge too far for RPASs, the future will almost certainly see systems capable of this. The debate on combining autonomous RPASs with weapons will continue. The more autonomous that RPASs become, the more contentious this discussion is likely to be.

Despite the disadvantages of RPASs, such as their limited survivability in contested airspace, and the danger of losing the communications to them, the advantages prove to be more important. Miniaturisation will enable more mission systems to be carried by RPASs, that increasing their ability to survive. EW can profit from RPASs as a cheaper platform for conducting ES and EA operations. They can be used as communication hubs to increase the much-needed robustness of communication networks that support 5th-generation air power. Even though the push for increased survivability of RPAS will increase the cost, RPAS will increasingly be used, first, as a safer and more economical alternative to manned aircraft, and second, to expand all areas of air power to the extent of one day superseding piloted vehicles.

The Role of EW in Limiting Destruction

Recently, because of an increasingly digitised and interconnected world, more attention is given to EW as a force that can attain effects and not just enable air power. When EW can debilitate digital systems, particularly communications, limiting it to a support role is poor use of assets. While EW ever being powerful enough to directly win battles is doubtful, it certainly is strong enough to influence many aspects of civilian and military life. This section investigates those aspects by using Warden's rings to show how EW can expand its traditional enabling role and seriously affect military and civilian systems.[193] First, the need to limit destruction in modern small wars is discussed, followed by limited targeting and the use of EW to achieve effects. The chapter ends with a figure highlighting many areas that EW can affect.

A trend in modern warfare is to limit destroying targets in theatre.[194] This need emanates from a humane concern about collateral damage to civilians. The practical side to this concern is reducing infrastructure destruction. This reduction positively reduces opposition and possible negative follow-on-effects during and after main hostilities. Important to note is that limiting the damage might not always be an important factor in war. The question about what will happen if a large conflict occurs where nations fight for their survival can be answered by considering that desperate nations are likely to increase their destructive response to influence the battlefield. Reducing casualties is a noble cause

193 United States Marine Corps, "Mcrp 3-32d.1 Electronic Warfare," 1-1.

194 Kainikara, *The Cassandra Effect*, 98.

till the survival of ones' nation is at stake; humanity only goes so far.[195] It remains to be seen if Western countries will see a war within the next few decades that is about their surviving as a nation. Warfare that is limited, at least from a Western perspective, will probably continue to be the major type of conflict. For now, with contemporary conflicts calling for destruction to be lessened where possible, technology can assist.

An advantage of modern air power is that it can bypass less important targets and focus directly on the CoG of the opposition.[196] Yet, to limit collateral damage, recent examples of air power often see military equipment and personnel being the prime targets. As weapons have become more technologically advanced and precise, destruction and the risk of collateral damage have reduced. The next step seen is to use weapons with a limited yield like the small diameter bomb (SDB). There is also much interest in weapons with smarter fuses and options such as tailored yields which result in potentially less collateral damage. These weapons are intentionally created to damage the surroundings less while still being able to neutralise the target. Despite the irony that increased technical capabilities of sensors, and the further development of weapons with tailored weapons reduces destruction, the restrictions on targeting might also be reduced. Because more precise weapons make less collateral damage, the target options may expand. It is likely that developing smaller weapons will continue so that those in the future will possibly allow for on-demand in-flight adjustment of weapon damage. For now, particularly for Western countries, the moral compass limits the options available in many air campaigns, and the consequential less efficient use of air power will shape how the air weapon is used for many years.

While limiting targeting to military equipment and personnel minimises collateral damage, it may not always militarily be an efficient method of employing air power as it does not affect the more important CoG's. Warden notes that 'It makes little sense to expend scarce resources against anything other than centres of gravity, yet the majority of planners in both the military and the commercial world devote practically no time to identifying those centres.'[197] When targeting is not focused on the multiple rings, the strategic paralysis of the enemy might not be achieved. Focusing on CoG is the most efficient way of changing the behaviour of the enemy. Yet, within irregular warfare, the political landscape accepts only a limited target set. Simply put, there is not much appetite for destruction.

While larger scale battles will probably still extensively attack targets correlating with Warden's five rings, the often-smaller irregular wars, will predominately see targeting of

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195 Ibid., 47.

196 Stephens, "Airpower Reborn," 149.

197 John A. Warden, "Smart Strategy, Smart Airpower," ibid., 106.

the enemy's fielded forces with, at least, kinetic effects. There is another option. If strategic paralysis is still desired, it is possible that EW, with its local and temporary effects, may be able to assist. A spin-off from the reduced options for targeting, is that more attention can be given to methods to achieve non-kinetic effects on Warden's five rings.[198] Thus, an expectation is that systems capable of achieving non-kinetic effects, of which many are found in the EW area, will become increasingly important to air power.[199]

EW is crucial to supporting conventional operations. In recent years proliferating military and civilian systems using the EMS has increased the potential of EW systems. They critically directly influence the battlefield and achieve outcomes. However, the possibility for EW to cause effects does not negate the need for systems capable of creating kinetic effects. Although 'war is violence', EW is mostly unsuitable for unleashing physical damage.[200] Military need to retain the capability to physically harm opponents, yet, as the world becomes ever more digitised, EW is becoming a more potent tool. Warden states that 'Planners… cannot predict what will happen and therefore should never make deterrence, coercion, decapitation alone, psychological operations alone, or similar mind-based concepts the heart of their operations.'[201] As Warden points out, war is uncertain, and a broad range of tools needs to be available to reach many effects.

Using Warden's rings to correlate EW actions fits remarkably well with Boyd's approach. While Warden focuses on the physical effect to reach strategic paralysis, Boyd focuses more on the perceived effect that influences opposition to behave differently. Because nearly all EW actions are temporary and localised, the perceived effect is important to matching targets to EW assets. Ultimately, the reason for attacking a certain target is the perception it leaves with the leader.[202] When attacking CoG's, it is important to attack them in parallel to achieve paralysis, needed so the system 'cannot repair itself, protect against future attacks, or make competent counter attacks.'[203]

Focusing on CoG, the five-ring model developed by Warden is useful to prioritise targets. While the method can be used with physical methods of targeting, it can also be used when targeting from an EA perspective. As Warden points out, the energy of the enemy combines physical and psychological energy.[204] EW now has some capacity to influence

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198 Clodfelter, "Theory, Implementation, and the Future of Airpower," 122.

199 Kainikara, *The Cassandra Effect*, 47.

200 Clausewitz et al., *On War*, 90.

201 Warden, "Airpower Reborn," 104.

202 Stephens, *Going Solo*, 142.

203 Warden, "Airpower Reborn," 115.

204 Ibid., 103.

both of these categories.[205] Warden's five rings: Leadership, Processes, Infrastructure, Population and Fielded Forces, all use, and can thus be influenced by, the EMS.[206] Although limited in scope, Figure 5 shows areas making use of the EMS and the many systems that EW assets can, at least temporarily, target and influence.[207] It shows some areas of dual use: areas that civil and military both use, such as GNSS (global navigation system satellite). Other examples are roads and railroads which are normally used by the population but are also critical to military logistics and transport. Within the boundaries of Warden's rings, the following overview gives some examples of how EW can temporarily and locally influence targets that make use of the EMS.

Leadership: Leaders need communications to lead and command those under them. This communication can occur using military and civilian systems and be targeted in many ways. Media is another area that is important to leadership who use it to control and indoctrinate their population. But media can also be used by friendly forces to send messages to large portions of the population. Examples of EW influencing leadership were seen in Rwanda where broadcasts that led to violent behaviour were limited by EW assets.[208]

Processes: Many processes are identified during conflict: recruiting fighters, acquiring weapons, financing the war, and keeping the armed forces and the population fed. Although the effects are temporary, some of them can be targeted by EW assets. Recruiting becomes more difficult if the communication is hampered, while blocking it can also hamper logistical processes, since these are sometimes automated, including using GPS for tracking items.

Infrastructure: Many infrastructure systems are controlled by systems using the EMS. Road signs, automatic bridge openings, systems controlling water levels, aircraft navigational aids, and railroad signals and switches are examples. Interfering with them can degrade the capability of opposing forces to manoeuvre. The advantage, rather than physical destruction, is that this can be reached locally and temporarily. The EW effects will unfortunately still negatively impact upon civilians.

Population: When Warden included population in his rings, he did not mean for them to be physically targeted.[209] A humane approach limits the ability to influence this important

205 Royal Netherlands Air Force, "5th Generation Air Force," 6.

206 Warden, "Airpower Reborn," 107-09.

207 Adamy, *Ew 104*, 8, 41.

208 Erik Lin-Greenberg, "Airpower in Peace Operations Re-Examined," *International Peacekeeping* 18, no. 4 (2011): 444.

209 John Andreas Olsen, *John Warden and the Renaissance of American Air Power* (Nebraska: Potomac Books, 2007), Chapter 5.

CoG. With EW assets, it is possible to influence population within geographical boundaries and for a limited time. By focusing on their communications, their use of infrastructure, limiting their ability to use the internet, and hampering logistics that ensure continued distribution of goods, it is possible to influence the population and thus produce varying levels of discomfort.

Fielded Forces: Many military areas use the EMS. Because of its large area, that sees dual military and civilian use, fratricide in the EMS spectrum (Spectricide) is likely to occur when using the EMS to target fielded forces. An example is using civilian communication to detonate an improvised explosive device (IED) by opposing troops in irregular warfare. Many approaches can counter an IED threat with EW. An IED can sometimes be detonated using remote triggering, or electronic equipment, or can be remotely damaged to make the fusing inoperative. The most common approach is jamming the signal, so it does not reach the IED, which temporarily allows friendly forces to pass through an area.

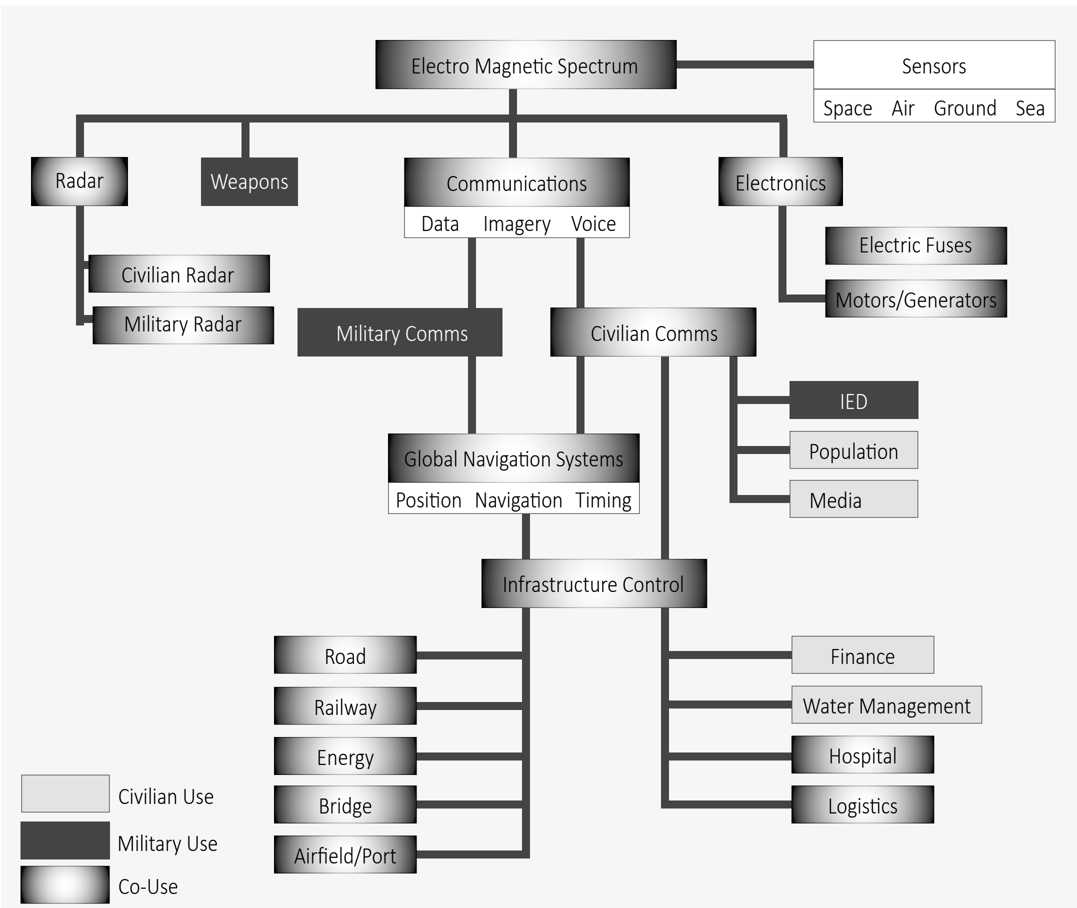

Figure 4 - C0-use of the Electromagnetic Spectrum

EW remains critical enabler because, without EW support in fighting an enemy with modern assets, friendly aircraft are unlikely to reach their targets. EW already boosts the efficiency of a campaign by enabling the targeting of Warden's inner rings, potentially resulting in a quicker victory and less bloodshed.[210] This quicker victory can significantly reduce the length of a war.[211] However, EW can achieve more. An understandable trend is to limit the destruction during small wars, which has been largely enabled by developments in weapons. However, this can reduce the effectiveness of a campaign because it will not allow strategic paralysis of the enemy by parallel attacks on all five of Warden's rings. EW can assist by creating temporary and local effects that have less collateral damage than attacks by physical means. The world being increasingly digitised and interconnected, EW is not only a critical enabler but more and more an asset for creating effects on the battlefield.

The 5th generation is now, but also the future. Because air forces are only just realising what 5th generation means to their organisations, it will be years till experiencing and adjusting allows a 5th-generation air force to fully use its new capabilities. So, while this chapter did not relate specifically to the future, 5th-generation air forces do.

Space systems, enabled by communication using the EMS, and becoming more widespread with decreasing cost, can influence and be influenced by EW. The high vantage point of satellites can prove important when EW systems are placed within satellites. With the bar lowered substantially to launch small satellites into custom orbits, these quickly deployable, customised, light-weight satellites will have the ability to partially replace traditional ISR assets.

RPAS are already used quite extensively in warfare, and this trend is likely to continue. EW is starting to find its way on RPAS, indicating that their long enduring platforms are ideal places to house some types of EW. If RPAS are not fully autonomous, EW, in turn, is capable of severely hampering RPAS operations. EW may be particularly important when RPAS are used in large numbers, as kinetic methods to target RPAS are limited by available ammunition.

While EW is an enabling form of warfare, the increasingly connected military and civilian systems means that EW can be more. EW should now produce effects instead of just supporting other assets. With the present desire to limit destruction, especially collateral damage within warfare, EW can potently disable targets temporarily and locally without permanent damage that will severely impact local populations.

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210 John A. Warden, "Strategy and Airpower," *Air and Space Power Journal* XXV, No. 1, no. Spring 2011 (2011).

211 "Airpower Reborn," 123.

EW systems can profit from the interconnectedness of 5th-generation systems by pulling and pushing information. In turn, the EW systems can help increase the tempo of operations and the decision superiority created and needed within 5th-generation air power.

8.
Conclusion

Because of the late arrival of powered flight, air power and EW have always co-existed and influenced each other. As the EMS has been increasingly used, the importance that EW has in air warfare has grown. Whilst World War I saw some EW taking place, World War II was where EW played a major role. Jamming, spoofing, or destroying networks of radars, navigation aids, and long-range communication hubs influenced the outcome of battles. Successfully applying EW to enable friendly and disable enemy transmissions in the EMS became paramount in air warfare and continued to be an important factor throughout the Korean and Vietnam War.

The Vietnam War saw significant advances in EW, such as being integrated into tactical aircraft. This was possible because advanced technology enabled electronics to be miniaturised. EW follows air power in evolution cycles; rapid development takes place mainly during the larger wars and conflicts. By Vietnam, all the contemporary airborne EW roles and missions were flown and from then, EW evolved.

Operation *Desert Storm* was tantamount to being a forebear of 5th-generation air warfare. Much of the technology then used related to the EMS and thus to EW. Stealth was introduced on a limited scale, and data communication, more precise weapons, and increasingly used sensors, especially targeting pods, all contributed to the success of Operation *Desert Storm*. EW was important in enabling the decision superiority of the allied forces. EA, especially when combined with stealth aircraft, enabled undetected flight into enemy airspace to attack even the heaviest defended targets. EP minimised the casualties sustained, and ES enhanced the situational awareness of allied forces.

After the Cold War, when defence budgets were decreased and interventions in small wars increased, came a move towards expeditionary warfare with less emphasis on large scale warfare. Focusing solely on expeditionary warfare is dangerous. Acquiring capabilities ideally follows what is required of national security which includes defending the nation. This need may not always entail the purchase of expeditionary assets. The reduced number of aircraft that nations owned led to a potentially dangerous situation because the military capabilities no longer met the demand of possible situations that countries could encounter. National defence policy was adjusted to fit within the capabilities needed for limited expeditionary warfare. This movement also influenced EW as less attention was given to dedicated EW assets; many countries invested mainly in protecting their aircraft. For decades, the required capability was no longer based upon the needs of national security.

Recent global events have shifted the focus from expeditionary warfare to a balanced approach that also covers purchasing assets needed to defend the nation. This movement may result in an increased acquisition of dedicated EW assets needed in large-scale conflicts. This reflects a growing awareness that some EW capabilities are essential. Crucial are capabilities not easy to acquire and, equally important, to be proficient with. Wise governments understand and accept that air power, including capable EW systems that can cope with a broad range of situations, is expensive but necessary. Ideally, governments invest according to capabilities by which they can achieve success rather than being bound to a fixed budget.[212]

5th-generation air power is enabled by technological advances. Technology is only of worth to national power if it stays ahead of technology developments implemented by possible adversaries, and this is what 5th-generation systems are attempting to achieve. Technology has always been important to air power and many of its practitioners tend to focus on technology as the sole means of change. Technology is pushing the capabilities of air power, and aircraft are now multi-functional platforms that can tackle diverse tasks, often within the same mission. Miniaturising electronics, increases in processing power, advances in sensor technology, improvement in materials, and more autonomy of systems are all changes that push the boundaries of what aircraft can do. However, although these changes are important to the air domain, air power is not, and has never been, solely about the technology capabilities.

Because 5th-generation technology allows a much larger and quicker flow of information to occur, organisations need to adapt to make better use of this information. Too much information can paralyse an organisation and 5th-generation systems certainly can do this. The amount of information means that air forces will increasingly rely on computer systems to analyse the information and then receive a product that is needed to make the right decision. Fortunately, technology is slowly reaching the point where computer processing power, and the important but complex programming of its processing power, enables computers to autonomously analyse incoming information and make informed decisions on which information to pass on to the humans in the loop. All these needs mean that, besides technology change, air forces need to adapt organisational structures, procedures and doctrine. These needs also call for changes while working with allied, coalition, and national forces, and with other departments that closely cooperate with air

212 Kainikara, *The Cassandra Effect*, 90.

force assets. Change is mandatory and no different from business. If a military organisation does not manage to change fast enough to react to increasing technology, it will not survive when challenged.

Most systems communicate, or will soon communicate, with other systems in the theatre and beyond, and this makes EW highly relevant in 5th-generation air power. Building and using networks is essential in the increased capabilities of modern-day forces. The high instance of systems networking, and the consequent heavy use of the EMS to achieve this, has huge implications to the field of EW and will steer the direction of developments within EW.

Networking capabilities helps armed forces build situational awareness needed to engage the enemy on their own terms, but networking also creates a vulnerability. On the one hand, interconnectivity allows for precision and time-driven targeting that is needed to quickly engage enemies while minimising own and civilian casualties. This is important since Western society rightfully demands their military to minimise civilian casualties. On the other hand, large-scale interconnectivity suggests dependency and being a target. EW is important both to continue networking on the battlefield, but also to deny the adversary the ability to network.

Tempo is the key to winning future battles.[213] The ability to assimilate huge amounts of information to gain the advantage quickly is crucial to success. The capacity to maintain the interconnectivity by winning the battle for the EMS allows troops to keep the tempo that is needed to win battles. Temporarily removing the ability to network can severely cripple modern forces because they lose tactical, operational and strategic situational awareness during conflict. The mentioned vulnerability can be particularly true to 5th-generation enabled forces. EW depends on information, either gaining or denying it, and is becoming increasingly relevant because the interconnectivity of systems on the battlefield is rising sharply. [214]

Although definitions of 5th-generation fighters vary, most include stealth, improved sensors and data collection, advanced networking capabilities, and the ability to employ advanced weapons that allow aircraft to make full use of their 5th-generation features. All 5th-generation fighters are influenced by, or influence EW in many ways.

Stealth, an EP feature of EW, gives the advantage of being able to come closer to the enemy unnoticed. Designing stealth aircraft is disadvantaged by less flexible design, and the ability to carry fewer weapons. However, their increased survivability and freedom to manoeuvre currently appear to compensate for the disadvantages. Because stealth also implies using

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213 Olsen, *Airpower Reborn*, 135-38.

214 Adamy, *Ew 104*, 171.

passive sensors, stealth aircraft better use EW sensors to gain situational awareness of the surrounding. Furthermore, EW is essential in keeping the flow of information going using the networks that link the stealth aircraft with other assets on the battlefield. Stealth is also a logical reaction to the advanced air defence systems that some countries own. Even using stealth aircraft, it is likely that combining EA and stealth is needed to survive in a modern battlefield.

Miniaturising technology from the start is important to both air power and EW as the latter influences the number and type of sensors available on aircraft. Miniaturisation leads to more types of systems making use the EMS, because small aerial systems can increasingly be equipped with a wide variety of capable sensors. Also, miniaturisation makes the sensors more capable by increasing their capacity to process the data. Since most EW equipment was initially too cumbersome to fit on all but the largest aircraft, miniaturisation first made possible airborne EW, and explains why 5th-generation aircraft can reach levels of situational awareness not possible with previous generations.

Improved sensors acquire much information that can be shared with other systems. This 5th-generation characteristic requires robust data networks that are difficult to detect but capable of sending large volumes of information. Networks can add considerable capabilities to 5th-generation forces, but they also bring a vulnerability and is the primary reason that EW is so important to 5th-generation air power. Networks can be targeted with EW assets but, without the interconnectivity, sharing information stops. Without the information flow and the ability to analyse large amounts of information to enhance situational awareness, the ability to increase the tempo of operations and improve decision superiority, is lost.

Space, cyberspace and RPAS are evolving technologies that can influence EW significantly in the next decade and beyond. All three are technologies that have seen much growth in the past decade and are increasingly influencing many areas of warfare. Smaller countries with space assets are becoming more common; their cyberspace operations are capable of damaging both military and civilian systems, and progressively more capable RPAS are allowing increased aerial presence.

Traditionally, EW enables others to reach their goals. Now, EW has its own power. The digitisation and interconnectedness of this world makes many systems vulnerable to EW. This is not necessarily negative, since governments and military demand limiting the destruction during hostilities, and EW is capable of temporarily and locally disabling certain systems. If armed forces are to operate at their best, it is necessary to affect centres of gravity simultaneously, and not in order of importance. By creating parallel effects, the opposing system can enter a state of paralysis, which will be challenging to overcome.[215] Using non-lethal forms of EW to gain effects is often a retrograde step from physical destruction and allows forces to influence multiple Warden's rings to reach strategic paralysis; something not always possible if only kinetic effects are used.

EW influences all aspects of modern warfare. Because EW is such an important tool in 5th-generation forces, there is an increased need to educate a wider audience in aspects regarding EW. Because of its technical nature, EW is not an easy topic to grasp; the knowledge of airborne EW, even within air forces, is often inadequate. This lack of knowledge is not solely due to the complicated subject matter or a lack of interest. EW is a sensitive field, and this further complicates the education challenge. The unfortunate but understandable lack of knowledge, coupled with the high cost of EW, can make policy and decision makers question its need.

In many theatres, air power assets cannot operate without a healthy balance of EW systems that support the various aircraft used. The battle in the EMS must be won, and in this modern age, increasingly capable EW systems are needed to achieve this. Much of the fight for airborne EW is political. Politicians and military leaders must educate themselves carefully in the advantages and disadvantages of air power and the accompanying EW assets. Education helps when deciding which tools of their national power are best suited to handle situations. Responsible governments will strive to own a diverse range of capable air power assets, including extensive EW capabilities, to cope with the various conditions of a rapidly changing global order. Ensuring both military and policy makers understand air power, what to acquire, when to use it, and of equal importance, when not to, is a crucial step to building a competent 5th generation force with superior electronic warfare abilities.

215 Olsen, *Airpower Reborn*, 71.

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Defence forces worldwide need to transform their air forces into organisations that can accommodate 5th generation air power technologies in joint warfighting. Within 5th generation organisations, electronic warfare deserves considerable attention. Air power in a high threat environment cannot be successful without vast defensive, and increasingly offensive, electronic warfare capability and support. In a 5th generation information driven air force that is highly reliant upon communication to achieve maximum effects, effective electronic warfare capabilities must be assured to gain and keep control of the electromagnetic spectrum by today's and tomorrow's joint warfighters. There is a symbiosis between air power and electronic warfare.

This book:

- Describes the historical symbiosis between air power and electronic warfare
- Delves into the contemporary effects of defensive and offensive electronic warfare and the relationship with air power
- Examines various military, technological and societal developments affecting electronic warfare
- Pinpoints 5th generation developments in joint warfighting that are both influencing, and being influenced by, electronic warfare
- Discusses the potential for electronic warfare to increasingly create significant effects in warfare, thereby rising above the role of an enabler.

The reader will gain a deeper understanding of the importance of electronic warfare within air power, as well as insight into factors surrounding the critical relevance of electronic warfare to 5th generation warfighters.