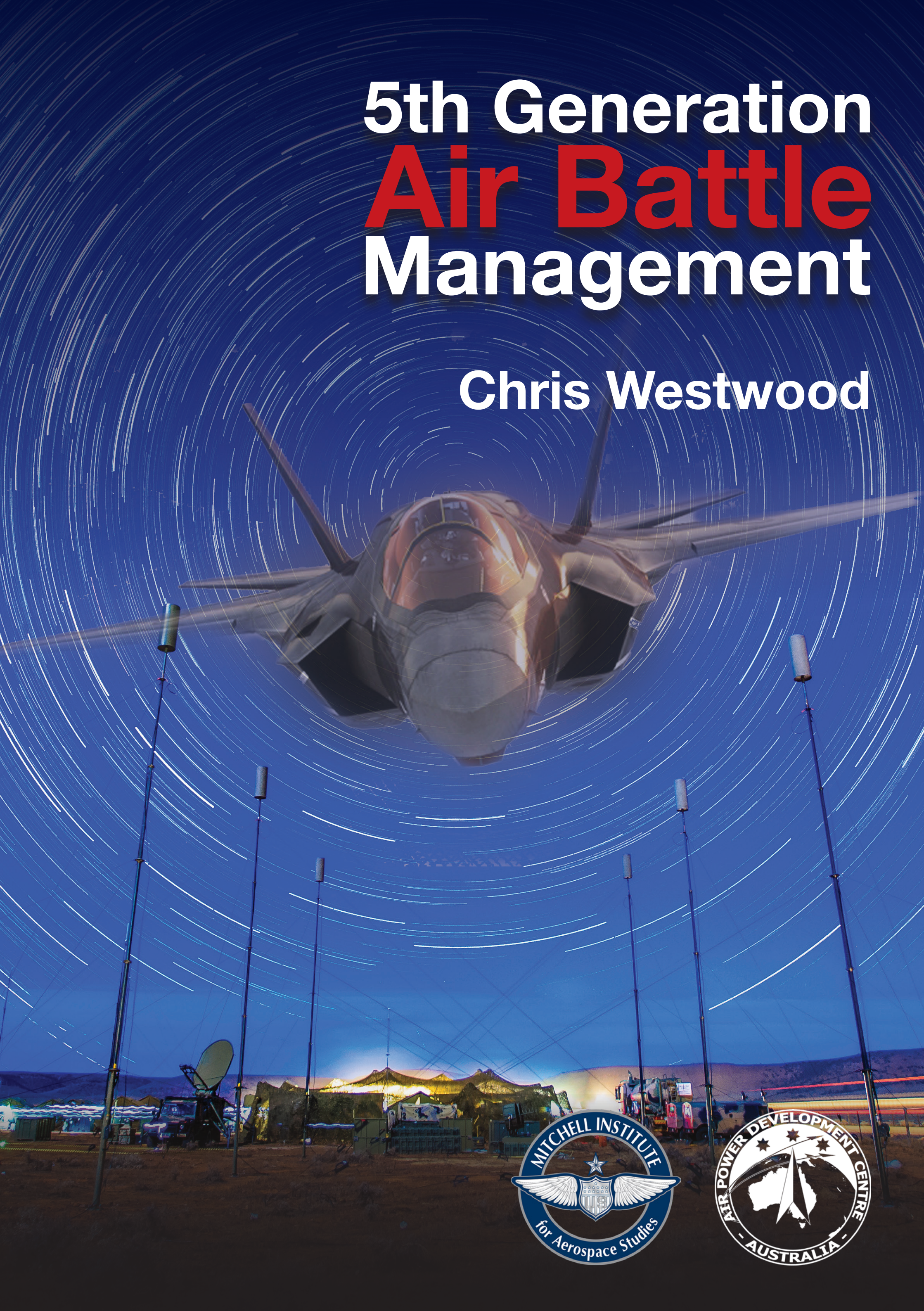
5th Generation Air Battle Management

Chris Westwood



Mitchell Institute for Aerospace Studies
Air Power Development Centre Australia

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ABOUT THE AUTHOR

Air Commodore Chris Westwood (Retired) served for 34 years in the Royal Australian Air Force (RAAF) as an Air Battle Manager, retiring in 2016 as Commander of the RAAF's Surveillance and Response Force Element Group. He served in command, operational and executive appointments throughout the RAAF's ABM functional capabilities, including the Air Defence Ground Environment, Jindalee Over-the-Horizon Radar System, and E7A Wedgetail AEW&C (during acquisition).

Since leaving the RAAF, Chris has maintained his interest in advocating for technical warfare capabilities as an independent consultant, particularly in the ABM environment. He Chairs a technical start up company, and provides coaching and mentoring to future leaders.

Chris has published various articles, papers and a book, mostly themed around the application of technology in warfare. He holds a Master of Arts (Strategic Studies) (2009), an MBA (1997) and a CAF Fellowship (1996).

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FOREWORD

The U.S.-Australia alliance is a cornerstone of peace and prosperity in the Indo-Pacific. Australian and U.S. forces have shared battlespace in every major conflict since World War I. We continue to operate together on a regular basis to fortify our shared global interests. Yet, both nations face an increasingly challenging, multi-faceted threat environment that will require their Air Forces to dramatically rethink how they employ aerospace power in support of their respective interests and common interests advanced through a shared security strategy.

This paper is the first instance in what promises to be an enduring and meaningful collaboration between the Mitchell Institute and the Royal Australian Air Force's Air Power Development Centre to advance the aerospace power dialogue. The effort is also particularly timely as both the U.S. and Australian Air Forces undertake critical modernization efforts to regain the competitive advantage necessary to deter and, if necessary, defeat potential adversaries in future conflicts.

Underpinning modernization efforts is the shared recognition that success in the future battlespace depends foremost on the speed and integration of information. The sheer volume and quality of information available to fifth-generation fighters, given their multi-spectral sensors, processing power, and connectivity, means they represent a leading element in this new operating paradigm. The concept of a *Combat Cloud*, however, transcends not just fifth-generation fighters, but also aerospace power writ large. By harnessing technological advancements in computing and information technology, the Combat Cloud promotes the ubiquitous and seamless exchange of information across platforms, domains, services, and coalition partners. This will enable commanders to make faster decisions that better integrate actions across domains in a manner that enhances the effectiveness of the whole, compensates for vulnerabilities, and maximizes overall capacity to exploit opportunities.

Practitioners of aerospace power will quickly recognize the close connection the Combat Cloud has with battle management, which combines situational awareness, operational decision-making, and force direction. Chris Westwood offers an insightful overview of what '5th Generation warfare' looks like in the Air Battle Management context, to include the leverage provided by Combat Cloud functionality. Critically, he underscores that transitioning from an industrial age paradigm to one required in the information age is not just about hardware and software, but instead requires a holistic approach based on a common vision that spans the entire defense enterprise.

The imperative for change is clear, as our adversaries are pursuing similar concepts to harness information to achieve a powerful military advantage. On each other's wing as in past challenges in peace and war, our nations' air forces must adapt to sharpen our collective aerospace power edge beyond that of all adversaries.

LTGEN David Deptula (USAF ret'd)
Dean, Mitchell Institute for Aerospace Studies
June 2020

FOREWORD

I am pleased to introduce this paper as the first step in what we anticipate will be a long and fruitful collaboration between the Mitchell Institute and the Royal Australian Air Force's Air Power Development Centre. Both organisations have established an enviable track record for contributing to national- level air power discussions, and now, by working more closely together, we hope not only to cement the close friendship between our two Air Forces, but also to capitalise on the synergies that come from shared intellectual endeavour. Of course, this is representative of the deeper connection between the United States and Australia.

Indeed, now more than ever, Australia's close friendship with the United States is providing an essential underpinning of strength and resilience to our shared interest in the security of the Indo-Pacific. There can be little doubt the regional security environment has evolved significantly, with competition and rivalry having become defining features.

So we're seeing a diversification of the circumstances where air power will need to contribute to our national security and prosperity goals. That's why we need to go from platform-oriented thinking to effects-oriented thinking in our development of future air power options. In addition to traditional combat power, air power must be able to deliver effects that will be relevant across the spectrum from cooperation to competition to conflict. Air power's value will be measured by its ability to achieve synergies across domains to generate access, presence, influence, and deterrence in support of our national security goals.

At the same time, Australia has been undertaking a fleet-wide update to our platforms, almost unprecedented in our history. This will see our focus shift from standalone air power capabilities, to a networked fleet capable of delivering effects in our region. But as members of the Profession of Arms, we must guard against the tendency to focus only on winning in battle in our respective domains. Building the capacity to engage in the contest of ideas helps hone the intellectual edge we see as critical to prevailing against non-traditional threats into the future.

This paper rightly acknowledges the new paradigms of the battlespace in which 5th generation assets will need to operate. But we cannot hope to succeed if we only rely on traditional understandings of military utility. For air power to realise its full potential in an age of heightened competition, we need to recalibrate our thinking so that air and space power become tools of national power that are constantly operating. Not just in outright conflict scenarios, but all the time, for national influence.

GPCAPT Jarrod Pendlebury
Director, Air Power Development Centre
June 2020

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INTRODUCTION

There has been a lot written and spoken about 5th Generation warfare since Lockheed Martin coined the term to describe the significant leap in technology and capability associated with the F-22 and F-35. The 5th Generation technologies as applied to fighter aircraft are characterised by very low-observability and vastly improved situational awareness through a network-centric combat environment.[1] A recent Royal Australian Air Force (RAAF) working paper authored by Dr Peter Layton, *Fifth Generation Air Warfare*, provides a comprehensive overview of the 5th Generation air warfare construct.[2] Dr Layton's paper brings together much of the published literature into a compelling treatise that explains both offensive and defensive aspects of the 5th Generation air battle, as well as venturing beyond the US views of 5th Generation, providing a description of both Chinese and Russian approaches.

Dr Layton rolls up 5th Generation air warfare technologies into four parts: Networks, Combat Cloud,[3] Multi-Domain Battle, and Fusion Warfare. In doing so, he has helped move the fifth-generation discussion on from the F-35 and F-22, and into the environment within which the fifth-generation battle will be fought. Military theorists such as Dr Layton, LTGEN (USAF ret'd) David Deptula, RADML (USN ret'd) Mike Manazir, and Wing Commander (RAAF) Chris McInnes,[4] amongst others, are now thinking and publishing holistically about 5th Generation warfare - the environment, the Command and Control (C2) demands, and importantly, the organisational and the human requirements that follow.

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1 https://www.airforce.gov.au/our-mission/fifth-generation-air-force

2 Layton, Dr Peter, *Fifth Generation Air Warfare,* Working Paper 43, Royal Australian Air Force, Air Power Development Centre, June 2017.

3 First published by: Deptula, Lieutenant General (USAF Ret.) David A., *Evolving Technologies and Warfare in the 21st Century: Introducing the 'Combat Cloud '*, The Mitchell Institute for Aerospace Studies, Arlington, 2016.

4 McInnes, Wing Commander (RAAF), Chris, *My Fifth Generation,* The Sir Richard Williams Foundation – The Central Blue, 2017.

The aim of this paper is to examine what 5th Generation (hereafter referred to '5th-Gen') looks like in the Air Battle Management (ABM) environment. The paper will deconstruct 5th-Gen into its component parts, and in so doing, propose a baseline characterisation to help a broader audience understand what 5th-Gen is, why 5th-Gen is real, and why it is important. The paper offers a model as a lens through which a simple characterisation of '*n*-generation' can be explained. The paper traces the history of ABM through this model to set the context for the characterisation of the future of ABM as an important element of a Multi-Domain Command and Control (MDC2) endeavour. The paper describes some of the human challenges that will accompany the transition from 3rd and 4th Generation Air Battle Management to 5th Generation Air Battle Management (5G-ABM). While the paper focuses on the air domain, many of its observations apply across all warfare domains.

THE GENERATIONAL TRIAD MODEL

When discussing generational change, many commentators interweave concepts, technologies, threats, missions, the environment and similar constructs, creating a new language along the way that makes the conversation largely 'community-based'. This can make it difficult to explain what exactly the *generational change* is, particularly in highly complex areas such as defence, especially to those from outside the community. Regardless of the domain, it is in the whole community's interest to be able to explain generational change in simple words, using common and plain language. The Generational Triad Model seeks to do this, initially agnostic to the subject matter and domain.

Generational change happens when three inter-related axes meet:

- When new technology enables, invites, or indeed demands changes in thinking;
- When foundation architecture[5] facilitates the effective use of that new technology and concepts;
- When the intersection of technology and foundation architecture causes a change in the *nature* of the activity – that is, not just *how* an activity is undertaken, but *what* is actually being undertaken.

Along with these three axes, there exists a series of human considerations that can either help or hinder the ability of an entity to embrace and compete in the changed environment: policy, organisation and people sit at the heart of this model and represent the 'levers' available to an entity. At the top of the axis is the 'threat', often a forcing function in its own right. This model is as relevant to the corporate world as it is to the defence and geo-strategic environments. Figure 1 depicts this relationship.

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5 'Foundation Architecture' is discussed later in this paper.

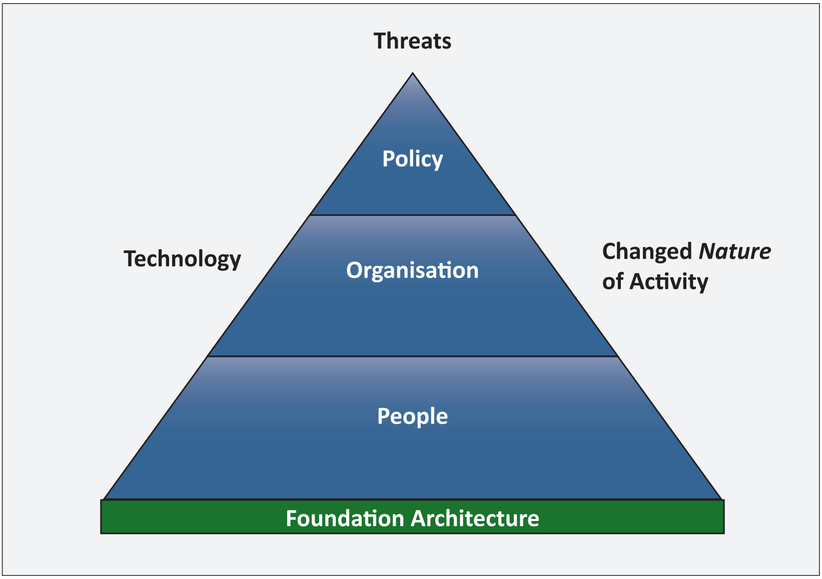

Figure 1 - The Generational Triad Model

Most of the individual elements included in this model are not static. Technology continually evolves; threats change; and policy, organisations and people also change or adapt over time. Even architectures change within the constraints of their foundational characteristics. A closed architecture will seldom allow its foundations to adapt to enable new or revolutionary technologies to be easily and quickly integrated. Instead, new technologies are often 'bolted on' to the existing architecture, often impairing the effectiveness of these technologies, until such time as that revolutionary change is demanded by the user community, motivated by the need to meet emerging threats or by the promise of the technology itself.

The one key area that indicates a revolutionary change *is* occurring is where the *nature* of the activity changes. The advent of the iPhone and its associated 'apps' represents a recent example where society has fundamentally changed the nature of what it does, not just in how it makes phone calls. There are many other examples: the printing press, the automobile, television, space exploitation, the Internet. All of these and many others fundamentally changed the nature of human activity in their specific domains causing 'Generational Change'.

In technology terms, this phenomenon is the first step in the 'S-Curve'.[6] While technology evolves continually, periodically a technology is introduced that provides a catalyst for a 'step' into a new future, where the nature of what we do is fundamentally changed. This is when a generational change occurs. This is where '5th-Gen' (or '*n*-Gen') as a construct in military conversation has its origins.

An Example from History – The Battle of Britain

The Battle of Britain lends itself to an introductory explanation of the Generational Triad Model. In the 1930s Britain developed technology that led to the emergence of the Spitfire and Hurricane fighters. At the same time the Chain Home radar network was developed, along with a sophisticated communications system, which allowed 'detections' of enemy aircraft to be displayed inside a central operations facility at Bentley Priory near London. Here specially trained RAF officers would prioritise threats and assign them to one of the four Groups established as part of the 'Dowding System'.[7] Once a raid appeared on a Group Operations Room map table, a 'Fighter Controller' would review the situation and decide when and where to 'scramble' his squadrons to defend against the incoming raid. He would communicate with the appropriate Sector and order the squadrons into the air. The Sector Fighter Controllers guided their pilots to an interception with the German aircraft. This process connected the battle management elements (radar, communications and C2) with the response assets, and ensured that scarce fighter resources were in the right place at the right time, creating the world's first Integrated Air Defence System (IADS).

The air defence of the UK could now be orchestrated in something approaching real-time. Integrated Air Defence became a new role for the British armed forces and one that would change the nature of warfare thereafter.

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6 http://www.galsinsights.com/the-innovation-s-curve/

7 http://beyourfinest.com/dowding-system-2/

While the advent of technology was important in the Battle of Britain, it was the orchestration via the first IADS that proved decisive.[8] This was acknowledged by Winston Churchill:

> "The Germans would not have been surprised to hear our radar pulses, for they had developed a technically efficient radar system which was in some respects ahead of our own. What would have surprised them, however, was the extent to which we had turned our discoveries to practical effect and woven all into our general air defence system. In this we led the world, and it was operational efficiency rather than novelty of equipment that was the British achievement".[9]

The Generational Triad Model in a *Battle of Britain* context is represented in simple terms in Figure 2.

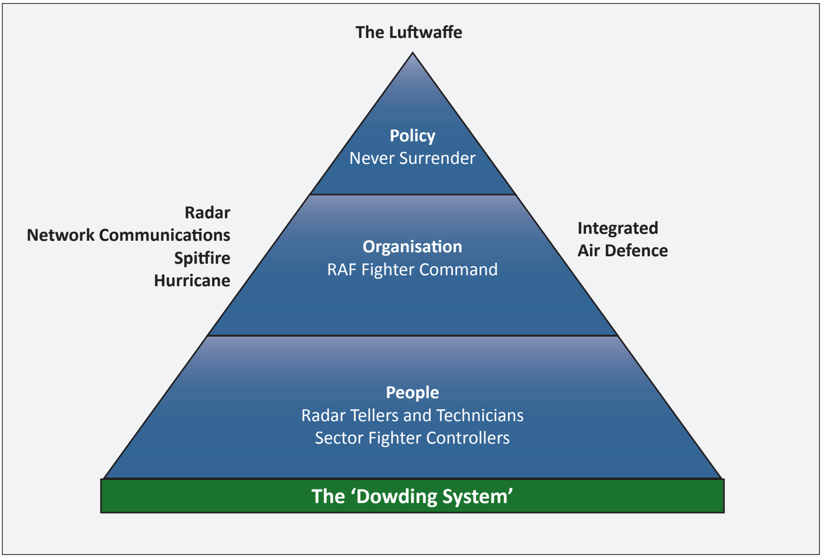

Figure 2 - The Generational Triad Model: The Battle of Britain

8 Newsletter of the James Clerk Maxwell Foundation, Issue No. 8, Spring 2017.

9 Winston S Churchill, *The Second World War Volume 1 – The Gathering Storm,* Houghton Mifflin Company, Boston 1948, P 140.

FROM 1ST GENERATION INTEGRATED AIR DEFENCE SYSTEMS TO 5TH GENERATION AIR BATTLE MANAGEMENT

A brief review of the generational increments in ABM from the Battle of Britain provides a useful context to consider what 5G-ABM will look like. These generational increments are illustrated in Figure 3.

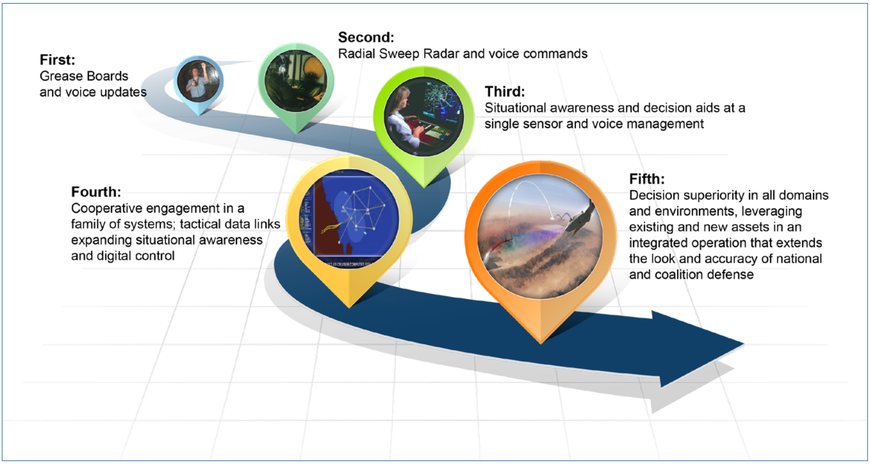

Image courtesy Lockheed Martin

Figure 3 - Progression of ABM to 5G-ABM

- **1st Generation ABM**. The 'Dowding System' that underpinned the RAF's victory in the Battle of Britain represents 1st Generation ABM – the first Integrated Air Defence System (IADS). This type of system was quickly copied around the world as an effective way of connecting ground-based technology, C2 and response assets. In Australia the RAAF was given responsibility for ground-based early warning radar operations on 7 November 1941. From this date until the end of hostilities on 15 August 1945, a total of 142 ground radar units were brought into operation. More than 6 000 RAAF and Women's Auxiliary Australian Air Force (WAAAF) personnel operated these radars and their associated Fighter Control Units (FCU), serving in this 'secret war' of communications and electronic technology.[10]

- **2nd Generation ABM**. Following WWII, ABM was characterised by radial sweep radars on land and at sea, operated by Radar Plotters and Fighter Controllers, utilising organic communications to 'direct' aircraft, missiles and guns, typically in the Air Defence/Anti-Air Warfare role against 'enemy' bombers. Sophistication was increased as the effectiveness of the sensors that fed the C2 system was enhanced, as jet fighters became commonplace, and as the technologies and capabilities of organic voice communications were developed.

- **3rd Generation ABM**. In the late 1950s and early 1960s, the first of the rudimentary computerised ABM 'systems' began to emerge, firstly in the NATO Air Defence Ground Environment (NADGE) and the US Semi-Automatic Ground Environment (SAGE), then gradually around the globe, including in Australia.[11] The introduction of computers to the ABM environment generated early decision support aids, and enabled computer-generated symbology to be manually placed alongside radar detections, along with the listing of related aircraft and mission data in 'totes'. These symbols were known as 'tracks'. These tracks could be passed throughout the C2 system via terrestrial circuits or by voice. In effect this broadened the role of ABM systems to an Area Air Defence role, and in some cases to National[12] and Regional[13] levels. The concepts and doctrine supporting Area Air Defence began to proliferate in the mid 1970s and 1980s.

- **4th Generation ABM**. ABM systems leveraged the rapid growth of information technology and availability of communications

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10 http://www.raafradar.org.au/WWII_1939_-_1945.html

11 The RAAF's 'HUBCAP' System was introduced in 1967.

12 For example, Australia's National Air Defence and Airspace Control System (NADACS) concept, published as JSP (AS) 13 circa 1980.

13 For example, NATO's NADGE was converted into NATINADS in 1972, joining 84 radar sites and associated CRCs throughout Western Europe. NATO AWACS was later integrated into the NATINADS.

bandwidth in the 1990s and 2000s. Digital information from multiple dissimilar sensors could now be processed to form a much richer picture of the airspace. Airborne C2 systems such as the E-3 AWACS, E-2 Hawkeye, and later the E-7 Wedgetail, acted as mobile sensors, ABM and communication 'nodes', enabling eyes and ears to be much closer to the edge of the battle-space. The sharing of the air picture throughout the C2 environment became common-place. More advanced sensor technology, including phased array radar, integrated Electronic Warfare capabilities, trusted combat mission systems, and cooperative communication and data link capabilities, were now operated by a new breed of Air Battle Managers (ABMs) with far greater inherent IT and network literacy that was part of the 'Gen Y' workforce persona. ABM operations became increasingly domain-agnostic. The ABMs effectively transitioned to become Joint-ABMs, operating simultaneously with air, maritime and land forces.

Yet even as these 4th-Gen systems are still being fully realised and fielded, movements in technology indicate that the next generational change is already upon us. Spearheaded by the arrival of 5th-Gen aircraft (both as a friendly capability and as a threat), and through technologies and foundation architectures that have been largely derived from these aircraft, 5G-ABM is imminent.

5G-ABM THROUGH THE LENS OF THE GENERATIONAL TRIAD MODEL

Figure 4 applies the Generational Triad Model to the key characteristics of 5G-ABM. Each of the components of the model is discussed in detail below.

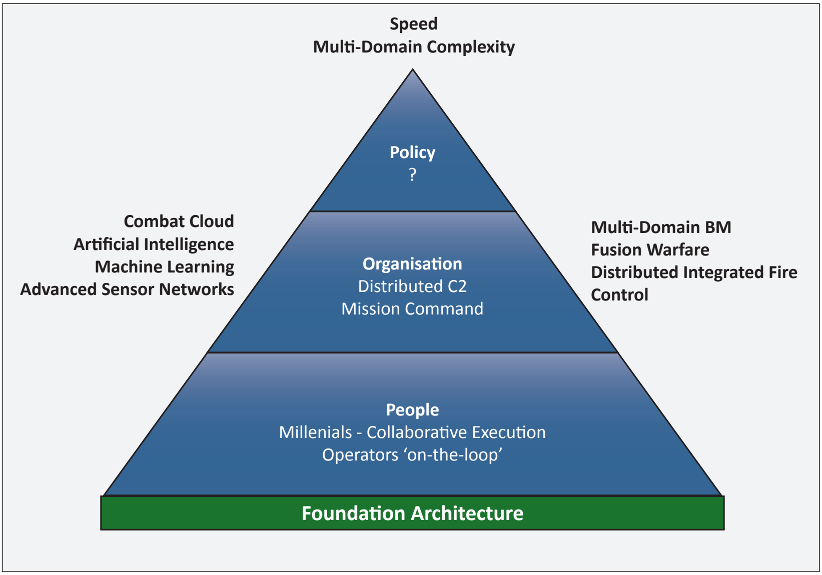

Figure 4 - The Generational Triad Model: 5G-ABM

Threat

The uniqueness of the 5th-Gen threat environment is not so much characterised by hostile or rogue nations with overwhelming military capabilities and the intent to use them, or the lethality of specific weapons systems or technologies. All of these are, and always have been, important factors when considering the nature of the future battle space, and determining a suitable force structure, and doctrinal and conceptual response. The threat characteristics that make the 5th-Gen threat environment so much more challenging than previous generations are the *speed and launch distance* of effects, and the *multi-domain complexity* of the battlespace. The blurring of the boundaries between kinetic and non-kinetic components complicates these characteristics.

Within the Indo-Pacific region, three states (China, India and Russia) are known to be developing hypersonic capabilities that can travel at 5 km/s at very high altitudes whilst manoeuvring to avoid counter-attack. This region also has numerous territorial and cultural disputes that continue to evade resolution. Periodically, these disputes escalate quickly into localised conflict. Recent examples of this are the action between India and Pakistan in Kashmir, and the maritime encounters between Vietnamese and Chinese craft in the South China Sea.

While global trade and communications have increased inter-relationships between states, they have simultaneously increased trade tensions and reduced the reaction time during periods of increased threat. High-speed, long range, precision weapons may change the existing balance between military, diplomatic and economic responses to disputes. Localised conflict may well escalate quickly as different interpretations of the 'rules-based global order'[14] are applied. Action that was previously seen by states as unacceptable may now be worthy of consideration.

Countering the high-speed weapon threat compresses reaction times. When combined with increasingly subtle and fleeting detectable signatures, the challenge of sensing and the subsequent extraction of timely, actionable intelligence to inform a BM System becomes very difficult. These characteristics drive an imperative for sensing systems capable of 'strategic reach', and an ability to correlate disparate, weak signals (i.e. indicators and warnings) from across many sensing domains. The need to discover signals from across disparate sources in itself then drives a need for predictive analytics – the ability to most effectively apply Intelligence, Surveillance and Reconnaissance (ISR) resources in a way that maximises the probability of discovering the key 'missing pieces'.

These considerations underpin an emerging imperative for multi-domain operations (MDO), with enhanced emphasis on space and cyber capabilities (strategic reach), and all-source fusion (to counter the weak signals) informed

14 Leslie, Josh., *The Problem with Rules-Based Global Order as Strategic Policy Guidance',* The Regionalist No. 2 – Institute for Regional Security, 2016.

by predictive analytics. The MDO concept takes joint warfighting to another level, and presents a fundamentally different challenge to the BM systems, including in the 5G-ABM environment.

Technology

The technologies that are creating the 5th-Gen 5G-ABM environment are somewhat inter-twined, but can be broadly grouped under three areas: the Combat Cloud, Artificial Intelligence/Machine Learning and Advanced Sensor Networks. The technologies that underpin these areas are now very real and are being rapidly developed around the world as nations and industry players seek to pull lead on each other in the 5th-Gen sprint.

The Combat Cloud. The 'Combat Cloud' as a concept was introduced in 2016 by LTGEN (Ret.) David Deptula, Dean of the Mitchell Institute for Aerospace Studies.[15] He defined it as "an operating paradigm where information, data management, connectivity and C2 are core mission priorities…. The concept represents an evolution where individually networked platforms – in any domain – transform into a 'system of systems' enterprise, integrated by domain and mission agnostic linkages."[16] This concept was visionary, but perhaps somewhat aspirational in 2016. Today (only four years later), the technologies needed to realise the combat cloud are real and have begun to leave the labs. Likewise, the foundation architectures that will enable these technologies have now matured to the extent that fielding is imminent. The Combat Cloud, as a tangible and definable 'framework,' could be deployed within the next few years. Key technical characteristics that have enabled the Combat Cloud include:

- *Low SWAP-C, High Performance Computing*: Foundational to 5th-Gen systems is high performance computing systems with low space, weight, power and cooling (Low SWAP-C) requirements. The ability to put large amounts of computational horsepower on tactical platforms is the enabling technology for all other technological

15 Deptula, Lieutenant General (USAF Ret.) David A., *Evolving Technologies and Warfare in the 21st Century: Introducing the 'Combat Cloud '*, The Mitchell Institute for Aerospace Studies, Arlington, 2016.

16 Deptula, p1.

advances that make the combat cloud and 5G-ABM possible. Now, every node on the network has the potential to be both a control and a communications node. This has given rise to the potential for Distributed Control Nodes (DCNs). With the addition of very few 'generational bridges' (in most cases only software), almost any deployed asset can contribute to the sensor and communications networks. This in turn enables C2 and BM functions to be much more resilient than in 3-4th Gen, and able to survive even the most complex of network attacks. This gives rise to the C2 concept of 'Agile Control', which was recently described in the 'ADF Concept for Command and Control of the Future Force'.[17]

- *Intelligent Multi-Modal Networks (IMMN):* A critical technology for combat cloud functionality is the capability to monitor multiple tactical and strategic networks for status and available bandwidth, and to autonomously route data and message traffic across the available communications bearers based on current and anticipated prioritised information needs and anticipated threats. This capability needs to coordinate across those nodes that are fully IMMN-enabled and, importantly, with platforms in the combat cloud that are unaware of the IMMN, such as legacy aircraft, ships, and land platforms.
- *Closed-Loop, Multi-Sensor Distributed Fusion:* Automatic real-time fusion of multiple types of data collected by sensors distributed across the battlespace is key to situational awareness, particularly in a world dominated by 5th-Gen stealthy platforms. An automatic, closed-loop concept is where sensors throughout a theatre provide their information to a fusion network, the fusion engine will automatically detect when it needs more information and from where, and will then provide controls to the sensors to provide that information. This control of sensors by the fusion engine is based on real-time information requirements. The 'Distributed Fusion' process is where one fusion engine can communicate with other fusion engines (potentially DCNs) to influence how sensors are used to ensure the

17 'The ADF Concept for Command and Control of the Future Force', Version 1, Commonwealth of Australia, 2019.

system of systems is robust against loss of communications links to natural causes or enemy action.

Artificial Intelligence/Machine Learning. A key technology driver for the 5G-ABM environment is the advancement of automated decision-making, and human/machine teaming needed to facilitate huge information sets and faster-than-human speed of command. Machine learning is nothing new; it has been under development for four decades. However, recent advances in techniques for unsupervised or minimally-supervised machine learning, combined with the availability of massive amounts of affordable computational power and very large datasets, has thrust this technology into the forefront of military (and commercial) system development. Machine Learning has made it practical to field automatic systems for learning patterns of life and detecting deviations from those patterns across multiple domains. Critical applications already include detecting cyber intrusions and attacks, and finding suspicious or hostile actors hiding in a sea of routine activity.

In 2017, AlphaZero, the game-playing AI created by Google sibling *DeepMind*, beat the world's best chess-playing computer program (Stockfish 8) in a 100-game contest (90 wins, 8 losses, 2 draws). AlphaZero taught itself how to play in less than four hours, using a machine-learning approach, given no human input apart from the basic rules of chess.[18]

If the same process is applied to the 5G-ABM environment, ultimately the human is unlikely to be able to compete across a range of activities. In some applications, such as real-time management of complex sensor networks, this appears to be a very attractive option. In others, such as enabling weapons engagements, this presents clear doctrinal and policy challenges, both internally to military C2, and more broadly at national and international levels. The policy implications are discussed later in this paper. Suffice to say, left unchecked and if supported by a 5th-Gen foundation architecture, the development of AI and Machine Learning will undoubtedly force a change to the nature of the BM activity as 5G-ABM matures. Other members of this technology family include Data Analytics and Autonomy:

18 https://www.theguardian.com/technology/2017/dec/07/alphazero-google-deepmind-ai-beats-champion-program-teaching-itself-to-play-four-hours

- *Data Analytics:* Beyond the capabilities of machine learning, data analytics drives the discovery of new relationships in data collected by the 5G-ABM system of systems. Advances in IT power modern Data Analytics. The vast amounts of data available can now be mined via automation, with the machine detecting anomalies that have historically remained hidden below the noise. This leaves the human to steer the algorithms that set the rules of automation, then focus their efforts on the mining output. The human tells the machine to look for a pattern; the computer finds the pattern and points it out to the analyst or operator. Even with the massive amounts of data that will be available to the 5G-ABM system, Data Analytics will enable mining to be undertaken in real-time.
- *Autonomy:* While some 4th Gen BM systems included a limited level of system automation and tactical decision aids, advances in machine autonomy hold out the promise of moving the human from their current position 'in-the-loop' for sensor processing, track management and engagement management to a new position 'on-the-loop'. This enables the operators to focus on decision-making based on processed information – which is the strong suite of human intelligence – rather than the routine massaging of data into information, which is well within the capabilities of current machine autonomy.

Advanced Sensor Networks. The early revolutions of the ABM environment were based largely on the development of radar and associated communication systems. In Gen 1-3, advances in radar technology were a key feature of the ABM system development. By Gen 4, radars were becoming far more sophisticated and were joined by EW sensors. 5G-ABM takes this sensor evolution to a significantly greater level. Multi-static and multi-frequency sensor networks (including multi-band) are increasingly being developed to provide enhanced performance against stealthy platforms while also providing some protection against kinetic and electronic threats. Electronically steered arrays are becoming the 'norm' in 4th and 5th-Gen sensor development, enabling operators to select targets and 'scan doctrine' and increasingly leaving the energy/time management function to the sensor control system.

5th-Gen sensor networks will take this concept and apply it to the entire sensor network, increasing both effectiveness of the sensor network through the application of the best sensor and waveforms available to meet the real-time characterisation needs, and efficiency by closely managing the sensor network resources as a whole. This is referred to as Enterprise Sensor Management. This includes understanding sensors that can be controlled, and also passive data feeds that cannot be controlled, e.g. Overhead Persistent Infra-Red (OPIR), Air Traffic Control (ATC) radars, etc. Coupled with distributed fusion, the 5th-Gen Enterprise Sensor Management will provide a real-time optimisation function that humans simply cannot match. Add 'self-healing' to the Enterprise Sensor Management, and negative influences on the overall sensor net can be countered, again in real time. These influences might include kinetic or non-kinetic effects, communications disruptions, atmospheric issues, unforseen unserviceabilties etc. Add machine learning to this mix, and the 5th-Gen sensor network offers a substantial capability edge over its 3rd and 4th Gen forebears. There are also other members of this technology family that are set to fundamentally change the nature of the BM activity:

- *F-35 Sensor and Datalink Capabilities*: The F-35 will come into operational service as the most advanced, fully integrated, fully fused package of multi-spectral optical and RF sensors in aviation history. Described as having Joint Director of Laboratories (JDL)[19] 'Level 4' fusion, this system automatically manages itself, detecting signals across relevant operational bands with unprecedented time and angle accuracy, and analysing which signals hierarchically require further analysis using operator and threat-based prioritisation. The system actively manages both active and passive collections against related tracks, as required, maximising situational awareness while significantly reducing operator workload. Using an advanced high-bandwidth stealthy datalink, each aircraft shares its observed tracks with other F-35s, increasing the speed and accuracy with which the formation can characterise the threat environment across large

19 White, Franklin E. *Data fusion lexicon*. Data Fusion Panel, Joint Directors of Laboratories, Technical Panel for C3, Washington DC, 1991. https://apps.dtic.mil/dtic/tr/fulltext/u2/a529661.pdf

volumes of the battlespace. Relevant tracks can then be shared across common data links like Link-16. In the future, additional methods for transmitting this rich volume of decision-quality information will be available for distribution to 5G-ABM networks and other platforms, effectively bringing these advanced sensors directly into the 5G-ABM systems, and thereby connecting, or perhaps creating, the 5th-Gen battlespace.

- *Passive Sensors:* The BM counterpart to stealthy platforms is situational awareness with little or no active emissions. Advances in data fusion now enable tracking and classifying of platforms operating in the battlespace using ESM sensors when geometries are favourable. Passive radar enables tracking platforms in environments where there are sufficient background emitters. The wide deployment of commercial wireless communications over an increasing portion of the globe is fundamentally changing the characteristics of sensor networks over land and the littoral space. In addition, traditional passive sensors have been somewhat limited in their ability to provide large amounts of data across a battlespace to a sensor network, especially when compared to active sensors. This is about to change. Some modern ESA radars are being developed with an inherent passive sensor capability with very wide-band front ends, ingesting radiation across large bandwidths and geography. They will have the capabilities to capture huge amounts of data.

Foundation Architecture

The technologies discussed above are revolutionary, but they will fall short without a 5th-Gen infrastructure designed to allow them to function to their full capacity, within the environment that they are intended to be used in, and for the purposes for which they are being developed. In other words, the foundation architecture needs to be designed and built from the ground up with these technologies and the demands of the future battlespace at the front of mind. Continual evolution of 3rd and 4th Gen architectures with emerging technologies 'bolted on' may have been historically adequate for a peacetime training role, or in an operational but uncontested environment. However, for the future 5G-ABMs that are perhaps making their first contact with the Defence recruiting agencies today, that is not good enough – they deserve to be equipped with a foundation architecture that will embrace, and continue to embrace, technology to enable them to fight and win.

A 5th-Gen battlespace demands a move away from large-scale, closed proprietary infrastructure, to agile, affordable, company-agnostic frameworks that will both survive and function in a future peer-contested military battlespace. Key to this foundation architecture are two principles: the architecture must be truly open; and the architecture must be designed and built from the ground up to operate in an intense and genuine 5th-Gen operational environment.

Open Foundation Architecture. One of the key lessons learned from acquiring and maintaining the 4th generation ABM systems is that building systems, and systems of systems, on an open architecture foundation reduces sustainment costs by as much as 50%, while freeing the system acquirer from the tyranny of the OEM.[20] This is why the US Government has mandated that future major defence acquisition programs must employ open systems architectures using a Modular Open Systems Approach (MOSA).[21]

A key benefit of employing Open Architecture is the ability to add and remove capabilities as things change. These capabilities can be 'best of breed' and/or off the shelf if desired, agnostic to the developer of the capability being sought. This is often referred to as 'Rapid Capability Insertion – RCI'. These days a more correct term would be 'Multi-Speed Capability Insertion – MSCI.' The speed at which capabilities are inserted into a BM System should be entirely up to the end-user. Some capabilities will need to be inserted as quickly as possible to meet a threat or changing military, government or funding priorities. Conversely others may wait to enable allies to make the change at the same time, or even choose to delay until bugs and interoperability issues are ironed out. There may also be sovereign and/or

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20 Zimmerman, Phil, Tracee Gilbert, and Frank Salvatore. *'Digital engineering transformation across the Department of Defense.'* The Journal of Defense Modeling and Simulation (2017): 1548512917747050.

21 Congress, U. S., Title VIII, Subtitle A, Section 805. *'S. 2943 National Defense Authorization Act for Fiscal Year 2017.'* (2017). https://www.congress.gov/bill/114th-congress/senate-bill/2943/text

industry priorities to consider. The 5G-ABM system must be flexible in this regard.

With a truly open architecture, the acquirer is no longer obliged to acquire through the OEM with rigid timelines and large scale, expensive upgrade programs. Governments and militaries around the world should be insisting on truly open standards for 5th-Gen architectures. This of course demands an open business model as much as it does an open architecture.

Redundancy and Resilience (R2). Redundancy is 'the inclusion of extra components which are not strictly necessary to functioning, in case of failure in other components'[22]. Resilience is both the capacity of a system to operate through an attack, and to recover quickly from damage sustained, whatever may be the cause. These two concepts are merging in 5th-Gen as redundancy becomes less a physical construct, and more architectural in nature, and as resilience is being 'baked' into a system's architecture.

- *Redundancy:* 5G-ABM systems will be increasingly targeted with highly synchronised, multi-domain, multi-source effects. Therefore, unlike 3G and 4G systems, 5G-ABM systems will not necessarily choose physical redundancy as a first step in mission redundancy, such as back up facilities, communications and spare sensors etc. Instead, redundancy will be architected into the whole capability. Each node will have a full set of functional capabilities that are available in software, enabled by low SWAP-C. Software technology has got to the point where most functions can be virtualised. So a given hardware platform can support a much broader range of functions which enables redundancy to be distributed throughout the battlespace. Multiple communication options, managed by computerisation with the human 'on-the-loop', using IMMN and machine learning, will provide the architectural 'core' of 5th-Gen redundancy.

- *Resilience:* Resilience is a fundamental requirement for any mission-critical system, particularly one that must operate in the face of active multi-domain peer-level attack. Resilience must be built in to 5G-ABM systems, operating across the BM enterprise. Resilience needs to be sustained as capabilities are inserted and the threat

22 Lexico.com

environment evolves. Cyber, for example, is now a core capability and must be built into the foundation architecture, not added on. Bolting on perimeter protection and periodically scanning for malware is no longer sufficient to protect any major enterprise, including the defence forces. Likewise, the increasingly hostile RF environment requires that 5G-ABM Systems be electromagnetically robust and indeed have the capability to manoeuvre in the EM domain – another core architectural requirement. With the advent of 5th-Gen platforms such as the F-35, the separation between ISR collectors and tactical platforms is becoming blurred and is gradually disappearing. The 5G-ABM system will need to deal with multiple security levels, including moving suitably sanitised information between security levels at need and in real-time. Multi-Level Security must now be built into the 5G-ABM system foundation architecture.

The 5G-ABM system must be able to manoeuvre throughout the non-kinetic environment, reducing the potential for non-kinetic attacks to be critical. The 5G-ABM system will also need to identify when it is being undermined (kinetic or non-kinetic), and then 'self-heal'. Much like the redundancy construct, the self-healing resilience process will often see alternate communication paths, C2 nodes or sensor priorities change, with the human observing these changes from their position 'on (or off)-the-loop,' allowing the technology to quickly return the system to its battleworthy condition.

The Changing Nature of Air Battle Management

New domains are being added to the military lexicon, and new missions, roles and tasks are appearing on a regular basis as technologies and threats evolve. The nature of activities that confront our militaries is clearly changing. Many of these new activities have been discussed in academic literature for some time, and are now appearing in published conceptual and doctrinal works.

Multi-Domain Battle Management. The concept of the Multi-Domain Battle has been discussed widely for several years. Dr Peter Layton describes the concept as an extension of the network centric and combat cloud construct, “into other domains including land, sea, space and cyber”.[23] Multi-domain is an extension of the ‘Joint’ construct, which generally sees the various Service Arms fighting alongside each other in pursuit of a Joint Force Commander’s intent. An integrated force goes beyond a joint force and exploits technical systems enabling the various service arms to work together with less exploitable seams, shared situation awareness and common command arrangements. The multi-domain force goes further again, operating throughout the various battlespace domains as a holistic force, the aim being to dominate in the domain/s as and when required to achieve a desired operational result, often with limited temporal dimensions.[24]

- *EM and Cyber:* Just as today’s Joint Force Commander (JFC) is unlikely to deploy his/her Joint Force if they know they cannot compete in the air, space, maritime or land domain, so too tomorrow’s JFC (or multi-domain Commander) should be reluctant to deploy their forces if they know they cannot compete in the EM and/or Cyber domains.[25] Historically, EW and Cyber missions have been employed to support activities, be they offensive or defensive, strategic or tactical. 5th-Gen Battles will be fought through, and in these domains. More importantly, battles in all other domains will depend on EM and Cyber dominance at some point in their execution. Battle Management now demands that EM and Cyber manoeuvre be fully integrated and dynamically managed inside and alongside all other domains.

Fusion Warfare. USAF General ‘Hawk’ Carlisle introduced the concept of Fusion warfare in 2017.[26] He argues that the complications arising from the multi-domain nature of the future war, coupled with the sheer volume of digital information available throughout the battlespace, will introduce both human and technical challenges that will inevitably lead to ‘fusion

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23 Layton, p 5.

24 Layton pp 9-10.

25 Of course they may not have the option to stay at home. They may need to resort to asymmetric warfare, not just in a matériel sense but in terms of better Strategy and Tactics, Techniques and Procedures (TPP).

26 Layton, p 29.

warfare'. Fusion warfare would challenge the traditional C2 doctrines and pit machines against machines in an OODA loop contest.[27] In the 5G-ABM environment, the OODA loop will remain critical. The big difference between 3-4 Gen and 5th-Gen is the speed at which the individual elements are occurring, and the degree to which the human does, or does not have the capacity to participate. Dr Layton suggests that multiple OODA loops will exist throughout the multi-domain battle, and that the side that 'best harnesses the power of multiple OODA loops may prevail'.[28]

RADM Manazir has suggested that OO could well be machine driven, while human does the DA part.[29] This is an interesting suggestion. Data Analytics and Machine Learning algorithms can enable advanced analysis as the battle is ongoing. This could either inform decision-making, or become decision-making. Fundamentally, the technologies and architecture will allow machines to at least assist (if not fully undertake) the D and A as well as the OO part. Whether the lawyers and/or policy makers will embrace that is another thing altogether. This concept is forcing a re-think of the human's role in the BM environment. As much as we like to think that the human must always have the final say for weapons engagement and the like, this is unlikely to be achievable against a fusion-savvy peer adversary. The speed of the future battle will move the human from being 'in the loop', to being 'on the loop'. The key is using the technologies smarter than the adversary. In this regard, Winston Churchill's quote from earlier in this paper remains insightful.

Integrated and Distributed Fire Control. Integrated Fire Control (IFC) enabled through Threat Evaluation and Weapons Assignment (TEWA) is critical to coherently delivering precision effects across domains. Drawing

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27 The OODA (Observation, Orientation, Decision, Action) loop concept had its origins in the Korean War where an American pilot, Col John Boyd, identified the advantages of having good visibility and sensitive controls on board the US Sabre jet fighters. Boyd explained that the US pilots simply had a shorter total period between observing an event, orientating themselves to the possible ramifications of the event, making a decision and acting. The value of a relatively short decision cycle was realised.

28 Layton p 6.

29 Manazir p 4.

on advances in technology including AI/ML and the large amounts of data accessible in the Combat Cloud, TEWA provides the nexus in 5G-ABM for development of fire control solutions for optimal engagements. This is achieved by combining multi-domain situational awareness with advanced fusion capabilities to evaluate all possible engagement options in a very short space of time.

An optimal engagement builds upon the 'any sensor, best shooter' paradigm by delivering the most appropriate effect, be it kinetic or non-kinetic, to a specified target at the 'least cost'. This involves consideration of all engagement modalities: hard/soft kill (including Directed Energy and Cyber); cost of engagement; and magazine management rather than just kinetic Single Shot Probability of Kill (SSP_k).

INSIDE THE TRIANGLE - THE LEVERS

To date, this paper has focussed largely on a technical and operational description of what is changing in the ABM environment that will lead to a generational change. In reality, there is not a lot that nations and militaries can do to stop this global move to 5th-Gen. Technologies and architectures are coming, which will shortly have the effect of forcing a change in the nature of warfare. 5G-ABM is with us now, albeit in its infancy. It is difficult to envisage a serious war in the near future that is not a multi-domain affair.

Inside our Triad exists the major 'human levers' of this change – the 'what now' for those nations and militaries keen to position themselves well in the 5th-Gen battlespace. These are the things that do require the attention of organisations if they wish to compete effectively. Policy, Organisation and People, are all shaped by the leaders and change agents that influence a nation, a military or indeed any entity. Policy is generated by people, and can be changed. We shouldn't be wedded to out-dated policy that may constrain future war fighters. Likewise, an organisation that has served a military well through Gens 1-4 can be changed to better facilitate 5th-Gen. Indeed, several military organisations have begun to shift towards 5th-Gen constructs already – most notably the RAAF. And People, we know, are changing: the millennials are making their way into leadership positions now and they are bringing with them a fundamentally different approach to problem solving and task execution.

People[30]

The 5th-Gen force will not be limited by the amount of information available to it; instead it will be limited by the cognitive ability of the human and machine team to understand and react to the tempo and complexity of the operational environment. 'While 4th generation Battle Management platforms were centres of fusion and decision making, 5th-Gen Battle

30 Much of the 'People and Organisation' sections was drawn from an interview with SQNLDR Robert Vine, RAAF, Aug 2018.

Management platforms will be centres of cognitive capacity'.[31] The future 5G-ABM systems will bring to the 5th-Gen force a team of warfare specialists that can effectively scrutinise a complex environment and provide considered input to the collaboration process. This will reduce the load on other platform operators so that they can optimise employment of their platform, without restricting their actions should the nodes become isolated.

Without technological restrictions to define its characteristics, the 5G-ABM system can instead be defined by the characteristics of the personnel that will fight using it. 5G-ABM systems will be operated by the 'millennial' generation; a generation observed to have a preference to work in groups that offer a sense of unity and collaboration over division and competition.[32] The 5G-ABM system must encourage this behavior, not by creating tactical 'committees', but by allowing the collaborative processes that are commonplace in millennials' daily lives to find a place. Rather than rely on a centralised commander giving individual direction, a 5th-Gen team would identify a problem, collaborate to determine options and then implement a course of action. Such a culture will decrease the system's vulnerabilities to attacks against C2. In a future conflict where a team of aircraft is faced with a tactical problem and cut off from Command, a 5G-ABM organisation must allow it to fuse all of the available information, collaborate to determine a course of action and then rapidly implement its plan.

In addition, a 5G-ABM system must embrace people who are more comfortable with understanding how AI/ML works in a human/machine team to exploit both human and machine cognition in BM systems. Effective machine cognition systems require data high in quality and quantity. A 5G-ABM system will need people who understand how the systems work to both generate trust within the human/machine team, and to develop tactics that effectively employ the 5th-Gen systems.

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31 SQNLDR Robert Vine, RAAF.

32 https://www.forbes.com/sites/forbestechcouncil/2018/01/25/the-millennial-arrival-and-the-evolution-of-the-modern-workplace/).

Organisation

The limitations of gen 1-4 BM technologies drove where and how decisions are made. Each platform within such a system is able to gain and disseminate only a limited amount of information, and fusion of multiple information sources can only occur in centralised platforms. Command and Control authority is therefore given to centralised Battle Management nodes as they are the only platforms to have all of the information that is necessary to make effective decisions. These generations of BM systems are able to mount large-scale, coordinated operations only through rigid adherence to a hierarchal organisational structure with centralised decision makers; however, these systems require assured communications to pass information and decisions. The effectiveness of a 4th gen force is quickly reduced when even a small number of communications mechanisms are interrupted, leaving disjointed forces overwhelmed and unable to coordinate an effective response without contact with a centralised Battle Management node.

Fifth generation technologies remove the limitations that drive how Gen 1-4 forces operate. All platforms within a 5G-ABM system are able to gain, fuse and disseminate large quantities of information through the combat cloud. A 5th-Gen system will understand the dynamic information needs of the various users and would prioritise and distribute data to ensure the absolute needs are met. This gives many platforms the level of information necessary to make decisions. With these limitations removed, the 5th-Gen force must re-consider the most effective way to delegate decision authority in an environment that will be more complex and contested than those faced previously. The 5th-Gen Battle Management organisation must be able to coordinate operations with contested communications and a highly complex information environment. To do so it must remove the critical vulnerability of a centralised organisational structure. The 5G-ABM system is no longer a few centralised platforms, but a mesh of multiple systems and platforms that have the ability to fuse multiple information sources and make decisions. The 5G-ABM organisation must be able to facilitate the technology.

Such a Battle Management system will require a significant cultural change amongst Operators, Commanders and Staff. The 5G-ABM system will require the concept of Mission Command to be fully embraced; training and experience must be provided to Operators to give them the confidence to understand and act on Commander's Intent without real time deference to higher level Command. Commanders and Staff must be given practice in developing orders and intent that allows them to guide tactical action without the constant communication for which they have become accustomed. Without events that guide a change towards a culture of command that is comfortable with being 'on-the-loop' rather than 'in-the-loop' the 5th-Gen force will be led by 3rd generation Commanders that will ultimately limit the effectiveness of the force.

Policy

Effective transition to a 5th-Gen force is contingent on early and measured consideration of emerging policy challenges. These are a product of the adoption of new technologies and changes in the nature of the missions assigned to the military. To achieve generational change existing paradigms of operation will need to be reset and the human dimensions of the triad evolved. It is policy settings rather than technical constraints that are likely to be the largest impediment to migration to a 5th Generation force.

Key among the policy challenges is broad adoption of AI/ML and Autonomy. While already acknowledged as national and international policy issues in a range of domains including land transport and medical care, in a military context there are additional considerations. These include delivery of lethal force and protection of human life, which add additional legal and ethical dimensions that need to be addressed and resolved.[33]

Even in the absence of the delivery of lethal force the ability to 'remove the human from the loop' undermines existing paradigms of authority and requirements for positive identification and control during military operations. In a coalition environment differing perceptions and national caveats magnify these issues and will require significant, early attention to harmonise policies and ensure necessary levels of interoperability are achieved.

In the broadest sense, policy done well can set the tone for victory: "Never Surrender". Policy done poorly goes a long way towards guaranteeing defeat.

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33 Peter Layton, Algorithmic Warfare: Applying Artificial Intelligence to Warfighting, Air Power Development Centre, Canberra, Australia, 2018.

CONCLUSION

As the F-35 and other 5th-Gen platforms are being introduced into military service around the globe, technologies are being developed by the world's militaries and defence industries to ensure that the significant leaps in technology do not remain locked up in the cockpits of 5th-Gen aircraft. These technologies are now being developed for the environments within which the 5th-Gen platforms will operate, effectively characterising the 5th-Gen Air Battle Management environment.

This paper has described a series of operational and technical elements of a 5G-ABM environment, collated around a simple model in order to explain what 5th-Gen looks like in the ABM environment, and why it is important. While the language and concepts around the technology may appear a bit science fiction to some, they are all in fact real. They will be in our battle space in the very near future. 5G-ABM is quickly becoming a key mission.

The emerging 5G-ABM technologies and foundation architectures are in part responding to the changing threat environment. In particular the threats associated with hypersonic speed and complex, coordinated, multi-domain effects, that will quickly out-manoeuvre a Battle Management system that relies on humans in the loop, hierarchical C2, and exploitable communications and IT systems. The foundation architectures needed to capitalise on the technologies should be an absolute priority for the world's militaries.

Likewise, the policies, people and organisations that have supported 3rd and 4th Gen ABM systems will need to change to compete in the 5th-Gen battlespace. These are the key levers that Government and Military leadership can pull to shape their organisations to meet the 5G-ABM demands.

Attempting to fight a 5th-Gen battle with 3rd or 4th Gen Battle Management system will become increasingly untenable as 5th-Gen threats become more sophisticated and more prolific, and as 5th-Gen threat nations become more comfortable with their tools.

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5th Generation Air Battle Management

The 'Combat Cloud' as a 5th Generation military concept was introduced in 2016 by LTGEN (Ret.) David Deptula, Dean of the Mitchell Institute for Aerospace Studies. Today, the technologies and foundation architectures needed to realise the Combat Cloud are real and have begun to leave the labs.

These technologies and foundation architectures are in part responding to the changing threat environment. In particular the threats associated with hypersonic speed and complex, coordinated, multi-domain effects that will quickly out-manoeuvre a military that relies on humans in the loop, hierarchical Command and Control, and exploitable communications and IT systems.

In this paper, Chris Westwood explores a series of operational, technical and human elements associated with the move towards a 5th Generation battlespace, through the lens of the Air Battle Management environment. The paper presents a simple model which aims to help a broad audience understand what 5th Generation is, why it is real, and why attempting to fight a 5th Generation battle with a 3rd or 4th Generation battle management system is becoming increasingly untenable.