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Air Warfare Communication in a Networked Environment

An Interdisciplinary Analysis

**Joint Air Power
Competence Centre**

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FROM:
The Executive Director of the Joint Air Power Competence Centre (JAPCC)

SUBJECT:
Air Warfare Communication in a Networked Environment

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This study offers a vision of the future and then identifies specific elements of coordination and communication necessary for operations in this future environment. Although 4th–5th generation aircraft interoperability is a focal point today, this study is about much more than that. The diversity and asymmetry of Joint Air capabilities, plus leveraged improvements in communication capabilities in a future network, offer an opportunity for positive C2 transformation.

This study is a conceptual review of a theoretical, but likely, future operational scenario that allows for dynamic integration of disparate platforms from the bottom-up perspective. The value in this study, and its subsequent relevance to NATO (both ACO and ACT), is to define air platform behaviour in this future networked environment so the development of both the network and command structures can evolve in concert with the likely evolutional behaviour of the assets over which they will exert control.

Unlimited connectivity is no longer a thing of the future, yet combined decision-making and data-sharing (what we do with the information) are not evolving at the same speed as technology. Soon, clusters of disparate platforms will be allocated and combined to function as specific force packages, organized by capability and hierarchy, and ideally irrespective of service, country, or degree of human presence. As technology continues to develop and improve communication (speed and amount), humans and artificial intelligence will have to develop new 'social contracts' in order to comply with and execute the Commander's intent.

We welcome your comments to our document or any future issues it identifies.

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EXECUTIVE SUMMARY

Network technology is expanding at an exponential rate. As technology improves, effectively unlimited connectivity is no longer strictly a future concept; however, combined decision-making and data sharing processes (or maybe 'protocols') are not evolving at the same speed as technology. Machines will boost communication in a networked environment to levels yet to be determined. This will require nations and the Alliance to alter current communication patterns. Recent studies have provided metaphors to relate the communication within networks comprising men and machines, most notably references in the military spectrum to combat clouds and killing webs. These metaphors highlight the need for humans and artificial intelligence to develop new 'social contracts' in the form of new communication patterns in order to achieve the desired effects on the battlefield while still complying with the Commander's intent. Furthermore, tactical scenarios that require the integration of 4th, 5th and future generation assets will have to be analysed under a new, more general C2 concept in order to avoid mixing tomorrow's capabilities with yesterday's C2 structures.

The study is broken down into four sections, the first being the introduction.

The second part (Chapters 2–6) provide an academic foundation, which will define the environment through detailed analysis of platforms, machines and systems of machines. These platforms interact to perform air power functions. This part will close by exploring models to help understand the relationship between communication levels and C2 and will likely be most interesting to the academic community working in the field of robotics and behavioural sciences.

The next part (Chapters 7–9) provides an operational perspective, taking the academic discussion and the explored models from the previous chapters and extrapolating them onto aircraft and air power functions and operations. It reviews trends in the evolution of air power and provides statistical analysis of efficiency realized through advances in technology, such as Link 16. This part will likely be most interesting to proponents of air power, not only those who fly aircraft today, but also historians, strategists and policymakers.

The final part (Chapters 10–13) is a vision of the future, offering a thorough review of future concepts including Dynamic Airspace Synchronization. Along with proposals for a new way of thinking about the

future of Joint Air Operations, the command function and C2 writ large, this final part blends the conclusions derived from the previous parts and offers points for consideration in the use of air power as technology continues to advance. This part will likely be most interesting to current and future senior decision makers within the NATO Command Structure and to those with interest in NATO's Air C2 system.

This study explores how improved communication capability (between man and machine as well as between machines themselves) will change the way by which NATO conducts Air C2. It recognizes that data processing speeds have improved exponentially and new mission computers and communications gateways are significantly cheaper than new platforms, but also that unrestricted communication is not always a global solution for every tactical or operational problem. While many studies today are focused solely on 4th–5th generation aircraft interoperability, this study takes a broader look at the entire networked operating environment, of which plane-to-plane connectivity and interoperability are but a subset. In doing so, it begins with a critical assumption that certain levels of networking and linking have already been achieved in order to look at the behaviour of air platforms in this future networked environment. The advent of technology that improves methods of communication across the air domain offers an opportunity to explore ways to transform the level of Command and Control across NATO. Furthermore, the diversity and asymmetry of Joint Air capabilities across the Alliance may necessitate such a transformation in the framework of improved communication to ensure future interoperability.

According to SACT's perspective[1], Command and Control is comprised of four interconnected phases: collecting, decision-making, effecting and connecting. This communication-based process replicates the 'sensing, interpreting, deciding, and acting' sequence present not only in human behaviour, but also in that of other organisms or mechanisms. NATO's C2 poses a unique command challenge as it requires consensus among 28 nations. It must solve the complex challenges of diversity and asymmetry through consensus

at the Strategic level, and through integration and interoperability at the Operational and Tactical C2 levels.

Positive transformation into new topologies for air power execution may be approached through different paths. Air, Maritime and Land battlespaces will likely be redefined into a more holistic joint battlespace. Different platforms will not necessarily be tied to certain specific roles within the respective Component, rather machine-speed decision-making will permit dynamic re-tasking and re-allocation of force packages without regard to service or nationality. These packages will be matched real time to an evolving situation, which will make the network and the platforms operating within the network more responsive, adaptive and effective. The study approaches this concept with the understanding that information sharing limitations, national security, and other caveats, constraints and boundaries are still present. Regardless, communication within the network is the main factor driving evolution within the Alliance. NATO must sustain the technological advantage that has defined NATO's Joint Air Power over the last decades.

Borrowing the concepts of Command and Control maturity levels and the methods by which the levels may be increased expressed by Alberts et al.[2] (specifically that a more mature system is more efficient and effective), this study begins with a review of Command and Control and different levels of maturity of the C2 system as a function of communication. The panel that developed the 'NATO NEC Maturity Model' for C2, referenced frequently throughout this study, concluded that decision rights allocation, patterns of [platform] interaction, and distribution of information all impact the evolution of Command and Control. This study expands upon that principle and identifies that the distribution of information in the form of higher degrees of communication is the area most easily addressed by NATO and could result in movement toward a higher level of C2 maturity within the Alliance.

The central thesis of this study, that hyper-communication will increase maturity in the current C2 structures, is then further explored from the perspective of

the synchronization of different platforms featuring different functions and operating within a complex system. Extrapolation from analysis of the communication patterns of biological examples is applied to statistical analysis of NATO aircraft behaviour evolution in a pre- and post-Link 16 era. This concept is then further applied to future air platforms operating with improved communication capability enabled by the increased information exchange rates in the future network. This is then juxtaposed against NATO's current Air C2 doctrine to highlight how, in the future, NATO might have to automate certain levels of decisions to achieve advances in C2 maturity.

One of the central premises of this study is that the 'Command' part of C2 will not fundamentally alter during the course of C2 evolution. The allocation of decision rights regarding critical parts of the Kill Chain (primarily kinetic engagements) must remain in human hands. A second premise is that the future 'net' is a cognitive and adaptive network which is fast, robust, resilient, and redundant. This vision of a net is conceptual, but when this net becomes a reality, C2 will change with it, introducing automatic features in certain activities and functions, which will remain consistent with the Core Roles of Air Power identified in the AJP 3.3 series.

Many steps in the F2T2EA (Find, Fix, Track, Target, Engage, and Assess) model can be more efficiently done at machine-to-machine speeds, controlled and synchronized by cognitive computing which is managing this future network. Recognizing that the 'Engage' function is primarily tied to the Command and Kill Chain issue described above, improving the speed of the other steps of the process will speed up the OODA loop and increase operational tempo for the Joint Commander while leaving lethal decision-making in human hands.

Machine-to-machine communication through datalink could potentially replace some functions that today are either human action or voice dependent. Automated actions, such as auto-sorting and weapons management, across the flight formation (resident in a few nations' missile allocation capability), third

party targeting, or research into manned and unmanned teaming, have already approached this level of collaboration. However, this is by no means a capability fully realized across NATO's Joint Force. Hyperconnected platforms become mutually supporting enablers from a bottom-up perspective (platform level), and a hierarchy within their functions and roles may address mutual support and other needs through the depiction, in real time, of who has the best available position, sensor or weapon in support of the Commander's decision.

Contextually, the force behaves as a faster whole through communication. One platform's sensor may coordinate for a second platform's weapons system to engage while using a third platform as a jammer, or as a SEAD asset with the proper platform's configuration. Altogether, they would share a software-driven motion policy and behave as the aforementioned whole. Today, coordinating this relatively basic synchronization of functions requires time (human speed) and likely relies on voice communications for both coordination and most levels of execution. This is likely not a survivable model in a future, contested networked environment.

The method by which NATO develops and utilizes airspace, founded upon the principle of avoiding fratricide, limits flexibility and in many cases makes real time synchronization more challenging. This future network, and its capability for coordination between platforms at machine-to-machine speeds, offers the new possibility to dynamically co-utilize airspace as opposed to today's segregation-based utilization. The cloud metaphor best explains how control distributes through the joint battlespace to allow for higher decentralized execution. This study proposes the term Dynamic Airspace Synchronization (DyAS) to discuss potential real time co-use of airspace by multiple disparate entities across the Joint Force, including both air and surface based Air Power platforms.

The value in this study, and its subsequent relevance to NATO, is to define air platform behaviour in a future networked environment so the development of the

datalink network and the future command structures can evolve in concert with the likely behaviour of the assets over which they will exert control.

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2. Alberts et al. NATO NEC Maturity Model. Produced by the Centre for Advanced Concept and Technology, 2010, p. 24. [electronic document], available at: http://www.dodccrp.org/files/N2C2M2_web_optimized.pdf [17.09.2015].

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Part I

Introduction to the Study

'The future network will be a functioning grid, operated by a self-aware mutating pseudo-AI machine. Humans operate too slow, and humans in committee are even slower. This machine-operated network will have awareness of the sensors, weapons and capabilities of each platform operating within the network and can self-organise to optimize the utilization of each platform.'

Vice Admiral Breckenridge, USA N
Director, CJOS COE

Remarks at the 2016 Maritime Expeditionary Operations Conference.

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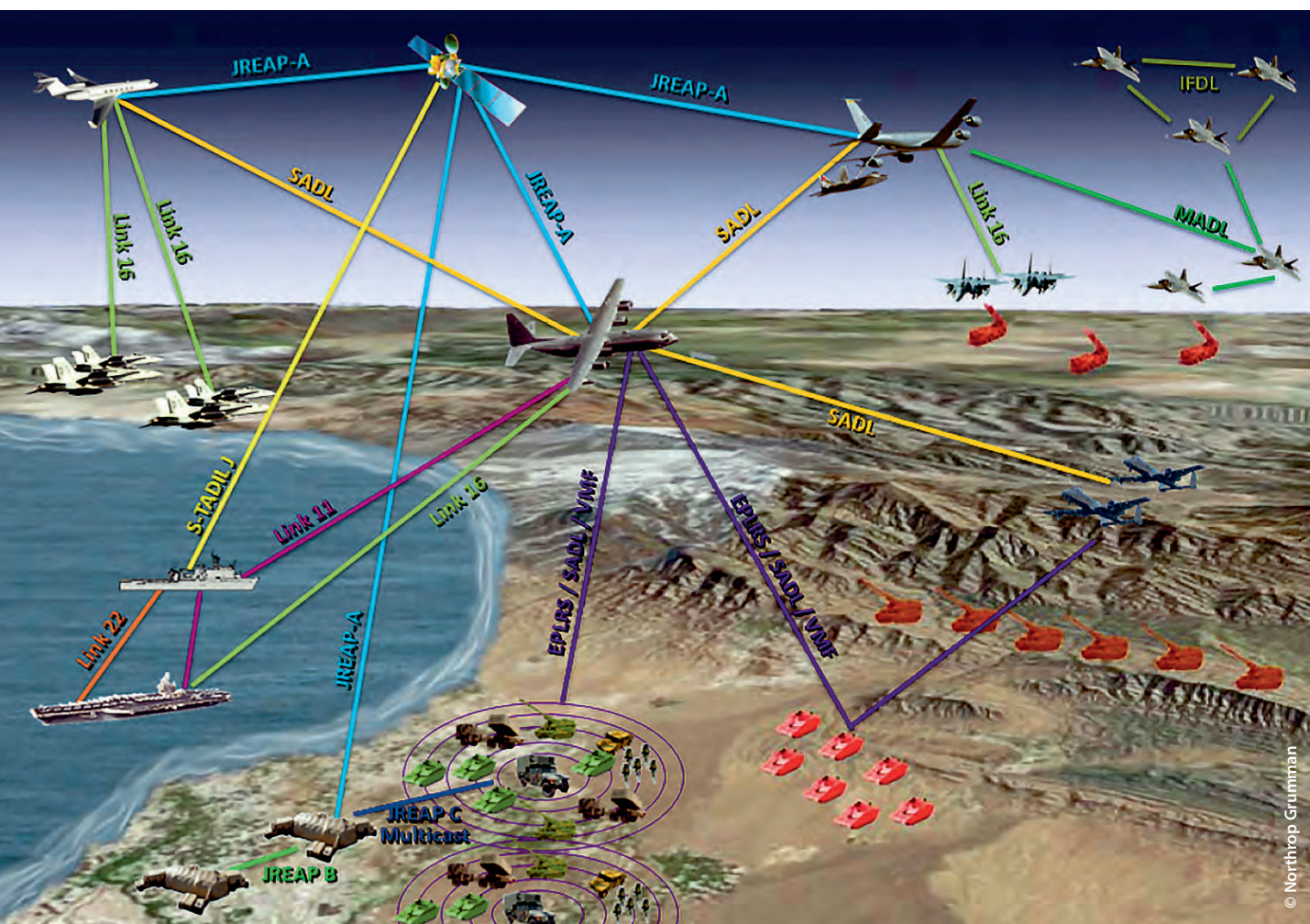
CHAPTER 1

Aim and Methodology

1.1 Introduction

Information exchange is the key foundation for the employment of NATO Air Power, as demonstrated by the evolution of digital technology integrated into 4th and 5th generation aircraft. From both on-board and off-board sensors, aircrew have seen a dramatic increase of information immediately available to the pilot/operator. Improving the manner in which this information is shared amongst the airborne platforms and Combined Air Operations Centres (CAOCs) has

been shown to have a dramatic impact on mission effectiveness, as exhibited by an increase in friendly force-to-adversary kill ratio, an improvement in the Intelligence, Surveillance and Reconnaissance (ISR) collection process and in the refinement/shortening of the detect-to-engage sequence. It is remarkable that this success comes despite heavy reliance on numerous, and sometimes dissimilar, methods of information exchange through different types of datalinks.

1.1.1 The Combat Cloud Metaphor

Metaphorically, the total amount of rain required from a cloud to water a farm would be less if the cloud had enough situational awareness to discriminately target dams and fields, and release the right

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amount of water only when and where considered by the cloud commander. By doing so, the cloud would be more efficient and more effective. Imagine that this perfect cloud needed the integration of an optimal number and allocation of cirrus, stratus, nimbus and cumulus to achieve the perfect rain for the desired effect, and that through an internal mechanism, the cloud could mutate into that ideal configuration.

A central premise in this metaphor is that the cloud gives network participants unfettered access to information, which subsequently drives action. Therefore, if a future network can share critical information nearly instantaneously across all levels of warfare, then an improvement in mission accomplishment can be achieved by providing operational commanders a higher level of situational awareness in order to 'rain' Air Power with improved efficiency.

Furthermore, once this future network and corresponding increase in situational awareness capability is achieved, it will likely produce a measurable impact on the individual platform behaviour within the system. As technology develops to transfer some mission functions from the operator/pilot to the platform computer via machine-to-machine interface, the resultant increase in the speed of information exchange may result in new levels of C2 maturity within the network. This will be realized in concert with an evolution in individual unit performance, and both will likely result in the need for an adaptation in NATO's C2 structure.

1.2 Aim

Although the title of this study is 'Air Warfare Communication in a Networked Environment', it is necessary to note that this study is not entirely about Command and Control; rather, it focuses on communication. This study approached Air Warfare from the perspective that C2 and Communication are intrinsically linked. While recognizing that communication is the scaffolding of any C2 structure, communication capability writ large will evolve and all systems/participants must adapt. In light of this reality, many references to C2 will be included along with the discussions of communication and evolution of communication capability. Furthermore, this study is about Air Power viewed through a wide lens in order to avoid different service or national biases when approaching communication and its impact on Command and Control.

Leveraging the existence of this future network, this study's two main themes describe the potential for: 1) Improved situational awareness and 2) new options for man-machine teaming which will allow for faster decision-making amid emergent situations in the battlespace.

This study seeks to identify the nearest achievable goals, the portion of the roadmap we can anticipate from our current position and from within our budget constraints. Stated another way, we are seeking to outline the next maturity 'Stage' of Air C2, which will be achievable once the technology allows for unrestricted and robust connectivity among machines. Once that level of maturity is determined, it will be easier to conceive how these future topologies will be formed and managed, including a process for the efficient and coordinated interaction of legacy and future assets.

1.3 Terms

1.3.1 The Roles

As a premise to begin the research, it was assumed that the 'Air Power Roles', as defined in NATO Doctrine AJP [Allied Joint Publication] 3.3, will remain relatively

constant in the near future (next 3–4 decades) in order to compare modern and future air warfare activities from a common perspective. Throughout this study, these 'functions' will be further correlated to 'action verbs' in a cause and effect relationship of agents operating within a system.

The study postulates that improved situational awareness at the Tactical level will be leveraged through dynamic distribution and effective execution of Air Power capabilities throughout the joint battle space. Further, the resultant synergy of actions among the platforms achieved both from this improved SA and from the improved ability to spatially coordinate at machine speeds will impact not only platform execution but also the speed of decision-making. All of this will be done without altering the current Air Power Core Roles found in NATO doctrine today. This study will primarily address air activity (in terms of the aforementioned Roles) and airspace, but, by extrapolation, many of the theses and conclusions may be applied to other platforms operating in other spatial domains (land, maritime).

1.3.2 The Platforms

In this future network, different generations of platforms and network participants (both emerging technologies and current systems) will coexist and form clusters to efficiently and effectively accomplish each task, much like different types of clouds form the optimal one for the raining mission in the prior example. This optimal coexistence will require expansion of today's data exchange processes throughout the various datalink architectures, and in many cases it will be based upon the observed evolution of biomimetic behaviour models and their extrapolation to current and future generations of Air Power assets from a bottom-up approach (various degrees of local interaction). In this study, the term 'bottom-up' refers to exploration of the communications benefit at the smallest Tactical level (small number of cooperating air platforms) rather than taking a holistic view of communication pushed down from the cloud to the tactical units for execution. Extrapolations of concepts from this bottom-up perspective will then be applied to larger Component and Joint level C2 structures.

This study explores behavioural evolution as a foundation for future information exchange protocols, and as a foundation for a re-evaluation of future C2 procedures for the elements under the Joint Force Air Component Commander (COM JFAC) who tasks the available Joint Air assets based on the COM JTF's air apportionment decision.[1]

> *'It is about building integration from the ground up so that forces can work seamlessly together through multiple networks, rather than relying on a single point of failure large network.'*[2]
>
> *Real Admiral Manazir*
> *on Shaping Kill Webs*

1.3.3 Synchronization

Furthermore, the study will explore the concept of self-synchronization within a closed system, and how that might apply to a future network operating with improved machine-to-machine data transfer. Self-synchronization is the ability of a group to synchronize and organize complex activities to execute pre-authorized tasks utilizing a communication network with minimal human involvement. As self-synchronization is a feature present in many swarm models, this study also explores the emerging patterns of increased collective effectiveness through local platform interactions while maintaining the integrity of both the 'Command' function and the human decision-making requisite for NATO operations.

1.3.4 The 'Problem Space'

The 'problem space' refers to the physical limitations faced by the different network components to move in concert within a given, limited battlespace, while avoiding conflict and fratricide during task execution. Once weapons and sensors federate through connectivity, the spatial constraints regarding commits, engagements and general platforms' orchestration will constitute a spatial challenge, demanding some sort of orchestrated motion policy.

This level of platform automation and self-synchronization may be approached by converting certain regions of the joint battlespace in fluid, continuous areas. For example, whereas today's air platforms operate constrained by the boundaries of a classic Airspace Control Order, the future force will benefit from a more dynamic and adaptive co-use of airspace, especially given weapons' extended ranges and potential high-traffic airspace scenarios. In other words, platforms will safely and dynamically positon themselves through the battlespace in accordance with a capability criteria while adopting a new morphology as a whole, as per the cloud example.

1.3.5 'Components' and 'Components'

As this study will discuss terms stemming from biologic sciences, robotics and also from within standard NATO military lexicon, there occasionally will be terms that have different meanings depending on use and derivative context. Each of these terms will be explained during the course of the study as it arises so that the context may be understood relevant to the current topic, however, it is important up front to identify the term 'component', as it will be used in two different manners throughout the entire course of the study.

A 'component' with a lower case 'c' will be used to indicate a part or piece of a set, whether a mathematical set (of data) or a part of a biological or social community.

A 'Component' with a capital 'C' is understood to be part of the NATO Command Structure, one of the Air, Maritime, Land or Special Operations Force 'Components'.

1.4 Assumptions

This study begins with the assumption that a future datalink network exists, and that the 'command' function during joint planning, joint and tactical execution, and the different Air Power Core Roles listed in AJP 3.3, will remain unchanged. Additionally, this future network has already been engineered and is functional, resulting in the capability of the network to support

the level of communication analysed in this study. The four Core Roles are; 'Counter Air', 'Attack', 'Air Mobility' and 'Contribution to ISR'. The fifth Role listed in AJP 3(B), 'Support to Joint Personnel Recovery', will not be considered, as the network's impact on it is mainly a consequence of the combination of the other four.

Command and Control (C2) is conducted in today's environment through a 'network of networks.' The time to generate the information needed for decision-making and tactical execution correlates directly to the speed, clarity (lack of ambiguity) and reliability of information provided by and across the network, especially during dynamic operations. Therefore, this study approaches a discussion of future network communication with a critical assumption that the network is reliable and sufficiently stable to support the information exchange requirements (IERs) of the myriad network participants.

This study will not address short-term technical solutions regarding current or future datalink protocol integration to generate the level of communication necessary to achieve the advance in C2 maturity identified in this study, as those are technical solutions currently under development by many NATO nations. Rather, this study will primarily focus on evaluation of the behaviour model of the datalink network participants, which may evolve, based on the speed, dimensions and fluidity of the information passing across the links.

Furthermore, this study assumes NATO nations will procure air platforms at varying rates, subject to national budgetary constraints. This will result in the future air force being comprised of modern and legacy air platforms of varying types and capability. The assumption is that those air platforms will be able to communicate and coordinate using the network described above. This study is not focused on the capabilities of any specific

emerging technology, rather it will discuss future data-links and 5th generation (and beyond) aircraft in terms of capabilities and requirements, rather than specific airframes and their embedded technology.

Finally, this study assumes that Alliance defence budgets will continue to be constrained, resulting in sustained political will to support the principles of NATO's Smart Defence (SD) and various Pooling & Sharing (P&S) initiatives. Additionally, this study assumes that Future Combat Air Systems (FCAS) will be mostly based on highly interconnected platforms and federated sensors.

1.5 Methodology

This study is interdisciplinary, as each part, although they all are interconnected, is oriented to a specific audience. The study begins with descriptions of multiple theories, disciplines and perspectives that could be related to the evolution of communication and their impact on air warfare communication. For this reason, the reader may expect terminology that differs from the standard military publication.

The study continues by addressing the various tactical options communication makes possible. The different topologies (or spatial distribution of the assets based on communication and hierarchy) are also introduced and extrapolated to modern warfare. Various C2 trends from past to present are analysed under the perspective of communication and speed.

The study then reviews a universal C2 maturity model and explores the three areas of influence that NATO can affect to alter or advance the C2 maturity level. Technology, as one of the areas NATO may influence, is manifested for this purpose as a communications network, a datalink. After analysing different spatial constraints that platforms experience once hyper-connectivity is achieved, the 'platform of platforms' concept is introduced as a step towards the 'system of systems' concept.

The study reviews biologic communities and models, demonstrating the link between improved communication and improved overall mission effectiveness.

Communication in the animal kingdom is discussed, which sets the stage for later discussions on machine-to-machine communication and potential options for a similar type of communication amongst computers/robots under human monitoring/management. Next, the current stage of C2 development with regard to communication and the presence of data transfer in each Component is further analysed. Then, the study draws a parallel comparison between the prior discussion involving bio-mimetic models and statistical data comparing manned aircraft performance pre-Link 16 to with-Link 16.

This comparison references multiple studies, most notably the raw mission performance statistics from numerous Tactical Leadership Programme (TLP) classes. An extrapolation is drawn from this data, theorizing the behavioural changes and platform communication ability in the envisioned future network, and conclusions are drawn related to both air platform performance, Air Power core roles, and the NATO command structure's ability to conduct C2 in this new environment.

This study then proposes a new concept for airspace management for this new, dynamic environment. Dynamic Airspace Synchronization is a radically new method by which airspace may be coordinated for co-use by disparate platforms in a dynamic environment, managed in real time at machine-to-machine speed. If adopted, it will fundamentally alter the method by which the NATO CAOCs employ airspace.

Finally, analysis of the role of the command function is conducted and a discussion of the sections within a CAOC is included to address how they might need to evolve in concert with C2 evolution of air platforms.

1.6 Limitations

1.6.1 Classification

Research and analysis associated with this study included both open and classified sources. To permit the widest dissemination, the published study has been kept at the unclassified level.

1.6.2 A Discussion on Datalinks

This study does not intend to offer short-term technical solutions regarding current or future datalink protocols integration; rather, the focus is on the behaviour model of the network participants, which may evolve based on the speed, dimensions, and fluidity of the information passed across the network.

The inevitable outcome of a datalink discussion might lead toward a debate over different types of datalinks. To achieve these higher degrees of C2 maturity through communications affecting the joint-combined force, NATO developed a Datalink Migration Strategy (DLMS)[3] to manage communications interoperability within the Alliance. Although it is an intriguing discussion and a technical challenge for NATO (as new 5th generation aircraft are being built with a discrete and proprietary datalink capability which currently has interface challenges with legacy datalinks), this study does not address the technical development of datalink protocols. There is a current technical challenge presented when trying to share 5th generation aircraft derived information to 4th generation or other legacy aircraft; however, numerous nations are investigating

that specific challenge from an engineering perspective, which is beyond the scope of this study. It is hoped that this study will help to prevent this same problem from recurring when 6th generation and beyond aircraft are introduced into NATO's inventories.

Furthermore, the study acknowledges that there are neither technological nor doctrinal solutions which guarantee perfect situational awareness and optimal performance through data transfer/information links for the Joint Force in contested environments. Tactical initiative under communications failure should always be inspired by the commander's intent and the in-place commander's interpretation of the context. A robust and redundant backup option for air combat through standard battlespace distribution should be available in case of network degradation.

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Part II

Machines, Systems and Teams

'So-called fifth-generation aircraft often are mistakenly viewed as simply the next iteration of airframes: fast, stealthy replacements of obsolescent legacy platforms. In fact, the capabilities of fifth-generation aircraft, and their integration into a network-centric Joint Force, will change the roles of manned fighter aircraft in air, ground, and maritime operations. Distributed information and decision-making will be enhanced as air operations become much more capable of providing information in support of the deployed decision-maker, and kinetic and non-kinetic support elements can be cued in support of air, ground, and maritime combat requirements.'

Dr. Robbin Laird

A 21st Century Concept of Air & Military Operation.

CAUTION: *Part II is technically deep and conceptually challenging, although an understanding of these biologic and robotics concepts is critical to a full understanding of the conclusions extrapolated to manned aircraft discussed in Part III. This section is targeted toward the academic and engineering fields, those working concept development as well as think tanks. Readers are invited, if desired, to read Parts III and IV if they already have sufficient background in this area.*

CHAPTER 2

The Cloud Context and the Relationship to Air Power

This chapter will discuss development of aircraft and other Air Power platforms from an interdisciplinary point of view, and more specifically from a communications perspective. In this case, the evolution of capability is viewed not as a function of the speed or range of an aircraft or sensor, but of its information gathering, processing, and/or sharing capability.

2.1 Generations of Aircraft

From an evolutionary perspective, jet fighters can be classified into five generations. These generations and their ability to form collaborative clusters through communication will set the characteristics of the future cloud. Early generations of aircraft were separated based on significant improvements in engine performance and aerodynamic platform capability; recent generations are divided by information technology and stealth.

Dr. Robbin Laird explored the history of the evolution of fighter aircraft in his thesis on 21st Century Concept of Air & Military Operation[1], which provided this study a foundation for levels of technology associated with generations of aircraft. The first three generations of jet fighters lasted about a decade each – from the end of World War II through the Cold War and Vietnam. The fourth generation began around 1970 and continues to constitute most of the fighters in service, although recent versions of some fighters are so improved that they are sometimes called generation 4.5. Fifth-generation fighters are air superiority and multimission aircraft that achieve increased performance through numerous advances in airframe and propulsion and increasingly sophisticated avionics, including flight control systems.

Although an exact definition is not agreed upon, this study considers that fifth-generation fighters are

distinguished from generations 4 and 4.5 mainly by their inherent stealth and a significant increase in information capability (a network-centric or distributed concept of operations), although they are much more capable in many respects. Looking globally, there is currently a debate over which specific platforms today can be considered 5th generation. One possible definition to help shape that conversation might be that a 5th generation platform allows some degree of effective management of a disaggregated set of capabilities. In this case, disaggregation refers to a means of creating resiliency by spreading capabilities across diverse platforms, including hosted payloads, smaller satellites, and tactical and strategic capabilities.

Fifth generation platforms are likely to become enablers for other platforms, empowering their different functions and helping to control the supported/supporting balance within the force through dynamic, semi-automated management. Computing capacity, sensors, and communications systems enable them to gather, exploit, and disseminate information to an extent that can multiply the effectiveness of military forces throughout a theatre of operations. In other words, there exists a potential for a non-stealth platform, or 4th generation, to effectively hide behind the information cloud generated by the 5th (or future) generation platform and yet still generate effects, as long as sensors, jammers, decoys, weapons and physical position of the force are orchestrated properly.

As fifth-generation aircraft enter service in larger numbers, they will generate not only greater firepower, but also significantly greater integrated capability for the non-kinetic use of aircraft and an expanded use of connectivity, intelligence, surveillance, and reconnaissance (ISR), communications, and computational capabilities built around a man-machine interface that will, in turn, shape the robotics and precision revolutions already under way.[2]

Dr. Robbin Laird,
Second Line of Defense
A 21st Century Concept of Air & Military Operation

One of the notable differences between 4th and 5th generation platforms is the focus on stealth as an enabler. Stealth technology is employed with the goal of degrading part of the adversary's kill chain ('find' and 'track' functions) through advances in airframe design and material. However, a modicum of stealth can be achieved through jamming, cyber or other methods, which enables less stealthy airframes to operate under some umbrella of protection.

Furthermore, these less stealthy aircraft can receive information derived from the more capable sensors on the 5th generation platform. The challenge of cross-generational information exchange is the crux of current discussion regarding 4th and 5th generation aircraft integration; however, it is in reality the information capability of the 5th Gen aircraft, both in gathering and also in providing to the network, that truly separates the two generations. If one accepts that the jump from 4th to 5th generation aircraft is less about speed and stealth than it is about information derivation and dissemination, an extrapolation to the capabilities of the next generation of aircraft becomes possible.

Chapter 12 will discuss the impact to the JFAC's Air C2 model of a future environment, populated by air vehicles that act as active and passive sensors, shooters (including EW attack and directed energy emissions), and data disseminators at machine speeds. Aircraft capabilities will continue to evolve over time, but the key element to future air platforms' integration lies in the network. The aforementioned challenge with spatial distribution in this network may be solved by a review of the concept of battlespace ownership and exploitation, and of how the battlespace could be dynamically reallocated to allow the best available platform to achieve the desired effect, in accordance with a given predefined hierarchy and a common, conflict-free motion policy.

With multiple generations of aircraft in use, the challenge becomes integrating the information derived by one generation of aircraft (or platform) and spreading that information across all the participants in the air domain, including those from the Maritime and

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Land Components. As NATO looks towards the future, it will experience this same challenge with the development and fielding of 6th and further generation aircraft. The nature of the Alliance and the national acquisitions process of each of the member nations have demonstrated procurement of technology will not occur simultaneously across the Alliance, so this challenge will continue.

2.1.1 Generations, Acquisitions and Technical Evolution

This study will use the generic term platform in lieu of aircraft, ships, tanks etc. These platforms must be seen as the elements that integrate the cloud through communication, extending the generational feature to a wider, joint and combined perspective. There is a direct correlation to platforms participating in a network and their activities in terms of functions and states. However, the intent of this discussion is to break service mind-sets regarding a specific type of platform and the functions it performs. When appropriate, this study will discuss specific aircraft only when required to address a unique or specific focal point (i.e., 4th and 5th generation aircraft integration).

In this study, the platforms are 'diverse' when they belong to different nations, technological generations or even technological cultures. They are 'asymmetric' when their functions are different and more or less complementary to other platforms' functions.

One of the challenges in this area is the speed at which technology advances in the commercial sector against that in the military sector. Although timelines may vary depending upon national acquisition structures, this basic tenet affects the entire Alliance: that is, this is a dynamic domain, which pits the military requirement for security, reliability, and durability against the agility and speed of evolution in the commercial sector.

> *Moore's Law versus our acquisition cycle: Moore's Law says every 18 months information technology changes and it takes us six years to acquire something. So, by the time we acquire it, it's four times out of date.*
>
> *General Hawk Carlisle, US Air Force*
> *PACAF Commander*

Industry experts have projected that computer processing power can double in intervals of approximately two years, although Intel's CEO recently indicated that

30 months was an accurate predictor through 2017[3]. This means that the cloud may become a technical reality, but the military acquisition process for platforms to operate within that cloud may take decades.

For the military, this is a reversal of research roles from earlier decades. Previously, military research for specific military aims was conducted, declassified, and then developed into practical technology for applications in the civilian world. Today, emerging technology is likely to originate in the civilian sector and then be adjusted for military applications. For this reason, civilian academic research into large groups of robots operating in a network to accomplish pre-defined tasks provides much of the background for this study.

Furthermore, today's fiscal environment will likely continue to impose budgetary constraints in the future and result in NATO continuing to have advanced technology aircraft operating in conjunction with less advanced platforms. This implies there will be an enduring interoperability requirement between legacy platforms and the most modern capabilities. Thus, platforms integrating into the future cloud must evolve by incorporating these technologies.

2.2 Air Power Delivery

According to NATO doctrine (AJP 3.3), Air Power can be delivered, or identified, in terms of roles, missions and sorties. Each Core Role fosters different types of operations. For example, the Counter Air Core Role includes offensive and defensive operations. This section covers what the 'current cloud' does and its associated terminology, as it may be extrapolated to future models.

Core Roles, and subordinate types of operations, are executed by teaming platforms that communicate with each other as needed. Platforms are designed and instructed to 'display' different functions in mutual support of one another throughout the course of the mission. A 'mission' involves a set of orchestrated platforms, normally measured in a number of sorties, tasked to conduct Air Power Core Roles within a defined battlespace.

As this study involves multi-role (multifunctional) platforms, it will use the term 'function' to address specific platform's profiles, represented mainly by 'activities' or 'skills'. These functions, such as 'jamming', 'shooting', 'track' or others, may be a product of the design of a certain platform, or a product of the contextual contribution of two or more platforms. The application of this concept is seen by translating the functions of air power platforms within NATO doctrine to action verbs displayed as a menu of choices[4] for the platform to execute. This will in turn represent the different 'states' of a platform from which the functions are executed.

Platforms are able to execute functions while delivering Air Power in accordance with their design, which contains finite states (a number of platform conditions to do something, either alone or teaming) separated by thresholds (those decision points necessary to change from one activity to another). Some platforms, for example, will execute mainly defensive functions. The presence of an enemy or intruder (signalled or referenced by 'Bandit', 'Hostile', 'Leaker' or other APP-7 (Joint Brevity Words) identity and context-related references) may meet the necessary threshold for this defensive platform to change state and display other functions in support of the defended assets of the force.

> *Each service and partner will provide ways to think about how the F-35 transforms their approaches; and the sharing of these ways to think will empower the overall joint and coalition combat capabilities for US and allied joint and coalition forces as well.[5]*
>
> Dr. Robbin Laird, Second Line of Defense
> 'The Coming of the F-35', 2015

The number of finite states (functional states) that modern Air Power platforms (multi-role) include is much higher than the number of states displayed by legacy platforms. Communication through data transfer makes new schemas of dynamic support possible among these assets. This complex arrangement

will be executed by a C2 structure underpinned by communication. This concept will be further developed in Chapters 3, 4 and 5.

2.3 The Combat Cloud

The advent of 5th generation aircraft into the NATO inventory will bring an enhanced ability to collect and disseminate an increased amount of information across the network over previous generations. Different generations of aircraft, platforms in the future network, will operate together performing air power functions in a manner similar to the cloud metaphor. As a concept, the Combat Cloud has been coined by Lieutenant General (ret.) Deptula in the following manner:

The 21st Century demands a new, more agile and integrated operational framework (…) to shift away from the structure of segregated land, air and sea warfare (…). Desired military effects will increasingly be generated by the interaction of systems that share information empowering one another. This phenomenon is not restricted to an individual technology, nor is it isolated to a specific service, domain or task. This concept can be envisioned as a 'combat cloud', an operating paradigm where information, data management, connectivity, and command and control (C2) are core mission priorities (…) and will require a C2 paradigm enabling automatic linking, seamless data transfer capabilities, while being reliable, secure and jamming proof.[6]

Lieutenant General (ret.) David Deptula, US Air Force Evolving Technologies and Warfare in the 21st Century: Introducing the Combat Cloud, 2016

Information Technology and Air Power theorists frequently refer to this concept to describe their view of the future of information (and information-based) warfare. Commonly known as the Combat Cloud, the vision is that every air vehicle is a sensor and an effector and all sensors feed information back to the cloud which is then accessible as needed by other sensors,

effectors, or decision makers in near-real time. Other metaphors, such as the killing web or honeycomb force distribution, refer to a similar concept, albeit with minor nuances. A distributed force will therefore likely adopt a new topology consisting of a dynamic, ubiquitous effector composed of certain assets joined by wireless connectivity.

Chapter 8 will discuss the capability of legacy, 5th (and beyond) generations of aircraft to simultaneously execute and employ many of the Joint Air Power functions outlined in NATO doctrine by analysing three different examples. As aircraft with this improved capability become more prolific in NATO, the Alliance should address methods to increase data exchange between new robust sensors and other platforms.

2.3.1 Commanding the Cloud, Controlling the Cloud

Although the combat cloud concept refers primarily to information distribution, this study will also include references to the different topologies of the elements forming a cloud. It will also address potential common motion policies to contextually maintain or mutate the distribution of the cloud. Beyond information management, this new interpretation of the combat cloud concept introduces a challenge for the commander.

One of the premises of this study was that the 'command' function would not substantially change. 'Commanding the cloud' involves a human commander who will need the new structures necessary for 'cloud control' within these new-networked environments. In these environments, as per the Alberts et al. concept, all fractals (assets, platforms, elements or any other part of the distributed force effecting) may overlap with individual entities and groups belonging to multiple fractals dynamically[7]. Furthermore, in the future network, there will be a distribution of the capability to deliver effect rather than keeping it centralized in a single platform, per the already mentioned cloud, killing web or honeycomb metaphors.

For the purpose of this study, Command and Control (C2) are two separated but interrelated functions that

may be applied to subsets of the force in accordance with environmental and contextual factors. Even though some studies consider the terms 'control' and 'management' equivalent, the activity 'control' in this case relates to the human in the loop and his or her ability to supply the command inputs to the force as required. Management though, can include pre-programmed software-based automatic features inter-acting and teaming with human inputs while control-ling the force.

2.4 Swarms

Stemming from its biological origins, the term 'swarm' in today's world of Nano-robots and micro-UAVs (Unmanned Aerial Vehicles) has taken on multiple meanings. Aligning with the combat cloud concept, this study will restrict the use of the term 'swarm' to a particular qualitative aspect of its definition speci-fically related to network and platform interaction: A swarm is a group of platforms operating together, through local interaction and for the benefit of the whole colony's task.

At a recent infantry officers course at Marine Corps Air Ground Combat Center Twentynine Palms, Calif., Lieutenant General Bailey (USA MC) observed infantry officers riding in the back of MV-22 Ospreys in a raid scenario with tablets that were tied in to an F-35. Bailey and others observed from a simulated F-35 – a room with multiple computer screens that showed all the information an F-35 pilot would have at his disposal while flying. A Marine in one Osprey could change the plan for the raid based on new information, and that change was sent to both the tablets in the other Ospreys and to the F-35 pilot.

'The plan changes and I can send him that change in a burst, not try to get on the radio and go through a satellite and come back; I can just send him the exact changes and modifications', Bailey said. 'And so you pull all that capability together, and you can see how that platform will be able to revolutionize the battlefield and give the Marine on the ground a

capability that we've never had before. I think that's a game-changer when you start talking distributed operations and you start talking the environment of the future.'

Lieutenant General Ronald Baily, US Marine Corps Deputy Commandant of Plans, Policies and Operations 22 December 2016 Interview with US Naval Institute

2.4.1 Quantity and Quality

The swarm may be as large as the entire network, or as small as two units within the network, depending on the network's topology of choice and the desired degree of maturity in terms of systems integration. However, as a system of two or more platforms, the swarm can orchestrate and accomplish Air Power functions/tasks through self-synchronization. Semi-automated synchronization features will likely be embedded in the cloud through communication (machine-to-machine information exchange), which will make human command and control more agile.

2.5 Hyper-connectivity

For the purpose of this study, hyper-connectivity will refer to the availability of high-speed connections among the members of a community, team, force cluster, or other entity. This postulate is beginning to be realized in the so-called connected cars, where the entertainment system, autopilot, internet options, streaming services and other features will soon de-mand a high volume of information traffic.

The term does not mean all the available on-board data may be transferred among the different emitters and receivers with no restriction. Not everybody in the network needs to see/hear everything. Certain agreements must be in place, as well as a hierarchy, to provide the right information to the right users, whether man or machine.

Other services, like banks or international police de-partments, may be hyper-connected, but protocols

and agreements are in place to determine what information is to be shared and what information is not shared in order to facilitate the common benefit. This study assumes hyper-connectivity as a fact regarding data transfer speeds, but studies these agreements and their morphology in accordance with potential C2 and tactical management options.

Each C2 element in each network (a fraction of assets effecting together in time and space) will organize the will to share, the need to know, and the final agnostic agreements that will be further administrated by the resulting management architecture and the net's functional distribution. This is achieved through various types of topology, further explored in the next Chapter.

2.6 Game Theory

Broadly, Game Theory is the study of different mathematical models of conflict and cooperation between rational decision makers[8]. Game theory permits a comparison of the agent's behaviour without becoming entwined in the details of an aircraft's or platform's unique capabilities. As the purpose of this study is to outline platform behaviour changes as C2 matures, Game Theory provides a suitable foundation for comparison

of behaviour changes. It also is a mechanism to demonstrate the best choice of force configuration (spatial distribution) to confront emergent tactical contexts (changes in the environment).

Therefore, platforms operating in concert will frequently be referred to in this study as elements, agents, clusters, or participants in an activity (or 'game'), depending on the discipline, science or example referenced. We will refer to these platforms as players or participants, according and abiding by the associative and competitive rules of a specific game.

2.6.1 Evolutionary Stable Strategy

One of the meanings of 'strategy' included in the Oxford Dictionary (12th Edition) is 'a plan designed to achieve a particular long-term aim'. When a certain trend of changes, mutations, or alterations in the adaptive behaviour of an agent shows a continuous sequence of positive payoffs, it brings favourable balance and equilibrium to the colony writ-large. Furthermore, it results in a stable, successful strategy, effective in terms of achieving the desired aim or reaching a certain equilibrium. This axiom may be extrapolated to diverse and asymmetric platforms or agents in scenarios featuring co-evolution. In other words, the platforms in the network evolve mission

roles and functions together for the mutual benefit of all network participants.

For this reason, in a typical strike package, it is common for the clearance aircraft (Sweepers) to fly ahead to protect the strikers/bombers (Hammers). This spatial combination of assets is strategically stable through different aircraft generations, as the successive payoffs of these missions (platforms' performances) sustain the best trend of Measures of Effectiveness (MoE). Bombers and fighters co-evolved into multi-role aircraft or other forms of support through datalink among the different platforms executing the same roles.

2.6.2 Efficient Evolution, Efficient Clouds

Games are about competition. Games like basketball or soccer base their tactics on various players' distributions optimized in performance (e.g. to save energy) and effects (e.g. to score more than the opponent does) in order to win the game. A rapid shift from offensive to defensive actions in these games often results in a mutation of the spatial distribution of the players to achieve the new goal. Similarly, in the future ideal cloud, capability distribution would be optimal, that is to say, the right amount and combination of fractions of complementary effectors, where needed and when needed. Distributed control of an Air Power force may result in a ubiquitous force in the future.

Doctrine expresses how efficiency and effectiveness in the exertion of Air Power can improve through centralized control. 'Centralized control places the responsibility and authority for planning, directing and coordinating air capabilities with a single commander and his staff. It maximizes operational effectiveness and avoids duplication of effort by allowing commanders to prioritize, synchronize, integrate and de-conflict the actions of assigned, attached and supporting capabilities in time, space and purpose to achieve assigned objectives as rapidly and as effectively as possible'.[9]

Measures of Effectiveness (MoE) and Measures of Performance (MoP) are metrics used to verify the accomplishment of these Air Power actions. A Measure of Effectiveness is defined as a 'metric used to measure a current system state'. The MoE will help answer the question 'Are we on track to achieve the intended new system state within the planned timescale?' This may require multiple MoE per intended system state to fully capture the changes. The MoP is defined as a 'metric used to determine the accomplishment of actions', usually referring to one's own force's actions. Each level will normally develop MoP for the actions they will execute[10].

The Pareto optimality (the balance between efficiency and effectiveness) is used in this study as the most efficient allocation of elements within a team of assets from a quantity/quality perspective. In the past example, if the sweepers are not needed because another platform (Maritime Component's AEGIS for example) can cover and protect the bombers, a more efficient allocation of forces may be possible which still generates the same measurable effect.

This interrelation between platform mission/function evolution and the equilibrium described by both the evolutionary stable strategy concept and the Pareto optimality are recurring themes throughout the document and will be extrapolated in further Chapters to demonstrate applicability toward air platforms executing Air Power functions.

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CHAPTER 3

Topologies and Models: The New Force's Architecture

3.1 Introduction

This Chapter studies the systemic perspective of the force distribution. Structures, architectures, topologies, and their command and control options are analysed in order to understand how to fit the 'platform of platforms' concept into the most suitable C2 models.

A future distributed force will likely feature a different organization than a typical strike package does today. It will include a topology, a hierarchy and communication procedures as will any other organized force. But this organization, as a whole, may be viewed as a wireless 'organism' in the same way as that of the cloud in the previous chapter's example; a single physical body in the visual spectrum, performing in accordance with its selective rain capabilities through different particles' interactions (an amorphous entity that acts as required to achieve a desired effect).

This [combat cloud] concept highlights an evolution where individually networked platforms transform into a broader 'system of systems' enterprise integrated through domain and mission agnostic information links. This approach will not only change the way we define new requirements, but more importantly, the way we think about C2 and operate the systems associated with this task. A distributed, self-forming, all-domain combat cloud that is self-healing and difficult to attack effectively significantly complicates an enemy's planning, and will compel them to dedicate more resources toward defence and offense.

Lieutenant General David A. Deptula (ret.)
'Evolving Technologies and Warfare in the 21st Century: Introducing the "Combat Cloud"'

3.1.1 Organisms

An organism may be defined as an assembly of parts functioning together with certain stability. It also includes the idea of 'tool' within its etymology, so another approach would suggest that an organism is a multifunctional tool with an embedded coordination

mechanism. Each organism will, through evolution, adapt to the environment by adopting a specific form, in order to become the most effective and efficient tool in each context.

The nervous system of an organism is a mechanism for the transmission of signals within the organic structure. As organisms, systems like the Integrated Air and Missile Defence System (IAMDS) are composed of a set of elements. This 'nervous system' (comprised of information transmission systems such as ICC [Interim Command and Control]/ACCS [Air Command and Control System] and the means of transmission, reception and interfaces in the IAMDS example) must consist of a means of information transmission and reception that allows for the elements' orchestration.

The desire is for the organism that executes Air Power to pursue goals and objectives in air and space, and, once the effect is achieved, to measure the effectiveness of its own performance. Through assessments of time, tangible results, and investments, it can determine 'what is next'.

3.1.2 Competition

In order to link concepts such as 'system,' 'model' and 'element,' and extrapolate the concepts to Air Power, we first need to define a generic complex network consisting of several elements such as players or platforms that work together against an opponent regardless of service, technological generation or nation. These elements adhere to a set of standards (categories, rules, hierarchies and relationships), that enable them to function in concert in pursuit of a measurable mission objective. In other words, the system, functioning as an amorphous cloud entity, will have to find a model or the performance of operational framework for offensive and defensive functions, as this system will be involved in competition with another system. For NATO, this performance must be measurable and tangible.

This approach to Joint Air Power is executed recognizing that a future team of Air Power assets will be constructed with dissimilar platforms, and it will combine legacy and modern, manned and unmanned capabilities as required to generate an effect.

3.2 Air Power Topologies and Clusters

A cluster is 'a group of similar things or people positioned or occurring closely together' (Oxford Dictionary, 12th Edition). This includes the term 'contiguity' (spatial and sequential organization), which is the reason why we can see a single, irregular body when looking at our imaginary cloud. In other words, the elements of a combat cloud have a spatial and sequential organization that renders them a single actor from an effects perspective.

In terms related to platforms executing Joint Air Power functions, a cluster is a group of elements incorporating mechanisms of synchronization of these different functions (dissimilar roles). Today, this mechanism is primarily the Air Tasking Order (ATO) or Tactical Control[1] when on station. The ATO is the adaptive tool that contextually allocates the players for task execution and activates a 'nervous system', a communication network to permit the orchestration of the elements. This allocation and management of resources at the Tactical level, including reactive activities upon environmental changes, is a way to explain Command and Control.

3.2.1 Different Topologies, Dissimilar Agents

Dissimilar players with multiple nationalities and functions may cluster together to combat a common opponent. The dissimilarities between players, combined with random environmental changes, may make C2 challenges very complex.

Complexity in a system may include simplicity of different features,[2] but it will always involve some form of communication between the elements. Communication connects them and relays information to clarify each other's identity and hierarchy and to synchronize their different activities through mutually inducing state changes. The graphic representation of either the
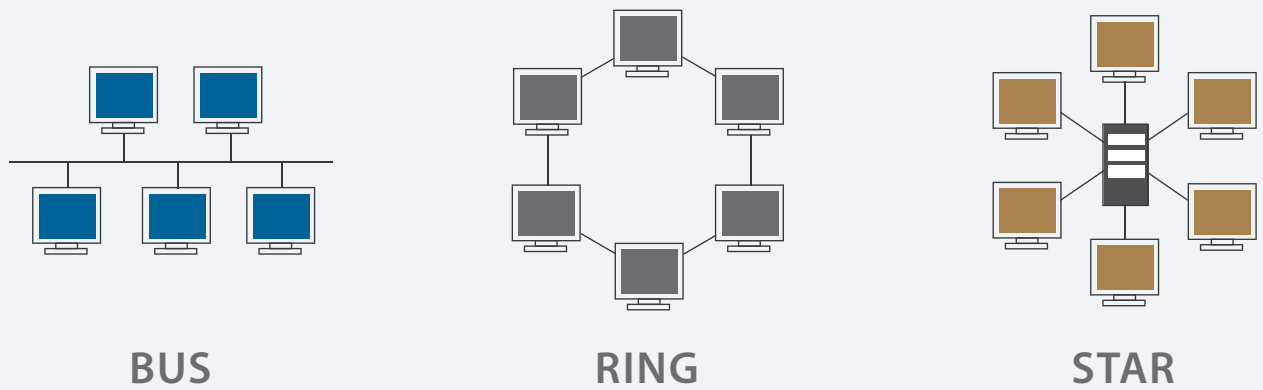
Figure 1: Different topologies for communication featuring different distribution of the flow of communication – Bus, Ring, Star.

M © ideart/shutterstock
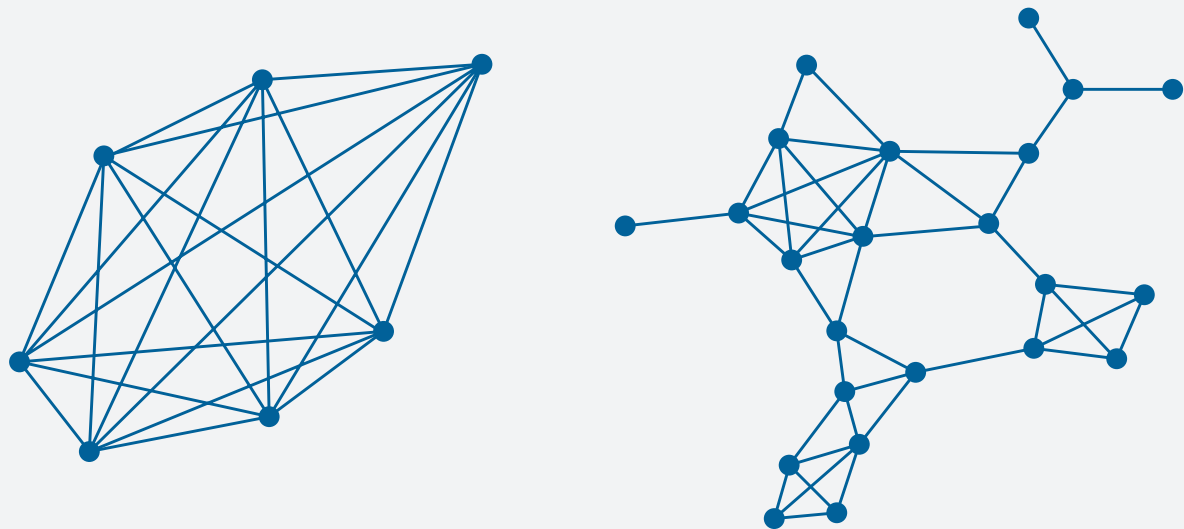
Coordination by Consensus
All swarm elements communicate to one another and use 'voting' or auction-based methods to converge on a solution.

Emergent Coordination
Coordination arises naturally by individual swarm elements reacting to one another, like in animal swarms.

Figure 2: Two main topologies representing different cumulative hierarchies of choice, showing mesh and hybrid distribution of the flow of communication.

M © Scharre, Paul. Ph.D.
Robotics on the Battlefield

physical distribution or the flow of information among the elements of a set is referred to as topology. It shows the communicative structure of the cluster: how the parts relate to the 'brain' or the command element, and how the parts inter-relate amongst themselves.

Another similar definition of topology is 'the way in which constituent parts are interrelated or arranged.' (Oxford Dictionary, 12th Edition) The associated topology and the patterns of interaction may graphically explain 'the game' and each defensive and offensive

tactical context (understanding the cluster as a team), much like a basketball coach arranging the point guard, centre and forwards during a timeout by depicting the next play on a board.

When dissimilar agents featuring a certain hierarchy form a cluster, their ranks and functions may be expressed through the appropriate topology in terms of command, control, and management.

In accordance with the different cumulative hierarchy of choice adopted by the cluster or clusters of elements, there are four main models or topologies.[3] These topologies include Centralized, Hierarchical, Coordination by Consensus (also called Mesh in other classification models), and Emergent Coordination.

As this study aims for a functional approach, pre-selection of a particular C2 model regarding spatial distribution of the assets is not intended. Different topologies may emerge dynamically if the environment demands such level of adaptation, like some sort of 'cloud mutations' fitting each tactical context. Emergent coordination arising through compatible software among dissimilar elements is a desired feature, as long as it expedites decision-making and execution and does not interfere or bypass the required human involvement.

Other topologies define how the network connects the command element with the different managers and players, like ring, star, or bus, among others. The rules of the game, the tactics of choice or external independent variables (weather, opponent's actions, etc.), or other contextual circumstances may dictate the network's redistribution. Optimality must be found through a quantity/quality/asymmetry balance. These balances will not be achieved if the assets cannot 'talk' to each other.

Imagine the airspace as a 3D Cartesian system with X/Y/Z axis and the platforms as points forming different sets (groups of elements) on it. A brief and simple algebraic comparison (at a conceptual level) of how and why the air domain sustains models resembling contiguity may be done by correlating the three conditions that define a topological space. These conditions include:

- *Convergence* (a tendency in the sequence of capabilities of choice and their potential combinations to come together to meet a specified objective);

- *Continuity* (the ability to establish a relationship through distance and to maintain a solid input-output relationship through changes) is related to Convergence; and

- *Connectedness* (the potential to cause the elements to be path-connected).

This comparison can be further extrapolated to predict the continuous and preferred structure of space supporting a dynamic and flexibly linked force. That fluid airspace would permit the formation of 'open set' topologies, exploitable in real-time by the interaction of the elements in the set as necessary to accomplish static or dynamic tasks, and in accordance with the demands of the highest degrees of maturity of the model.

If sensors, shooters and weapons' guidance can be federated and modern weapons' range increases far beyond the 50 or even the 100 NM boundary, the battle will need a new battlespace concept. Latest generation weapons like the Meteor missile or the SPEAR 3[4] will be on-board 3rd and 4th generation assets, managed by a 5th generation aircraft or any other control element, which may be ground-based air defences and other Joint Fires C2 elements. This concept will lead to the 'true jointness' option, when all the available assets cloud simultaneously with increasing degrees of self-synchronization.

> *The Holy Grail of interoperability is operating the same equipment, but clearly countries have sovereign decisions to make with respect to that. We recognize that when we can't get that Holy Grail, then we have to find procedural ways through standards and data and all of that to get that interoperability that helps us out on the battlefield.*
>
> *General (ret.) Frank Gorenc, USA AF*
> *Former Commander Allied Air Command*
> *Defense News Interview, March 2015*

3.2.2 Interoperability Shortfalls

Consider the Joint Force as a set of elements that team together. The options that allow the dynamic formation of clusters within the 'Air Power' subset introduce interoperability conflict when mixing dissimilar and asymmetric platforms clustering together. There are some degrees of hierarchy and compatibility among the players (like the pieces in the chess game), and their differences and the communication schema of choice may dictate their most efficient topology for each task and threat combination.

Common to all is the need to sustain positive MoPs to ensure each platform is operating with the best interest of the entire force in mind. The cluster, as the organism, must function with certain stability, so the desired output is also stable. Overall mission effectiveness of dissimilar and asymmetric platform operations are limited due to different:

• standards of technology;
• Tactics, Techniques and procedures (TTP);
• communication;
• currency;
• rules;
• language;
• service and/or personal biases;
• conflicting mission profile
  (endurance, speed, envelope requirements).

The cloud cannot be formed through bottom-up, local interaction if there is not an acceptable degree of interoperability when forming efficient platform-weapon-sensor topologies. Although many studies are investigating some of these interoperability limitations, this study specifically focuses on communication. Chapter 5 will further explore communication as a function of C2 maturity.

3.3 The Reins of Command

In Joint Air Power clusters, interoperability is expected and is expressed in many joint and tactical publications. However, so far, many observe that interoperability is truly realized only at the level of standardization of Tactics, Techniques and Procedures (TTPs) rather than as an integrated and fully interoperable Joint Force. The morphology of Air Power Core Roles and their associated types of operations (the framework for all Air Power-related activities, functions and skills) is evident in AJP 3.3, and many of the possible combinations of these Roles, functions and skills can be found at a Tactical level in the 'Manual 80-06'. Also a third publication, the 'ACO (Allied Command Operations) Forces Standards[5]', establishes rules and guidance to improve interoperability. These publications provide the structure and control mechanisms by which the COM JFAC employs Joint Air Power and are a necessary starting point for this study's discussion on the potential future evolution of C2 enabled by communication technology.

3.3.1 Core Roles Orchestration

The four Air Power Core Roles are used to achieve strategic, operational and tactical objectives. Per AJP 3.3 and the NATO Joint Air Power Strategy (in DRAFT as of May 2017), these are: counter-air, attack, air mobility and contribution to ISR. Execution of the Core Roles is not unique to the air component. Land and Maritime Components also have platforms which can perform Air Power Core Roles.

Air Power Core Roles orchestration is a responsibility that the Commander Joint Task Force (COM JTF) assigns the COM JFAC, who plans, integrates, monitors, allocates, and tasks the assets in accordance with COM JTF's apportionment decision (AJP 3.3). If we introduce Air C2 as 'the allocation and overall cluster management of the platforms of the Air Power set within certain boundaries of the battlespace,' each tactical context would demand the use of certain Air Power Core Roles to form the appropriate topology to accomplish the required mission.

Different roles and different platforms may intertwine, as long as they can 'talk to each other,' to 'help each other' in a supported-supporting relationship within dynamically variable topologies (mainly featuring emergent coordination and mesh topologies). Their common language (a code comprised of symbols, icons,
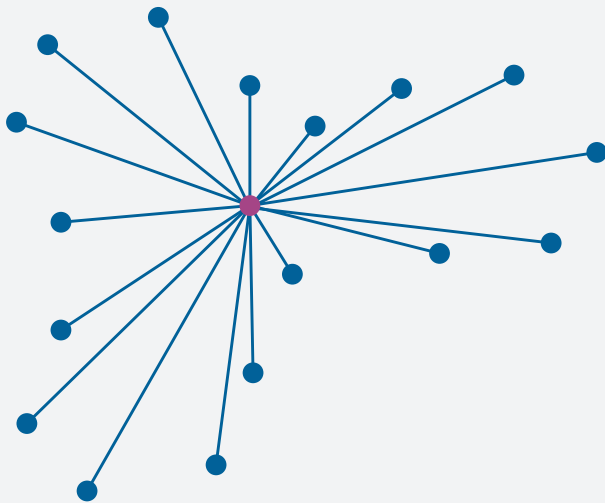
Centralized Coordination
Swarm elements communicate with a centralized planner which coordinates all tasks.
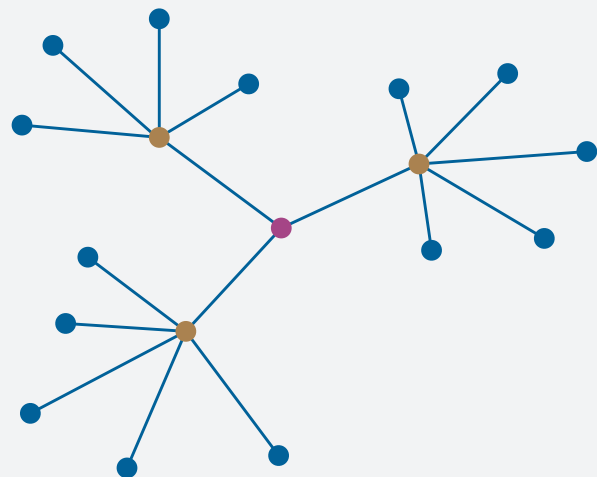
Hierarchical Coordination
Swarm elements are controlled by 'squad' level agents, who are in turn controlled by higher-level controllers.

Figure 3: Two more topologies representing different cumulative hierarchies of choice.

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Robotics on the Battlefield

sounds, and code words) must feature a level of data quality to eliminate ambiguity to the maximum extent while synchronizing functions on the battlefield.

3.3.2 Orders Transmission

Throughout the history of warfare, forces have needed to communicate to pass coordinating instructions. Language and syntax evolved to project concepts, actions and intent. The Maritime community developed a method of passing orders via visual means, such as flag hoist. In the modern air domain, language evolved as a requisite of speed of operations. This is because the 'signal' portion of the 'command and signal' concept for each operation is equally important as the 'command' portion, if not more so with respect to coordination of effort and level of C2 maturity necessary to synchronize effect.

Verbs denote activity. To mix dissimilar activities, a valid, coherent synthesis of verbs of action may be formed and transmitted to the different parts of the organism or cloud. By doing this at the planning level,

the different functions that can be executed by each platform are orchestrated in accordance with a coherent sequence of actions. This requires subjects (the elements, platforms, and even sensors or weapons), objects (the action's receivers) and verbs (the actions themselves). The hierarchy within the cluster (the brain or brains, the presence of the command element on the battlefield through an in-place management element) will then be able to interpret the environmental changes and transmit orders to the subordinated parts following the main schema of the F2T2EA kill chain. The tactical expression of each function may be interpreted as a contextual skill for one or more of the participants.

These linguistic options are expressed mainly in the brevity words glossary, the APP-7, for those communications that are speech-based and that, beyond orders transmission, pass information about tactical contexts. Note that each brevity code word is labelled in accordance with the contextual 'ownership' of the term, which may belong, through standards, to one or more services. This means an inter-service cluster with

Figure 4: Birds, operating as a platform of platforms, are synchronized to achieve a common effect.

a certain degree of machine-to-machine communication may have to renew efforts to develop adequate data quality, while overcoming cultural, national and technical differences when designing the communication skills (channel and code-based) among two different platforms and, through interfaces, between machines and humans in the loop.

3.3.3 Wireless Clusters, Wireless Reins of Command

The clusters formed in the coming decades may perform in a similar way to the ones offered in the 'organism' example. The off-board platforms, sensors or weapons, complementing or supporting a main platform through wireless means, will execute functions managed from other neighbour platforms, and cluster formations and orchestration will be dynamically dictated by a criteria of optimality regarding the desired effect.

The potential realized by this type of behavioural data exchange could result in a complete redesign of a typical strike package, or even rethinking the way the entire ATO cycle is built and implemented. Regardless, this allocation of forces integrating talking machines will demand a new, more mature structure permitting flexible topologies. Some of the orders will be automated, and the human presence in the loop restricted to certain management functions, so these clusters will become a semi-automated team.

In order to attain a proper C2 structure that is able to form optimal topologies, orchestrate these hierarchical and multifunctional tools and affect the environment with a high degree of automation while still being man-controlled, we must first visualize the next step in C2 maturity before we can achieve it.

3.4 Platforms of Platforms

Today, air mission planners decide how to shape the options concerning necessary Air Power Roles/functions needed to accomplish the mission. Because platforms today operate as individuals in the battlespace, the planners also develop the airspace necessary to accomplish those tasks, making sure the assets are co-ordinated, de-conflicted, and distributed by function.

In an eerily similar manner as the 'arrow flock' in Figure 4, the US DoD (Department of Defense) Strategic Capabilities Office and Naval Air Systems Command recently tested micro-UAVs deployed from F-18 Super Hornets.

103 Perdix drones were released and then self-synchronized (see next Chapter) to execute 3 mock missions.

In the future, there is a potential for certain assets to overcome spatial segregation by executing this airspace development function in the air during the mission, rather than having airspace pre-determined and pre-selected for a specific mission role. Could Perdix or a similar cluster of elements be considered a single platform operating in its allocated, self-deconflicted battlespace?

Due to the complex nature of combat, Perdix are not pre-programmed synchronized individuals, they are a collective organism, sharing one distributed brain for decision-making and adapting to each other like swarms in nature. Because every Perdix communicates and collaborates with every other Perdix, the swarm has no leader and can gracefully adapt to drones entering or exiting the team.

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3.4.1 Clouds of Clouds, Platforms of Platforms

The developers refer to Perdix as a 'collective organism', which assumes that this organism has an embedded or connected C2 feature that enables its operation within a wider tactical net. Bertrand Russell's paradox explains that a set of books is not a book. This makes this set of books a 'normal' set, but an 'abnormal' set is a set, which is also a member of itself. For example, a bag containing bags is a set defined by the class of all its elements. A set of abstract ideas is an abstract idea itself. A set of clouds is a cloud if (metaphorically) the cloud commander has control over selective cloud performances without spatially segregating the cloud's parts.

A set of aircraft is obviously not an aircraft. Nevertheless, different off-board or third party platforms connected through a solid, robust wireless protocol may be aggregated through connectedness within unrestricted battle-

space (and not only airspace, as it may include ground and sea spaces). It may, as a set, perform as a single entity by aggregation of Mission Computers (MC) in a mesh or partial mesh topology, computers which will communicate with each other by transferring semantically compatible data. Moreover, communication may happen not only between brains (MC to MC or brain-to-brain) but also to generate steering orders to comply with the common motion policy of the cluster (MC to Flight Control Computers [FCC], or brain-to-fin).

Nowadays, the MC to MC (Multifunctional Information Distribution System [MIDS] to MIDS) interface, which exchanges battlespace awareness through datalinks, exemplifies the brain-to-brain concept. Brain-to-fin is exemplified by a platform's brain talking to another platform's fin, resulting in an action, in the form of a steering input, being generated from a command by the first platform's brain (computer).

In this instance, the resulting cluster can be considered a single platform. Although physical cables do not connect them, they are obviously connected within this networked environment. In this base, the brain-to-fin model generates motion policy.

Furthermore, every cluster needs a hierarchy in order to maintain decision rights at the appropriate command level. A swarm of bees is not a bee, despite the fact that it behaves like a single organism concerning certain common functions. A swarm of interconnected dissimilar platforms, or a cluster of elements transferring data to each other is neither a plane nor a missile nor a RPA, but as a system, it can orchestrate a certain number of functions through self-synchronization and 'cloud' against the opponent.

1. Such as AWACS or other C2 node.
2. Olsen, Megan M. 'Variations on Stigmergic Communication to Improve Artificial Intelligence and Biological Modelling'. Partial fulfilment of Ph. D. requirements diss. University of Massachusetts-Amherst. Dissertations. Paper 477. (2011) http://scholarworks.umass.edu/cgi/viewcontent.cgi?article=1478&context=open_access_dissertations [29.11.2015].
3. Scharre, Paul. 'Robotics on the Battlefield Part II. The Coming Swarm' Center for a New American Security. [e-report] Available at: https://www.cnas.org/publications/reports/robotics-on-the-battlefield-part-ii-the-coming-swarm [13.11.2015].
4. Laird, Robbin. 'The Weapons Revolution Continues: MBDA Shapes a Way Ahead for Strike Platforms in the Kill Web'. SLD Info, Oct. 2016. [online] http://www.sldinfo.com/the-weapons-revolution-continues-mbda-shapes-a-way-ahead-for-strike-platforms-in-the-kill-web/ [10.10.16].
5. Both publications are classified 'NATO Restricted'.

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CHAPTER 4

Communication and Talking Machines

This Chapter will review several fundamentals of communication and associate them with certain bio-models operating in continuous, non-segregated spaces. It will also identify self-synchronization as the ability of an agent to perform certain functions co-ordinated in intent, time, and space with other (battle-space) entities.

4.1 Talking Agents: Multifunctional Environments and Finite State Machines (FSM)

A Finite State Machine (FSM) is a machine or agent capable of different behaviours based on certain states. If dissimilar platforms are going to cloud together, it is necessary to understand the menu of activities each machine can display in each state. Then, correspondence among them can be established to form the proper subsets for each task.

As this chapter refers to different evolutionary systems belonging to different disciplines, for the remainder of this discussion, the word 'agent' will define each one of the elements within that system. These agents will be approached as a set of elements or platforms that may conduct actions and demonstrate behaviour across time and space.

4.1.1 How FSMs Work: the Turnstile Example

Multifunctional machines can be complex. Consequently, a cluster of multifunctional machines attempting to self-synchronize through automation might result in poor performance due to excessive complexity, especially when involving hierarchical patterns of communication.

An example may offer a helpful perspective: Consider a turnstile as an agent that displays 'locked' behaviour until it meets the threshold 'insert ticket'. The turnstile then transitions to the second state of 'unlocked.' Once the turnstile is used (new threshold), the state becomes 'locked' again.

The basic role of the turnstile in an urban metro/subway system is to filter access. It therefore has only two main functions: to either facilitate or deny access. If a person without proper access rights (a ticket) tries to access the system, the turnstile remains locked. This is how a set of turnstiles or barriers operate when monitoring humans: coupling spatially and ordering the flow in toll ways, metros, airports and other facilities, but always featuring these two distinct states, 'locked' and 'unlocked'.

Motion policy for the network may be generated by the turnstile in the form of a timing feature between state changes, i.e. how often the turnstile will let an approved user pass the checkpoint so as not to overload any critical node is a method for controlling flow of commuters, like traffic lights also do. The coupling of turnstiles and other agents within the system to control this motion policy (spatial movement of users [people]) requires a certain level of communication and coordination in order to manage this motion policy (to rapidly and selectively separate authorized and unauthorized movement within the spatial boundaries of the system).

Amongst other reasons, humans have orchestrated the turnstile function in this manner to avoid saturation as rush hour commuters arrive to the boarding station. If the turnstiles did not exist, it could mean that some areas of the system would collapse or intruders would gain access. This drives the need for a control mechanism to coordinate efficient own force's motion policy for the entire system.

Taken together, these spatial limits and the desired motion policy of the different cooperative agents (commuters, trains and turnstiles) within that specific network space are critical in the selection of the type of topology to use when developing the network.

In a complex environment, such as metro systems in modern cities, turnstiles share spaces and work with computers, biometric sensors and humans to control the flow of human traffic. Communication makes it possible to connect a simple agent, such as a turnstile designed for physical access acceptance or denial, to a complex database shared by other agents and managed by humans supported by a software-based Decision Support Systems (DSS). The turnstile does not decide by itself, rather it decides (takes action) utilizing actionable information against a decision tree provided in advance by a manager, which can be either human (man-in-the-loop) or software-based at that specific level.

4.1.2 The Foraging Ants: Similar Agents Acting as FSMs

In his paper 'Emergence of Temporal and Spatial Synchronous Behaviours in a Foraging Swarm' presented to the European Conference of Artificial Life, Chevallier discussed the swarming behaviour of spike ants. Chevallier's[1] scientific model, inspired by the foraging behaviour of spike ants recreated in a 2D simulation, involves three states: foraging (active), sleeping (inactive), and observing (ready to activate-collecting information). Thus, the spike ants may be considered FSMs with three possible states.

Similar to the turnstile 'state' example above, these changes are normally deterministic, i.e., they do not contain random development of future states within the system. At this level, the spike ants will show certain temporal and spatial coupling in the transitions. This means they self-organize to determine when they should rest, observe, or forage. Additionally, they determine their own movement for these activities, similar to humans in big cities trying to avoid rush hours. The benefits of synchronous foraging are inversely proportional to the consequences of asynchronous foraging, which could mean increased chances for collision and reduced foraging time.

Now consider the presence of an intruder (actionable information) in the spike ants' ecosystem. The ants would have to develop a fourth state, defending

(active), in addition to the other three states. For this single agent-based (ants) model, states and thresholds are modified by the interaction with the other ants and by the environmental dynamics. This interaction results in new conditions, which are then followed by new actions and associated motion.

Imagine that the spike ants are not able to provide defence against the intruder and a third party (non-ant) can do it in exchange for potential support that one of the three ants' states may offer. If cooperative non-ant FSM agents are able to develop behaviours (states) which support the ants, a functional set may be developed which outlines this relationship, including the requisite state changes necessary to result in the desired outcome.

It was previously discussed that many Perdix agents can be considered a single platform. Eventually, a certain group of different agents (some displaying more complex functions, and some more basic) will evolve its pattern of collective behaviour. This occurs in part as a consequence of successful mutations generated by Darwinian competition against a common threat. It is also a consequence of the interaction with other potential symbiotic allies that perform dissimilar functions in their own interest but which also provide common benefit. The combination of the two facilitates co-evolution of the disparate Perdix agents into more symbiotic parts of the larger whole.

4.1.3 Identification: Friend or Foe

Basic FSMs are sub-parts of more complex systems. Analogously, Identification Friend or Foe (IFF) is a tool which utilizes track interrogation (with a return signal in the form of actionable information) to facilitate Combat ID actions at the Tactical level. In this case, the IFF network of sensors detects intruders within a pre-defined airspace, and although a certain level of automation is technically feasible today, the majority of IFF information is still entered manually for use by other elements of the network. Furthermore, changes between IFF 'states' are done manually through turning the appropriate knob. The most common states for IFF are 'interrogate,' 'stand-by' and 'off.' IFF allows for identification

through communication (interrogate-reply) to a variety of platforms sharing a communications plan. Thus, when the reply (next intruder) results in a change in the environment, a new action in terms of motion policy and/or the execution of other functions may be taken (defend against next intruder, activate a new sensor for correlation, or even fire). Metaphorically, the IFF would be a type of communication-based sub-agent/sensor utilizing a similar state policy to that of a more sophisticated 'turnstile'.

A classic example is when interrogation demands further ID actions to determine whether or not the intruder is hostile. In this case, other on-board or off-board tools (system sub-parts) will add their Finite States to this ad hoc network/cluster to complete the required functional menu, and once the determination is made, to successfully complete the response action.

In a complex system, an IFF interrogator does not necessarily have to be physically collocated with the platform that will complete the engagement. Even if the IFF interrogator is generally a mission essential tool in accordance with the standards for a Counter Air asset, an intruder can be labelled as hostile based on off-board/third party IFF information (in addition to other required behavioural features) and the engagement could be completed by a non-equipped IFF platform through correlation. In this case, the non-IFF platform will act as an off-board weapon of the interrogator-equipped platform, or as an off-board sensor of the shooter, as long as they are voice or data networked.

4.1.4 Oxpeckers, Zebras, and Ostriches: Dissimilar Agents

Consider the savannah as a complex system (or complex ecosystem). In nature, this intricate interconnectivity amongst sub-parts also exists within the symbiotic (mutualistic) relationship shared by oxpeckers, zebras and ostriches. Oxpeckers not only clean the zebras, but also fly and alert the zebras when predators approach, like a Radar Warning Receiver (RWR) does for an aircraft. Ostriches (smell and see) and zebras (smell and hear) also federate their sensors to cover wider threat spectrums, identify friendly and

factor hostile agents within their sensor range and provide warnings across the network to other friendly agents. The three types of agents may be viewed as an Integrated Defence System based on a simple harmonization of four basic states: 'resting', 'foraging', 'observing', and once a threat presence is detected over a threshold (stimulus), 'escape' (response to the threat). Each state will feature different functions in each species/agent.

4.2 Stigmergic Communication

This section will describe internal communication mechanisms embedded in the aforementioned eco-systems or models, where a level of multifunctional cooperation within the animal kingdom is possible through Stigmergy. Francis Heylighen in his paper 'Stigmergy as a Universal Coordination Mechanism: components, varieties and applications' defines Stigmergy as 'a communication-based coordination mechanism, in which the trace of an action left on a medium stimulates the performance of a subsequent action'.[2]

The oxpecker-zebra-ostrich example explains Stigmergy from the perspective of a multi-agent coordination mechanism that relies 'on information exchange through a shared environment'.[3] Each agent would incorporate a different threat sensor or interrogator, federating their different capabilities across a broader spectrum than the individuals could alone through communication. This multi-agent coordination illustrates the environmental change, the signal, the action and the multi-agent cooperation present in a case of stigmergic communication within a network. Animals and insects organize and align their states with both similar agents and dissimilar species in functional schemas, demonstrating different topologies for actions such as foraging or defence, with the associate motion policy and spatial distribution. Stigmergic motion and communication are relevant based on prior allocation of decision rights (pre-defined automatic responses).

Stigmergic communication is related to the capability to interpret the current systemic 'stage and state' of the group performing a task. Through stygmeric communication, agents are also able to transmit environmental changes that may induce state changes in the other agents. The 'task' factor is introduced virtually in Stigmergy, as the communication patterns and codes are pre-briefed and shared.[4]

Stigmergy is based on messages deposited in a shared environment and perceived by others through local interaction and interpretation. As the environment changes, (intruders, weather or other variables acquired by the agent's sensors), the signalling technique (signalling understood as the sensorial expression in the form of actionable information that will facilitate the emergent strategy) must be semantically connected with the best common payoff for the local agents and for the whole system. Extrapolation of this model indicates the potential for this to be exported to clusters of dissimilar machines through the development of a script of the proper cause-effect algorithms for each given circumstance.

For the purpose of this study, stigmergic communication will be considered as the transfer of information that automatically reduces conflict, augments shared awareness and manages supported and supporting agents for the completion of a common plan among cooperative platforms. Leveraging the observations of Stigmergy in the animal kingdom, a similar mechanism will likely eventually transfer to the machine-to-machine symbols and icons automatically exchanged through datalink protocols.

Stigmergy can be defined as a mechanism of indirect coordination in which the trace left by an action in a medium stimulates a subsequent action. It then analyses the fundamental concepts used in the definition: action, agent, medium, trace and coordination. Stigmergy enables complex, coordinated activity without any need for planning, control, communication, simultaneous presence, or even mutual awareness.

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4.2.1 The Mechanics of Stigmergy: Decentralized Execution

Decentralized execution is the delegation of execution authority to responsible and capable subordinate commanders to make on-scene decisions that exploit opportunities in complex, rapidly changing or fluid situations.[5] The communication profile adopted by certain species has an embedded feature, a sign that leads to collective benefit without the continuous validation of a command authority or a controller. Under this profile, execution is fully decentralized but still highly effective. Signalling may appear in the form of a quantitative mark in the environment (a measurable amount of pheromones, for instance) or as part of a coded set of signs (qualitative Stigmergy). Upon reception, agents will change state and execute their programmed functions accordingly. This can generate robust, complex, intelligent behaviour at the system level.[6]

This means a pair of agents can organize their contextual tactics to match a common strategy without the presence of a decision maker/tactical manager or needing a rigid command/decision hierarchy. Some features of the current datalink protocols, like the auto-sorting among similar fighter aircraft, use qualitative Stigmergy to suggest proper de-conflicted air-to-air targeting. In military terms, there would be a correspondence among the environment, the agent, the communication, the action generated in the receptor and the Commander's intent. Contrarily, the Commander of the zebra-ostrich-oxpecker cluster does not even have to exist to successfully orchestrate their defensive display behaviour.

Note that, through Stigmergy, the supporting-supported relationship does not mean a rigid hierarchy, as it is emergent and contextual. These relationships may be self-synchronized from the bottom to the top and will contribute to a specific and measurable common payoff. In the case of the aforementioned zebra-ostrich-oxpecker ecosystem, the symbiotic payoff of the respective agents in the network is security for the non-flyers and nourishment for the flyers.

This example highlights that different technological generations may integrate in the same clusters. In other words, an increased maturity in communication will allow for clusters of multifunctional machines to automatically select the best combination of sensor usage and the best choice of weapons in a de-conflicted space. If a mechanism federates the 'what', 'where', and 'when' sensors and weapons are used within these local interactions, control is distributed, as the 'who' will be contextual.

The synchronization matrix that structures the different mission factors would still exist, but sustained by parallel actions and automatically triggered once the environmental alterations dictate state changes in the different platforms. Furthermore, this sets the stage for a future discussion regarding aircraft (agents) of various technological capability functioning, within the same network, to work together to achieve the larger team's desired effect.

4.3 Stigmergic Coverage

4.3.1 Communication and Orchestrated Motion

The challenge is to imagine how dissimilar platforms within a cluster can couple their manoeuvre through enhanced communication when sharing a task, especially when the teams are formed by manned and unmanned assets from different services and environments.

Spike ants were previously presented as Finite State Machines with three possible states. Note that this particular study was based on a single species displaying simplistic rules and behaviours. Threat presence within the spike-ants system was introduced to explain how the competition fundamentals would include new ants' functions or third party options. If the ants evolved to incorporate certain IFF-like interrogating ability, they would obtain a reactive reply (fight or flight). Upon reaching a threat threshold, offensive or defensive states could then be incorporated to their FSM construction to react and survive. The different ant allocation diagrams show a specific behaviour in the transitions between states (Figure 1), behaviour
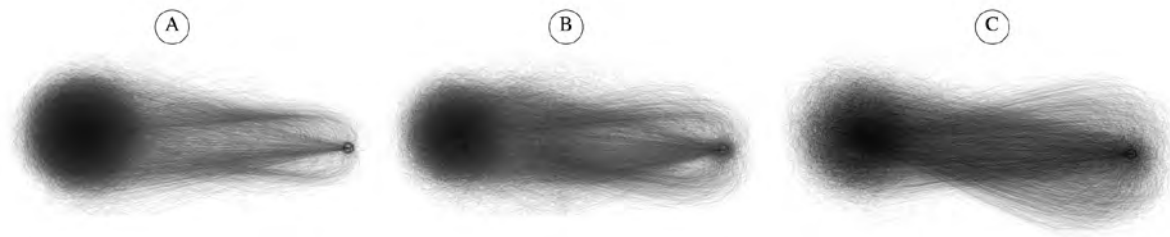
Figure 1: Chevalier et al. research on spatial distribution of Spike ants considered as three-state FSMs. Three behavioral regimes emerge in the population: (A) Asynchronous, (B) Synchronous aperiodic and (C) Synchronous periodic.
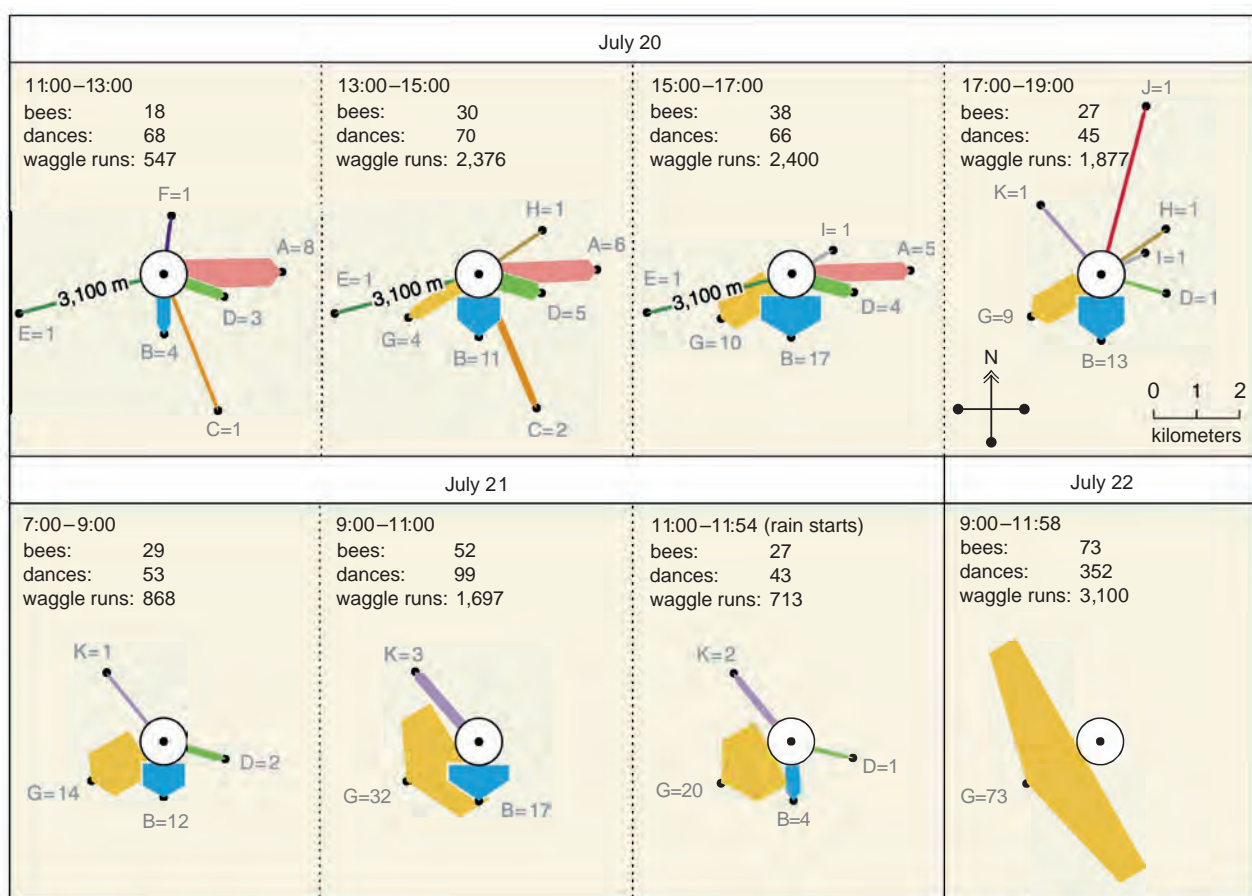
Figure 2: Distance and direction to the feeding stations are coded in the bees waggle dance. This 'dancing function' marks the environment and allows for collaborative detection, decision-making and subsequent exploitation of food resources through an orchestrated motion policy, similar in the usage of external references to aircraft operating under broadcast control.

expressed in the Rajnbar-Sahraei experiment (Figure 3) in a certain spatial distribution and motion policy with respect to the intrusion and to the other three functions.

Spatial and temporal couplings are enhanced by communication when swarming. That is also the conclusion of Chevallier et al. when measuring the emergence of temporal self-organization featured by swarming spike ants.[7] The spike ants mark the terrain as they move, communicating the 'where' and 'when' the distributed force should exert certain 'what' functions.

For example, Seeley[8] discusses in his paper 'Group Decision-making in Swarms of Honey Bees' how bees use what could be called a bullseye reference system when determining the best place to look for flowers to pollinate. Drones fly in all directions from the hive, and upon return, report to the hive by marking the environment through a dance, incorporating the sun, the hive, and the food target in the dance's geometry to inform the other bees. The next series of drones are then re-aligned to make use of the information provided earlier, and in short order, the bees have refined and maximized the efficiency of the drones via stigmergic communication.

This could be extrapolated to the functions of Air Power and manifest in the form of stigmergic communications forcing state changes to employ functions across the force (kinetic and non-kinetic engagements, active and passive sensor employment, electronic attack, directed energy and others). These functions, through management, mark the spatial and temporal flow of the cloud, which moves with a single meaning (executing the motion policy of choice) under a distributed effort. Further examples of different agents' (biological and mechanical) self-synchronizing functions through stigmergic communication are provided in the following Chapters.

4.3.2 Extrapolation to Tactical, Hyper-connected Platforms

Across the animal kingdom various examples exist of stigmergic communication. Whether it is bees, ants, fish or birds, each communicate within their swarm to synchronize motion policies to other members (agents).

Extrapolation from the animal kingdom to modern, interconnected weapons and sensors (as part of an 'air power social structure') may apply if these modern platforms are considered agents clustering together in a competitive environment.

In this Air Power social structure, the role played in alignment, attraction, and mutual support by Ground Based Air Defence (GBAD) platforms, like the Patriot or the Norwegian Advanced Surface to Air Missile System (NASAMS), or airborne platforms, like the F-35, may be viewed 'in terms of flocking and schooling,'[9] defensive motion policies within the animal kingdom. These systems will 'mark' the battlespace as they fight, generating new, emergent spatiotemporal patterns consisting of the best (efficient and effective) fighting topology for each context incorporating an optimal coverage algorithm, as per the cloud metaphor. In this flexible, communication-based scenario, the available battlespace may not be large enough for segregation of these modern sensors and weapons due to their increased range and performance. This requires a conceptual transition from segregation to synchronization of battlespace utilization.

To put this in context of NATO doctrinal terminology and associated brevity words (APP-7), if some ants (defenders) had a chance to repel the intrusion, the most suitable agent will automatically 'delouse'[10] the threat affecting the more vulnerable agents, and the motion associated with this engagement would automatically induce de-conflict orders to the rest of the team.

A research team at the Maastricht University's Swarm-Lab discussed spatial motion in swarm networks in their paper 'A Multi-Robot Coverage Approach based on Stigmergic Communication'. In it, the term Voronoi diagram is introduced to explain spatial distribution of platforms operating in a swarm.

The Voronoi diagram of spatial partition of the plane (upper panel in Figure 3) represents the boundaries between the agents, coordinated through Stigmergy.[11] Upon detection, the intruder (red mark) dictates a change in the environment and forces the agents to cross their state threshold in two manners:
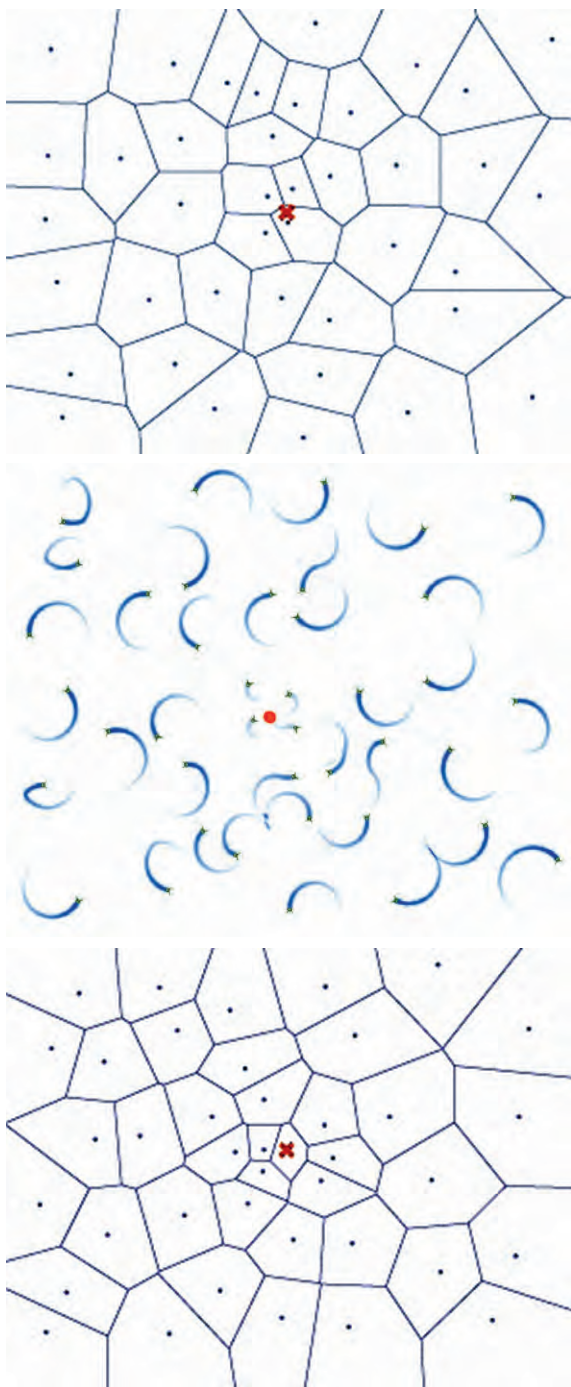
Figure 3: Voronoi diagram – A 3 panel overview of machines conducting 'surveillance' according to a fixed motion policy (angular speed and a basic collision avoidance algorithm) and their resultant defensive repositioning using stigmergic communication upon detection of an intruder (the Red X).[11] Note the adjustment to allocated space for each agent dependent upon the new state.

- First, agents may change their motion policy (repel or attract), depending on the function of the agents with regard to intrusion. The defenders will be attracted to the red X and the more vulnerable agents repelled (self-preservation).
- Second, agents may change their agreed boundaries for de-confliction after the new motion policy is in-place and the proper intruder response action is implemented.

Once the intruder is detected, the neighbourhoods of each agent around the intruder become smaller so as to permit effective identification and to prepare for proper action.

Figure 3 represents three steps of the Ranjbar-Sahraei et al. experiment.[12] It illustrates the evolution of the stigmergic coverage executed by a multi-robot group before and after an intruder is detected. The agent's function is to maximize coverage through federation, to execute effective intruder detections and to avoid collision. These functions will dictate the team's motion policy.

This multifunctional scenario featuring an intrusion can be readily extrapolated to battlespace distribution and platform behaviour when dealing with weapons, sensor and communications coverages, distance to friendly and foe platforms, hostile range, weather and terrain, available space and routes and reactive manoeuvres, among other factors. In fact, an example of machine-based, optimal spatial management (ALPHA), based on Artificial Intelligence (AI) within a group of flocking fighters, is already available for combat simulation, and is discussed in Chapter 8.

4.3.3 Agent De-confliction in a Continuous Space

Voronoi-based techniques depict how optimal coverage can be achieved through a multifunctional swarm to validate Chapter 3's 'platform of platforms' concept. These techniques associate spatial regions (see Figure 3 and Figure 4) to each agent, and each agent may become a functional On-Scene Commander (OSC) of a certain number of spatial regions attached to a specific function involving motion, sensors or weapons.
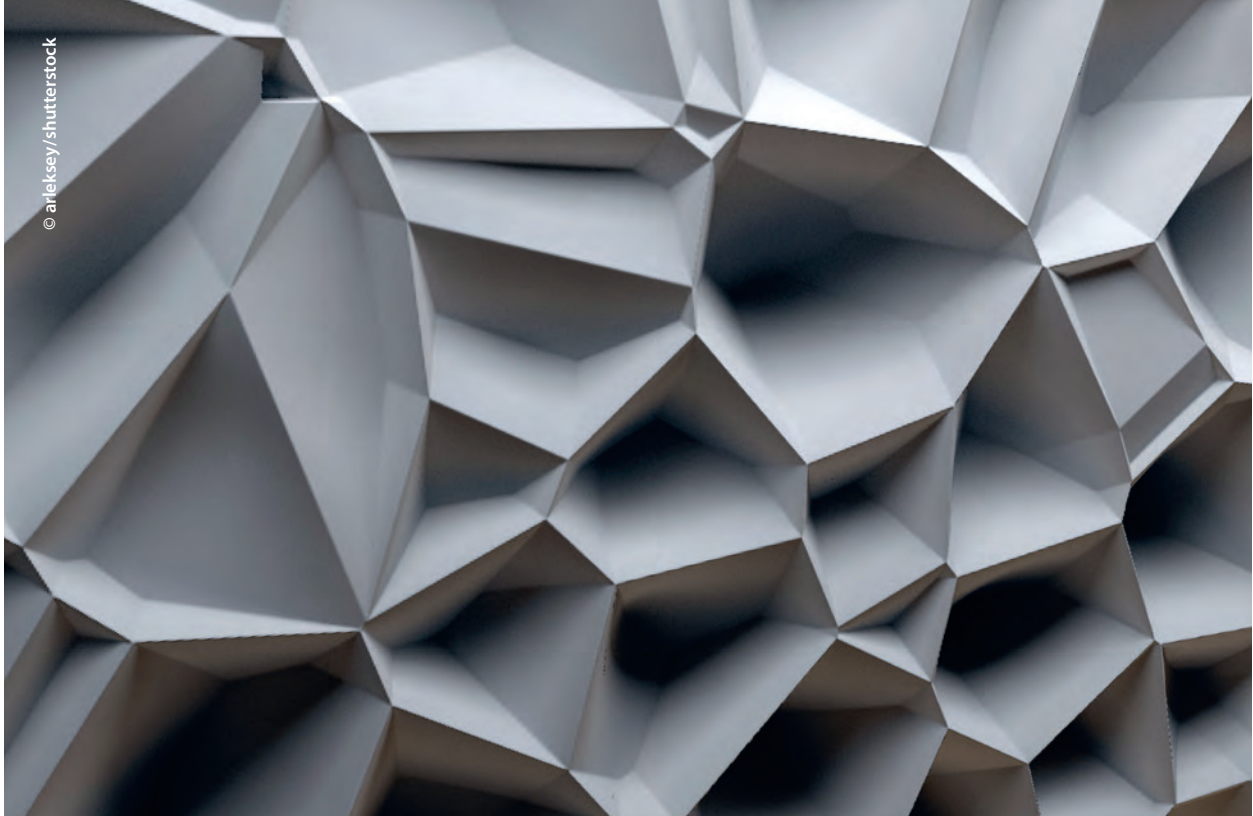
Figure 4: A 3-D representation of a Voronoi-based cell distribution featuring each platforms available space.

For the function 'avoid collision,' every machine will stick to its Voronoi cell. For other functions, cells may be shared through mutualism, and federated through sensors and weapons employment. Each agent will then oversee the execution of the supported/supporting functions within a given period of time.

Once the environment is altered, an agent will change its state and mark the change through signals. When sensed, other agents will adopt an updated motion policy with respect to their own motion boundaries and overall spatial environment. Each agent will avoid conflict with its neighbour agents (in motion, sensor and weapon employment) while giving continuity to the collective task. The cluster of robots incorporate certain characteristics of a topological space (see Chapter 6) and solve conflicts, such as collision, fratricide, or double (inefficient) targeting of an environmental reference or target. When competition arises (an adversary agent is encountered), if targeting is not possible either through the agent's evolution (development of an agent's new function) or through mutualism (symbiotic alliances with other agents who already have this function), a cluster unable to adapt and develop the targeting function will become ineffective and the mission will fail.

A desirable condition for optimal communication architectures is nodelessness. If collision or fratricide can be avoided by automated machine-to-machine communication without a directing or controlling element, single points of failure are avoided, a much better output is expected and victory is possible. A node is a point that centralizes and redistributes the flow of communication across a network. Agents exerting stigmergic communication maintain the three local conditions of continuity, convergence and connectedness (see Chapter 6) during task completion, even if an agent leaves the community. The stigmergic coverage causes the agents to adapt dynamically to the available or desired space, redistributing assignments and displaying the optimal topology while avoiding single points of failure through self-healing motion policies. The concept of motion policy as Continuous Airspace in a new C2 structure will be further analysed in the next Chapter.

4.4 Airspace–Battlespace Considerations

4.4.1 Is the ACO a Voronoi Spatial Model?

The Voronoi model above demonstrates the ability to re-allocate spatial distribution of the force to

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New geometry of battlespaces, when machine-to-machine synchronized.

accommodate changes in agent functions. Airspace today operates in a similar manner, albeit with two significant differences. First, changes in airspace allocated to an agent are not done through stigmergic communication; rather they are executed through a time intensive manual method. Secondly, even if a Voronoi diagram could be the most restrictive representation of an Airspace Control Order (ACO), with small, segregated Airspace Control Measures, (ACMs), it only refers to the individual motion policy of each asset or formation (airspace allocation only), and does not fully account for the collaborative employment of sensors and weapons across that same airspace.

An abstract of airspace/air warfare for the Voronoi partition would result in a 3D composition of the airspace-ground/sea spaces shared by a specific cluster of ISR aircraft/High Value Assets (HVAAs)/Fighters/Defenders and Surface-based missiles. Sensors and weapons ranges would dictate the geometry of the interceptors' regions. Defensive ranges and escape routes would configure the airspace region where the protected platforms would be defended from the intruders' weapons. All engagement zones, stop lines, and BENO lines (Be No further than)

would be coordinated real-time, machine-to-machine, through self-synchronized data transfer in accordance with the whole cluster's optimal motion policy. As discussed earlier, a transformation in the mechanism by which NATO manages airspace from segregation to integration is required to leverage the self-synchronization capabilities of modern and future platforms.

4.4.2 Dynamic Airspace Allocation

A similar solution, based on technological innovation and the elimination of fragmentation, has been undertaken by the Single European Sky Air Traffic Management Research programme (SESAR) to avoid airspace capacity shortages. In this case, civilian air traffic lanes are dynamically opened, expanded, or restricted to manage congestion of the network. Although this is not via stigmergic communication, analysis and execution decisions are conducted by a human decision maker (air traffic control manager), who is aided by a software-based DSS. The 'Automated Support for Dynamic Sectorization' dynamically adapts the air traffic common motion policy to the increasing demand within European skies.

© SESARJU
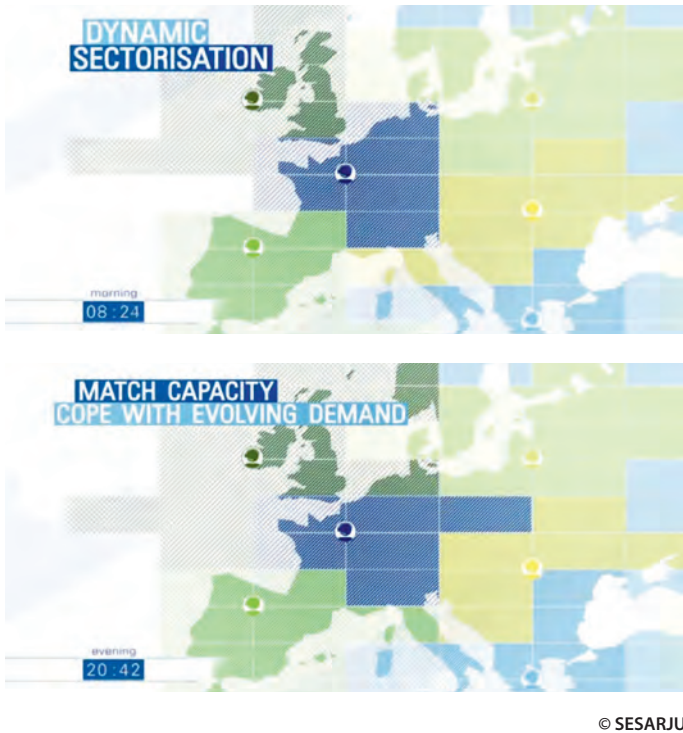
Figure 5: Screenshot. SESAR Dynamic Sectorization varies hourly to adapt the airspace structure to the real traffic flows.

However, if one were to accept a network where each agent's (aircraft) on-board computers could communicate between agents, this traffic management function could conceivably be passed from human manager to agent computers to manage themselves. This is one of the initial theses for Dynamic Airspace Synchronization, applied to the civilian sector, which will further be discussed in Chapter 10.

Further steps are being taken through Eurocontrol's 'Dynamic Airspace Configuration' concept, or DCA in Dynamic Mobile Areas (DMA). The project (Figure 5) addresses research and development of dynamic airspace configurations to incorporate all airspace elements – such as en route and terminal ATS routes, conditional routes, airspace reservations and ATC sectors – into new forms of airspace configurations designed to be dynamically managed, to respond flexibly to different performance objectives, which vary in time and place.[13]

Self-synchronization (in military terms) is defined as the: 'Ability of a force to act in a manner coordinated in intent, time, and space with other battlespace entities, without being ordered to do so specifically; synchronization of force entities without direction from their commanders.'[14]

The Striker Brigade Combat Team Case
RAND Institute, 2005

4.5 Self–synchronization

With each platform spatially allocated in its Voronoi cell (robotics example) or ACM (in today's airspace allocation), the most important part of efficient force management is to decide dynamically who supports whom, when, and with what functions. This decision process demands certain degrees of self-synchronization of agents across the system in order to be effective.[14]

Similarly, literature on Network-Centric Warfare suggests the importance of self-synchronization. Emergent self-synchronizing behaviours are introduced and analysed by many authors, and linked with the agility and effectiveness of the military force. A deep analysis of self-synchronization and Network-Centric Warfare can be found in the paper 'Military Self-synchronization: An Exploration of the Concept' by Bezooijen, Essens and Vogelaar.[15] In their publication, the authors analyse the operation of entities in the absence of traditional hierarchical mechanisms for C2, linking shared situational awareness and mission effectiveness, again in the form of MoEs. The texts also link the term self-synchronization with the aforementioned evolutionary trends of multifunctional packs or cluster.

In the previous SESAR example, all the platforms were civilian aircraft within an air traffic system, i.e. similar agents in the network. However, NATO 'agents' operating in a complex and dynamic environment will not necessarily be of a similar platform type and will therefore have drastically different motion policies based on the construction of the platform. Nonetheless, the asymmetry of the cluster (the lack of similarity of the

elements) is introduced as an advantage, by Van Dyke Parunak[16] in his paper 'Making Swarm Happen'. This especially applies in contested environments, and can also be appreciated in the case of a network with a diverse symbiotic relationship but convergent to a single goal.

If two dissimilar platforms can meet in the battlespace and are able to self-synchronize to achieve a basic mutual support relationship,[17] they can be viewed as exchanging stigmergic communication. If they can also avoid spatial conflict during motion and weapons usage, they are also distributing the space in accordance with stigmergic coverage. This ability to self-synchronize is critical, and is a necessary step before an evolutionary change in C2 can be achieved.

4.5.1 Evolution through Self-synchronization

Potential new behavioural trends are emerging from local interaction of different aerial platforms that communicate through a given battlespace. Paul Scharre[18] affirms that robot swarms are a product of design, while animal swarms are born from evolution. Machines or robots working together may differ from biological swarms, but in effect, they may operate in a similar manner in a given tactical context if they are considered FSMs able to phase their different states and their associated functions in an effective way to accomplish the task. Moreover, if men and machines team together, they can be seen to co-evolve, as the relationship between aircraft and pilots has similarly evolved.

In the beginning of the aviation era, early aircraft displayed basic states and functions and had few or no options for pilot communication (e.g. hand signals and single frequency radios). Through technological evolution, current and future aircraft will not only fly and project power, but will also manage other platforms, with a wide variety of functions, through machine-to-machine data exchange. For example, manned-unmanned teaming between Apache helicopters and tactical RPAs is currently being developed. In this example, the Apache manages the RPAs, demonstrating an emerging application of this

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concept. Further discussion on Manned-Unmanned teaming as it relates to NATO's current level of C2 will occur in Chapter 7.

4.6 Swarms and Efficiency

Although the term swarm evokes images of Nano-drones flying in a fashion similar to bees, the elements or components of swarming do not necessarily have to be multiple similar machines flying together in a close formation. Swarming can be viewed more simply as the local interaction of two or more elements with the ability to self-synchronize and create effects that favour the entire team's objectives.

The ability of individual platforms to create effects beyond those for the benefit of the individual is linked to the ability of the units in the network (players on the team) to share information. The process and evolution of air platforms swarming to create overall team objectives can be seen by exploring the history

of aircraft capability and mission effectiveness relative to the amount of information brought 'into the cockpit' by evolutions in computing power and datalinks. The remainder of this section is devoted to providing a foundation of terms and principles of this concept which will be further explored with case studies and real world examples in the following section of this report.

4.6.1 A Battlespace to Swarm

As a military option, swarming has several potential meanings. This study includes all the potential Air Power elements that could form the future cloud (manned and unmanned, surface-based and airborne) under the swarm umbrella to facilitate extrapolation.

Military swarming is primarily related to certain types of modern weapons featuring wider sensor array and area saturation. By design, it is based on local interaction, a certain degree of emergent behaviour, mass (represented by a number of elements), and shared or distributed intelligence, all of which permit bottom-up synchronization. A specific military definition is supplied by Parunak,[19] which refers to swarming as a 'battlefield tactic that involves decentralized, pulsed attacks.' In many cases, the term swarm connotes large numbers of individuals that become 'an intelligent whole.' Riot behaviour or even the massive presence of light weapons associated with certain scenarios are examples of swarming events among humans in recent history.

As exhibited in the Voronoi model (see Figure 3 and Figure 4), integration of dissimilar platforms (defenders and avoiders in the spike-ant example) through communication and functional distribution will enhance the basic rules of repulsion (for collision avoidance) and attraction (for target engagement and neutralization).[20] The end result is a state change of these FSMs to adapt to the change in the environment.

Swarming models bring three main advantages to the battlespace:

- First, swarming (when quantity is a goal in itself) adds clutter to both the adversary's targeting process in

the tactical arena and to its Observe, Orient, Decide and Act (OODA) loop at command and management levels.
- Second, the synchrony of the force is more rapid (fluid) in transition: Attack and defence topologies emerge from the common behaviour of all platforms in a shapeless and formless way, like the 'adaptive water' martial arts concept.
- Third: Swarming does not only entail multiple robots flying together but also illustrates self-synchronization between two or more elements in local interaction. This is already happening at low levels through the datalink protocols among clusters of platforms sharing a community (aircraft in the strike package), and it will soon enable automation of basic functions among participating entities.

Today, some level of automated synchronization is achieved through data transfer among modern platforms enabled by different link protocols and information exchange capabilities (such as MIDS, the interface mentioned in Chapter 3 which exchanges battlespace awareness through datalinks). This allows for qualitative-based forms of swarming operations amongst the limited number of platforms capable of communicating in this manner.

4.6.2 Advantages of Swarming in Military Applications

The advantage gained by self-synchronization is not only due to the communication and information sharing achieved by the technical interface of the MIDS, but through other means of connectivity, as well. These new means (e.g. gateway communication pods) feature fast connections for the Joint Force, serving as network interfaces (even to man-portable devices). This allows not only situational awareness improvements, but also enables automatic and distributed tactical support among dissimilar platforms with different capabilities. The 'gateway concept' is the wireless pre-condition for reaching the requisite level of communication necessary to operate the joint, distributed kill web involving wide battlespaces and allowing for this early stage of 'qualitative swarming' applied to a Combined Joint force[21].

Furthermore, swarming introduces a better spatial distribution of assets, functioning as an array with greater sensor fidelity and weapon effectiveness within a given area.[22] This is already happening, especially within 5th generation assets, as they federate their sensors and weapons through internal fusion engines at platform level and through secure datalink at flight level.

Efficient spatial distribution of resources to enable efficient mission accomplishment (in the form of collaborative Stigmergy regarding platforms and sensors' distribution) is obviously the goal of any operation, but NATO must ensure, as this capability grows in the future, that this swarm and its associated responses are still controlled and supervised by command in military applications. The 'Unity of Command' principle of joint air operations (AJP 3.3, 1–5) must prevail, while triggering the decentralized execution aspect of these joint operations. Quantity, although a quality in itself, may turn to be functionally undesirable if the swarming colony becomes uncontrollable and unmanageable[22].

To approach a new C2 model for Air Power based on air warfare communication in a networked environment, this study considers the 'swarming' concept from an algebraic perspective.

4.6.3 Quality vs Quantity: Acceptable Ratios

Certain activities require quantity or high intensity when the desired effect is achieved through saturation, but swarming doesn't always equal quantity. Some of the benefits of having high quantities of swarming agents synchronizing functions may affect the swarm's efficiency and its management, dependent on the ability of the network to 'handle the loa'.

However, insufficient agents in a multifunctional swarm may jeopardize the effectiveness of the swarm. Moreover, the required data processing, involving large clusters of dissimilar platforms in complex tactical contexts, would hamper management and C2 with today's processor's speeds. Some complex weapons, like the DARPA Gremlin's concept (see Figure 6), consist of a number of synchronized unmanned platforms, which become a 'platform of platforms' interacting with other Air Power assets.[23] This type of system might base its effectiveness in quantity but, due to the lack of releasable information, the C2 aspects of these systems are still uncertain and the degree of 'fire and forget' of these systems is currently unknown.

Figure 6: DARPA depiction of a multi-platform aircraft swarm (Gremlin).

4.6.4 Mission's AMR and Optimality

As this study has a critical assumption that communication capability is tied to the achievable level of C2 maturity, the authors focused on measurements of swarm performance stemming from communications ability rather than those related to quantitative variations in the swarm. Imagine a formation of fighter jets that could increase their effectiveness against a given threat through communication, not through increasing the number of aircraft. This would likely result in a more efficient force allocation to address the threat. Yet quantity (mass), as a principle of warfare, will remain a component of any force allocation which must be balanced against quality.

Quality and quantity, as well as efficiency and effectiveness, form an efficient equation resulting in a Pareto optimal allocation (Pareto efficiency). This means that none of the variations in the cluster size (adding or subtracting elements) is possible without at least one objective being affected adversely, including logistic efficiency as an objective. If a quality increase is cheaper than a quantity increase, the option is clear. If two datalink-equipped aircraft achieve at least the same MoEs as a non-datalink four-ship formation against an opponent of a certain type and with a given risk level, the new Pareto efficiency is 2 vs. 4, while before was 4 vs. 4. For more information about quantity and quality balances refered to different swarm topologies see Scharre, 'Robotics on the Battlefield Part II: The Coming Swarm'[24].

In tactical terms and in a competitive scenario, quantity and quality are approached from the Acceptable Merge Ratio (AMR) perspective. The AMR is the ratio of friendlies to adversaries within Factor Range (FR) and balances the accepted risk with the compared quality (technology and awareness) of the two opponent aircraft and the quantitative logistic effort required. If AMR is acceptable, the payoff can be expected to be positive and the task initiated. If AMR is not acceptable, a quantitative or qualitative variation will be necessary, allowing for a better FSM cluster in terms of MoP and MoE. The next Chapter will analyse, through the use of models, how communication can enable the evolution of Command and Control capability.

Example F-15E Acceptable Merge Ratio in an Air-to-Air Role	
Acceptable Level of Risk	AMR vs. Aware MIG-29
Negligible	N/A (don't merge)
Low	> 2:1
Medium	2:1
High	1:1
Extreme	1:2 +

© US Air Force

Figure 7: Notional F-15E Acceptable Merge Ratio in an Air-to-Air Role based on Risk Level. The level of risk acceptance in the left column drives the required ratio of friendly to adversary aircraft.[25]

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3. Van Dyke Parunak. 'Making Swarming Happen' Presented at the Conference on Swarming and C4ISR. Tysons Corner, VA, 2003: 6 http://abcresearch.org/papers/MSH03.pdf [07.12.2015].

4. Ibid. 2. p. 9.

5. AJP 3 (B) 1–6.

6. Ibid. 3.

7. Ibid. 1.

8. Seeley, Thomas. 'Group Decision-making in Swarms of Honey Bees'. Behavioral Ecology and Sociobiology 45 (1): p. 19–31. Available at: https://www.researchgate.net/publication/227263086_Group_decision_making_in_swarms_of_honey_bees [14.01.17].

9. Giuggioli et al. 'Stigmergy, collective actions, and animal social spacing'. Proceedings of the National Academy of Sciences of the United States of America. Vol. 110 N. 42 Oct. 2013 [e-document] Available at: http://www.pnas.org/content/110/42/16904.full [11.10.16].

10. Delousing indicates a procedure by which friendly aircraft remove (through various means) adversary aircraft who are targeting or following other friendly aircraft, preventing the adversary form accomplishing its mission.

11. Ranjbar-Sahraei et al. 'A Multi-Robot Coverage Approach based on Stigmergic Communication' [electronic bulletin] Maastricht University, The Netherlands, 2012. Cited 17. Available at: http://www.weiss-gerhard.info/publications/MATES2012_RS_W_N.pdf [26.01.2016].

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14. Gonzales et al. 'Network-Centric Operations case Study. The Stryker Brigade Combat Team. RAND, 2005. Available at: http://www.kinection.com/ncoic/nco_stryker_brigade_combat_team.pdf [12.12.16].

15. Bezzoijen et al. 'Military Self-synchronization: An Exploration of the Concept' 11th ICCRTS. Coalition Command and Control in the Networked Era. Tilburg University [on line document] Available at: http://www.dodccrp.org/events/11th_ICCRTS/html/papers/065.pdf [19.01.2015].

16. Ibid. 3, p. 7.

17. Even at the basic level of space and time de-confliction which is already performed by many robots, including unmanned cars.

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19. Ibid. 3, p. 3.

20. Ibid. 3, p. 8. And also in Rajnbar-Sahraei et al.

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More information available at: https://www.aeroaustraliamag.com/airborne-gateway-connects-typhoon-f-35b/ [15.05.2017].

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CHAPTER 5

Command and Control (C2) Models

Engineering is quite different from science. Scientists try to understand nature. Engineers try to make things that do not exist in nature. Engineers stress invention. To embody an invention, the engineer must put his idea in concrete terms, and design something that people can use.

Y. C. Fung and P. Tong,
Classical and Computational
Solid Mechanics (2001)

5.1 Introduction to Models

A model is the representation of a system. Models are vehicles for learning about the world. Thus, models may be used in solving or predicting the systemic future of the C2 paradigm, especially if a trend of evolution has been detected and reflected in the future model in terms of optimal maturity.

Conceptual models are widely used. The following six factors are present in many communication models:

• *Emitter:* the agent transmitting the message;
• *Receiver:* the agent receiving the message;
• *Channel:* the medium for message transmission;
• *Code:* the language used in the message;
• *Message:* the information;
• *Context:* the meaning and utility of the message.

5.1.1 Why a Model?

Forming the optimal topology through platform allocation and proper function synchronization is not easy and requires modelling and simulation. As a 'complex whole' may be approached as a 'complex system,' a model is useful to help determine the most appropriate topology for a future Air Power network which is

Stages of Modern C2	Waypoints	Navigating Megatrends	Discovering Fundamentals	Key C2 Result
Stage 1	Napoleon (France)	The looming of industrial-style warfare	Expanding C2 art in the single leader, single battlefield model	Pushed C2 art
Stage 2	Moltke (Prussia)	Transportation and communication revolutions	A 'system of expedients' over multiple battlefields	Envisioned systems warfare
Stage 3	Tukhachevskii (Russia)	New operational level of war and the front edge of the aviation age	'Expedients' refined into clear C2 subfunctions	Made C2 tangible
Stage 4	Dowding (United Kingdom)	Range and speed of the aviation era in full swing with increasing battlespace depths	Sophisticated SA feeds and teams of controllers performing C2 subfunctions form an adaptive system for defense	Systematized feeds and teams
Stage 5	Boyd (America)	Computer-based data management and the front edge of the information age	Transferring competition fundamentals into a system of 'insight'	Incorporated competition fundamentals
Stage 6	Uncertain	Network-centric C2 operations and cyber warfare	Uncertain	Uncertain

Figure 1: Maykish's 'Stages of Modern C2' identified that improved communication was a common component to advances in C2.

based on hyper connectivity. This will help define the topology or series of topologies that best fit the desired outcome in terms of C2 maturity.

Models utilize a flow of communication to allow analysis of its success or failure, which can be diagnosed and measured, in order to assist prediction of causality and effect. This Chapter will review different types of models appropriate for analysis of Command and Control and identify the predominant model used by

this study to extrapolate evolution in air power communication and its subsequent effect on Command and Control.

Resident within NATO's recent military operations are different structures for Command and Control. Some are more oriented toward specific expeditionary operational environments, others are more tailored to a unique or small mission, high responsiveness requirements, or utilize a reach-back command structure.

Therefore, this study, in an effort to avoid mission creep (making the model fit the operation) or a particular bias toward one particular model, will use a baseline (non-military specific) model for comparison of data regarding communication in the case studies (Section III of this study) instead of existing military C2 models. However, a brief examination of different types of models is conducted to provide the foundation for the relationship between C2 maturity and communication.

5.2 C2 Models

Many definitions of Command and Control (C2) cover various aspects of both command of forces, and the related span of control over those forces. Although C2 is most frequently associated with military operations, as Alberts et al. suggest[1], specifically viewing C2 only through the military lens creates a semantic problem, as a variety of systems will manage new situations by selecting some form of C2 without following the classic schemas of military organizations. They suggest that a more universally accepted way to view C2 is as specifically linked to communications and, furthermore, that different ways to view C2 are worthless if they do not incorporate a means to measure the presence of quality.[2]

5.2.1 Legacy Military C2 Models

Paul Maykish analysed the evolutionary pattern of the most noteworthy historical military C2 structures in an article titled 'C2 Rising'.[3] He viewed historical operations as campaigns rather than single tactical battles, and identified the evolution in C2 as a trend based on the orchestration of certain sub-functions displayed by several notable military leaders, from Napoleon to Moltke, to Dowding and Boyd.

These leaders were able to allocate the right class and amount of assets with the proper C2 schema. Maykish concludes in his paper that a trend of C2 evolution becomes evident through analysis of the level of communication. Maykish then identifies

a main characteristic of this C2 evolution: speed. If maturity, as a concept, is related to an increase in the ability to respond appropriately and more swiftly as related to the environmental changes (increased agility), a given C2 structure may be analysed according to these two variables to determine its level of C2 maturity.

The C2 Maturity Model. Considering speed and communication as indicators of maturity, one must address two questions to proceed with analysis of a given C2 structure:

• How will a robust and redundant networked environment affect the current C2 structures? In other words, as communications speed increases, does the current C2 structure contain sufficient capacity to handle that level of information exchange or is a level of saturation reached?

• What will the impact of hyper-connectivity be in the current employment and further evolution of NATO's actual capabilities, platforms, and weapons?

The need for Operational Agility consists of speed, resilience, security, networking, and Stratcom. This is the basis for a C2 architecture.

General Mercier SACT
C2CoE Conference
Opening remarks, Norfolk, July 2016

5.2.2 The C2 Conceptual Space: C2 Evolution

In the frame of the US DoD Command and Control Research Program and the NATO System Analysis and Studies (SAS-065), Alberts et al. proposed a Maturity Model for network-enabled operations. The scope of this SAS Panel study was to investigate the methods by which operational capability can be provided and enhanced through the exploitation of new technologies, new forms of organization or new concepts of operation.

The analogy used by the authors of this NATO Maturity Model is cartographic: 'A maturity model is like a map, it helps you to determine where you are relative to where you want to go.'[4] As the impact networked environments will cause in the existing C2 structures is uncertain, the use of a model will serve as a conceptual tool to help locate and understand the 'intermediate destinations' that these evolutionary trends will meet once information age warfare changes the way we plan and conduct operations.

5.2.3 NEC Maturity Model:

According to the NATO NEC (Network-Enabled Capability) Maturity Model (see Figure 2), the potential C2 structure of a teaming cluster can be projected over three axes,[5] which integrate the C2 approach space. This space contains the factors affecting the

efficient and effective formation of new, task-oriented topologies. These axes measure how the team works together as a result of the achieved degree of collective C2. Each axis acts as a grid to quantify evolution in behavioural features, because of element interaction and commander orchestration.

The following three axes will depict a theoretical model of C2 maturity:

First Axis: Allocation of decision rights to the collective. The first axis depicts a situation where players (or assets) with disparate cultural values and significant organization and management differences can evolve from mistrust to a shared, robust, and flexible decision-making process within the team's (or cluster's) organization. At the highest level, players give up their respective rights for the benefit of the endeavour
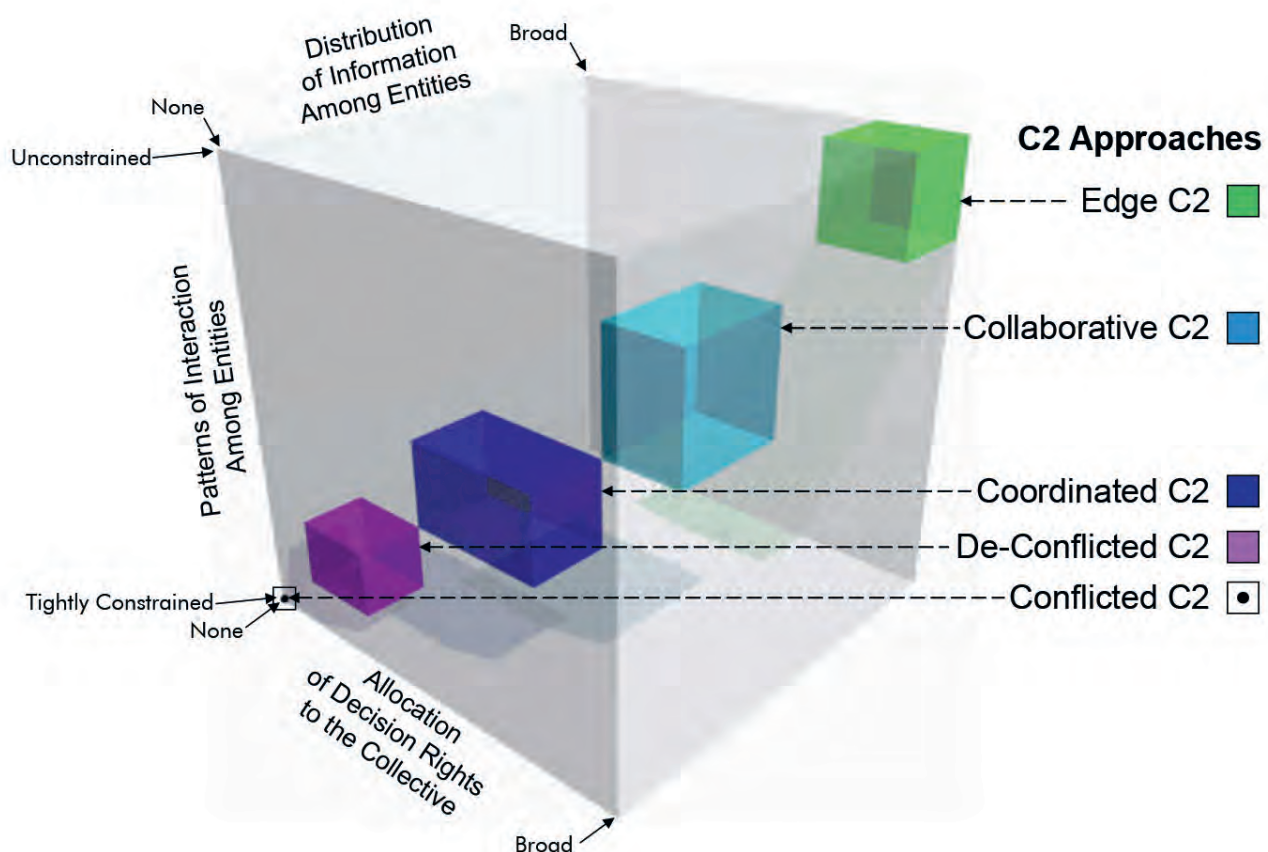

Figure 2: The NEC Maturity Model in 3 dimensions.

© Alberts et al. SAS Panel, Department of Defense

as a whole. This feature is related to the strength and validity of the team's contracts and regulations, which shape the team's code of conduct, as well as the emergent behaviour of the players in light of these rules and contracts.

Mistrust amongst the team (confusion or ambiguity amongst agents in the network) is diminished through clear communication. In the real world, this trust issue, even when discussing automated information exchange between machines, can be a fundamental challenge with NATO's Alliance of 28 nations and multiple services' cultures. Of note, this study does not discuss 'need to know' and 'need to share' architectures based on mutual confidence levels (trust) or challenges arising from restrictive national security policies. These are Axis 1 & 2 issues.

Second Axis: Patterns of interaction and information-sharing behaviours among the entities of the collective. This second axis describes a situation where players with different communication competences, capabilities, skills, and communicative options can reduce uncertainty in support of the leader's decisions. This feature is related to the players' willingness to interact through the generation of the proper communicative context and code of choice.

Third Axis: Distribution of information among the players. This final axis denotes a situation where the information needed to accomplish required tasks is readily available to each player. As the flow of relevant information (quality and quantity of information) within the C2 system is tangible, this axis can be considered a team's direct Measurement of Performance (MoP), and is mainly related to the channel and code of communication.

5.2.4 The Importance of the Third Axis

Of notable significance is the relative importance of axis number three and its impact on the other two. The first two axes imply a trend of evolution in the social, political and cognitive domains in which the gradient of change (time) could be measured in terms of human generations.

For NATO, evolution along axis 1 would mean an increasing degree of integration in the political, military, and social domains. This would be reflected in the governing agreements of the Alliance and its three core tasks.[6]

A change to the language interoperability of the Alliance to the point where all network participants conversed at 'native language speaker' level would show evolution on axis 2. This happens currently in some multinational arrangements, like the Five Eyes agreement. Effecting a change along these axes when all 28 NATO nations are involved is not easy, as different national, cultural and linguistic perspectives colour the discussions which can take significant time to resolve.

The Connected Forces Initiative, or CFI, consists of a 'comprehensive education, training, exercise and evaluation program'[7] that matches evolving C2 features measured by axis 2 through training and education of NATO units and personnel, while the terms of the Alliance Treaty, for example, belong to the approach space designated by axis 1.

The third axis, however, lives in the conceptual region of the information domain. The evolution of the human element is predominantly affected by multiple limiting factors, including beliefs, confidence, or interests, and usually takes a significant amount of time. In contrast, technologies within the information domain have improved exponentially in only a few years and with them, so has the Joint Force's ability to communicate. In other words, Computer Science walks faster than Social Sciences, and it is pre-eminent in the cloud formation.

Game theory suggests the tremendous impact communication has on cooperation among players. Through an analysis of Flood's Prisoner's Dilemma,[8] the level of cooperation and a lack of successful communication due to ambiguities are demonstrated to be related. The Prisoner's Dilemma explains how the absence of communication leads to competition, even within the same team, which generates devolution. Better communication equates to higher mission effectiveness, and the opposite is also true.

Altering axis 3 by multiplying connectivity options, like email did with respect to the classic postal systems, would cause a pronounced effect as it would be possible to 'widen the channel', and connect the team through universal sounds, icons and symbols (or conventional rules which shape the proper code). An example of this idea (even if a command element is not allocated in the following case) is illustrated when people engage (teaming) in online video games on worldwide servers, sharing the rules and functions written into the game itself, but not sharing a common language or national culture. These games also generate common motion policies, steering the players of games like 'Pokémon Go' through the game's virtual interaction with the real-sensorial world. Even though 'Pokémon Go' is not considered a 'teaming' game (rather, it is a single player game), options for local interaction and potential association of the players are available via Bluetooth. Players only need a willingness to play together, according to an agreed upon set of rules and a fast connection for the images to flow across the network. The communication features of the game are designed to facilitate universal interaction regardless of the individual player's language.

The NEC universal C2 model (see Figure 2) is an important result of the SAS Panel study and serves as the foundation for C2 maturity discussions in this study.

5.3 The C2 Model: Maturity Levels

The three axes comprise five degrees of maturity, which affect the universal C2 structures the team may adopt. These levels are identified by the coloured cubes within the larger grey cube in Figure 2.

The lowest level (Conflicted C2) shows the region where there is no cooperation among entities. This is primarily because decision-making is broken down into several stand-alone patterns. Essentially, inefficiency, mutual interference, and conflict (even in kinetic engagement) exist among two or more cooperative entities. A classic example of Conflicted C2 would be a Joint Force where the services (Army and Air Force, for example) do not coordinate their fires spatially or

temporally. This may be caused by technical issues (code, or channel issues), procedural shortfalls, or simply a lack of will. A historical example of this level of maturity would be the Falklands conflict in the 1980s, where the Argentineans did not have a viable joint plan, which resulted in separation and even conflict amongst the services. The associated topologies in such a situation will likely be fractured in several self-standing bus or star diagrams.

Another common example of this is seen when different platforms utilize different units of measurement (reference), for example, miles vs. kilometres. This results in interoperability failure and operations are subsequently limited to the Conflicted level of maturity.

As one advances along the three axes simultaneously, you reach different levels of C2 maturity, which demonstrate increased amounts of player interaction.

The second level, called 'De-conflicted C2,' is characterized by geographic separation to avoid mutual interference as the predominate method of coordination. The chance of fratricide engagement is minimized or suppressed, but there is no coordination of mission. A good example of a De-conflicted C2 system is basic Air Traffic Control (ATC) management, based on time slots and spatial segregation without flexibility. The associated topologies may consist of one well-structured single star, tree or bus.

The third level, titled 'Coordinated C2,' shows patterns of association in time and space, achieving limited synergistic engagement among clusters, when a common task is given. Returning to the prior example, modern ATC techniques for dynamic airspace configuration and the flexible use of airspace make it possible for the coalition of airspace users (civilian and military) to perform better and achieve synergy by dynamically activating and deactivating certain blocks of airspace. Partial mesh topologies may appear, resulting in a hybrid topology inspired by the prior ones.

The fourth level of C2 maturity is called 'Collaborative C2,' where the effect is greater than the sum of the parts. This approach to effective C2 synergy results

when different entities or clusters of entities (a team or different associated teams) exhibit the following factors:[9]

1. Negotiating and establishing collective intent and a shared plan.
2. Establishing or reconfiguring roles.
3. Coupling actions.
4. Rich sharing of non-organic resources.
5. Pooling of organic resources.
6. Increasing interactions in the Social Domain to raise shared awareness.

Of note, exchanges of tactical information via datalink affect factors (1) and (6) enormously. This is especially true if an emergent opportunity (event) occurs during the team's performance, leading to dynamic tasking. Then, these new terms of the game must be either re-briefed or coordinated in real time, depending on what level decision rights are allocated, regarding function allocation and supported/supporting options. This is directly related to axis 3's variations, as the volume of data exchange between players increases. This is a result of synchronization of the players' local interactions through communication. As the rate of data exchange increases, the potential for new activities also increases exponentially. The resultant topology will be more mesh-oriented.

Factors (1) and (6) show time and cycle compression under data sharing. Factors (2), (3) and (5) may be considered a consequence of the previous two factors and show cooperative patterns through adaptive capabilities and execution of functions or tasks to achieve a new supporting-supported relationship schema. This allows for efficient and effective emergent, hybrid topologies, featuring mesh properties. Factor (4) is self-explanatory. Today, the execution of Joint Dynamic Targeting within a Coalition, with decision rights for most dynamic engagement remaining at the higher levels of command relayed through an Air Battle Manager, approximates this level of C2 maturity.

The fifth and final step in C2 maturity is the 'Edge,' where the players dynamically overcome the spatial distribution challenge and allocate multifunctional

resources to best solve each contextual challenge at machine-to-machine speed. Through the self-synchronization of their various functional activities, the C2 system acts as a 'platform of platforms,' entering the conceptual region of 'swarming.' Different multi-functional mesh organizations will be allocated, interconnected, and self-synchronized.

5.3.1 Principles of Innovative C2

As expressed by Professor Dr. Jeff Reilly (Director Joint Education, US Air Command and Staff College) at the C2 Centre of Excellence annual conference (Norfolk VA, July 2016), emergent mesh features present in his principles of innovative C2 are:

1. Availability of distributed information, which allows for integration of disparate capabilities and platforms through a network.
2. A continued human presence in the loop, to prevent transition from automated response to autonomous response.
3. The federation of clouds through cyber requirements will result in a migration from a sensorial-based spectrum to a cyber-based spectrum. Commanders will need to conform to a world in which they cannot see or feel the environment prior to making decisions, because the future environment will move faster than those senses can react.

As Reilly stated, the speed of information transfer is critical to integrating dissimilar platforms in such environments, but can be slowed by human involvement in the process.

5.4 A Model for Evolutionary C2: The Hypothesis

Leveraging the previous discussion of models, and recognizing the link between speed, clarity and amount of information transfer and the overall maturity of the C2 structure, this study proposes that a future C2 model relying heavily on unrestricted communications could be framed within this hypothesis:

Network-oriented C2 and future warfare functions exploiting the information domain will allow the Commander to dynamically reorganize the current functional and spatial distribution of Roles among aerial/joint platforms and expedite task accomplishment.

A model based on the third axis of the NEC Maturity Model (Distribution of information among the players) appears to be the most suitable region of the C2 approach space for short-term evolution. This assertion is based on the observation that NATO has limited resources to address movement in the other two axes, and realization of any movement, were it desirable by all Alliance members, would likely take generations to achieve. For example, in a few short years datalink protocols have already solved immature C2 features whose solution along axes 1 and 2 was not possible in previous decades. This contention will be further demonstrated in Chapter 8 through the analysis of aircraft performance during the TLP flying course.

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3. Maykish, Paul. C2 Rising: A Historical View of our Critical Advantage. Air and Space Power journal, Jul.–Aug. 2014.
4. Ibid. 2, p. 35.
5. Ibid. 2, p. 48 ff.
6. As agreed to in the 1949 Washington treaty and subsequent guidance in NATO's Political and Strategic Context (most recently issued in 2010).
7. NATO's Connected Forces Initiative. [on line] 2015. http://www.nato.int/cps/en/natolive/topics_98527.htm [22.10.2015].
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9. Ibid. 2, p. 57–60.

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CHAPTER 6

Part II: Summary and Conclusions

6.1 Summary

This section of the study examined the relationship between platforms and sets and defined different topologies, which could be used to link those platforms together to function as a true 'platform of platforms'. In the process of reviewing the evolution of generations of aircraft, a link was established between those platforms, their ability to pass information, certain biomimetic models, and the maturity level of Air C2.

The concept of the combat cloud was explored, not as a reach-back capability, but as a visionary concept outlining the utopia of cognitive computing and in-

formation management, which will augment future machine-based operations. Communication trends based on Stigmergy and several associated models were considered for interdisciplinary extrapolation between the animal kingdom and modern technologies. Qualitative swarming of self-synchronized platforms was also examined.

The study then explored past and future C2 modelling options, trends in the evolution of C2 and explained how data transfer can improve tomorrow's C2 architectures within continuous airspace, where flexible supporting/supported relationships would be highly automated through data transfer.

6.2 Conclusions

The complexity of developing future Command and Control options could be reduced through the

adaptation of new terminology and examples that allow for a better comprehension of the resulting model. Considering the different elements of Air Power as a set and viewing the different topologies as systems and associated C2 options as new mechanisms for combining information may allow for improved future C2 capability. Speed of information flow and clarity of information exchange may be improved by machine-to-machine communication. In unrestricted battlespace, the different elements and their associated spatial distribution may be seen as a topological space in terms of Continuity, Connectedness and Convergence.

Extrapolation from the animal kingdom to modern, interconnected weapons and sensors may apply if these modern platforms are considered agents clustering together in a competitive environment. As spatial and temporal couplings are enhanced by communication when swarming/flocking/schooling in these bio-models, hyper-connectivity among future platforms will allow for self-synchronization of tactical activities on the battlefield. New clusters of weapons and sensors may be dynamically formed, and new supported-supporting relationships will emerge through machine-to-machine communication.

This platform orchestration will include new motion policies to reduce conflict and supress fratricide. Stigmergy in the form of data exchanges among dissimilar platforms will augment situational awareness, tactical advantage and the force's efficiency.

Therefore, the operational tempo may be increased by decreasing and simplifying the number of human interactions across the system of networks required to achieve a certain effect (reduction in Boyd's OODA loop decision-making cycle time) by delegating to machine level communication those iterations not requiring direct human management.

6.2.1 The Future Network is a Cognitive Machine

This future network has the characteristics of cognitive machine operations, approaching true Artificial Intelligence (AI) and featuring enough resiliency,

bandwidth, and robustness to support the level of data flow across the network. This is likely a generational leap forward and therefore should not necessarily be applied to today's aircraft, unmanned vehicles or other assets capable of exerting Air Power. This network will link all joint assets together into one cohesive battlespace to make best use of all available assets in the Joint Force, at machine speeds, to achieve an effect.

Clouding at the Edge level of C2 maturity may need continuous and fluid battlespace. As the thesis proposed, the networked environment will allow the commander to dynamically reorganize the current functional and spatial distribution of Roles among aerial/joint platforms through semi-automatic control features. The ACMs will 'follow' the platforms in that dynamic scenario.

Future Air Forces will be formed by elements that communicate with each other in methods beyond today's standard voice calls or sign-based messages (recognizing that even as this study is being written, not all NATO aircraft are datalink compatible). A world of real-time spatial synchronization through virtual generation of airspace geometry and platform-to-platform steering inputs is envisioned and will likely be realized in the next few years. A new nervous system of executive messages in the form of cueing or direct orders to off-board platforms MCs and flight controls, including data-linked weapons in this paradigm, will soon replace some of the current planning and execution features.

6.2.2 Platforms Will Self-synchronize to Coordinate Motion Policy

Some degree of coordinated motion policy will likely be present among the cloud components, the platforms in the future network. This will require that future ACMs used for spatial reference and de-confliction will be self-generated by each platform, be adaptive to real time changes in airspace employment (weapons launches etc.), and be shared simultaneously through the network with the rest of the network participants. All of this will likely be done while those

Individual particles self-synchronize to form a specific platform for a given task.

distributed, redundant nodes (platforms) self-synchronize and reorganize in order to accomplish the assigned Air Power Core Roles.

6.2.3 The Integration Challenge: Modern and Legacy Platforms Must Be Interoperable

Many of the challenges regarding 4th to 5th generation integration are technical in nature and are likely to evolve though national solutions. This derives from national concerns about security protocols and information sharing. This implies that, for example, the different F-35 user nations may solve integration issues between the F-35 and their legacy fighters before NATO determines a holistic method of integrating European based F-35s with neighbour European 4th generation platforms and, ironically, before there is full integration among the 5th generation community within NATO.

Furthermore, human language has inherent ambiguity between sender and receiver. However, because of the clarity of communication provided by machine-to-machine exchange across the network, smart swarming platforms may find new patterns to distribute their functional activities across their designated roles/types of operations, whether supporting other assets or receiving that support, without compromising safety. The premise is that the control of information, especially the control of the flow of information (Continuity and Connectedness), will link the subset of choice (Convergence) with the command element, again shortening the decision timeline across the OODA loop.

With the capability of modern aircraft to process larger amounts of data in real time, extrapolation to potential future generations' capability shows a clear link between the data information exchange and the

versatility and utility of these platforms. This is founded upon the ability to communicate data rapidly, both by integrating information from its sensors and by exchanging that same information with other participants. The evolution in this communication model shows a clear link to evolution in Command and Control frameworks.

As a consequence, the Alliance should look to maximize the impact these aircraft have in the execution of traditional Joint Air functions and sequence them through the orchestration of different Core Roles accordingly when the platforms 'cloud' their functions together. Additionally, there will be a tangible benefit realized in improved Tactical Command and CAOC capabilities to exercise Command and Control as these assets improve both the amount and clarity of information collected and sent back to the CAOC or to any future C2 element.

6.2.4 The Evolution of C2: The Information Exchange Capability of the Future Network May Drive a New C2 Structure

The principles of military innovative C2 mirror many of the fundamentals in the more general C2 Maturity Model, especially those regarding Axis 3. The third principle links the virtual and sensorial spectrums, as in the aforementioned Pokémon Go game (see 5.2). A form of this type of brain-to-fin scenario related to airspace and motion policy will be explored in Chapter 10. A 'wider channel' permitting higher data exchange rates is a precondition for maintaining faster decision-making, for maintaining the integrity of the chain of command (human decision maker in the loop) and for shaping the cloud and its virtual C2 to the real world.

6.2.5 A Look Ahead to Part III

The next section of this study will analyse the existence of C2 gaps or bottlenecks within the standard doctrinal Component Command's structure, with specific focus on the de-conflicted use of airspace made necessary by the level of technical communication conducted among today's elements (aircraft or surface-based platforms). This is highlighted by the

lack of efficiency (or optimality) in forming successful clusters of platforms to achieve the most suitable addition of capabilities with proper flexible mutual support relationships. It may create gaps which break the potential contiguity of the force for a variety of reasons. These include:

a) Lack of Convergence, i.e. the output is not valid and the topology is ineffective. In this case, the allocation of the elements for the specific task is not valid or does not converge to produce a valid output once certain interconnections are established (i.e., mixing submarines and tanks to perform Defensive Counter Air would not converge, as the processes involved are essentially different due to lack of spatial contiguity and the proper functions of each class of elements. For Alberts et al, 'convergence' at a horizontal (peer-to-peer) level means a collective ability to apply information and resources to achieve the collective purpose.[1]

b) Lack of Continuity, i.e. the successive outputs are not stable due to inefficiency or to lack of effectiveness. In this case, a binary link necessary for the effective work of the set cannot be established or relayed due to distance or code issues and generating a discontinuous cause-effect schema (e.g., laser-designated operations as the only option for a Composite Air Operation (COMAO). Unless ground lasing is available or other PGMs are loaded within the allocated assets, the performance will be weather dependent, associating the results to this independent variable).

c) Lack of Connectedness: In this case, the elements within the set cannot exchange information or data for common awareness of other elements due to lack of contact or communication (i.e., mixing any element unable to communicate, even if they share context and locality).

When the Combat Plans division generates an ATO, they evaluate the available resources to produce the best possible effect when binary or higher combinations are necessary. They also check that the degree of interoperability among the clustering resources assures the desired outcome (Convergence) and that doctrine is taken into account for Continuity.

Connectedness, though, has increased exponentially in recent years, and so have the options for a more mature C2 architecture allowing for the cloud concept to be possible through different adapting topologies.

The challenge to cooperation in this congested airspace environment may be solved in the near future through a technical solution (likely a datalink gateway featuring nodelessness through a mesh or a partial mesh-hybrid topology). The specialized division of labour among the different platforms operating within a single and fluid airspace (including ground and sea-based platforms) can be approached either hierarchically within a defensive or offensive system (or both simultaneously).

The next section of this study will also discuss the academic principles established in Part II through the specific lens of NATO's air operations. A review of the current state of Air C2 will be conducted in an effort to identify those specific areas within Policy and Doctrine which might be addressed through technology (communications improvement at machine speeds) which may result in an evolutionary jump in C2 maturity.

Additionally, three different examples and two real-world applications of networked forces will demonstrate the concept of platform swarming and evolution of both efficiency and C2 maturity, which derive from an increased ability to share information.

1. Alberts et al. NATO NEC Maturity Model. Produced by the Centre for Advanced Concept and Technology, 2010. p. 24 [electronic document] Available at: http://www.dodccrp.org/files/N2C2M2_web_optimized.pdf [17.09.2015].
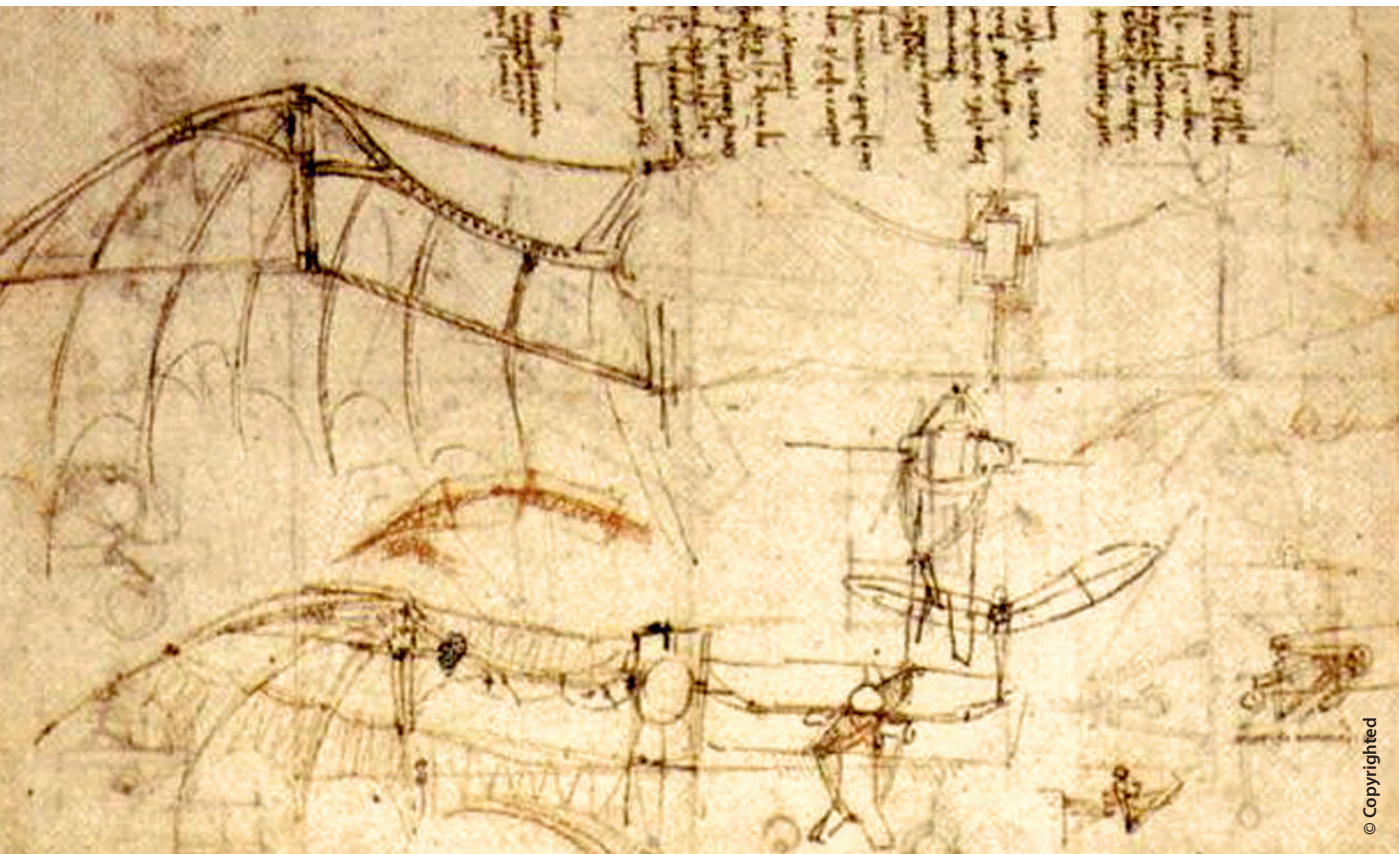
Part III

Trends in the Evolution of Air Power

'Just as World War I was fought with 20th Century mechanized forces using 19th Century practices, we are in danger of going into 21st Century warfare fighting with 20th Century practices. The combat cloud is meant to address changes that we see happening with 21st Century warfare, specifically changes that are occurring because of the way we are deploying and using information systems and the way we've been able to access information. But significantly, the fact that there are other people who are trying to deny us access to that [same information]. In fact the control of information will become as decisive as targeting any kind of physical destruction.'

David Fahrenkrug,
Author '21st Century Warfare: The Combat Cloud'

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CHAPTER 7

The Current Cloud – Today's Joint Air Power Interoperability

7.1 Overview

This Chapter will review Air C2 as it is conducted today by each of the NATO Command Structure Components. It is important to remark that this Chapter is not intended to be a comparison of the Components, rather this Chapter is an assessment of the C2 maturity level at which NATO operates today, and a review of the Components' distinctive communication characteristics related to battlespace management that make NATO C2 possible.

A brief overview of Planning, Execution and Connectivity Features will be conducted, followed by a more detailed exploration of airspace development and resource management. This will establish a baseline for the C2 maturity level at which NATO currently functions and provide a stepping off point building upon the themes discussed in Part II of this study. The remaining Chapters of Part III will provide a roadmap for how NATO may advance C2 maturity level leveraging the communications capability (axis 3 discussion in Part II applied to air power) from a more robust future network.

Defining a starting point in terms of C2 maturity is a foundation upon which to begin modelling further steps in C2 evolution.

7.1.1 Planning, Execution and Connectivity Features

There are many C2 similarities between the components. For example, 'control' procedures still rely heavily on voice/text, whether by an Airborne Warning And Control System (AWACS), Maritime Air Intercept

Controller (MAIC – shipboard) or Joint Terminal Attack Controller (JTAC – land based).

Therefore, the section on the Air Component will focus heavily on planning for the use of Air Power, as well as highlight the extremely complex system of systems method of decentralized execution currently in use. The Maritime section will highlight two different C2 models used in Maritime battlespace in order to identify varying levels of operational C2 maturity. Finally, the Land Component discussion will focus on the connectivity methods employed to integrate Joint Air assets because the Land Component, more so than each of the other Components, exerts air power with segregated airspace due to the role that assault helicopters and artillery fill in Land doctrine.

Execution of AC2 today is heavily reliant on chat tools. While providing a rudimentary text messaging collaboration capability, these tools lack the capability to present a common visualization and representation of data and they do not offer 3D collaboration or approval of airspace requests in real time. Most AC2 functions revolve around a deliberate planning process and the procedures do not adapt well to time sensitive mission execution requirements, requirements which demand real-time changes to airspace, coordinated with all applicable airspace stakeholders in order to facilitate immediate approval.

Anthony W. Potts and James W. Kelton, USA Army
The Need for Dynamic Airspace Management in Coalition Operations[1]

It is interesting to note that, internal to each component, when operating in a small battlespace with organic assets, the level of coordination required is less complex; therefore, it may be seen to raise the achievable level of C2 maturity (like is able to communicate more easily with like). However, in the joint environment, all of the issues regarding language, syntax and ambiguous communication are brought to light, restricting C2 maturity until they can be overcome.

7.2 Joint Force Air Component Commander's C2 Structure

Based on the Joint Commander's guidance and the campaign objectives, the Air Component plans, integrates, allocates, controls and tasks joint air operations. Direct support air missions to the Land and Maritime components, as well as those Components' air contribution to the joint mission, will be discussed in the following sections. Nevertheless, many aspects of the Air Component Command (ACC) C2 structure are applicable to the other services within the Joint Operations Area (JOA). Doctrinally, the Air Component Commander is in most cases both the Air and Missile Defence Commander and Airspace Control Authority across the JOA, although overwater portions are typically delegated to the Maritime Component Commander. As such, there is a system of networks of various architectures which connect to provide the COM JFAC's staff both situational awareness of the battlespace and connectivity to subordinate C2 nodes. The NATO standard C2 tool for use in CAOC's is in transition from the Integrated Command and Control system (ICC) to the Air Command and Control System (ACCS) which will be fielded in the next few years.

The ICC is 'an integrated Command, Control, Communications and Intelligence/Information (C3I2) environment that provides information management and decision support to NATO air operation activities during peacetime, exercise, and war.'[2] NATO's ACCS will provide significant changes, reflecting a wide range of current threats and incorporating new software user interfaces and advanced sensor fusion capabilities.[3] Although ACCS has some improved level of machine-to-machine coordination potential, especially for some types of operations, it will still require a significant amount of manual interface at various levels of command and control.

7.2.1 Airspace Control Procedures

Airspace control is executed today through a combination of positive control (via radar contact) and procedural control (via voice and system generated messages) through joint battlespace management (via

airborne or surface based C2 nodes). Separation of numerous types of air vehicles (aircraft, Unmanned Aerial Systems [UAS], Missiles [air-to-air, air-to-ground and surface-to-air], Artillery shells; all platforms that use airspace) is fundamentally safety driven in order to prevent two vehicles from occupying the same space at the same time.

Parameters for all pre-planned air missions within the JOA are assigned to aircraft via the Air Tasking Order (ATO). The Airspace Control Order (ACO) integrates the pertinent Airspace Control Measures (ACM) and formally assigns that aircraft into airspace defined by both geographic boundaries and time for the accomplishment of the mission as directed in the ATO. While fighter-to-fighter and other datalinks allow seamless communication between some aircraft and other specific platforms, and AWACS can provide voice or datalink instructions to change an asset's assigned airspace, there remains a relatively rigid control process to avoid conflict and fratricide, which remains one of the C2 fundamentals (as stated in AJP 3.3).

The foundation behind this safety first concept is two-fold: Firstly, since not all players in the airspace can effectively communicate with each other, a process has been constructed to permit participants of lower technology to join the team. This process of airspace segregation hinders effective and efficient co-use of the same airspace, but accomplishes the goal of allowing all players to participate while preventing blue-on-blue engagements or conflicts generated from contiguous use of airspace by disparate platforms. Until communication improves for all players (Axis 3), NATO will be restricted to this level of coordination to ensure safety. This viewpoint is a fundamental theme in current Air Power Doctrine.

Secondly, and perhaps more profoundly, NATO and other Western Allies have had supremacy in the air domain for the past 20 plus years. From Kosovo to Afghanistan to Libya, NATO has grown accustomed to operating without a near-peer adversary in the air and therefore has become culturally averse to the loss of even a single aircraft.

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Combined Air and Space Operations Centre at Al Udeid Air Base in Qatar.
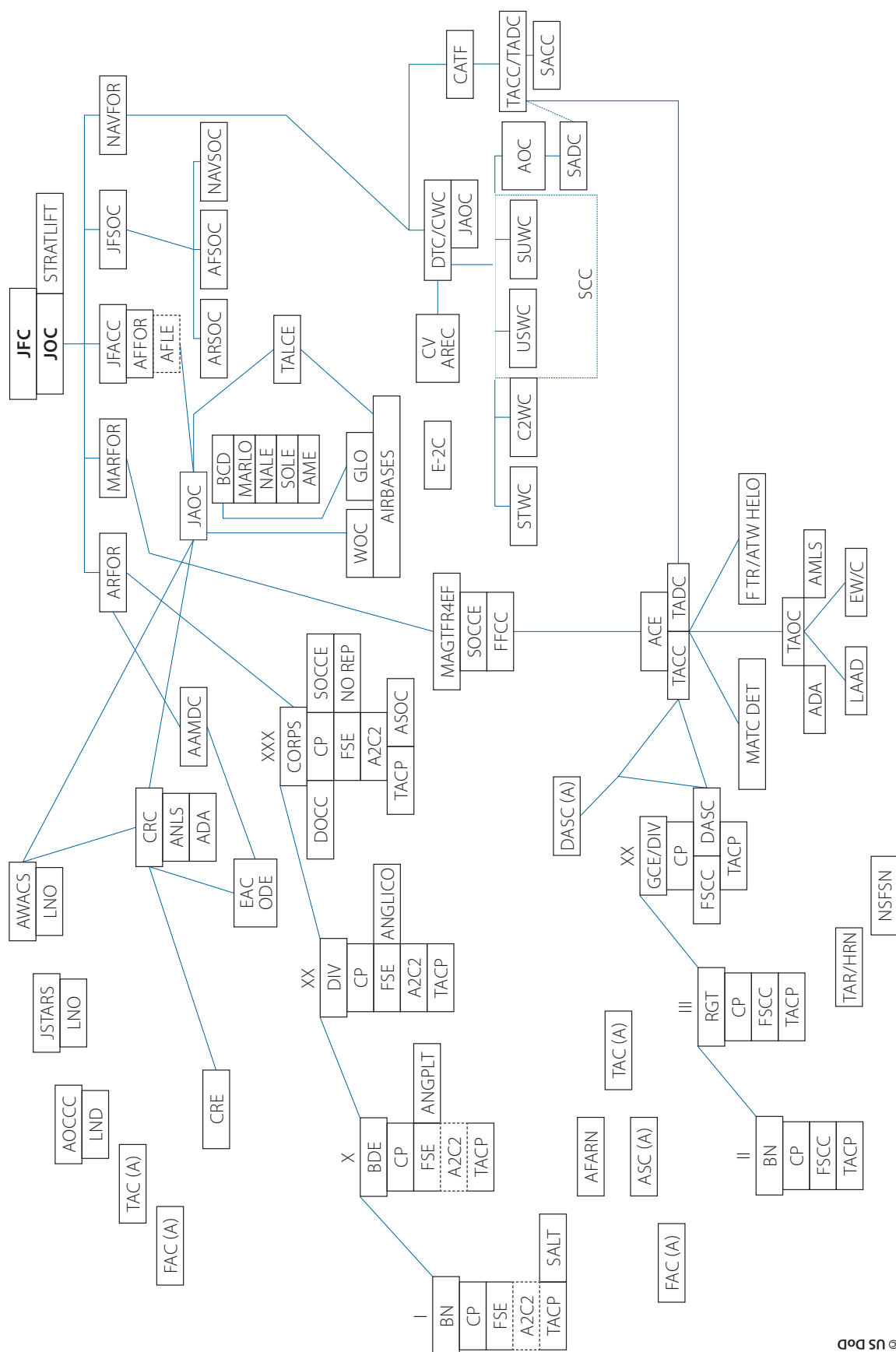
Figure 1: A notional depiction of the network of networks in place across the COM JFAC, subordinate C2 nodes and associated air platforms, showing the complexity of today's 'network of networks' air C2 architecture. The figure is displayed to demonstrate the potential communications challenges due to this complexity behind the current Air C2 structures. An additional challenge is that nearly all of these individual entities have segregated battlespace associated to their particular communication patterns.

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Air Power's Core Roles are orchestrated in accordance with the ATO cycle's timeframe, but some of the types of operations and TTPs related to dynamic operations, in emergent tactical contexts, have to be executed on station through real-time management. In both cases (pre-planned and dynamic operations), voice and datalink coexist as message formats. In many situations, voice calls and datalink complement, correlate, reaffirm, and/or authenticate the same message that flows in these different formats, thus reducing ambiguity and contributing to faster information completion.

Nevertheless, messages are contextually tied to a segregated portion of the airspace. Weapons management coordinates fighter allocation and Surface-to-Air Missile (SAM) allocation via voice within the ARS, which is the acronym of acronyms for Air Control Centre, Recognized Air Picture and Sensor Fusion Post. But the Fighter Area Of Responsibility (FAOR) and the Missile Engagement Zone (MEZ) do not share the same language. In addition, the language of the ROZ (Restricted Operations Zone), where a ground unit is operating, is completely different from the language of the FAOR, except in the cases of Close Air Support (CAS) and Strike Control And Reconnaissance (SCAR) procedures. In other words, the different functions of these surface-based and airborne systems cannot normally be fully complementary and automatically sequenced by the SAM and Fighter allocators because their pattern of control remains within a different Core Role allowing only a 'De-conflicted' C2 level of maturity.

Some types of missions have a pre-established C2 maturity above the 'De-conflicted' maturity level into 'Coordinated,' such as the SCAR and CAS missions above, owing to the level of communication necessary to perform those missions. Datalinks and mobile C2 nodes support decentralized execution of Air C2, but this does not mean that automated functionality on board modern platforms, especially 5th generation or dissimilar services' platforms (Land GBAD or Maritime Aegis for example), address the necessary airspace segregation between platforms, activities and services. The result is an inadvertent 'constraining' of the freedom of manoeuvre of the JFAC's (or Maritime/Land commander conducting air power activities) assets and a self-imposed limitation of the C2 maturity level.

Those researching the future of dynamic airspace control are beginning to explore the option of machine-to-machine manipulation of available airspace, in effect exploring ways to take the higher level of coordination executed in CAS type missions and extrapolating that, through faster networked communications, across the entire joint battlespace (Chapter 10 discusses this in more detail). This may help solve current airspace limitations encountered by the JFAC where the concept of airspace segregation is still in use today. Therefore, the integration of the various subsets today is limited and the topologies remain primitive. This is seen not just in the Air Component, but across all services' battlespace.

7.3 Maritime Component Air C2

The Maritime force executes Command and Control by separating offensive and defensive functions into the Composite Warfare Commander (CWC) Chain of command. This CWC structure is in use across NATO with bi- and multi-lateral naval forces. Aircraft operating inside the airspace delegated to the Maritime component will be Tactical Control (TACON) to either the Air and Missile Defence Commander (AMDC), the Strike Warfare Commander, the Surface Warfare Commander or the Subsurface Warfare Commander, depending on the assigned mission. ISR aircraft or joint aircraft conducting missions that are operating inside its airspace but not necessarily directly supporting the maritime Component will normally be in contact with the AMDC for advisory support on threats. Figure 2 depicts a typical CWC structure.

Coordination of information between ships and aircraft is normally conducted over various datalinks, the most common being Link-11 and Link-16. Additionally, voice circuits are heavily employed by naval forces as, with the exception of inbound adversary fighters or missiles, the development of a maritime tactical problem normally occurs at a slow enough speed that

		Officer in Tactical Command			
		Composite Warfare Commander			
		Principle Warfare Commanders			
Air and Missile Defense Commander (AMDC)	Anti-Surface Warfare Commander (ASuWC)	Anti-Submarine Warfare Commander (ASWC)	Sea Combat Commander (SCC)	Strike Warfare Commander (STWC)	Information Warfare Commander (IWC)
		Functional Warfare Commanders			
	Maritime Interdiction Operations Commander (MIOC)	Mine Warfare Commander (MIWC)	Screen Commander (SC)	Operational Deceptive Group Commander	Replenishment Group Commander
		Coordinators			
	Air Resource Element Coordinator (AREC)	Force Over the Horizon Coordinator (FOTC)	TLAM Strike Coordinator	Submarine Element Coordinator	Helicopter Element Coordinator

This graphic is representative of the CWC structure and not intended to show any specific national or NATO maritime C2 organization.

Figure 2: Composite Warfare Commander Structure.

voice or chat circuits can effectively communicate Commander's Intent and adequately pass tactical information across the force.

7.3.1 Command by Negation

Furthermore, the philosophy of 'command by negation' exists throughout the maritime force. Once the Commander's intent is expressed through formal orders and delegation authority codified, the Commander then monitors the voice nets during mission execution and only becomes involved with tactical execution in the event the commander does not agree with a decision made by a subordinate or has to change a previously issued order. This process is extrapolated to 'subordinated machines' within the semi-automated cluster hierarchy. This is the maritime components' interpretation of decentralized execution; however, it still predominantly occurs over voice nets. While datalinks are used to exchange information and are employed to raise awareness of the battlespace; orders are passed via voice.

7.3.2 Force Management and New Patterns of Interoperation

Maritime component aircraft operating in Direct Support to the Maritime Component will normally be indicated as such on the ATO, though this is for situational awareness only. This helps delineate differences between the two 'Air Force' subsets on one comprehensive planning tool. Maritime forces supporting other components or joint missions will also be assigned and tasked on the ATO. This includes strike and strike support aircraft departing from aircraft carriers with overland tasking assigned through the joint targeting process. However, while the ATO provides basic information about aircraft allocation and mission type, it is quickly becoming an archaic conveyance of capacity due to its limited flexibility and inability to adequately describe the capabilities and functionality of future aircraft. This issue is a central point of the discussion regarding 4th–5th generation aircraft integration, which in turn is driving conversation within the

NATO Amphibious Assault ships bring flexibility for simultaneous surface and air based power projection.

Alliance about creating a more 'dynamic ATO' in the future. As this is a Joint problem, cluster formations and recommendations for adapting future airspace management will be addressed in Part IV of this study.

Additionally, as outlined by Second Line of Defence's article 'Aegis is my Wingman'[4] and expounded upon by Dr. Robbin Laird and Alex Lockie below, the Maritime component is exploring methods to leverage the enhanced sensor and battlespace management capability of the new generation of fighters by integrating the Aegis weapons systems with off-board sensors. Aegis is the combat system aboard many countries' modern destroyers and cruisers and is comprised of integration of a high-end phased array radar, computers, datalinks and ship-launched air defence missile.

So now with this development, an F-35 can pass targeting data to the world's most advanced missile defense system, an Aegis site, that would fire its own missile, likely a SM-6, to take out threats in the air, on land, or at sea.[5]

Alex Lockie. 'The F-35 just proved it can take Russian or Chinese airspace without firing a shot.' Business Insider.

Other C2-related initiatives in the US Navy involve distributed control. The US Navy and Boeing recently demonstrated new targeting technologies that greatly enhance aircrew safety and effectiveness through the rapid integration and distribution of target information across multiple aircraft. Utilizing an advanced targeting processor, an open architecture, high-bandwidth data link, and a Windows-based tablet integrated with the mission system, the demonstration proved that Boeing's EA-18G Growler electronic attack aircraft can detect targets over longer distances and share information more rapidly than ever before.[7] This means the automatic and agile data transfer of the EA-18G will likely change the communication format between this type of ISR-EW platform and the strikers, thus reducing the OODA loop in certain cases.

With a 21st century approach to air and naval integration, it is clearly possible to combine air and surface assets into joint operations to monitor, protect, and act as required. Now with multi-mission systems such as the F-35, F-22, and Aegis, the integration of these systems carries with it simultaneous capability to perform defence, security, ISR, or strike functions … F-35 as a 'flying combat system' working with surface assets can provide for Arctic security missions for Norway. The key really is the ability to integrate an aircraft with an on-board database of intelligence and to be able to distribute this intelligence to other elements.[6]

Dr. Robbin Laird
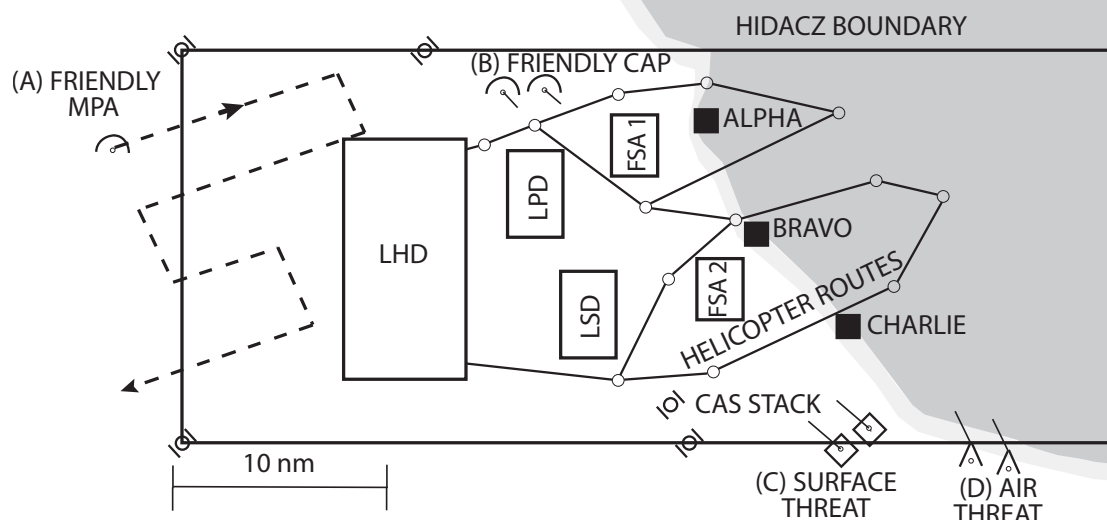
Combat Air Patrol (CAP), Close Air Support (CAS), Fire Support Area (FSA), Landing Helicopter Dock (LHD)
Landing Platform Dock (LPD), Landing Ship Dock (LSD), Maritime Patrol Aircraft (MPA)

Figure 3: Notional depiction of a HIDACZ Airspace Control Measure.

In addition, the Naval Integrated Fire Control Counter Air Network (NIFC-CA) makes possible the third party targeting between sensors and weapons such as the F-35 and the SM-6 (Aegis destroyers munition of choice in the US Navy).

7.4 Expeditionary Force Air C2

A separate element within the Maritime force is the Marine or Expeditionary force. As the principle objective of the Expeditionary Force is to conduct movement of ground forces from the sea to the shore, there is a high volume of logistics, helicopter and support aircraft (Close Air Support etc.) transiting between the ships and the shore. Normally, the COM JFAC apportions a subset of the JOA to the Expeditionary Force through implementation of a High Density Aircraft Control Zone (HIDACZ), where the term 'Density' clearly indicates the spatial constraints for the dissimilar platforms executing that wide menu of actions simultaneously. The history behind this construct stems from naval operations in the Pacific during the Second World War. Conceptually, not much has evolved in this doctrine because,

until very recently, maritime helicopters and amphibious assault ship based jets were extremely limited in airborne C2 and spatial awareness of other aircraft. Historically, the concept derived from the prime factor of safe de-confliction of ship to shore movement.

An embarked entity, usually a Navy Tactical Air Control Centre (N-TACC), will oversee execution of all air missions within the HIDACZ and coordinate handover to a follow-on C2 node for aircraft entering and departing. The N-TACC is not normally equipped with a datalink for Command and Control, and until recently, many of the Expeditionary Force aircraft have not been equipped with internal datalinks either. Almost all of the air C2 inside the HIDACZ is conducted via voice, thereby requiring non-organic aircraft to remain outside the HIDACZ until safe joining procedures are executed.

7.4.1 Joint Fires Coordination

The N-TACC closely coordinates with the Supporting Arms Coordination Centre (SACC), normally embarked on the same ship, in order to provide safe de-confliction of aircraft from fires and to provide aircraft

support to execute fire missions when requested by the SACC. This process allows the efficient movement by air of the ground force to the shore, provides a robust air support to naval shipping plan, and integrates other elements of fire (Naval Guns, Artillery, Army TACtical Missile System [ATACMS], and other systems) safely and efficiently into the airspace. Networks continue to be a challenge, and much of this coordination is done via voice or face-to-face between watches. The advent of the Joint Automated Deep Operations Coordination System (JADOCS) has improved the integration of Joint Fires and aircraft. However, the situational awareness of JADOCS is far from perfect and still requires a significant amount of voice redundancy.

As the other missions that concern the Maritime Component will occur simultaneously, specifically protecting the Expeditionary Force from air, surface, and subsurface threats during force movement ashore, aircraft performing other maritime missions (anti-submarine, anti-shipping warfare, APCMO) may be operating inside the HIDACZ, reporting directly to the CWC Warfare Commander as previously outlined. It is rare, although increasingly possible with the introduction of the F-35 to NATO aircraft carriers, that the Expeditionary Force will likely generate excess sorties (above those needed for Direct Support maritime missions) which will be made available for Joint level tasking. In that case, the C2 would function as any other Maritime sortie supporting Joint or other Component objectives.

7.5 Land Component Air C2

As stated before, some elements of the NATO Command Structure may adapt better to certain tactical contexts through lower C2 maturity levels, as lower levels require less interoperability amongst different types of forces. Although it may not be the most efficient method, segregation is sometimes easier than integration, especially when dealing with different technology levels or when dealing with more than one commander in the battlespace (multinational or civil/military). The decision to accept a lower level of

C2 maturity in any given structure must be balanced against the need to incorporate the less capable players into the structure and the impact that may have on mission accomplishment.

Driven primarily by the challenges in communication between elements of their own network, primarily helicopters and artillery, as well as with the other services and components, the Land Component traditionally operates with very segregated airspace. Forward Edge of Battle Area (FEBA), Forward Line of Own Troops (FLOT) and Coordination Level/Altitudes are generated specifically to keep other services' air platforms out of Land Component airspace due to interoperability and communication challenges. The classic De-conflicted level of C2, and this pattern of air platform integration, has characterized the interaction of the Land Component with the other Component Commands and other organizations within the Land Component's battlespace.

The different components liaise and segregate battlespace through the C2 architecture of choice to manage artillery fires and other functions in the third dimension through voice and rudimentary data networks (still with a significant amount of manual data entry), but in the future, these activities may be automated through machine-to-machine communication.

The number and variety of actors in the land environment (troops, civilians, Non-Governmental Organization [NGOs], and many other groups and actors), plus hybrid warfare and the peculiar physical context of each area, may dictate different levels of C2 maturity, forcing complex, hybrid topologies. Air and Land Component Commands will have allocated liaison officers at the organic levels depicted in Figure 1 or other mission-tailored structures, allowing for coordination (mainly de-confliction and fires, CAS and SCAR coordination) of the operations. This structure permits certain levels of Air-Land Integration (ALI), mainly through chat tools and voice communications. Integration of these tactical environments includes a variety of types of land and air operations plus other C2 related activities, like joint battle space management.

Some elements of the ground force (e.g. JTACs) already have the capability to be highly connected with air assets through downlink video and other means of voice and text communication, while other land forces will integrate in the C2 structure through basic communication systems. Maritime and Air Component aircraft providing support to the Land Component have very strict coordination procedures to safely enter and utilize Land component airspace, similar to the HIDACZ procedure previously mentioned. This process is highly manual, with a limited amount of automation.

7.5.1 Close Air Support (CAS)

Close Air Support is one of the operations that belongs to the Attack Core Role. It is a good example of how enhanced communication sparks ground-based and airborne platforms' co-evolution. The classic CAS structures link troops in contact (in contact with enemy forces) with supporting aircraft via voice and via video through systems such as the ROVER (Remotely Operated Video Enhanced Receiver) system. Other sensors and pods may be involved for target recognition, correlation, and potential laser designation.

The CAS C2 architecture utilizes Joint Tactical Airstrike Requests, centralized at a certain organic levels, and executed as pre-planned or dynamic CAS missions. As part of the Joint Fires process, CAS assets, manned and unmanned, share with many other platforms the condition of Best Available Weapon/Sensor (BAW/BAS). These are currently manually entered into Joint Fires software coordination tools commonly in use today, but may adopt a higher level of flexibility when supporting the ground troops in a future networked environment. In other words, machine-to-machine enabled communication may permit the network itself to select the BAS/BAW for an engagement, even when sensor and weapon are not collocated or belong to different Services/Components.

7.5.2 CAS Co-evolution of Ground-based and Airborne Assets: SADL and PCAS

Some Air Power network terminals associated with CAS operations are structured in specific datalink protocols,

© DARPA

Figure 4: Persistent Close Air Support (PCAS) enables ground forces and combat aircrews to jointly select and employ precision-guided weapons from a diverse set of airborne platforms.

like SADL. 'The Situation Awareness Data Link (SADL) integrates US Air Force close air support aircraft with the digitized battlefield via the US Army's Enhanced Position Location Reporting System (EPLRS). More than just a radio or a data modem, SADL provides fighter-to-fighter, air-to-ground and ground-to-air data communications that are robust, secure, jam-resistant, and contention-free. With its inherent position and status reporting for situation awareness, SADL provides an effective solution to the long-standing air-to-ground combat identification problem'.[8] This network enables a joint topology with a certain level of automation regarding CAS procedures, especially those related to the transfer of target and friendly forces' data.

The Persistent Close Air Support (or PCAS-Air) is able to handle not only weapons management, but intelligence, surveillance, and reconnaissance (ISR), and communications, as well as integral navigation, and high-speed data transfer. It works in conjunction with PCAS-Ground, which allows PCAS-Air to communicate with ground forces, and provides situational awareness by means of mapping software installed on commercial Android tablets. Together, the two sides of PCAS can synchronize forces, map friendly units, recommend travel routes and selection of weapons, as well as their deployment.

DARPA Persistent Close Air Support (PCAS) Project

Allows Commanders to Fight
in the 3rd Dimension

Synchronizes Airspace with
Maneuver, Fires and Logistics
Domains

Enables Dynamic Airspace
Updates and Mission
Command

© General Dynamics Mission Systems

TAIS Interface.

A step beyond SADL in air-to-ground networked operations is DARPA's PCAS program (see Figure 4). The option of 'jointly select' to choose the BAW from the best available airborne platform is a significant advance in dynamic cluster formation, utilizing optimality criteria within the CAS type of operation.

7.5.3 Battlespace Synchronization: TAIS-DACT

The need for more agile spatial coordination has been reflected in numerous works and technical developments, especially in the post-ISAF era. The US Army Tactical Airspace Integration System (TAIS) enhances dynamic airspace synchronization in the land environment and adapts the airspace to three main land component activities: manoeuvre, fires, and logistic lines of communication.

The battlespace in the land environment and its immediate 3D associated areas is shared with different elements of the ground force via the DACT, or Dynamic Airspace Collaboration Tool, a conceptual step towards the DyAS concept that will be explained in Chapter 10. In real time, TAIS planning and execution associated airspace is available through a web browser for DACT users, permitting almost immediate airspace activation and segregation to achieve the fastest de-confliction[9].

7.6 Manned and Unmanned Teaming in the Joint Environment

As identified in both Part II and this Chapter, sets of platforms operating in concert enable simultaneous execution of air power functions in a more efficient manner. The US Army's Manned-Unmanned Teaming (MUM-T) process below is just one example of a manned-unmanned set working together in a manner that advances the level of C2 maturity. Each of the Components, and many NATO nations, have emerging technology represented by the following example.

7.6.1 Tactical Helicopters Team with RPAS. MUM-T

US Army aviation is currently developing and implementing a MUM-T initiative in some tactical helicopter units. Within this initiative, manned and unmanned platforms, through data transfer, increase situational awareness and execute combat support and Intelligence, Surveillance, And Reconnaissance (ISR) missions.

This initiative is exemplified by the tactical employment of Apache helicopters teaming with RPAs. The combination of a ground control station, a compatible remote video terminal, and the proper tactical C2 architecture, allow for a real-time datalink enabled synchronization of these platforms. Their integration of manoeuvre, sensors, and weapons, and the tactical orchestration of their spatial display, is another advance in data transfer-based interoperability. Many programs, like the Lockheed Martin Unmanned Combat Armed Rotorcraft (UCAR), or the Bundeswehr University MUM-T Program, based on cognitive automation architectures, are currently researching the impact of manned and unmanned platforms teaming in these army-related tactical environments, as well as their C2 implications. The task-based methodologies that inspired this integration are analysed in the next Chapter.

Instead of relying on traditional approaches that mass fighters, bombers and supporting aircraft into major strike packages to attack particular targets, a combat cloud integrates complementary capabilities into a single, combined 'weapons system' to conduct disaggregated, distributed operations over an entire operational area.

Lieutenant General (ret.) David A. Deptula
'Evolving Technologies and Warfare in the 21ˢᵗ Century: Introducing the "Combat Cloud"'

7.7 Moving Toward Edge C2

The previous sections briefly discussed how the Air, Maritime and Land Component conduct Air C2 today. Different Components present different patterns of communication and different C2 structures. Implementation of data transfer through the various link protocols increases the maturity of these C2 structures, but sometimes these advances are not uniform at the Joint and Combined levels.

In smaller, confined battlespace with only a single unit or service's organic aircraft involved, NATO may approach a level of Collaborative C2. But in larger battlespaces, the distributed command structure, dissimilar communications capability of participating platforms, and different levels of both technical and platform performance capability of the numerous NATO nations have resulted in a C2 structure that operates between 'De-conflicted' and 'Coordinated'. This is insufficient for air warfare in a dynamic, complex and contiguous future battlespace where the air war will be a 360 degree problem (air platforms operating inside airspace with overlapping Red/Blue force Integrated Air Defence Systems [IADS]), and necessitates a more agile C2 structure operating above 'Collaborative' and approaching 'Edge C2'.

Chapters 4 and 5 discussed the impact of communication (the third axis) on the level of achievable C2 maturity. In order to move more fully into Collaborative C2 and begin to approach the Edge C2 maturity level, NATO must become a more integrated force capable of communicating between platform, HQ, Component Commander and Joint Force Commander at machine speeds, rather than today's somewhat archaic voice and manually entered text (chat) methods. The future network envisioned by this study will allow communication of battlespace geometry, weapons and sensor allocation and even be able to dynamically respond to changes in the environment with limited human intervention. This necessitates that all platforms participate in the network so that all may communicate with each other for the proper battlespace geometry of both sensors and weapons.

NATO is taking some steps in this direction, which will be explored in the next section. The article 'The Need for Dynamic Airspace Management in Coalition Operations,'[10] published in the C2 Journal, describes several plans, experiments (Coalition Attack Guidance, or CAGE)

and tools (such as those listed in this chapter, like DACT-TAIS and other tactical data systems or mission planning tools). All these tools and trials in the framework of the AMN (Afghanistan Mission Network) contributed to evolving coalition Air C2 toward Dynamic Airspace Management. Furthermore, Chapter 10 will define how this future battlespace could be organized for dynamic motion policy adjustments across all participating platforms. Chapter 11 will discuss research and experimentation through simulation, which is currently addressing improvements in human and machine interface with military applications, such as those trained in the framework of BOLD QUEST-type exercises.

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CHAPTER 8

Air Platforms Behavioural Evolution Viewed as a Function of Communication

8.1 Background

Legacy and current air platforms that share link protocols offer clear examples of behavioural co-evolution. This Chapter reviews three different perspectives of this technological evolution through improved communication among aerial platforms.

Previous Chapters discussed models and the extrapolation to the machine world of animal kingdom communication concepts. To analyse how hyper-connected fighters increase the efficiency of the force and achieve better values of optimality (a new Pareto efficiency), this study analysed different machine-based and biological models based on communication, primarily Stigmergy, where the objective was to self-synchronize platforms' motion, weapons and sensors.

Aerial platforms may be considered as complex finite state machines, especially when operating in a changing environment that demands flexible adaptation to certain supported-supporting combinations of functions.

This extrapolation is demonstrated in certain tactical profiles, through specific characteristic motion policies displayed by aerial platforms that solve the 'problem space' (see Chapter 1) and optimize the distribution of air power roles. A sequence of distributed sensors and weapons can be arranged through communication via data transfer. Some functions will be orchestrated and spatially coupled through self-synchronized features that are incorporated in a common machine-to-machine logic through code writing, as described in the fundamentals of stigmergic communication. This will favour co-evolution of dissimilar platforms, especially in some high intensity scenarios where two integrated systems oppose and certain mission profiles are necessary. In this case, speed (iteration cycle per unit of time and speed of information flow) is paramount to gain first, the tactical advantage and second, the operational tempo, which forces the adversary system to its culminating point.

Spatial constraints within these improved communication scenarios will be arranged and de-conflicted by the machines, through cueing commands or even through direct inputs to other supporting assets' (mainly unmanned) FCCs (Flight Control Computers). The mission flow will then be adapted to the best orchestration of functions, and the platforms will present basic swarming capabilities from a qualitative perspective.

This Chapter comprises three different sections in which fighter aircraft are analysed as agents in competition. All three are focused on the behaviour of different generations of aircraft in terms of communication, mainly comparing the pre-datalink and the datalink eras. The foundation for this analytical review is that communication improvements result in a measurable change in aircraft tactical behaviour. This change can be forecast into a future networked environment and into assumptions of future aircraft behaviour, based both on interdisciplinary observation and extrapolation of measured behavioural evolution, observed over different levels of datalinks. In analysing these three examples, the study will leverage previous discussions of maturity levels, FSM state behaviour evolution and bio-mimetic behaviour.

Furthermore, it is assumed the reader has a modicum of awareness of basic air manoeuvre and the execution of Air Power. Therefore, not all military technical terms will be defined, as their use should be apparent based on the context of the discussion. Although many tactical terms will be used, this Chapter will not focus on tactics of Air Power execution, but it will focus on the behaviour of the agents as they execute the Air power function.

8.1.1 Fighter Aircraft as 'Agents': The Three Sections

The first section uses a storyline as a scaffolding. This storyline illustrates different generations of aircraft performing the consecutive stages of the same air-to-air 2 vs. 2 intercept profile (constant manoeuvre, variable communication technology and on-board sensors and weapons). Emitter, receiver, context, and messages will also remain almost constant, as they are

part of this standard, fictional interception consisting of two 'Blue' fighter aircraft executing the last steps in a kill chain against two 'Red' aircraft. The objective in this section is first to break this manoeuvre in small bites (actions and actionable information) and then analyse the communication trends of each generation of aircraft along the selected storyline events.

The second section presents a linear study, based on RAND's Network-Centric Operations Case Study. This publication analyses air-to-air combat results with and without Link-16. In this case, the emitter and receivers are also constant. They also belong to the same generation of aircraft, country of service and execute a single, constant tactical profile (4 vs. 4 F-15s operating under AWACS Tactical Control). More than 12,000 sorties were analysed to obtain metrics related to efficiency variations before and after data transfer (Link 16) was available.

In the third section we consider a non-linear study derived from statistics obtained by the Tactical Leadership Programme's (TLP) analysis of multiple years of pre- and post-Link 16 aircraft training missions. The lack of linearity derives from the multiple variations in the composition and quantity of Red and Blue Air participants in each course of study. Even though the TLP Syllabus has remained nearly constant through the analysed period, full course data with datalink information is only available from 2010 and after.

Finally, a review of machine-speed communication in real-world applications is conducted, demonstrating the central thesis of this study and supported by extrapolation of the findings in the three aforementioned sections.

8.2 Communication Patterns in an Air–to–Air Engagement (2 vs. 2)

The storyline supporting this sequence of tactical events and its communication features is that a basic cluster of two similar aircraft, considered FSMs, has to solve the last portion of the kill chain by mutually

A 4-ship of F-15s (USAF) conduct an intercept of two Soviet MiG 29 Circa 1989.

observing and marking their tactical environment, and by acting and reacting accordingly through several state changes determined by certain transition thresholds.

The structural background of this case analysis is that the agent with the proper decision rights (either AWACS, ADC, or CAP Flight Lead) has triggered the fighters' intervention. A response is underway in accordance with the environmental rules (FAOR violation, force posture, threat's point of origin, or any other contextual factor). This case study is inspired by Chapter 4's FSMs operating in concert, and will break down the fundamentals of a standard air-to-air intercept.

In this case, the 'Lack of Friendly – Presence of Enemy' criteria for the 'turnstile' to transit states between the 'Target' and 'Engage' portions of the Kill Chain axiom (F2T2EA) is pending the final identification of the intruders. In the next paragraphs, this section will analyse what communication exchange options are available for each generation of fighter aircraft.

8.2.1 The Interceptor's Potential Functions Expressed Through Brevity Words

The list of functions that the interceptor (from now on the 'Blue' aircraft or formation) may execute during the subsequent Track, Target and Engage states is also diverse. Functions (activities or skills in other studies) are present in the Core Role's definitions and associated types of operations listed in AJP 3.3 and implicit in the different definitions contained in many of APP-7's Brevity words. The TBMFs, or Tactical Battlefield Management Functions, that would apply in a NATO standard air-to-air intercept will not be analysed, as they are part of current plans.

Many APP-7 brevity words define functions, commands and agent's states that could apply in those intercepts (APP-7 semantic fields representing air-to-air-operations (AAO) such as 'Abort', 'Banzai', 'Blind', 'Bogey Dope' and others). However, the following functions or means to achieve the overall goal are typically expected to be

displayed in the form of pairs of cause-effect algorithms regardless of their code words. Some functions will supply actionable information, and other functions will be involved in actions per se.

For the tactical case of a 2 vs. 2 intercept, a list of functions or skills has been selected. These functions are neither generation-dependent, nor listed in any priority.

This functional list and all the references to APP 7 are classified as they together depict a full tactical sequence. This classified list is available upon request by contacting the JAPCC.

8.2.2 The Storyline

The following list represents a standard air-to-air intercept including several of the brevity words just listed. The number of 'skills' displayed through this constant chain of tactical events increases as a result of enhanced communication, and this is what this section intends to prove, merging at the end in a color-coded table that lists the different communication features of the different generations accounted. This storyline, scripted in the form of sequential actionable pieces of information, actions and state changes, also identifies when the following thresholds (part of the cause-effect chain to change states in accordance with the Rules of Engagement (ROE) and other instructions are met.

The sequence is as follows:

1. The first event in the storyline is when the strength of the Red formation is determined, two ships.
2. The Red formation is sorted in azimuth and elevation.
3. The initial targeting is agreed within Blue (Actionable information and state change).
4. The manoeuvre of choice is initiated (Action).
5. The Bogey is identified and labelled as a Bandit (Actionable information).
6. The Bandit fires, and subsequent Blue warning (hostile act, actionable information, state change).
7. Blue warning information shared and state change induced to the formation.
8. Blue executes a defensive action. Action.
9. Blue fires back. Action.

Along this storyline, Blue and Red motion policies will be adapted to the task and the emergent tactical context. In some way, if each word is an acoustic image, the emitter and receiver will correlate each brevity word in terms of manoeuvre, and certain pre-briefed and trained motion policy executed. Once Blue recognizes the type of formation, speed, and dynamic behaviour of Red, with a description normally based on brevity words (NATO APP-7), this formal code, used to compress messages between pilots into brief semantic language (word symbols to convey an intent or description), will mark the battlespace and lead their 'spatial behaviour' during combat.

The desired payoff of the engagement will be included as part of the plan, as well as the accepted level of risk for the allocated force which will drive AMR decisions. As the current state evolves to a different one (Red aircraft manoeuvre, escape, shoot, jam, split or other marks of action that symbolize a new threshold for Blue to change state), the Blue formation will begin to use stigmergic communication to decide 'what to do' in each tactical context. Obviously, the speed and complexity of the scenario demands highly emergent behaviour with a lack of verbal communication, which must approach self-synchronization features within the flight.

For this case study, we will not review each of the Blue's potential Finite States and their spatial and temporal couplings; rather, we will focus on a few key states which highlight the communication-related behaviour response in the search for emergent opportunities during this time-critical engagement.

8.2.3 Storyline: 1st & 2nd Generations

These aircraft and their intercept controller, a basic subset of an 'air force', will display different evolutionary trends of communication regarding their respective technological generations. The 1st and 2nd aircraft generations (such as F-86 Sabre, and F-104 or MiG 21 initial blocks) had a simple radio, no or limited radar, no Beyond Visual Range (BVR) weapons, and would rely on voice calls and visual signs to achieve their goals.
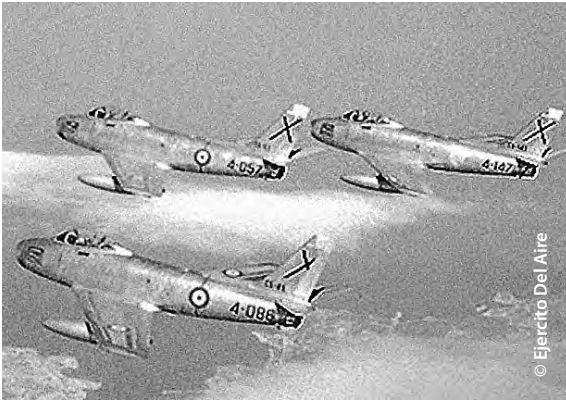
First generation jet aircraft.

Third generation aircraft.

Fourth generation aircraft.

Each of the state changes, follow-on environmental and actionable information, and further Blue actions are visually analysed and exchanged via voice or visual signals. There is no data transfer present in the communication patterns between the two interceptors (agents in the cluster). Self-synchronization occurs mainly based in Axes 1 and 2 ('Patterns of interaction' and 'Allocation of decision rights'). These features are related to the strength and validity of the team's contract and regulations, the rules by which they organize to execute the air mission. Training to generate proficiency, following established procedures and trust between the pilots is essential for successful mission execution. Communication skills, communicative options, shared codes, and willingness to interact are also paramount.

Axis 3, 'Distribution of information among the players' relies on the other two axes. Human language, visual signals, a reliable radio, and clear rules are the only source for synchronization. Emergent behaviour is therefore only synergistic when previously trained or shared.

The execution of Air Power functions and capability in Generations 1–2 relied heavily on rules and training to evolve, as their crewmembers exchanged only verbal communication during their tactical performance and sensors and weapons were mainly limited to visual ranges.

8.2.4 Storyline: 3ʳᵈ and 4ᵗʰ Generation with No Datalink

NATO generations 3–4 aircraft presented an additional semantic burden on the Blue pilots, which potential adversaries may not have: Language. Since a majority of decision allocation (pre-datalink) was passed via voice, the level of proficiency with language became a critical vulnerability that demanded training and standards in the exchange of information between aircraft of different nations, as tactical situations may be highly context-sensitive. These generations began to operate weapons and sensors beyond the visual range, and their crews began to operate more often in multinational environments. The advent of Datalinks began to mitigate this to some extent and provided a notable improvement in inter-flight communications and mission effectiveness.

© US Air Force

An F-35 and an F-16 flying in formation.

The most significant additions to Gen. 3 and 4 aircraft (types include but are not limited to Mirage-III, MiG-23, F-16A, F-18A and Su-30) were the on-board radar, medium range air-to-air weapons (both semi-active and active missiles), Radar Warning Receivers (RWRs), Electronic Warfare suites (including jamming and SIGINT pods), and mission computers allowing for software retrofits. In addition, most of these aircraft had multifunctional displays, which provided advanced pilot awareness through enhanced navigation and positioning, plus a certain degree of sensor and weapon fusion.

In the 3rd and 4th generation aircraft without datalink, pilots and on-board sensors observed the state changes and their associated environmental and actionable information and then correlated that information, inter-flight, via voice. Further Blue action and proper formation motion policy is then coordinated and exchanged via voice or through visual signals. Again, there is no data transfer present in the communication patterns between the two interceptors. Self-synchronization occurs mainly based in Axes 1 and 2, with the addition of coded communication that refers to sensor information. Operation Allied Force was the best example of a 3rd and 4th generation

scenario, where Have-Quick secure radios were the main, mission essential communication tool and spatial segregation the main de-conflicting option as datalinks were just emerging and not fully fielded or implemented across the Joint Force.

8.2.5 Storyline: 4th – 5th – Xth Generation with Datalink

This case will review a notional example of two interceptors sharing data through a Link-16 protocol including present and future generation aircraftfeatures. Note that these future features are not fully developed yet but are envisioned, as part of this study, in concert with the vision of the future network.

4th Generation fighters may integrate a MIDS terminal, which allows for data exchange across disparate platforms. Link-16 protocols may integrate a wide variety of platforms, not only aerial, but also ground and sea based, covering the entire joint spectrum. This provides a new option to leverage Axis 3, 'Distribution of information among the players', and permits tactical coordination between agents. For the first time, this agent-to-agent communication begins to bypass human limitations and semantic ambiguities present in the

linguistic competence and performance of the pilots or operators. Clear language is especially significant when cultural or physical differences (services, nations or even individuals at phonetic level) obscure communication or when time is a factor. Bandwidth and network assurance then also become limiting factors

In the case of a 2 vs. 2 engagement comprised of 4th Generation, datalink-equipped aircraft, the morphology of the Link-16 messages is composed of a label and a sub-label. For the given task, many of the functions necessary for a successful intercept, such as reaction and retribution in self-defence, will be automatically correlated, coordinated, and transmitted within the formation without any associated voice messages. As pilots will relay the majority of the 2 vs. 2 related information in machine-to-machine communication, optimality will increase which permits the Flight Lead to potentially utilize fewer aircraft in the merge while still accepting the same level of risk (a more efficient force allocation).

A fifth Gen. fighter introduces automated data fusion which can be automatically distributed among compatible assets, thus becoming a C2 sub-node. This capability will enable appropriately-equipped legacy (third and fourth generation) platforms to more fully participate in the battlespace. It also incorporates stealth technology, which although primarily defensive in nature, can be coupled with other fifth generation characteristics to provide advanced offensive capabilities. The full fielding of fifth generation platforms and their integration with legacy platforms will drive the development of new topologies along with supporting doctrine and C2 methodologies.

Comparison of the Three Storylines

The intercept could potentially result in the following sequence with regard to each generation involved. The table (see Figure 1 on the following page) shows the evolution through these aircraft generations from a communications perspective, including each aforementioned cause-effect step and a possible profile of reception of actionable information and subsequent action execution.

In Figure 1, and with the intention to remark on the evolution through communication of the different aircraft generations across the same chain of events, each generation's communicative profile is colour coded. 4th, 5th and Xth Gen. aircraft (dark blue in the diagram) still maintain voice and hand signal-based communications as an option among manned stations, which means that these platforms include all the colours, and 3rd & 4th Gen. NO LINK (in red) would include the green colour corresponding to the initial 1st & 2nd Gen.

8.2.6 Aircraft Communication Impact in C2 Maturity

Figure 1 shows how improved communication drastically increases the number of tactical options available to the aircrew, some through the pilots' interfaces, some directly to the machines. Context, channel, and message are constant throughout the entire generational spectrum. The only main change is the speed at which the code is transmitted: from human language to machine-to-machine communication.

Figure 1 also shows how the pre-Link platforms (Gen. 1 to 4, green and red colours) relayed verbal information via radio transmission for sensor correlation and motion policy. Sensor and weapons ranges have increased with every subsequent generation, but correlation and coordination had to be semantically compressed in the form of an increasing number of code words to match the state changes with the environment. This means the third Axis, 'Distribution of information among entities', remained constant, and C2 maturity could only increase either:

• Through the strength and validity of the team's contract and regulations, based on training, shared doctrine and standards. This is exploitation of Axis 1: 'Allocation of Decision Rights to the Collective'.
• Through reducing uncertainty among entities with different communication capabilities, skills, and options, allowing interaction through verbal (radio) and signal-based communication. This is exploitation of Axis 2: 'Patterns of Interaction and Information Sharing Behaviours among the Entities of the Collective'.

Intercept: Blue vs Red Context	Colour Code 1st & 2nd Gen - 3rd & 4th Gen (NO LINK) – 4th & 5th Gen (LINK)
Red Formation Strength Determination. Blue Shares Info	The strength of the Red formation is determined, two ships. Visually when the two contrails or aircraft are discriminated, or radar/IR/EO, when the resolution cell/sensor performance makes possible to distinguish two contacts. Inter-flight communication and picture update is via voice. The C2 element supporting the execution of the manoeuvre (surface-based or airborne) may supply the strength of the Red formation through data transfer. This based on passive sensor indicator of two Red radars emitting, or real-time data integrated (and correlated) from a third Blue asset (ground or sea-based sensor showing strength two) in the community, directly or through a gateway.
Red Formation Azimuth and Altitude Determination. Blue Shares Info	The Red formation is sorted in azimuth and elevation. Visually or radar/IR/EO through the proper search, scan or track modes. The sorting is shared inter-flight automatically via data, and integrated real-time in either Blue Head Up Displays (HUDs) or Helmet Mounted Sights (HMSs) as well as automatically correlated with IR-EO sensors in both Blue aircraft or in any 3rd party aircraft through the gateway or through direct communication. Blue formation may use all or only the Best Available Sensor, to deny detection and minimize footprint.
Blue Targeting. Correlate Info and Agree Action. State Change	The initial targeting is verbally agreed within Blue (Actionable information). Both platforms will discriminate their targets based on available weapons, target distance, aspect, speed and altitude once their visual/radar/IR/EO tracks have been correlated through voice/visual coordination, through on-board sensor fusion at platform level and further inter-flight correlation, or through off-board platforms (C2 element or 3rd party through gateway) contribution to inter-flight sorting quality.
Blue Action	The manoeuvre of choice is initiated (Action). By visual signals (hand, wing flash, rudder or other), by pre-briefed sensor distance, or as dictated by Red's emission profile or Red's manoeuvre detected through Blue active and passive sensors or EW suit. Also, as commanded or cued by on-board Blue mission computers, and once the potential WEZ (Weapons Engagement Zone) of the approaching Bogey is depicted by the on-board systems. These features will allow for the automatic network designation of the Best Available Interceptor/Shooter (surface-based or airborne).
Bogey Identified. New Action Required	The Bogey is identified and labelled as a Bandit (Change in the environment). Via voice when aircraft type, insignia or fin flash visually recognized. Via IFF interrogation or via checking that Bogey position, speed and/or origin do not adhere to ACO as displayed on the on-board SAD, or as detected through active and passive sensors or EW suit. Inter-flight communication through data exchange incorporates and correlates data from off-board platforms (C2 and/or 3rd party). Data presented real-time to platform/entity with decision rights.
Bandit (Theatre Enemy ID Criteria)	The Bandit locks-on or fires (hostile act and new change in the environment). Visually perceived or via RWR, IR or EO. Missile Approach Systems (MAWs) or 3rd party sensors would automatically warn each equipped platform and correlate data with RWR and other sensors. In high-risk intercepts, off-board unmanned platforms may be deployed ahead to trigger, ID or assess Bandit's behaviour, commanded by tactical manager and/or tasked by common Decision Support System.
Blue Warning Info and State Change	Blue inter-flight warning (Actionable information). Via voice (plain text or code word). Via data transfer once any sensor/eyes in the community detect the hostile act and fire origin is correlated with Bogey's position. Network-based correlation of fire origin and 'guilt by association' considerations. Labelling of tracks correlated with network sensors for multi-bogey final declaration.
Blue Defensive Action	Blue executes a RWR-induced defensive action (Action). Visually, or as cued or commanded via mission computer or mission computer-to-flight controls, so as to optimize manoeuvre against suspected/confirmed weapon. MAWs, RWRs and other sensors would sense, avoid and cue or command the network to de-conflict evasive manoeuvres through the proper common motion policy. Automatic 3rd party jamming may be triggered.
Blue Retribution. New Action	C2 Element clears for engagement. Self-defence or Counter-aggression Rules of Engagement apply (State change). Blue fires back (Action). Blue manoeuvres visually, and C2 awareness builds up via voice/data transfer. A 'Delouse' manoeuvre may be induced through command or cueing by the owner of the 'choice of weapon' function, and a 3rd party (air, ground or sea-based) may become the tactical option for retribution (Best Available Interceptor-Shooter). The selected platform will adjust its motion policy to get threat within WEZ. De-confliction would be managed through data transfer in accordance with the real-time WEZ and trajectory calculations of the on-scene members of the blue community, as well as their defensive and offensive assigned roles. Future platforms may execute off-boresight shots based on Electronic Support Measures or data transfer from the network.

Figure 1: Communication functions and Air Power activities displayed across multiple generations of aircraft.

The first two colours (Gen. 1 to 4 without Datalink) are channel and human language (code) dependent, as the message must be adapted to the new on-board sensors (radar and EW suite), and all correlation and coordination must be verbalized. The only way to mark the environment is verbal. The Link-16 generations have experienced an exponential evolution in the skills of the emitters and receivers, as well as in the adoption of machine-based codes that transfer information replicated in the form of icons, symbols, and indexes (the three types of signs). These are augmented by plain text or sounds to match the interface needs of each receiver.

Compatible codes could generate new patterns of interaction among future generations of manned and unmanned platforms. Then, tactical communication would be possible between dissimilar elements involved in a common – and even more complex – task (such as the oxpecker example in Chapter 4). As an example of these characteristics, the F-35 Distributed Aperture System (AN/AAQ-37 DAS) already swarms with the Ballistic Missile Defence System (BMDS) through dynamically injected threat information, thus augmenting early warning awareness regarding in-flight missiles' points of origin and trajectory.[1] This automated third party ISR contribution best illustrates the multifunctional cluster concept at machine-to-machine level.

8.2.7 The Importance of Language

Although this study introduces the concept of language in the discussion of generations of aircraft, it is important to understand the correlation between speed of information flow and C2 maturity level. The evolution of this concept, from hand signals to radio to computer datalinks to the envisioned future network, exponentially increases the distribution of information among the players in concert with the development of that level of technology. This concept endures across all aspects of discussion in this study.

From generation 1 to 4 without datalink, Axis 3, 'Distribution of information among the players' still relied heavily on the other two axes. The pilots must share all the available information from the on-board sensors through their linguistic competence (code proficiency at the level of the ideal speaker) and their in-flight linguistic performance (the usage of language in concrete and specific situations). According to many modern language theorists in the field of Psycholinguistics, syntax generally takes primacy over meaning and sound. For this reason, the creation of brevity words (a single noun or verb conveying a specific tactical meaning) allows clear communication as semantics compress due to the need for speed and clarity.

The human perception, especially when based on human language as a single code to exchange information among different agents, limited the evolutionary trend in the fighting cluster. That is the reason why brevity words are a product of consensus to maintain the necessary human communication standards. Lack of competence or poor performance will easily lead to miscommunication and ambiguities. Actionable information might not generate proper action if that semantic compression eliminates contextual nuances through faulty distribution or misunderstanding of the information.

Machine-to-machine communication overcomes many human language limitations. In response to scenarios where the same word would have different meanings (homonym), some research lines[2] incorporate different thesauruses to the databases, to facilitate contextual recognition of a certain word by Artificial Intelligence systems. This will avoid ambiguities and wrong state changes based on faulty information.

Beyond the aforementioned air-to-air engagement, many other tactical contexts will experience new trends of communication in the form of partial mesh topologies with a tactical hierarchy embedded. The MUM-T related technologies open a wide field in this area. The human management of these dissimilar clusters will exert this hierarchical role within the team through a common DSS that assesses the contextual hierarchy of every tactical function for each given tactical situation.

To summarize, when analysing a basic 2 vs 2 air engagement from a generational perspective, there is a measurable change in the quality and quantity of information shared between the aircraft upon the implementation of the datalink, which results in an evolution in tactics and aircraft behaviour. Extrapolating this datalink evolution into the future with the addition of machine language and machine speed provides a roadmap to help define the way Artificial Intelligence will solve problems. The final section of this Chapter will discuss the role of AI in an air to air scenario incorporating this principle.

8.3 Case Study: RAND's Air-to-Air Combat With and Without Link 16

This example is based on linear research, conducted by the RAND Corporation, of how situational awareness improves at both the individual and formation level when networked across a datalink. The Blue force packages are identical, except for the presence or absence of the Link 16 data communications network. Each MCP (Mission Capability Package) includes one AWACS aircraft and four Blue F-15s, and each F-15 has similar Airborne Moving-Target Indicator (AMTI) radars, Non-Cooperative Target Recognition (NCTR) sensors, IFF, and similar weapon systems. The four aircraft are divided into two-ship flights, each with a flight lead and a wingman.[3]

8.3.1 Datalink

The initial purpose of a datalink-based network was to enable a limited number of participants to quickly and accurately share situational awareness with other similar platforms and/or with the C2 element. During the end of the '90s and the beginning of the 2000s, intra-flight datalink started to complement voice exchange of information, which upgraded the verbal code, as seen in the previous section. While this constituted a large improvement, it remained greatly susceptible to relatively basic communication jamming techniques (channel dependency), and sometimes the link network itself proved to be unsecure and unstable.

8.3.2 Link 16

During the following decade a more robust datalink, Link 16, was implemented. Link 16 is a military tactical data exchange network where specially formatted messages convey tactical data and are exchanged via radio frequency at high speed, following a Time Division Multiple Access (TDMA) channel access method.[4]

The aims of the new datalink were: to increase the maximum number of simultaneous participants in the network, to increase the volume and the security of data to be transmitted, to allow a rudimentary level of C2 orchestration (multiple and different C2 arrangements between platforms inside the link), provide jamming resistance, and enable simultaneous ciphered voice communication.

8.3.3 RAND's Case. A Linear Study

The RAND study followed the Network Centric Operations Conceptual Framework,[5] which has a doctrinal connection with the proposed C2 Maturity Model in terms of efficiency increase. This framework allows for the conversion of the numeric scores associated with decision-making to decision-and-action synchronization and action results, and hence to mission effectiveness values.

Loss exchange ratios (number of Red aircraft killed divided by the number of Blue aircraft killed) from the JTIDS Operational Special Project is based on the results of 12,000 training sorties in tactical air-to-air combat. On average, Link-16 led to a two-and-half times improvement in the kill ratio (Red aircraft to Blue aircraft shot down), during both daylight and night time conditions.

Rand Institute
Network-Centric Operations Case Study
Air-to-Air Combat With and Without Link 16

Linearity consists of a strictly repetitive similar scenario involving (almost) strictly similar opposing forces,

using the same tactics with the same platforms and similar pilot's skills. Each of these constant values support the generation of relevant metrics. According to the RAND study, several hypotheses, similar to the premises for this project, served as the initial basis for this case study:

- A robustly networked force improves information sharing.
- Information sharing enhances both the quality of information and of shared situational awareness.
- Shared situational awareness enables self-synchronization, sustainability, and speed of command.
- These, in turn, dramatically increase mission effectiveness.[6]

Although these hypotheses were assumed within the operational community, they required validation. The RAND study also focused on information quality, and, in order to obtain proper metrics and among other parameters, the four desired values measured through intra-flight communication were:

- *Completeness:*
  Detection and awareness of the set of tracks.
- *Correctness:*
  Correct friend or foe labelling of the set of tracks.
- *Accuracy Location:*
  Correct spatial location of the set of tracks.
- *Accuracy Velocity:*
  Correct appreciation of all tracks' velocity.
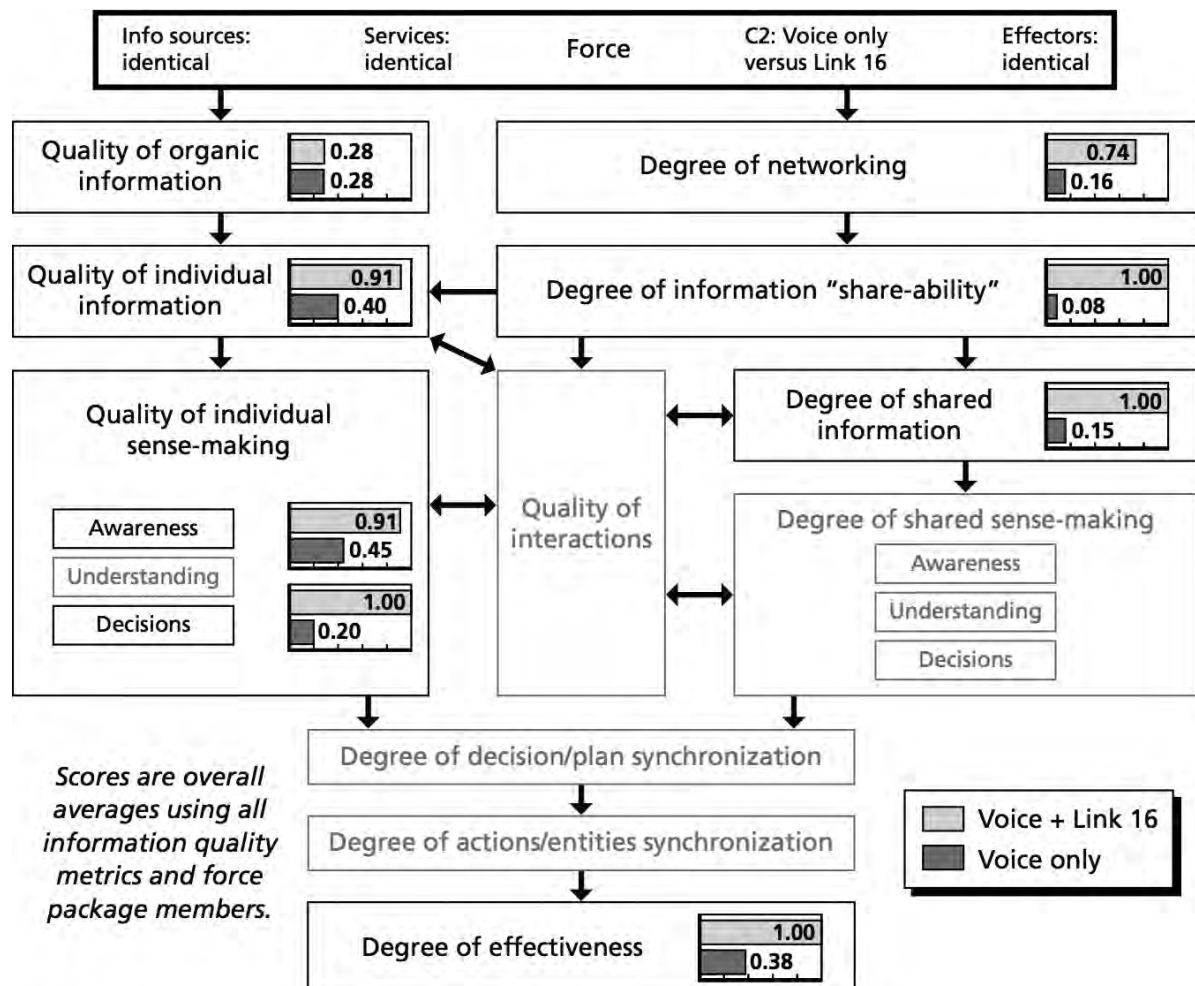
Figure 2: Complete Comparison of Mission Capability Packages Using Summary Metrics.

SINGLE AXIS FLOW FOR ROLE SEQUENCING
VISUAL SEPARATION – VISUAL SUPPORT
PACKAGE COMPRESSION IN TIME & SPACE
MUTUAL VISUAL & VOICE SUPPORT

SEAD-STRIKE-RECCE-SLOW

OFFENSIVE FLOW

LOW & TERRAIN

DEFENSIVE KICK

© JAPCC

Figure 3: COMAO formation in the pre-link 16 TLP operations.

These four values are the most important characterizations of an air track for a military pilot.[7] The study included track latency and currency considerations to validate the pilot's perception. After mapping all the available elements of awareness (actionable information), the associated advanced tactics (actions) were analysed. The different patterns without Link 16 (voice only) vs. Link 16 availability (datalink + voice) could then be measured and compared in terms of quality of information and degree of shared information.

The RAND study concluded that information empowers the flight lead and the wingman, especially the wingman. That knowledge has been proven to have a direct impact on mission effectiveness. As the quality of information improved, picture and situation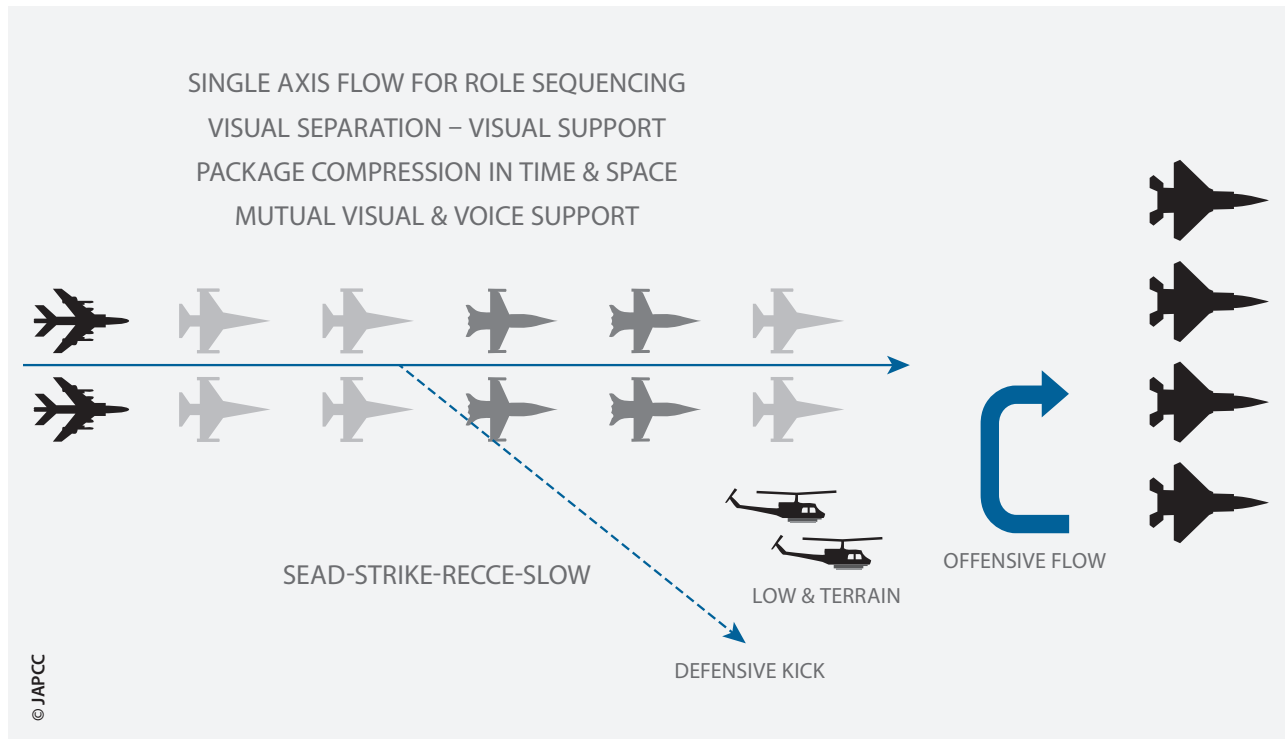al awareness building times were drastically reduced in favour of decision-making mental processes. Decisions were better, and made earlier. The complete comparison between Link 16 and Voice only forces regarding the previously mentioned factors, are displayed in Figure 2.

8.4 Pre and Post Link 16 Tactical Leadership Programme Results

This section expands the analysis from single formations performing single activities (2 vs. 2 or 4 vs. 4 in the prior sections executing Counter Air missions) to a more complex tactical environment consisting of larger numbers of aircraft in multiple formations conducting multiple coordinated missions simultaneously.

The Tactical Leadership Programme (TLP) is a multinational initiative located in Albacete Air Base, Spain. Over more than three decades, the TLP's Flying Courses have become a forum where multinational forces come together to train and execute COMAOs. This is the perfect arena to demonstrate how a higher maturity level for that specific Air C2 structure (to support a COMAO of about 20 to 30 aircraft) is achieved through exploiting all three axes of the Maturity Model: training, cultural and doctrinal standardization, and upgraded communications among different elements operating with solid local interaction.

A Mirage 2000 takes off from Albacete AB, home of the TLP.

8.4.1 Different Courses, Different Clusters, Different Networks

The TLP Flying Course provides a forum for a free exchange of information on weapons, tactics and capabilities among the participating nations. By providing an environment that encourages the discussion and development of multinational tactics, participants find the best way to gain full advantage of differing aircraft capabilities of the multinational forces' COMAOs.

During each course, a building-block approach is used to progress the crews through an average of 15 carefully structured sorties. These sorties are meant to challenge the participants to develop the tactical leadership skills necessary to plan, brief, fly, and debrief fully integrated, multinational formations. These 15 sorties belong to a syllabus extracted from the set of Core Roles and types of operations included in AJP 3.3. The average 26 assets that integrate each course specialize in one or several types of operations (mainly SEAD [Suppression of Enemy Air Defences], OCA [Offensive

Counter Air], DCA [Defensive Counter Air], APCLO [Air Power Contribution to Counter-Land Operations], ISR and C2). In each flying course, many combinations of these operations, even some effected through re-roles during the mission (dynamic cluster composition), are available through the syllabus execution.

TLP revolves around tactical leadership. Therefore, each sortie takes place in a highly dynamic tactical environment with a pre-defined specific mission task to be completed. A direct correlation between strength of language and communications skills of the participants and overall performance during the courses was observed. Once again, Nash's rule applies (see references to the Prisoner's Dilemma on Chapter 5), as the ability to complete a respective 'cooperative task' is proportional to the ability to communicate amongst the cooperating players.

8.4.2 TLP COMAOs prior to Link 16

For missions which predated Link 16, information exchange networks in the form of sequenced, supporting-

© TLP

Figure 4: The tactical scenario with multi-axis threat points of origin depicting force topologies associated to a multi-axis schema of manoeuvre throughout the battlespace based on weapons employment zones, factor ranges, sensor coverage and friendly activities supported, like CAS or Air Interdiction events. Different platforms' colours are related to their primary Core Role or type of operation. Red Air aircraft and GBAD systems are shown in red.

supported functions (triggered by a list of code words and other actionable information) were primarily established via voice, with the exception of limited data obtained through TACAN transmission and reception or other friendly locks, when available. As voice calls were insufficient to guarantee collision avoidance and prevent weapons interference among the members of the Blue team, prior editions of the BI-AC Regional Manual 80-06 included in the mission planning chapter pre-briefed airspace segregation features, such as BENO lines and altitude blocks, in order to ensure vertical and lateral de-confliction.

This classic formation schema was a good example of a limited network functioning at a 'Coordinated' level of C2 Maturity.[8] The syllabus normally limited and controlled the decision rights allocation, even though pilots often asked for higher level of delegation to enjoy more tactical flexibility. The network was voice-based; formation integrity rested on visual support and effective pre-mission synchronization. Changes to the formation were then associated to code words, but no alternative emergent motion policies were actually introduced as a derivative.

Each mission corresponded to a task cluster, as each of the COMAO members shared a common task at a 'Coordinated' Maturity Level. The associated communication topologies were basic, utilizing either a Bus or Tree topology that matched the formation physical

layout comprising consecutive nodes which perform a certain ingress-egress circuit, and a star topology for the C2 element, as it was usually the only TACON element.

Obviously, Axes 1 and 2 were the main references for task accomplishment and mission success. TLP participants built common awareness, communication skills, confidence, and knowledge about their different FSMs (mainly Tornados, F-16s, F-18s, Typhoons and Mirage 2000s), as each 2 or 4 ship formation of similar aircraft were dedicated to a specific role within the Blue team.

With the proliferation of swing role aircraft, the potential behavioural states increased giving the team more options to flex and swing from Role to Role. However, as analysed in the cross-generational 2 vs. 2 study, all of the actionable information and subsequent actions at COMAO level still relied on voice commands and voice information exchange.

8.4.3 The BOSS

The most remarkable step in interoperability within the TLP flying courses was taken when Link 16 was made available to all platforms and the entire force was integrated with the Battlefield Operations Support System (BOSS). The system permitted the construction of a fully linked force by integrating virtual tracks with real aircraft tracks within the battlespace. Furthermore, the decision-rights management (what level in the C2 structure certain decisions could be made) could be adapted by the instructors not only during mission design, but also dynamically during the mission execution, depending on the tactical process of the participants and the training objectives for the mission.

BOSS implementation in the framework of full Link 16 courses allowed the evaluators to have a clearer picture of both the real-world problem and the students' perception of the world to better evaluate tactical responses for each tactical context. In this process, the TLP instructors observed a change in the routing of information away from standard topologies (sender-receiver) into ones approaching more complex variants. The classic star, tree, ring, and bus topologies, regarding communication and related to the single ingress-egress axis motion policy depicted in Figure 3, began to show partial mesh connections among the participants, allowing for emergent, collaborative motion policies (see Figure 4).

8.4.4 TLP Airspace: The Tactical Depth

These full-datalink courses began in 2010–2011. As previously noted, TLP instructors simulated the Tactical Commander's role at both planning and execution levels in order to replicate the whole structure of the air battle, including the presence and management of airborne C2 assets, notional and real-life GBAD systems and notional and real-life Army, Navy, and Special Operations units, depending on mission profiles. Connectivity began to alter not only the basic tactics, but also the motion policy that the different platforms displayed in the wider airspace while they still maintained single altitude collision avoidance levels for safety and basic de-confliction.

The cause-consequence schema of every mission began to run faster, especially in those missions that presented higher gradients of tactical evolution and major state changes. That was the case in each of the Counter Surprise-Counter Aggression, Dynamic Targeting and the never easy No-Fly-Zone Enforcement missions. Each of these missions presents certain events leading to a chain of state changes and functional adaptation. These events may consist of an airspace violation, an aggression in the form of hostile intent and/or acts, an operational phase change or, among others, a political position by NATO leadership which leads to the development of NATO ROE.

Except in cases where conventional scenarios demand a clear display of friendly GBAD or the standard FLOT/FEBA geometry, the new tactical ecosystem involved a superimposed blue and red integrated systems. This included random points of origin of ground-based or airborne threat, as well as a display of blue forces throughout the scenario battlespace.

The 'defence in depth' concept, useful when the COMAO tactical plan was based on a single or double ingress axis, had to be changed by the 'tactical depth,' as threat and mutual support against it is not based on an ingress or attack axis, but on the current sensor and weapon (integrated through the Link 16) tactical display during the battle. Based on emerging Link 16 tactics, the participants were able to change their defensive posture due to availability of friendly and enemy data and adopt 'sensor formations' which allowed a better, emergent distribution of activities.

After analysing the statistical trends at the unclassified level, an increase of nearly 70% for both indicators, Weapons Efficiency, and Kill-loss Ratio, was noted.

Figure 4, courtesy of TLP, shows the motion policy adopted by the participants in such circumstances. The multiple points of origin of ground-based and airborne red forces and the subsequent sidestep manoeuvres supported by a peer-to-peer IADS forced blue platforms to complete their offensive and defensive displays based on shared situational awareness through data transfer. Observe that the single axis formation displayed in Figure 3 is now depicted by a multi-axis schema of manoeuvre throughout the battlespace in Figure 4, based on weapons employment zones, factor ranges, sensor coverage and friendly activities supported, like CAS or Air Interdiction events.

A closer look at a specific CSAR (Combat Search and Rescue) profile (Figure 5 and Figure 6) shows a high-density operations area. This high-density, time-sensitive CSAR profile is seldom flown by a multinational force composed of dissimilar platforms and is more commonly related to the HIDACZ-type ACM used in large scale Amphibious Operations, where intensive training and extensive voice coordination is the vehicle for TACON and air operations coordination. Slow mover protection, Close Air Support, SEAD, DCA, ISR, HVAAP [High Value Asset Protection], EW, and other types of operations may be orchestrated within and beyond visual range, and the state changes required to mix up all these roles are highly time-compressed.

The conflicts appearing in such scenarios, difficult to train to and difficult to manage in this multinational environment, are multiple. Clear Avenue of Fire (CAF), real-time identification, collision avoidance, pop-up threats (surface-based and airborne), and other potential undesired interactions (either with other Blue or Red assets) are often solved through a common code with higher data transfer involvement.

In accordance with TLP instructors' opinions and many course critiques filled by the TLP participants, the Link protocol made possible a great improvement in situational awareness and results in the CSAR syllabus mission, considered the most complex scenario due to the amount of synchronized activities in concert. Link 16 provides a real-time tool which incorporates not only situational awareness for the force, but also potential self-synchronization capabilities regarding commit criteria, delouse options, AMR considerations and, overall, environmental changes driving the mission.

8.4.5 TLP Statistics

The authors visited the TLP on two occasions trying to obtain tangible metrics to reconstruct trends and results and to obtain numeric results that demonstrated these strong evidences. The TLP Flying Branch has been collecting and processing statistics since 2005 for participants' awareness. These statistics compare the trends of the different courses, missions and platforms with and without Link 16.

Nevertheless, even though the syllabus has remained more or less constant and the participant aircraft have maintained a similar proportion (in force composition by Core Roles) the results are not as accurate (as linear) as the RAND results for the following reasons:

• RED AIR: Some courses allocated a higher level of Red Air assets than others. Even if the Syllabus has a standard profile and a certain weapon and sensor simulation for all Red platforms, a mission may have been flown against different Red Air platforms, such as an Alpha Jet force during one course but against F-16 Block 52 the following course. This disparity results, in the latter case, in a tangible result favouring Red.
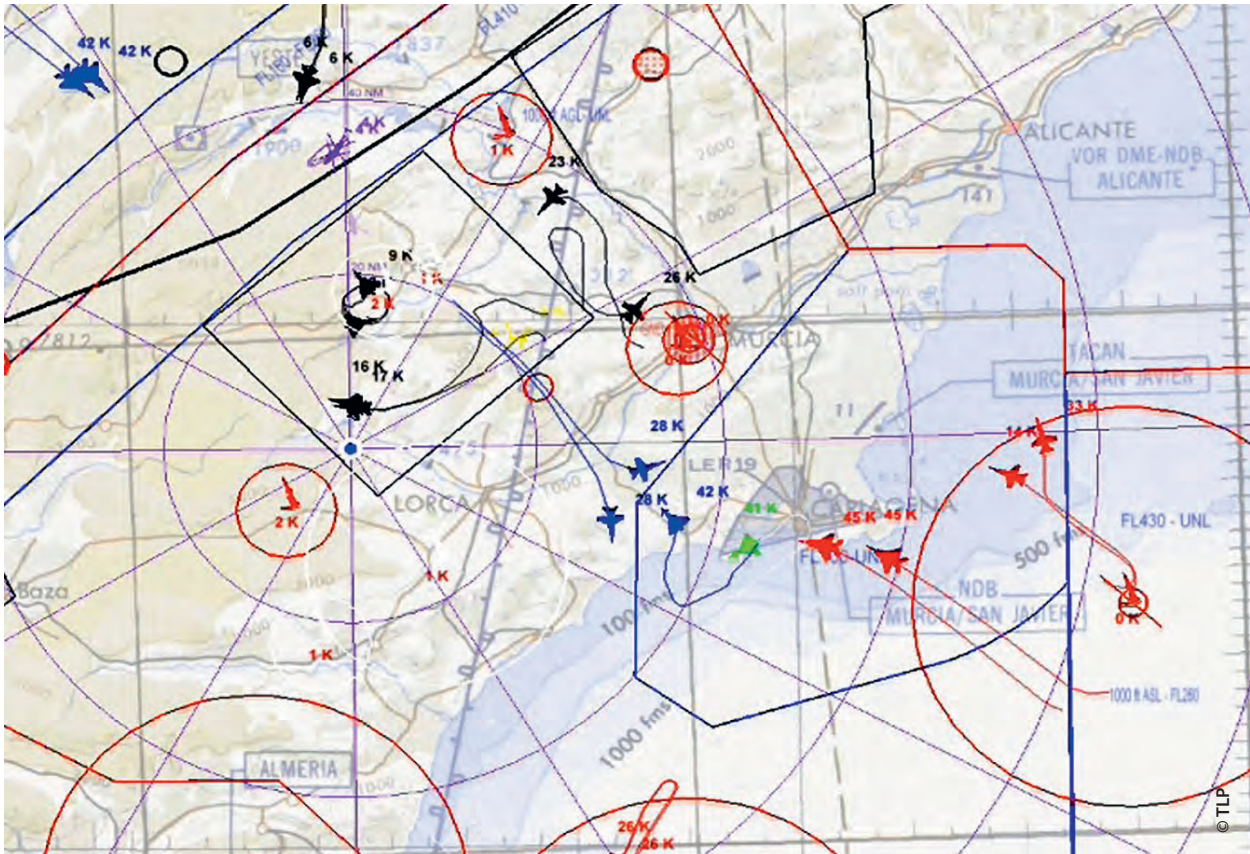
Figure 5: TLP's CSAR Scenario. Mission complexity forces high-density areas (CAS ROZ) with multiple, dissimilar platforms sharing a small portion of the battlespace. Communications and coordination relay fundamentally in advanced training and data transfer protocols.

In addition, on many occasions Red Air was provided by the host nation and briefings transmitted without a proper face-to-face session; meaning without having the advantage of sharing the whole mission development with Red Air as when they are in place. Different tactical behaviours were therefore observed, and results differed from the expected trends for that given mission. Finally, even though red shot validation was performed by TLP instructors, different Red Air shot doctrines were observed from the different platforms and nationalities, altering the final Kill-loss ratios.

• MISSION RE-ROLE: In some courses, lack of Red Air assets was solved by utilizing aircraft planned to be Blue assets instead as Red assets for a specific mission, altering the pattern regarding prior courses.

• PACKAGE POSITION: Statistics affecting different platforms are not taken into account. Some platforms, due to their package position, accumulate certain results regarding lethality or vulnerability that do not reflect a linear trend. Furthermore, Air-to-Ground results are excluded as they are dependent upon the type of Precision Guided Munitions (PGM) employed.

• METHODOLOGY CHANGE: At certain dates, slight changes in the methodology employed to calculate efficiency values were observed.

• THE 'EVOLUTION EFFECT': This refers to the initial disadvantage of the Link 16 aircraft, as their crews had to get the initial experience and skills through training to maximize results.
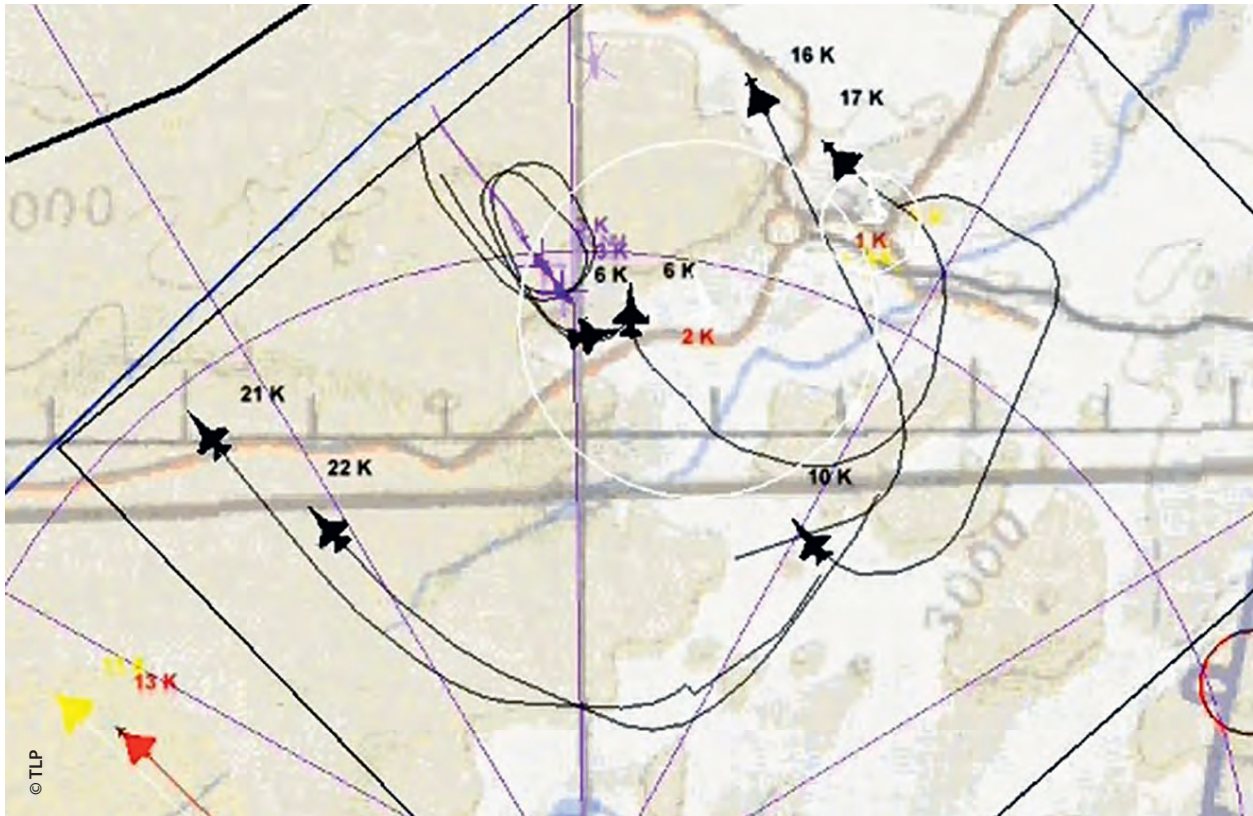
Figure 6: Further details of the CSAR pickup.

The only two values that made possible correlating TLP results with those obtained by RAND in their linear study were:

- Weapons efficiency:
  Number of shots to achieve a kill.
- Kill-loss ratio (Loss exchange ratio in the RAND study):
  Number of Red Air kills achieved for each Blue kill accounted.

The evidence collected, along with the different interviews with TLP instructors, strongly suggested that this increase in both indicators was a consequence of the Link community and its impact on shared situational awareness, which allowed for emergent and adaptive motion policies. Moreover, in the specific data obtained through segregating the same platforms' results with and without Link 16 when performing missions in the same role and package position, efficiency increased in a parallel value.

Nevertheless, other factors could not be ignored, and probably impacted these results in a minor way. These factors were mainly fewer airspace restrictions and new balances in air-to-air ordnance (AIM 120 C-5 and C-7 vs. AA-12 'Adder', PL-12 and Derby missiles).

Despite the fact that it is far from the 160 per cent RAND result in both accuracy and linearity, there are consistent and strong indicators confirming that improved communications process contributed to improved SA and led to higher lethality, lower vulnerability, and improved weapons efficiency.

Another collateral effect was included in the participants' course critiques; an increase in machine-to-machine communication, bypassing spoken language barriers, generated a positive impact in axis 2, as building up common trust was easier and faster than during courses without data linked aircraft.

8.5 Real World Applications

There are multiple, ongoing experiments to understand and measure the 'cloud performance'. Among other civilian applications, automated cars are beginning to show trends of improved (measured) performance.

Other plans and projects based on similar technologies aim to enable the 'command of the cloud' in the military environment. These military research lines must include the reins of command to synchronize these upgraded technologies with the classic military command decision-making processes.

Two of these are Australia's Plan Jericho and multi-national work on ALPHA AI. Australia's Plan Jericho is the first step toward joint construction of the concepts in Chapter 7. The Jericho project intends to generate a 5th generation Joint Force through inter-service platform integration in the same, shared C2 structure. The ALPHA AI program is the machine-to-machine extension of the derivative motion policy discussion in Chapters 3, 4, and 5. Alpha AI applies Artificial Intelligence (AI) to the management of an airborne force performing OCA.

8.5.1 Plan Jericho

As a single nation in the process of developing its air, maritime, and land components with new technology and new platforms, Australia is taking a unique

approach to future combat capability, which is well illustrated by the extensive library of articles published by Dr. Robbin Laird on Plan Jericho.

Leveraging the F-35A Lightning, the P-8A Poseidon, and EA F-18G Growler's ability to generate and provide information rapidly across a federated network, they hope to achieve a more cohesive, integrated Joint Force including maritime, air, and land forces. The key component of this study is the network itself and the ability to build a Joint Force from inter-connected disparate platforms to the benefit of the entire team. Although other nations are pursuing similar lines of effort, Plan Jericho is looking at simultaneously modernizing Air, Land and Sea elements with this overall vision in mind, advancing the entire team as a connected Joint Force, rather than figuring out how to make modern platforms 'backwards capable' as systems are developed independent from one another.

Plan Jericho will transform our Air Force for the information age. Exploiting new capabilities to their full potential will be the difference between being an Air Force with fifth generation aircraft, and being a fifth generation Air Force. We will work with Army and Navy to ensure we deliver a networked future Joint Force across the spectrum of air, space, electro-magnetic and cyber.

Air Marshal Leo Davies,
Chief of Australian Air Force

8.5.2 Alpha AI

As an extension of the prior sections of this Chapter and subsequent extrapolations on platform behaviour from improved network speed, Artificial Intelligence (AI), used to operate platforms, is under development in many nations. One interesting example that similarly demonstrates how machine-to-machine communication can operate air platforms at speeds surpassing an experienced human is realized through the Alpha AI program in the US.

Colonel Lee fighting against a virtual, AI-driven fighter force in the Psibernetix ALPHA AI simulator.

Psibernetix Corporation, in cooperation with the US Air Force Research Laboratory (AFRL), has developed the ALPHA program which is designed to increase 'autonomous capabilities to allow mixed combat teams of manned and unmanned air fighters to operate in highly contested environments'. Manned-Unmanned Autonomous Teaming in an air combat environment will certainly represent a revolutionary leap in capability of airpower in the near future. Air combat, as it is performed by human pilots today, is a highly dynamic application of aerospace physics, skill, art, and intuition to manoeuvre a fighter aircraft and missile against an adversary moving at high speeds in three dimensions … The selection and application of air-to-air tactics requires assessing a tactical advantage or disadvantage and reacting appropriately in microseconds. Future aircraft are likely to employ a high level of coordinated autonomous offensive and defensive capabilities, requiring reaction times, which surpass that of a human pilot, in order to survive in such hostile environments. ALPHA was assessed by an air combat subject matter expert: Colonel (retired) Gene 'Geno' Lee. As a former USAF Air Battle Manager, Mr. Lee is a United States Air Force Fighter Weapon School graduate and Adversary Tactics (Aggressor) Instructor, and has controlled or flown in thousands of air-to-air intercepts as a Ground Control Intercept officer, as a Mission Commander on AWACS, and in the cockpit of multiple fighter aircraft. Psibernetix and Geno worked together to develop tactics, techniques, and procedures to overcome ALPHA's payload and no-AWACS disadvantage, capitalize on blue's mistakes, and take advantage of numeric platform superiority (when the situation presented itself) [who was initially able to] easily defeat it. However, even after repeated attempts against ALPHA, not only could he not score a kill against it, he was shot out of the air every time after protracted engagements. He described ALPHA as 'the most aggressive, responsive, dynamic and credible AI (he's) seen to date'.

psibernetix.com

This is one avenue of research which parallels some of the conclusions of this study, especially an air-to-air engagement at near the Edge level of maturity. However, the Alpha comparison does have some limitations; the role of the command function is removed from that particular AI model, so the C2 maturity value is not exact, as ID and engagements require human management and command decisions are not clarified in the Alpha AI model.

However, it does offer an interesting parallel to theoretical behavioural models proposed by this study, especially in the construction of scenarios featuring a team of UCAVs traversing a battlespace and countering airborne and ground-based threats. These scenarios and today's potential for transformation through upgraded communication will be analysed in Part 4.

1. Lockie, Alex. 'The F-35 just proved it can take Russian or Chinese airspace without firing a shot'. Business Insider. Australia, Sep. 2016 [online] http://www.businessinsider.com.au/f-35-aegis-integration-2016-9 [15.09.2016].
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3. Gonzales et al. 'Network-Centric Operations Case Study. Air-to-Air Combat With and Without Link 16' [electronic publication] RAND. National Defence Research Institute, 2005: xv. Available at: http://www.rand.org/content/dam/rand/pubs/monographs/2005/RAND_MG268.pdf [04.05.2016].
4. TDMA is a mechanism by which communication time slots are digitally divided to permit multiple radios/systems/agents to simultaneously access a radio network.
5. Garstka et Al. Network Centric Operations Conceptual Framework. Office of Force Transformation. 2003. [electronic document] http://www.iwar.org.uk/rma/resources/ncw/ncw-conceptual-framework.pdf [04.05.2016].
6. Alberts and Garstka (2001) in RAND 2005: xvi.
7. Ibid. 2. p. 15.
8. Alberts et al. NATO NEC Maturity Model. Produced by the Centre for Advanced Concept and Technology, 2010. p. 55–57 [electronic document] Available at: http://www.dodccrp.org/files/N2C2M2_web_optimized.pdf [17.09.2015].
9. Etherington, Darrell. 'NHTSA's full final investigation into Tesla's Autopilot shows 40% crash rate reduction'. Techcrunch Digital Magazine. Jan. 2017. Available at: https://techcrunch.com/2017/01/19/nhtsas-full-final-investigation-into-teslas-autopilot-shows-40-crash-rate-reduction/ [23.01.17].

CHAPTER 9

Part III: Summary and Conclusions

9.1 Summary

Today, NATO Command and Control operates at a De-conflicted to Coordinated level, primarily to ensure safe integration of platforms with differing levels of technology into joint and combined missions. Furthermore, Tactical C2 is exerted primarily at Component level, thus segregating services' operations to avoid conflict, but hindering evolution towards the combat cloud and Best Available Weapon targeting.

Some specific technologies allow for higher degrees of automation through data transfer and proper interfaces. These communication features, which introduce new systems and technologies, open new possibilities for inter-service integration through data transfer.

As 5th generation fighters and future models of modern aircraft are procured, agility in the information domain with a potential for evolution in C2 will become paramount, not just across the Air component, but across the Joint Force and across the entire cloud.

In the future, motion policy and spatial constraints will be arranged and de-conflicted by machines through cueing commands or even through direct inputs to other (mainly unmanned) supporting assets' FCCs. The mission flow will then be adapted to the best orchestration of functions, and the platforms will present basic swarming capabilities from a qualitative perspective.

9.2 Conclusions

9.2.1 Overlapping Friendly and Adversary Airspace Presents a Complex Challenge to the Joint Force

An important challenge facing both the Joint Force Command and its respective Components is spatial

overlap with the potential adversary. A significant increase in weapon ranges and sophistication by near-peer military organizations has effectively compressed the available battlespace into one characterized by overlapping layered defensive systems.

This presents a spatial coordination problem for the Joint Force, which in turn, requires each Component to upgrade its C2 maturity level, leveraging improved connectivity to improve interoperability, in order to function with the agility and speed necessary to operate inside the adversary's threat envelope.

'The 5th Generation aircraft will enable the air combat cloud and allow me to use my legacy assets differently. Many of my 4th Gen fighters can be used to extend the network of linked systems providing reinforcing fires, and I can focus on the 5th Gen assets as the core nodes shaping distributed joint capabilities.'[1]

General Gilmary M. 'Mike' Hostage
in SLD Info, October 2016

9.2.2 Three Examples Demonstrate the Link between Improved Communication and Efficiency

At a maturity level of 'Coordinated', platforms show certain evolutionary characteristics that may be studied along certain constant profiles.

9.2.3 Storyline

A storyline was discussed regarding a standard 2 vs. 2 Air-to-Air intercept from the perspective of communication and the cause-consequence schemas observed during the motion policy of choice.

The selected behavioural features of different generations of platforms performing the same tactical profile reflected higher combat effectiveness and showed that improved communication improves the performance of the networked platforms in a remarkable manner.

9.2.4 RAND Study

The RAND case study was a linear analysis of the communicative intra-flight trends among F-15 4-ship formations executing a 4 vs. 4 with AWACS support.

In the Rand study case, the average force effectiveness increased by 160 %, directly attributable to the increase in SA provided to the pilot through LINK-16.

Significantly, it was noted that due to the level of available information (communication), pilot reaction times diminished, and offensive and defensive profiles emerged faster in the form of the most suitable motion policy and force (weapons and sensors) distribution.

9.2.5 TLP Upgraded Motion Policies

The third example analysed the upgraded motion policies adopted by the Tactical Leadership Programme's participants upon the incorporation of Link 16 fully-networked missions.

Where previously, communication between pilots and the C2 element had to be understood, correctly analysed, and processed to build coherent and complete situational awareness, datalink inherently facilitates these tasks by presenting relatively reliable, complete, and clear tactical situations in an already recognized display format. By presenting a comprehensive picture, datalink removes the importance of the pilot's linguistic performance, allowing the pilot to focus more on generating that mission-oriented bigger picture and managing the overall performance of the flight.

This facilitated the evolution of tactics and motion policies from classic ingress axis schema based on visual contact and mutual support, to multi-axis motion policies with tactical depth based on improved data from sensor formations. The same applies to any member of a formation as they are allowed (as demonstrated in the RAND case study) more time to concentrate on managing their own individual performance

while aiming for an overall increase in team efficiency and focusing more on the mission.

This was then further connected with the improved tactics emerging from the networked force. Furthermore, motion policies (spatial distribution of players in the battlespace) adopting a multi-axis tactical depth based on sensor formations evolved from the classic ingress axis tactics, where previously visual contact to achieve mutual support was necessary.

Even though the data contained too many variables to support a linear extrapolation, solid evidence was obtained reflecting an increase in weapons effectiveness and kill-loss ratio correlating to the Link 16 implementation at the TLP courses.

The logical derivation from these statistics and findings is that improved communications has led to improved pilot SA, which alters the evolution from one state to the next, resulting in a more efficient execution of the mission flow. Extrapolation informs that when a future network further improves SA across the force, another evolutionary jump in behaviour is likely.

As we move forward, this study finds that the information flow itself is the critical path enabling improved C2 maturity. Furthermore, any future network environment will only be as strong as the agents' ability to join and participate in the network. Therefore as NATO moves forward beyond 5th generation aircraft development, there will be an enduring requirement to integrate for the newest technology into legacy platforms. This requires more than just 'buying the latest hardware', it also requires upgrading legacy systems to ensure compatibility with newer technology as well as ensuring new technology is engineered with a level of backwards compatibility in mind.

9.3 Real World Plans and Projects Are Demonstrating this Study's Conclusions Derived from the Three Prior Examples

Plan Jericho and ALPHA AI are real world applications of the case studies and demonstrate evolution of C2 Maturity toward the 'Collaborative' level. In fact, ALPHA AI, when viewed against the conclusions of the 2 vs. 2 case, auto analyses at machine speed each of the turnstile pre-conditions, showing the effectiveness of communications efficiency. All of the 'language' and code words of APP-7 are now coded into the AI, improving both speed of the formation and the efficiency of the subsequent resultant motion policy. This shows ALPHA AI approaching the 'Edge C2' maturity level, except for the man in the loop still required for actual kinetic weapons employment.

As demonstrated in the real world examples, machine-to-machine speed allows improved speed of data transfer, with a much higher level of clarity compared to limitations of human speed (language or symbols, and other limitations as described in Part II).

1. Laird, Robbin: 'The Weapons Revolution Continues: MBDA Shapes a Way Ahead for Strike Platforms in the Kill Web'. SLD Info, Oct. 2016. [online] http://www.sldinfo.com/the-weapons-revolution-continues-mbda-shapes-a-way-ahead-for-strike-platforms-in-the-kill-web/ [09.10.2016].

Part IV

A Way Forward:
Prospective, Findings and Recommendations

'Using collaborative autonomy, CODE-enabled unmanned aircraft would find targets and engage them as appropriate under established rules of engagement, leverage nearby CODE-equipped systems with minimal supervision, and adapt to dynamic situations such as attrition of friendly forces or the emergence of unanticipated threats.'

Jean Lede, DARPA
Collaborative Operations in Denied Environment (CODE)

CHAPTER 10

The DyAS Concept: Dynamic Airspace Synchronization

In the future, the Joint Force will likely better exploit the air domain to generate effects. Today, efficient use of airspace is challenged by the limitations of connectivity and the desire to prevent fratricide. As future network development increases the level of C2 maturity, certain aspects (and the associated enablers) of the F2T2EA chain could be automated and executed at machine-to-machine speeds. The ability of computers to interface and interact across the network offers a new level of agility and opens the potential for multiple and disparate types of air platforms to simultaneously use the same airspace. These air platforms will likely be able to coordinate their multiple functions, including weapons and sensor employment, in real time while avoiding fratricide and maximizing mission accomplishment according to a pre-established set of priorities.

> *While providing a rudimentary text messaging collaboration capability, [today's airspace planning tools] lack the capability to present a common visualization and representation of data. Furthermore, they do not offer 3D collaboration or real time approval of airspace requests. Most AC2 functions are founded on a deliberate planning process and the procedures do not adapt well to time sensitive mission execution requirements – requirements which demand real-time changes to airspace, coordinated with all applicable airspace stakeholders in order to facilitate immediate approval.[1]*
>
> *Potts, Anthony and Kelton, James*
> *The Need for Dynamic Airspace Management in Coalition Operations*

10.1 A Future C2 Model

10.1.1 A Step Beyond in C2 Maturity: Power to the Edge

The previously mentioned Network Centric Operations Conceptual Framework has a doctrinal connection with the proposed C2 Maturity Model in terms of efficiency increase. Efficiency permits rational and optimal organization of the uncertain aspects of cause and effect once the force is committed. Different platforms, providing different functions across many different Air Power roles, having different readiness, training and standards, will have to share information, interact, and execute in accordance with the C2 architecture of choice.

The transition between the two highest levels in the maturity scale, 'Collaborative' and 'Edge', represents the step from formal coordination mechanisms to the emergence of self-synchronization through machine-to-machine local interaction. This local interaction may be assured via line of sight communications, but the redundancy and robustness of a communications gateway is necessary for a cluster's successful and dynamic adaptation to environmental changes. In order to transition from 'Collaborative' to 'Edge' (Alberts et al.[2]), the development of shared intent, awareness, and understanding must be available for the set of platforms through a main capability called 'power to the Edge'. This consists of 'a robust, secure, ubiquitous, interoperable, info-structure that extends to all participating entities (dynamic Information Exchange Requirements [IERs] on a need-to-share basis)'.[3]

10.2 The Platforms

The aggregation of different off-board capabilities within unrestricted battlespace may be considered a single entity as proposed in Chapter 3. As in the 2 vs. 2 storyline in Chapter 8, the actionable information fused in a MC from a certain number of sensors would be transmitted through the net to the most suitable platform to be decoded and analysed in the receivers' mission or fusion computers.

This study concurs with engineers at CLAEX (Centro Logístico de Armamento y Experimentación) who suggested to the authors during a meeting in Madrid in July 2016 that different platforms will have different information synchronization requirements. Not only will the machine language need to be converted and processed by different types of systems on different platforms, but certain platforms, due to hierarchy and mission roles, will have different levels of information requirements. The network must be able to filter the right level of information to the right platforms to best enable and empower self-synchronization across those platforms.

The shared information would then trigger an action, generate more actionable information for a third party platform, fall into the fusion engine for further correlation, or trigger an immediate reaction by the original platform if a threshold event was realized and the platform's state changed (see Chapter 4 discussion on Finite State Machines).

> *Coordinating by radio, the Apache crews also worked with other drones from small Scan Eagles and RQ-7 Shadows to far larger Predators and MQ-9 Reapers, another Predator derivative far larger and more heavily armed than the Grey Eagle or MQ-1. The Reaper typically carries four Hellfires and two 500-pound bombs.[4]*
>
> *Whittle, Richard*
> *MUM-T Is The Word For AH-64E: Helos Fly, Use Drones*

10.2.1 Manned & Unmanned

The set of dissimilar platforms may include the assimilation of both humans and machines. Regarding machines, automated (not autonomous) systems (robots) and humans can team to accomplish a task, self-synchronizing their mutual support in a shared space. Task-based construction of tactical options for these manned and unmanned teams has already been incorporated into Apache helicopters and various RPA platforms.

10.2.2 Automated vs. Autonomous

The difference between autonomous and automated systems must be understood. 'Automated' means the robot (or agent) behaves as a deterministic element of the team, like a turnstile (Chapter 4). This means the dynamic behaviour of a robot needs to be controlled and its trajectory, flight profile, force delivery and effect generation adjusted to meet the will and needs of the human tactical manager, even by negation when high degrees of automation are achieved.

In an automated system critical decision-making will always be in human hands or constrained to a decision set pre-defined by humans. The ethical dimension of lethal decision-making by machines, as outlined in Asimov's Three laws of Robotics and the respective legal consequences are discussed in the recently published JAPCC Project 'Future Unmanned System Technologies: Legal and Ethical Implications of Increasing Automation'. This study analyses, in depth, the limits of autonomous vehicles in military operations.[5]

In an autonomous system, the machine would develop its own will, 'becoming unpredictable and uncontrolled'.[6] Therefore, to preserve the Commander's role in the execution of Air Power activities, full autonomy involving decision rights should not be allocated to a machine. Robots may be allocated to platforms carrying weapons and/or sensors, or exist as weapons and sensors themselves. Their data, algorithms, corresponding practices and in general all interactions among hardware, software and data, should be examined through the brain Ethics[7] perspective.

Dynamic reallocation of every platform for optimal function or sub-function execution may be automated through code writing to enable the brain-to-brain and brain-to-fin communication concepts. The unmanned system's functional menu and spatial display may also be incorporated into the cluster, and the finite states of these unmanned systems could be administered by the battle manager or simply monitored when the environmental changes trigger state transitions.
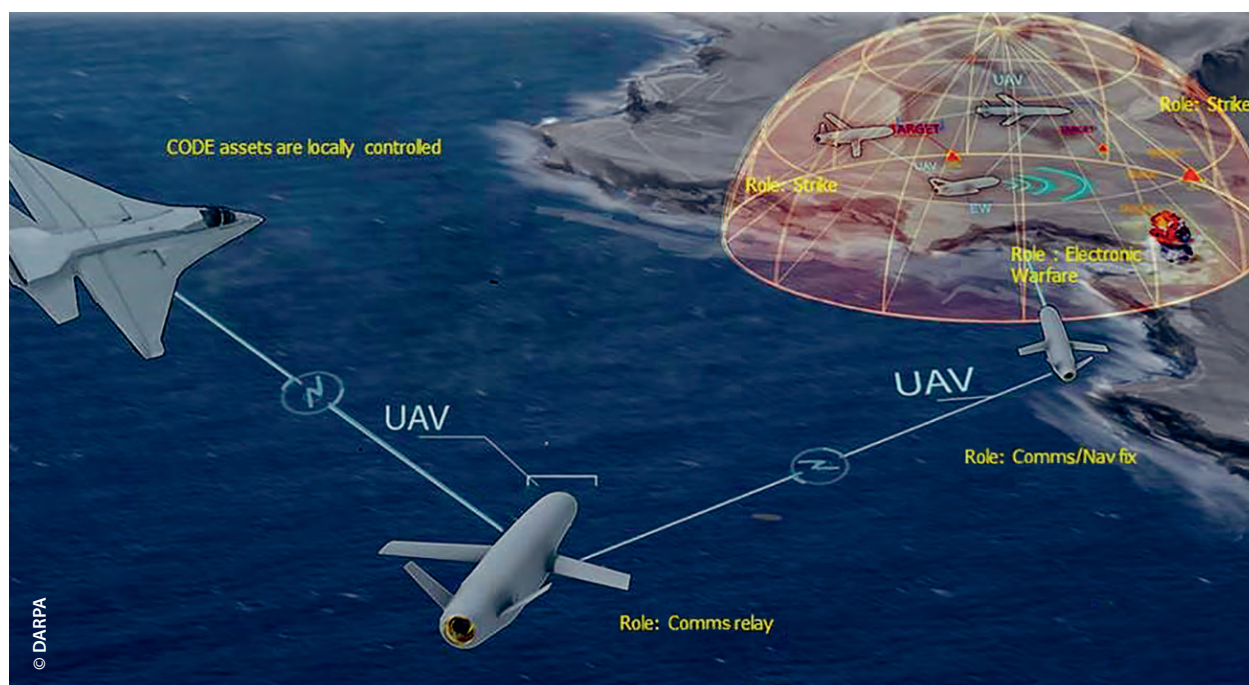

Figure 1: DARPA's Code Project.
Available at: https://www.darpa.mil/program/collaborative-operations-in-denied-environment

10.2.3 Legacy, Future & Robot Platforms

In a July 2014 article, Phil Linker states that 'unmanned aerial vehicles are at the forefront of an evolution'.[8] New elements and new agents may self-synchronize their performance (actions) based upon environmental state changes and upgrade their own functional states, as well as updating the cluster members' states by supplying actionable information.

The use of robots as deterministic combatants will open new possibilities, not only in the field of battle. Automatic features, like 3-D printing to obtain parts or other hardware are currently used to support logistic chains,[9] and will someday provide self-healing capabilities at platform or even at fleet level in the form of highly automated maintenance agents. The human presence in the loop is a topic currently analysed from many perspectives.

The options for increasing a cluster's performance are exponential. All joint community platforms in range, despite their generation, may be able to support each event dynamically, if connected and if code-compatible. New unmanned platforms will soon be ready to assume the riskiest profiles in support of various functions.

This concept is applied by the US's DARPA (Defence Advance Research Project Agency) regarding collaborative employment of UAS (Figure 1). The CODE Project (Collaborative Operations in Denied Environment) focuses 'on developing and demonstrating improvements in collaborative autonomy', thus allowing the capability of groups of UAS to work together under a single person's supervisory control. The unmanned vehicles would continuously evaluate their own states, environments, and present recommendations for co-ordinated UAS actions to a mission supervisor. The mission supervisor would then approve or disapprove such team actions and direct any mission changes.

Further unmanned solutions to support similar scenarios are under development in many other national agencies, most notably in missions for air operations support or air-to-ground roles such as Air-to-Air

Refuelling[10] or Attack.[11] Their convergence may be considered in the 2 vs. 2 storyline and associated mission profiles (see Chapter 8) to illustrate the impact of data transfer in the communication schema of the described air-to-air intercept. Soon RPAS/UAS will become fully integrated as a part of a Tactical C2 structure and move beyond off-boarding (third party) some sensors or weapons. Then, the platforms acting as task managers (a C2 asset, or even a tactical platform, using the RPA/UAS as an off-board capability) will be able to self-synchronize the unmanned vehicle to adjust the RPA/UAS motion policy to the optimal solution without jeopardizing the task.

The network will redefine itself following dynamic criteria. Offensive and defensive displays will self-synchronize contextually. Mutual support will be arranged through collective intelligence emerging from collaboration and prior experience. This can become possible if the 'problem space' is solved.

> *'The air environment (…) surrounds the globe and overlays the land and sea. Consequently, Air Power is inherently joint, as Air Power has decisive impact when orchestrated along with land, maritime, space and cyberspace power. Air Power is also pervasive, as aircraft are rarely physically constrained by national boundaries or terrain …'*
>
> *AJP 3.3 (B)*

10.3 Continuous Airspace

Game Theory was previously introduced as a method to frame examples of different topologies formed through the players' communication networks. Some games incorporate fixed spaces, like the basketball court or the chessboard.

Air Power has a particular advantage. Airspace is perhaps the most 'joint' of the battlespaces, as it is continuous and the domain itself is exploited by Maritime and Land Components, in addition to the traditional Air Component. When we picture or model the future

cloud, it does not adapt to a specific space, but distributes its effects through the 3-D physical region of interest and through the cyber domain.

Land and sea assets cannot normally transit each other's spaces. Coastlines mark severe boundaries for interoperability, even though data can be exchanged across this boundary. By contrast, air assets from any Component can overfly each of the other domains, thus interacting physically with all the elements involved and allowing for more flexible binary and multilateral interactions among subsets.

An example of this is seen upon examination of the Global Positioning System (GPS). This system supports all military sets (services) from the continuous Air & Space domain.

10.3.1 The Geometry of Today's Battlespaces

The Joint Force is able to use airspace to deliver effects and share awareness through information transfer without restrictions other than impermanence, limited payload, vulnerability (fragility and weather), and enemy opposition (per AJP 3.3 [B]). Local proximity of Air Power assets, with the sequential input of stimuli to the environment (adversary action) which results in a response (friendly action) and within the network, provide an example of the Air C2 term 'contiguity'.

Airspace is used as a continuous domain for communication, but not always for joint action of contiguous platforms. Today in NATO, when the Air Force subset is deployed, segregated airspace is traditionally utilized to de-conflict different platforms from different nations and services so their different abilities can be safely coordinated to execute common Air Power Functions. This means that platforms cannot group contiguously to form an organism-like cloud through bottom-up local interaction. This separation is necessary for safety within the limits of current technology, but effectively prevents an optimal topology from being formed.

Contemporary C2 utilizes an Airspace Control Order (ACO) to designate which spaces to activate when, for whom, and for what purpose (activity). It is similar to installing temporary fences in the air for de-confliction purposes.

The questions then become:

• How is the proper topology of assets positioned in a suitable region of the airspace (or battlespace)?

• How can we physically 'shape the cloud' in this segregated sky?

This process of developing guidelines for use of certain de-conflicted and coordinated airspace is currently referred to as Airspace Control Measures (ACMs). ACMs establish discreet 'lanes' or 'areas' of airspace (similar to those in the Voronoi example in Chapter 4, Figure 4) which serve to prevent conflicts among platforms and concurrent activities such as transiting, identification, fires, or manoeuvres.

Even though the airspace contained by each ACM works as a disjointed subset of the 'whole' airspace, the different ACMs can be spatially contiguous to other ACMs whether or not the activities in the segregated airspaces are contiguous regarding the sequential events within each boundary.

10.3.2 The Future Geometry of the Battlespaces

Looking to the future, it is likely that some aerial platforms will be able to interact without spatial boundaries. This concept is necessary if the platform of platforms is conceived as a single organism ranging the whole battlespace.

Furthermore, it is likely that these same elements or clusters of platforms will be able to send and receive data stating their support needs, or ability to provide support, to others without spatial caveats. This already happens within some datalink contexts, where mutual support among fighters is executed through so-called 'sensor formations'. In that context, sensors are federated so that a single sensor does the function for multiple platforms (Voronoi diagram as depicted in Figure 3 and Figure 4 of Chapter 4). Therefore,

dissimilar platforms will be able to form contextual, unique cause-consequence schemas through mutual, orchestrated support that do not require direct human management for some of the functions. Finally, their spatial distribution and their common awareness regarding manoeuvres, sensor positioning, weapons employment, and enemy activities will likely be highly automated, with human monitoring, in the same way the Navy executes via 'command by negation' (Chapter 7).

'A separate set of enhancements could prepare the [F-15] Eagle for an arguably more-important role as an airborne missile truck supporting the F-22. Boeing is developing a pod for the Air Force that helps F-15 and F-22 pilots communicate without breaking radio silence.'

David Axe
The National Interest, November 2015

10.3.3 Upgraded Quality through Local Communication

The redefinition of these cooperative local interactions among pairs or among reduced numbers of contiguous agents reconfigures their communication schemas and generates patterns of self-organization, all within the most complex and non-linear system. The third axis of the SAS 065 Panel/NEC Maturity Model, 'Distribution of Information Among Entities' will be the parameter of choice to analyse the evolution of swarming characteristics through data transfer, military C2 implications and its systemic impact. In the previous AMR example, improved communication in the form of more effective link protocols should increase effectiveness without adding fighters.

10.4 A Future Model

The open set topology was assimilated to a fluid battle-space in Chapters 5 and 6. A list of potential combinations of available capabilities and the potential to connect the elements' paths while maintaining a solid input-output relationship through changes was extrapolated to the continuous and desired structure of a dynamic and flexibly linked force. The three algebraic properties of Connectedness, Convergence, and Continuity were examined and assimilated to this fully connected cluster of platforms.

Hyper-connectivity (an increase in Axis 3 of the C2 model upgrading the system's maturity towards the 'Edge' level and enabling both brain-to-brain and brain-to-fin communication) will then permit the following:

Receivers and/or emitters may be either manned and unmanned vehicles, as data transfer can 'talk' MC-to-MC (Mission Computer to Mission Computer), or even MC-to-FCC (Mission Computer to Flight Control Computer) normally via the receivers MC. This last feature will allow subordinated motion policies within a hierarchy of platforms under human control and semi-automatic management, permitting:

- The selective employment of sensors, federating their use through the community, thus reducing tactical footprint or meeting fusion and correlation requirements as dictated per the Rules of Engagement. This is already a 5th generation systems feature.

- The automatic adoption of the most effective motion policy per contextual change, in order to update the supporting-supported functional schema of the cluster.

- The almost unrestricted ability for platforms to mark the environment through relevant data transfer, allowing Stigmergy to generate self-synchronization through the net, resulting in the generation of actionable information triggering the subsequent response action under human supervision.

10.4.1 The Space Invader's Paradox: How Spatial Conflict Is Solved

Classic '80s videogames, like 'Space Invaders (TM)' or 'Galaxian (TM),' featured Red Forces spatially allocated in 2-D formations fighting a single Blue spaceship. In
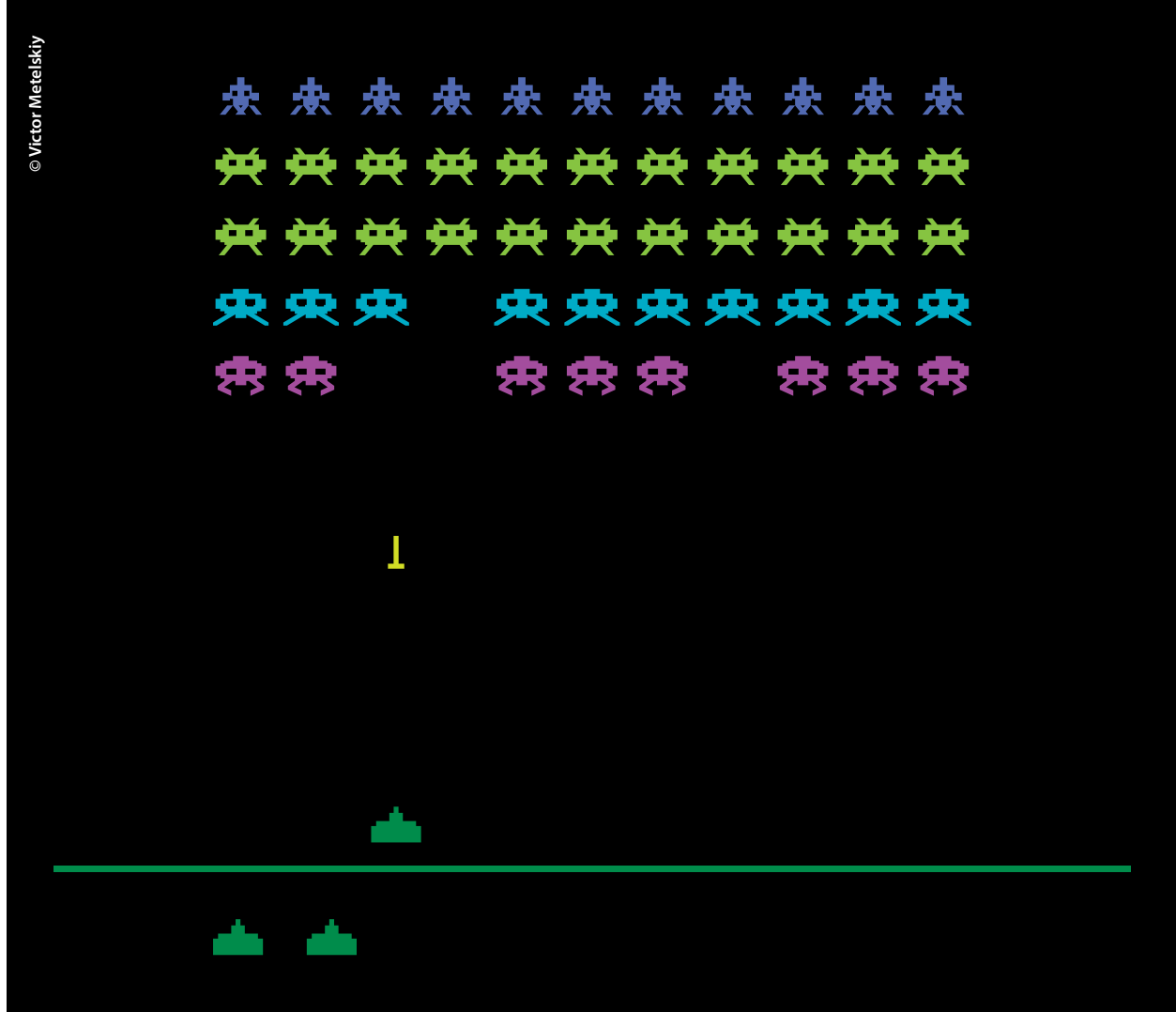
Retro style video game showing motion policy which demonstrates the Space Invaders paradox.

these imaginary battles, the platforms displayed two basic states: movement towards or relative to the Blue asset and weapons employment against it. Their relative Red-to-Red distance in most games never changed (symmetric agents), or in others only subtly changed when committing against the Blue player's ship in the 'Galaxian' game profile (low degree of platform asymmetry).

The good part of being a Space Invader was that you never crashed into another teammate (Space Invader). Moreover, they never killed each other, which was a paradox in such a small and congested screen, and where the maximum range of their weapons was higher than the screen boundaries. Therefore, as collision avoidance and Red-on-Red issues were automatically managed, the potential to empower every single platform in terms of situational awareness matches one of the conclusions of the RAND study in Chapter 8:

upgrading the wingman's decision-making capabilities through communication (Link 16 in the study) increases the efficiency of the force.

Other games (or movies such as 'Independence Day' or 'Star Wars') included forces flying collision-free profiles. Fratricide was eliminated, even though these fictional or software-generated platforms were operating within the same airspace boundaries.

The platforms included in these fictional films and games, and those included in the real world TLP missions, analysed in Chapter 8 as well as in recent publications and projects, like DARPA's OFFSET (Offensive Swarm-Enabled Tactics), must resolve certain common potential spatial conflicts while operating. This is especially difficult if these platforms are dissimilar and even more if they belong to different classes, generations or domains. These potential spatial conflicts are:

Space ships represent the 3-dimensional, 360-degree challenge of the future battlespace.

- collision;
- CAF or Clear Avenue of Fire pre- and post- target engagement (maximum range);
- Blue/Red blast avoidance (fragmentation pattern);
- undesired double targeting;
- non-targeted Red elements;
- maintaining the correct spatial distribution (order of battle per function) to sustain the desired AMR (Acceptable Merge Ratio including a Blue WEZ [Weapons Engagement Zone]-SEZ [Sensor Employment Zone] consideration) throughout the battlespace;
- loss of spatial bug-out options;
- loss of tactical depth;
- presence of 'Man in the Middle' threats within the cloud (associated to jamming techniques against the network).

Videogames solve the Blue-on-Blue or Red-on-Red dilemma (collision avoidance or weapons usage-related) by applying algorithms that allow for an adequate replication of realistic scenarios. In the simplest scenario, the 'Red replicates' do not collide and do not kill each other because the game maintains the Red community in a collision-free phase, thus solving the necessary contiguity demand the force needs to operate safely. The Space Invaders (or the less symmetric 'Galaxian' Red forces) are convergent in their mission objectives, they are software-connected for conflict-solving and they are continuous through all the regions of the screen, therefore they fight as an open set topology, featuring a platform of platforms.

> *'Teaming is where you might put a couple of different platforms and use them together to perform something. The loyal wingman concept will make an extension of the same aircraft.'*[12]
>
> *Brigadier General John Rauch*
> *Air Force Director of Intelligence,*
> *Surveillance and Reconnaissance,*
> *October 2016*

Extrapolating such virtual scenarios to a future networked battlespace, there are many options for mutualism among all these dissimilar platforms. Certain platforms may contextually seek a more aggressive WEZ, may be instructed to collide (a form of biological altruism for lower rank element-sacrifice; e.g. a pawn to save the queen) or have to maintain certain task-dependent separation or functional profiles with another platform (sensor and weapon-based).

Artists' depiction of congested civil airspace, with airliners sharing a common motion policy based on machine-to-machine communication executing their common task (transportation) in a collision-free environment.
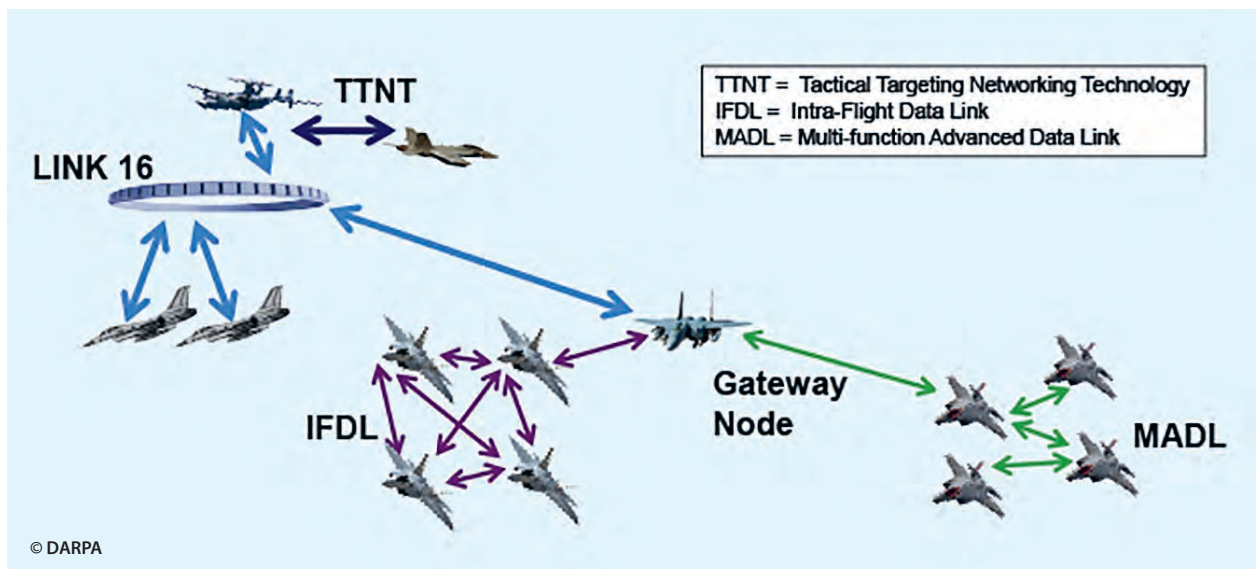

Figure 2: DARPA's Program: 'Advanced Airborne Networking Capabilities Sought for Hostile Environments'.

Eventually, the Alliance's networked environment will demand the nations' acceptance of their new control and semi-automated management position on the battlefield, which is one of the limitations detected in axes 1 and 2. Force generation processes will have to account for these asymmetric demands among different vehicle generations, and some nations may decline to perform the 'loyal wingman' or 'missile truck' role under the control and partial management of a 5th generation aircraft.[13] In other words, nations may be reluctant to supply forces to fill lower tactical positions within the 'platform of platforms'.

10.4.2 The Networked Environment Is Here

Obviously, each one of the aforementioned games are tied to a single processor linking these software-driven behaviours. During the research phase of this study, the authors determined many individuals and agencies have approached interoperability through data transfer and the associated networks as the key for immediate future developments regarding air operations. This DARPA recreation (Figure 2) of the architecture of an airborne network and its associated partial-mesh topology could be metaphorically compared to the screen of a game, where the common processor eliminates conflict among peers through providing situational awareness and signal compatibility to mark the environment through communication.

'When you infer an operational concept from the Tower of Babel story it requires a pre-definition of receipt and transmission from the best frequency-hopping software controlled radios, and a set of icons that are a universal subset of the combat fighting forces.'

Michael Wynne
Former Secretary of the US Air Force
AFA-Air & Space Conference, September 2014

Different aircraft generations, different radio frequency formats, different networks, different software, languages,

standards, and security challenges, are the 'Babel' threat the Alliance faces.

If disparate functional platforms are to be interconnected, not only for communication but also for action generation within the cluster, a hybrid/partial mesh topology for data transfer will support the overall motion policy and best available sensor/weapon selection as long as the tactical context demands that degree of maturity in the allocated force.

10.4.3 A Chess Network Example: Clusters Hierarchy in the Grid and Tempo Spatial Management

A common motion policy within the cluster, where real-time mutual support needs dictate motion policies in different platforms, demands clearly defined algorithms for motion profile-related decisions. This is mandatory for platforms in scenarios involving state changes affecting many agents simultaneously.

The example of certain subordinated chess figures attacking, defending or even sacrificing themselves for the collective is valid. The player adapts each movement, balancing the payoffs in term of the risk he or she is willing to assume for high value assets, or to the position of the king, queen, rooks, and bishops with respect to these subordinated players.

Imagine the standard chessboard as the battlespace and the 16 vs 16 pieces as the opposing clusters. Every piece exhibits certain characteristics. A cluster hierarchy must be established, taking into account contextual offensive and defensive variations that may affect the task. If chess pieces' value options are considered, the metrics assigned to a piece at the beginning of the game vary according to the tactical context, which reflects the current orders of battle of both players. If a pawn is considered the 'off-board' or third party platform of the queen or bishop for certain moves regarding a specific function (decoy, jam, engage), its value will adopt a different perspective and, therefore, its motion will be adapted accordingly to the overall cluster's motion policy. It would be ideal if the pawns automatically redistributed their positions to:

1. augment the threat to the other team;
2. dynamically open a spatial corridor for the queen to commit, when desired; and
3. automatically sacrifice itself in preservation of higher value pieces, if required.

Conversely, if the pawn is spatially and contextually in position to achieve the goals of the game (win by capturing the king), the pawn then automatically raises in value and the rest of the pieces become subordinate and supporting assets.

10.4.4 Operational Tempo

If chess was not a turn-based game, if all the pieces had on-board software, sensors and weapons and if there were black and white networks to connect them, both players could manage their pieces dynamically, minimizing human inputs. These are the fundamentals of a future, networked model. However, part of the mental effort to control all the potential movements in this perfect information game (all pieces are visible, everyone able to move any piece simultaneously) would have to be semi-automated, as it is relatively standardized in chess openings or classical chess defences. It is most likely the human manager would move the queen and the bishops, and the Tactical Command element would have allocated the decision rights regarding the king's security and the overall offensive strategy.

Manned and unmanned pawns, knights and rooks would adjust sensors, weapons, and motion to the context through the human management of the queen and the bishops and its command by negation prerogative. For instance, some pawn and knight movements would be automatically managed by the network in support of, or supported by, the man-induced queen or bishop movements. In addition, all would be orchestrated by a DSS in accordance with the natural and contextual hierarchy of the force. The advantage of the chess game is that the spatial neighbourhoods, the Voronoi diagram associated to each piece, is composed of 64 identical squares, so there is no 'problem space'.

The tempo of a chess game is dictated by the turn of the players, and it rewards the player's mental agility, as time is limited. Under a time constraint, the players must move sequentially in accordance with the game's rules. If the pieces were networked and the governing turn-based rule rescinded, upon moving the queen,

Scales of Power in Chess.

© pixabay

Example of a networked, multi-move turn of the game.

the bishop or the knight, other pieces, such as a pawn or even the king, would apply a self-defence policy (Retrograde) and move automatically as cued/steered through data transfer.

Standard openings, attacks or defences would be, to some extent, recommended by the network through proper code-writing, cueing the human player in the management of manned pieces (high degree of human management and higher hierarchy within the cluster [Brain-to-Brain]). This results in steering and engaging the unmanned pieces simultaneously through the network (human management, augmented mainly through automation with override options [e.g. Brain-to-Fin]).

Manned and unmanned proportions would be also tailored to each context. The auto-pawn option may be incorporated as sensor or weapon level, per the DARPA 'Gremlin' concept seen in Figure 6 of Chapter 4. The king's position, the queen's movements, and the tactical context recognized by the network would dynamically distribute the pieces, their mutual support, and their specific functions during combat. The allocation of decision rights would still remain with the human player. Each turn of the game would be

dictated not by a cycle of retribution or steps of a plan based on single movements, but on multiple movements orchestrated through automation. This would highly increase the tempo of the battle and force the opponent to a higher mental effort to understand the new context, as time remains constant.

Hierarchy would require new variable topologies to face the emergent tactical contexts. As different pieces would acquire different contextual value, Time-Division Multiple Access datalink solutions would migrate to Statistical Priority-Based Multiple Access or similar solutions. The contextual 'right to talk' and the level of executive orders that machines could launch or accept through the net relays would be under the supervision of the human communications traffic manager, especially the messages containing actionable information that demand kinetic actions. By maintaining tactical awareness of and command by negation options over all the automated flow of information, the team will maintain the non-deterministic aspect of the operations in the human side regardless of the level of automation and delegation.

All of these considerations dramatically increase the speed of tactical execution, which increases the operational tempo.

10.5 New Developments for a New Battlespace

Networked battlefields, like the networked chessboard of the prior example, may sustain new platforms' relationships, resulting in new, revolutionary functional topologies demanding new C2 architectures. Some of the new developments featuring these advanced machine-to-machine communication capabilities are MUM-T and DyNAMO.

10.5.1 The MUM-T Project: A Dynamic Tactical Hierarchy

Analysis of NATO doctrine (AJP 3.3 series and other tactical manuals) identifies dozens of functions related to air operations that may be exerted on the

© US Army

Manned and unmanned teaming between US Army Kiowa, Apache and an MQ-9 Predator during exercise Music 2011.

battlefield. Throughout this study, the authors have identified more than 40 potential functions linking both the OODA loop and the F2T2EA Kill chain.

In the chess example, the rules of the game establish the functional behaviour of each piece in the form of a distinctive single function or so-called 'manoeuvre'. Manoeuvre permits offensive and defensive options through pieces' induced contact. Nevertheless, in a more complex battlespace, the functional menu of the cluster members, in terms of potential state changes, is exponentially larger and linked to diverse exchanges of information among sensors and weapons.

A US Army-sponsored MUM-T-related line of research, followed a similar procedure by identifying:

• task categories (equivalent to roles and operations in this Air Warfare study);

• skills (verbs of action related to platforms);
• missions (types of operations).

The Army's Program Executive Office for Aviation's offices Project Manager's Unmanned Aircraft Systems, PM Armed Scout Helicopter and PM Apache have worked together with the goal to make the most capable, automated, lethal and interoperable systems available to our forward deployed Soldiers and our allies.

Manned Unmanned Systems Integration: Mission Accomplished, September 2016

All these elements were extracted from tactical doctrine regarding attack helicopters employment in ISR and Combat Support operations.

Busy sky. Airspace should be dynamically synchronized if all the traffic/weapons/sensors were conflicting/redundant in time, space and task.

The MUM-T study aims for the identification of critical (and optimal) topologies integrating manned and unmanned systems and establishes a correspondence among different tasks categories and associated skills.

A total of 25 skills were identified and rated in terms of training, performance, personnel, and equipment. Furthermore, and as discussed in the prior chess example, where different pieces had different values in different tactical contexts, the importance of each skill regarding mission success was converted to a 5-point scale, to reflect the contextual hierarchy of each skill within the mission, the training processes, and the factors affecting personnel and materiel. Redundancy in skills was filtered to avoid random hierarchical results.

Several tests and exercises have focused on this concept in recent years. On 16 September 2011, Program Executive Office for Aviation, or PEO, AVN sponsored the first ever Manned-Unmanned Systems Integration

Capability, or MUSIC, Exercise. The exercise was the largest demonstration of manned-unmanned interoperability ever attempted.[14]

These concepts and exercises led to optimal teaming solutions in terms of cluster formation, mission execution and emergent tactical contexts. Also, the contextual hierarchy of every team member, in terms of relevance of each tactical action through the execution of the tactical chain of events, is taken into account for a more flexible supported-supporting combination of assets and for a potential best available sensor or weapon policy within the cluster.

10.5.2 DyNAMO: A 3D Battlespace Network Architecture

DARPA is currently working on a project called 'Dynamic Network Adaptation for Mission Optimization' (DyNAMO). In this framework, DARPA solicits proposals

to enable manned and unmanned air systems to share information rapidly, securely, and automatically across diverse waveforms and networks despite adversary jamming.

DARPA's DyNAMO project is 'designed to pick up where C2E (Communication in Contested Environments) leaves off, ensuring that raw RF data successfully communicated between previously incompatible airborne systems is not only conveyed but also translated into information that all the systems can understand and process, whether that information relates to time-sensitive collaborative targeting, imagery, or networked weapons'.[17]

A functioning spatial network has to sustain each of the different components of the multinational force's communication requirements. DARPA's DyNAMO project aims to analyse information sharing with different types of manned and unmanned systems through developing technology that dynamically adapts networks to enable instantaneous free flow of information among all airborne systems, at the appropriate security level and in the face of active jamming by an adversary.[15, 16]

This concept approaches the 'problem space' and its implicit conflicts referring to collision, weapons, sensors, and common motion. The choices of sensors, weapons, and motion policies would be adapted dynamically to the tactical context, overseen by a manager. Mutual support across the different Air Power core roles and types of operations, in the form of dynamically coupled functions, would be highly automated, based on the given hierarchies, and this Axis 3 improvement in maturity would generate the conditions for the force to be able to partially swarm.

10.6 Dynamic Airspace Synchronisation (DyAS)

The DyAS concept proposed by this study is a new way of looking at airspace management, more specifically platform operations inside the airspace. In a departure from today's rather rigorous mechanisms of assigning floors, ceilings and spatial boundaries to individual platforms or formations, this concept proposes that, due to the increased level of machine-to-machine communication, future platforms will be able to operate in the same airspace with the ability to self-synchronize not only motion policy but also sensor/weapons employment. This will permit co-use of the battlespace by a large number of platforms of varying design and performance capabilities, maximizing efficiency while still addressing the fratricide concerns which govern today's methods of 'segregation' and de-confliction.

Many spatial resources become critical during the execution of certain operations, especially if the cluster's motion policy is automated to some extent. It would be ideal to match and correlate all network participants for spatial ownership when a function is assigned within that certain space.

As previously discussed, today's methods of airspace segregation are necessary based on today's level of C2 maturity, which limits mission effectiveness. In the future, a volume of airspace related to a specific function would be shared in real time through data transfer by the whole cluster and adjusted via the common motion policy. This battlespace feature is already executed by the TAIS-DACT system in land operations through visual interfaces, but not at machine-to-machine level. The difference is future airspace segregation would be based on machine-to-machine communication, as the images of the segregated (per function) airspace are displayed on the DACT interface.

When robots (unmanned platforms) become part of the cluster, they can be directed not only by their remote operator, but also from the rest of the force (MC-to-FCC) for de-confliction, emergent actions and/or dynamic task completion. An agent whose status within the force's context (state change) demands a certain alteration of its motion policy will swarm with the rest of the agents to obtain and maintain spatial advantage. As a whole, their WEZs, SEZs,

and green sectors (safe areas into which to steer) would be orchestrated to achieve the maximum sensor efficiency, weapons lethality, and platform survivability.

However, stages of modern C2 operations necessary to construct a force able to operate under such 'Collaborative' to 'Edge' level of C2 requires a new school of thinking. Information and decisions, once adopted at the proper level, will flow through the fighting force to the most suitable sensor or weapon, where clusters and/or single entities are fluid and not necessarily spatially-segregated. The space for each function may be segregated in real time from the common battlespace through data transfer. But these spaces may be transmitted even as automated, actionable information for other players, like a mark in the shared environment involving avoidance or other steering options, and not only limited to the depiction in a tactical interface of the battlespace per each function's spatial needs.

As pilots consider altitude a resource to be husbanded (for sanctuaries or Joint Engagement Zones [JEZ] procedures), the available airspace must also be considered as a resource, especially when highly congested with Blue and Red players. An example of highly congested battlespace is represented by Blue and Red air forces operating over an area covered by both Blue and Red IADS, where manned and unmanned teaming of disparate platform types becomes an option. Particularly in the context of highly congested battlespace, a force performing distributed and dynamic operations must be able to transfer data at machine-to-machine speeds, reflecting not only each platform's
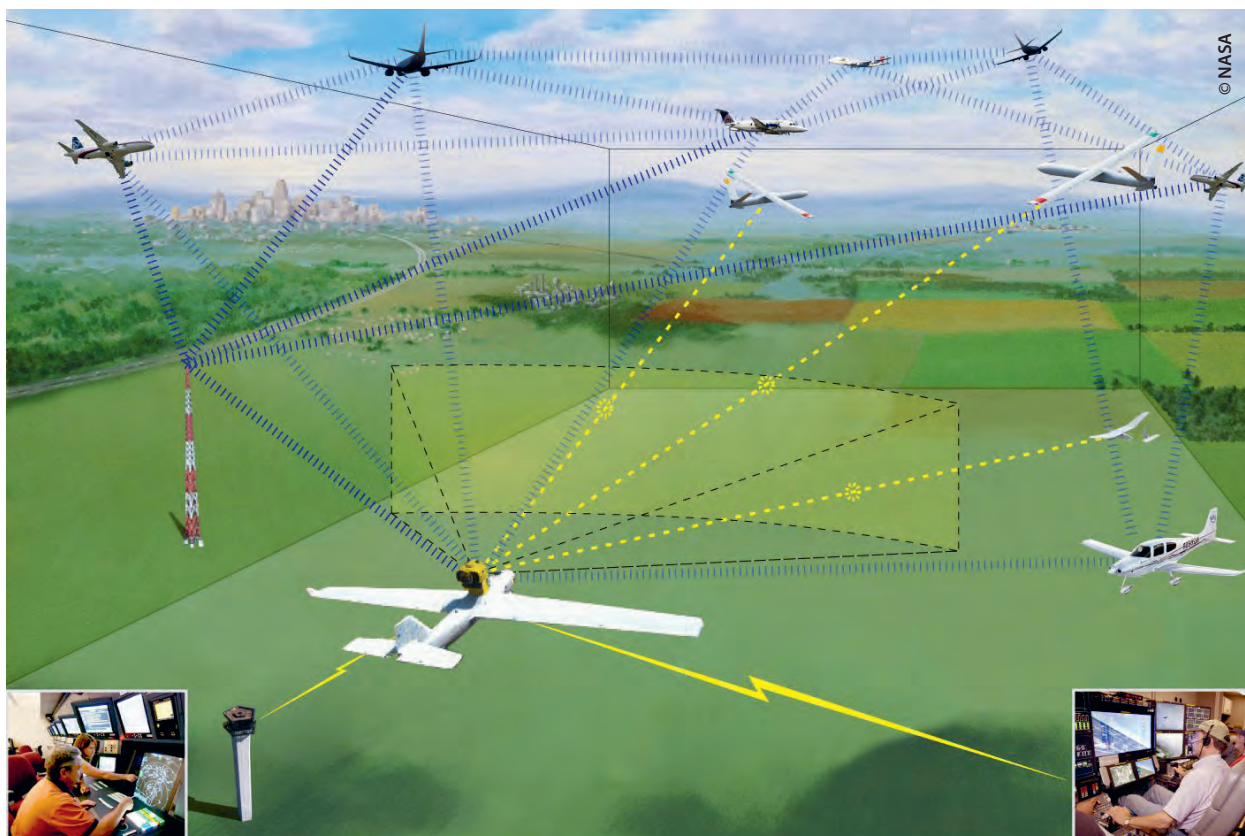
Unmanned Aircraft Systems Airspace Operations Challenge competition, sponsored by NASA, focuses on a variety emerging drone technologies but particularly the aircraft's ability to sense and avoid other air traffic. Hierarchical airspace segregation and common motion policies may be soon explored within the concept.

motion policy, but also offer cueing and/or steering within the cluster's hierarchy to match the cluster's tactical evolution (tasks of the other platforms and how those tasks impact use of the airspace).

10.6.1 Battlespace as a Resource: The Bourgeois Strategy

Evolutionary Game Theory is an application of Game Theory related to the evolution of animal populations when interacting with other species[18]. As the colony evolves, the agents adapt their competition profiles in search for equilibria. If that adaptation is successful with regard to the assigned task and promotes benefit for the colony, that strategy becomes an Evolutionary Stable Strategy (ESS). When assessing the TLP statistics, it becomes apparent that the motion policy 'sensor formation' adopted by certain data-linked aircraft at the Tactical Leadership Programme, in order to achieve better tactical depth, is a type of ESS. The Measures of Effectiveness (MoE) of this specific ESS are the Weapons Effectiveness and Kill Ratio variables analysed in Chapter 8.

The Bourgeois Strategy is one of the strategies that integrates Evolutionary Game Theory. It associates a certain resource with its ownership. Two competing entities will have to clarify ownership over that resource to incorporate it into their payoff matrix. 'Signalling,' or the sensorial expression in the form of actionable information given by a player, is the way in which some agents determine who owns the space around a resource.

Examples of this behaviour include individual male butterflies who defend sunlight patches on a first come-first serve basis for reproduction purposes, while the rest of the colony acknowledges this ownership.[19] Another example concerns bees that avoid double targeting or untargeted payoffs (missed flowers) when feeding or executing other functions around a flower.[20] Manufacturers are attempting to adapt this same type of interaction to unmanned automobiles.

Unmanned autos have the rudimentary capability to determine what space is available ahead in order to exert ownership over that 'resource space' once

pedestrians, other vehicles and other signals/stigmergic marks/threats to double use of space have been verified and accommodated

Communication solves the territorial dispute. Time and space conflicts among platforms that must be synchronized at the 'Collaborative' and 'Edge' levels of the Maturity C2 Model may only be solved through speed of data transfer and network capacity, especially when robots share the battlespace with manned systems.

10.6.2 Dynamic Airspace Today: Interfaces

Modern scenarios, current weapons, and sensors' ranges make it inevitable that friendly and enemy systems superimpose each other. Proliferation of platforms and proper identification of various players in the same battlespace is a significant challenge. The aforementioned spatial conflict, plus the identification required to eliminate ambiguities and convert the battle into a game of perfect information (which is an ideal case) requires, in some cases, spatial boundaries to submit to functional states of the different platforms.

Some software-based applications consider converting the resource 'space' into a complete information variable through data transfer and the proper interfaces. The Aero Glass Company has converted this concept of integrating spatial information into a visual display through an application, converting the airspace into a virtual 'chessboard' where the pieces and the relevant airspace (associated to a certain piece or just contextual airspace) can be seen.

If any spatial resource is altered (a restricted or dangerous area is contextually activated, or a platform changes its trajectory), the information is displayed in the form of dynamically built boundaries through different geometry.

This Aero Glass Company concept graphically solves the 'see and avoid' challenge between manned and unmanned vehicles when applied to networked environments. In a similar way, unmanned and manned cars will share 2-D spatial information for collision avoidance in the near future, not only based on proximity
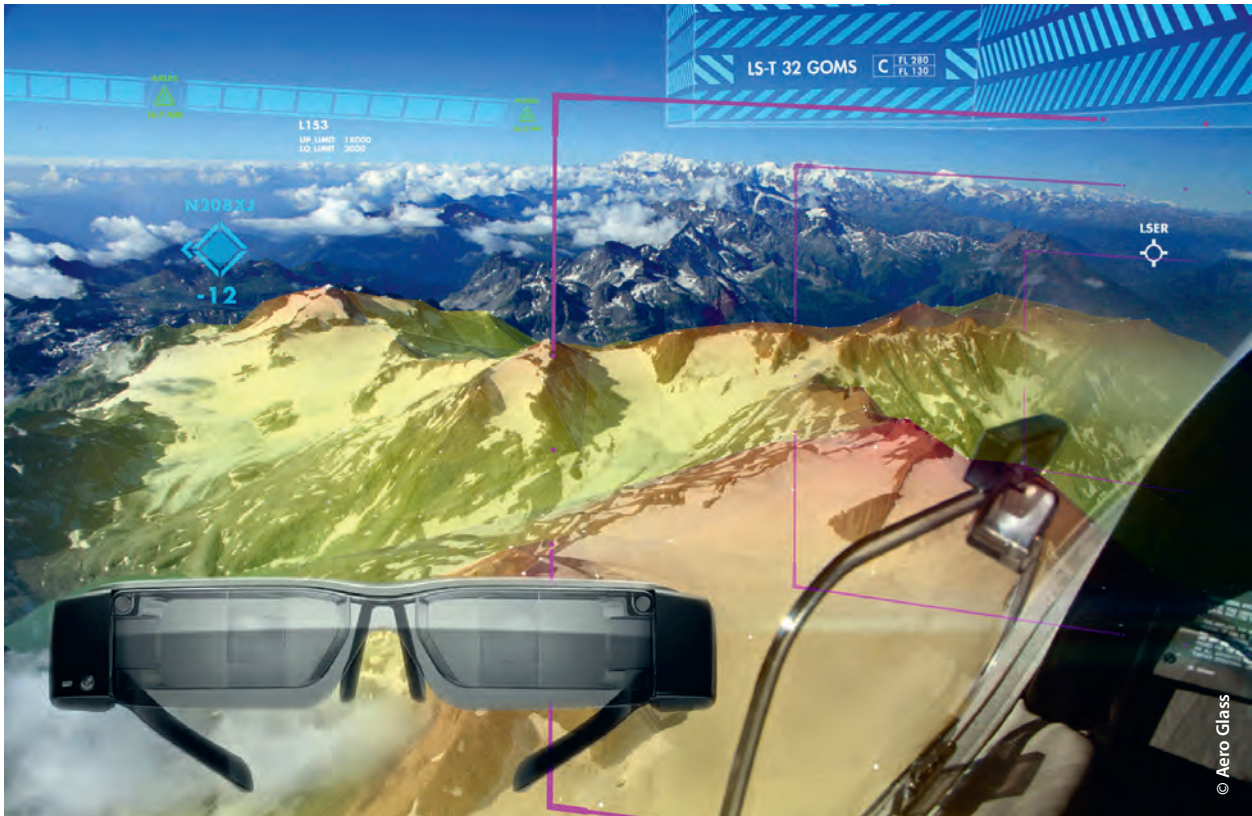
Aero Glass depiction of the boundary limits of active airways, traffic and heading display.
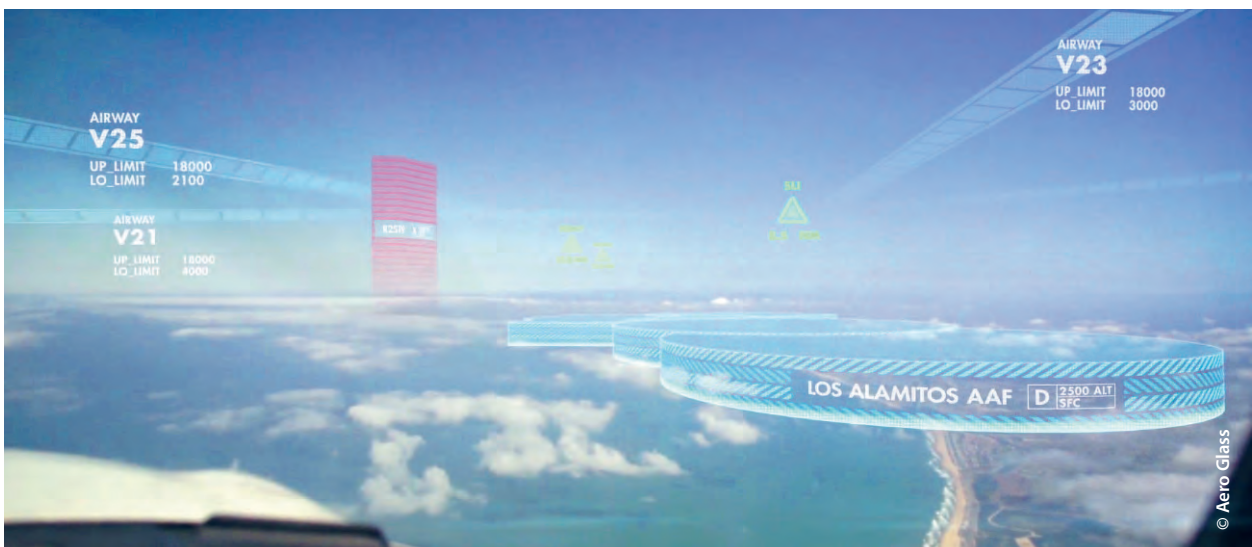
Aero Glass depiction of Class B and C airspace surrounding an active airfield. Note the display of other airways, relevant traffic and waypoints. This could easily be converted from ATC level of airspace information to include tactical information, such as (among others) ROZ, WEZ, MEZ, SEZ, and datalink track displays. Each mark in the environment would be generated by the platform taking ownership of that spatial resource, and validated by the force manager for the time necessary to display a specific function.

sensors, but also via a federated network hosting a robust BFT (Blue Force Tracker), redundant with a solid degree of data fusion for correlation purposes.

In the future battlespace, men and machines will share spatial awareness through interfaces. Battle Management Systems virtually recreate the fighting arena and the force distribution through it. Many BMSs incorporate decision-making support. They can also be connected to other real world elements (targets, areas, diverse platforms) through different sensors, as the Aero Glass solution features for aerial navigation. Interfaces will bridge human language and patterns of thinking with machine processes, as the HUDs and HMSs do in modern combat aircraft.

10.6.3 The Dynamic Airspace Synchronisation Concept: Functionality

The concept of Dynamic Airspace Synchronization is best expressed by an extrapolation and merging of the principles discussed above. The space associated to each function may be segregated in real time from the common battlespace through data transfer.

The Air Force recently unveiled a Small UAS Road Map, which among other things, calls for the increased use of smaller drones to accomplish missions now performed by larger ones. This includes initiatives to explore algorithms, which allow for swarms of mini-drones to perform a range of key ISR and combat functions without running into each other.

Brigadier General John Rauch, US Air Force, Director of Intelligence, Surveillance and Reconnaissance, October 2016, Interview with Scout Warrior

For example, the term 'danger close' is 'included in the call for fire when there are friendly troops or positions within a prescribed distance of the target.'[21] The 'danger close' bubble would be transmitted across the network by the Forward Air Controller (FAC) and converted to a 3-D visual display projected onto the aircraft HUD through a GUI (Graphical User Interface) like the afore-

mentioned Aero Glass glasses. CAS aircraft could also share the data through the Situational Awareness Display (SAD), the HMS, or even, for unmanned aircraft, directly to the MC's GPS-INS spatial input, to reduce the risk of fratricide. This is one of the goals of the DCAS (Digital Close Air Support) developments included in Chapter 7.

An attack would be automatically inhibited by an override function resident within the network (cognitive computing) if the Blue Force Tracker (BFT) was integrated and any blue track was to be within the graphic bubble, unless overridden by the agent with the proper decision authority. This agent will hold decision rights over battlespace ownership and/or function execution, depending on the Tactical battlefield management Functions (TBMFs) design and distribution. From basic collision avoidance to common orchestrated motion policy and fire coordination, Dynamic Airspace Synchronization solves these real-time collaborative needs. The airspace needed for each function within the already existing Core Roles would be automatically segregated and synchronized to the specific function's timeline once tasking is received and execution commenced. It would then be re-allocated once the function was concluded and the airspace no longer in use. A key component of this use of airspace is that it is limited in scope to only that which is needed. We are no longer talking about blocks of airspace with floors, ceilings and lateral limits segregated for large periods of time; rather an ellipse from shooter to target with the associate fragmentation pattern. This allows the airspace to go active after the missile is off the rails and then be returned to the force immediately after impact or 'time to go' completed. Furthermore, and similar to the SESAR-DAC/DMA concept, this airspace is dynamic, moving with both target and shooter, whereas current, older ACM models are static.

A further example of this concept is the classic JEZ (where the MEZ and the FEZ are collocated), where ground-based defences (missiles, radar guided AAA etc.) and fighter aircraft share the same battlespace, which becomes a limited resource for tactical action. If JEZ Operations were executed in the past, in terms

of C2 maturity the spatial conflicts mentioned before were solved through training (Axis 2) and mainly through identification procedures (IFF and Interrogator correlation). Nevertheless, if the radar of a Patriot battery or/and the F-35 Distributed Aperture System DAS becomes the best available sensor combination within a cluster, data transfer must increase awareness so other friendly assets tracking the same target do not penetrate the CAF sector, the blast area or the expected debris trajectory.

Data in the form of geometric representation of these 'spaces' plus the proper buffer can be replicated through the network in those platforms close to conflict with the target area. The choice of best available weapon may then become semi-automatic and force distribution may become more flexible. This concept can be extrapolated across any of the Air Power functions (or types of operations), from ISR to CAS to DCA, but is perhaps most advantageous in the complex airspace offered by the JEZ. Fighter and SAM allocators would base their coordination on their machine-to-machine mutualism in a given, shared battlespace.

10.6.4 Maritime Perspective on DyAS

This applies not only over land, but in the maritime environment as well. In this case, the SAM-capable ships and fighters must be able to effectively coordinate to execute the same DCA function. As it is envisioned that all platforms, ships and aircraft forming an IADS are participants in the network, it is further envisioned that a ship would be able to generate the same 'bubble' upon launching a SAM and provide network cueing to the DCA aircraft prior to execution.

10.6.5 Haptic Support to DyAS

One final extrapolation of this DyAS concept would be haptic processing between MC and FCC. In the event an aircraft were to be flown toward a SAM fragmentation bubble (impending fratricide), a haptic signal could be generated across the network to the pilots stick or seat or/and to the HUD or HMS in the form of a breakaway symbol, cueing a turn

Figure 3: Auto GCAS HUD image. Auto-GCAS Saves Unconscious F-16 Pilot – Declassified USAF Footage.

response (actionable information). In the event the pilot still does not turn away, the FCC could take over and command the aircraft out of the danger area (network-MC induced action) and return control to the pilot once the danger had past. This same principle was first incorporated, in a primitive form, in the Stuka bombers.

In case the pilots experienced a g-induced blackout, the automatic dive recovery system of the JU-87 Stuka would bypass the pilot's inputs and recover the aircraft's attitude. Today's electronic version of this mechanism is the F-16's Auto GCAS, or Automatic Ground Collision Avoidance System,[22] which automatically inputs the flight controls when a ground collision is imminent (see breakaway 'X' in Figure 3).

In a similar way, the network management system acts like the 'marking bee' executing its waggle dance-signalling manoeuvre in order to mark the environment with actionable information (cueing, steering) to other machines.

The impact of each specific function in the cluster's motion policy must be solved by this network management feature through:

- the hierarchical schema of the platforms;
- the mission profile for the Core Roles and types of operations in concert;
- the acceptable risk level based on a kill-loss ratio dynamic calculation;
- the desired spatial distribution for each tactical context;
- the information status of each platform;
- most importantly, the Commander's criteria, expressed through human managers in the C2 loop with proper override options.

10.6.6 A Functional Menu for DyAS Construction

Manual 80-06 (NR) includes 22 structure-related definitions related to the 'zone' concept, structures that integrate and define what Matthew Flintham poetically calls 'martial heavens'[23]. The most common ones are the FAOR, the Fighter or Missile Engagement Zones (FEZ-MEZ), the Desired Engagement Zone (DEZ) and the Restricted Operations Zone (ROZ).[24] Each zone is allocated to certain platforms and associated to certain specific air power functions. These functions and zones, related to the existing link between the OODA loop and the F2T2EA Kill Chain's structure, are the basic elements of the dynamic tactical management of the cluster through data transfer.

The manager will map the different functions present in the battlespace. The network will offer the best emergent (contextual) solution for a given task or emergent threat. In that case, the platforms will adopt the best motion policy according to the weapons/sensors and manoeuvre characteristics of the platforms involved, as well as the colony's spatial management (Voronoi cell arrangement).

Weapons' allocation is performed by a C2 element responsible for the selection of the best available weapon to complete the 'Target + Engage' phase. In a congested spatial environment, some sort of Bourgeois strategy must be adopted by the force, through data transfer, to ensure all F2T2EA related functions do not conflict. Pairing shooters to targets and de-conflicting the resultant sorting will become the result.

10.6.7 5th and 4th Generation Aircraft Interaction in DyAS

In the previous Patriot/F-35 example, these two platforms form a basic cluster. When the Patriot is selected to engage a threat by the TACON element, the airspace related to the shot (up to maximum range), the missile's actual and predicted trajectory, the impact, the blast and the debris, has to be provided to the F-35 sensor fusion engine to provide the pilot awareness and for tactical actions to avoid double targeting of the threat. It may also be re-broadcast from the 5th Generation aircraft, either directly, if that technical issue is resolved, or via a gateway node to the network, in a compatible format for other platforms in order to avoid fratricide.

Fifth generation aircraft incorporate multiple functions that can be augmented through simpler, cheaper, legacy off-board platforms. Multiple alternative FCAS projects from different nations are exploring incorporation of this concept. A manned manager, serving as the TACON node, could act as mission coordinator or even mission commander within a joint cluster. This node could monitor automated features affecting mission success, Command decisions, the execution of mission parameters under ROE and the contextual changes as the mission evolves. Proper functional distribution of the cluster's resources will dynamically change and will be re-distributed through the battlespace in accordance with the desired or the automated supported/supporting sequence while blue-on-blue conflict is avoided through the network.

10.7 DyAS Summary and Conclusions

Dynamic Airspace Synchronization is an evolutionary concept proposed by this study, which can be sequentially introduced through code writing as technology evolves, and which could entirely replace the methods by which airspace control is executed in a joint battlespace.

DyAS proposes the consideration of the battlespace as a resource that the networked platforms may synchronize through machine-to-machine data transfer.

By doing so, conflict and potential fratricide are reduced and weapons and sensors employment, optimized. Platforms would share information in accordance with a hierarchical and contextual schema, in the form of cueing and steering, targeting options, engagement orders, defensive and offensive manoeuvres, and path and obstacle avoidance, among others. Manned and unmanned vehicles would merge their tactical performance as the virtual and physical battlespaces would be correlated, with the Air Power Core Roles, operations and functions orchestrated and managed mainly by automated machine-to-machine communication. All of these features would always be under human supervision with override options. This flexible, automated supporting-supported relationship would increase situational awareness, tactical advantage and improve the operational tempo.

Effective DyAS is not possible today. However, with the advent of a future network that supports the maturity transition toward Edge C2, DyAS becomes a viable construct for future air operations.

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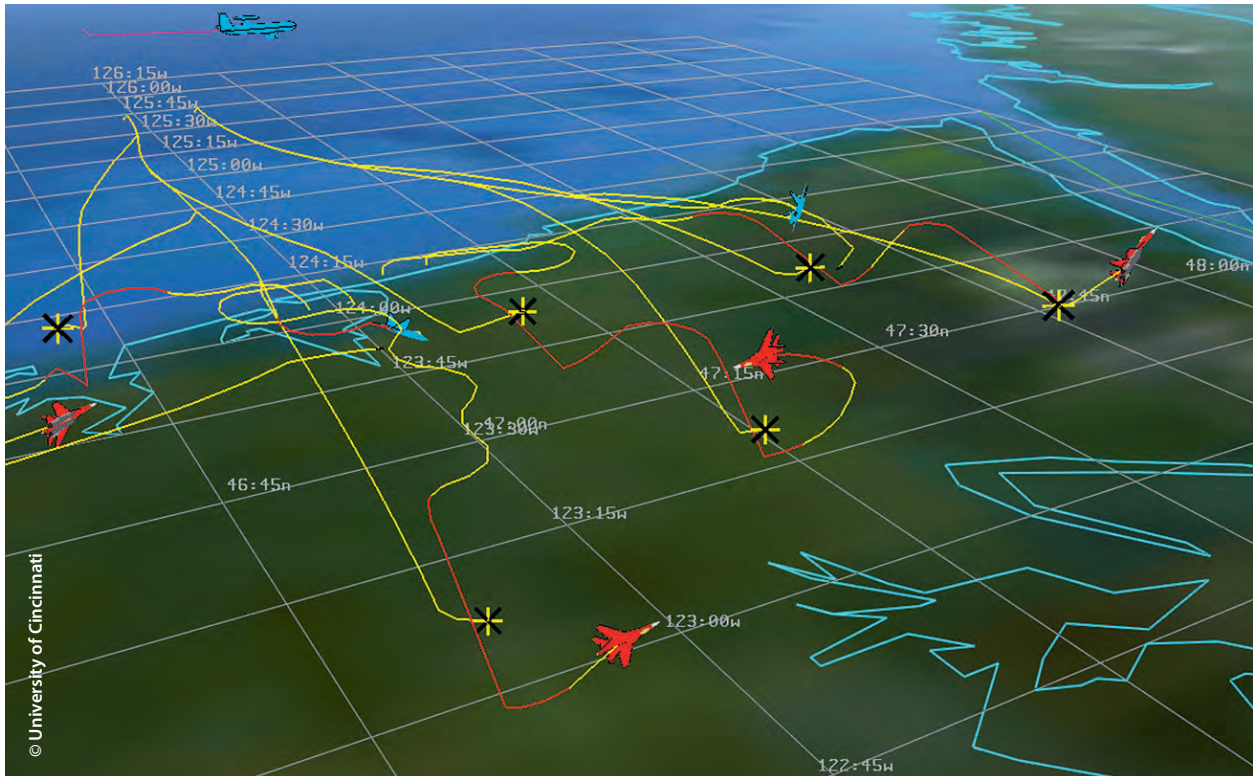
Psibernetix Alpha AI combat simulator pits manned against unmanned (AI) participants driven by air-to-air combat algorithms.

CHAPTER 11

Simulation and Experimentation of Air Warfare in a Networked Environment

11.1 Core Roles in a Simulator

Chapters 2–10 have laid the foundation for the thesis that Network-oriented C2 and future warfare functions exploiting the information domain will allow the Commander to dynamically reorganize the current functional and spatial distribution of Roles among aerial/joint platforms and expedite task accomplishment.

A key assessment in simulation to evaluate the DyAS concept will be a validation of the platform behaviour modelling at the Collaborative-to-Edge C2 level while

maintaining the role of the Commander and certain other decision rights, which may impact the behaviour, depending on the level at which those decisions rights are retained. It is also important to acknowledge that the types of operations and corresponding Core Roles simulated in each scenario will model different levels of automation, as more tangible ROE that govern some types of Air Power operations may limit associated automation. As an example, it will be easier to simulate and develop automated ISR than automated Attack platforms and concepts due to the doctrinal location of these Core Roles in the kill chain.

11.1.1 Core Roles Degree of Automation

The known part of these operations regarding future conflicts is supplied by the Core Roles, as the verbs affecting the desired effects in these future Air Power scenarios will remain constant. The unknown part is how communication among dissimilar platforms will

speed up the synchronization of these action verbs in continuous effecting sequences. Solving this question would contribute to the achievement of higher levels of integration.

Extrapolation from today's tactical management, current and common decision-making schemas and NATO unclassified doctrine suggest that:

1. Decisions regarding ISR and sensor employment/force distribution of sensors and enablers across the network may be delegated to the computers resident within the network to self-synchronize, including the orchestration of a common motion policy based on sensors' optimality.

2. Sorting and allocation of decisions regarding defensive response (examples include surface based missile engagement of hostile threat, reactive SEAD or other DCA functions) may also be delegated to the network, providing:

   a. Identification of friendly assets in the battlespace is assured;

   b. A proper firing algorithm is developed in accordance with ROE and certain sensor correlation demands to avoid ambiguities;

   c. The network, based on machine-to-machine communication and on the established hierarchy of platforms, is able to dynamically manage the airspace and a common motion policy per the DyAS concept;

   d. Engagement relies at least on human command by negation.

3. On-scene decisions regarding offensive actions (OCA, Strike etc.) must be retained by a human, whether airborne or resident at the (Joint or Tactical) Commander level:

   a. After the decision is made, the network may then assume a management function to synchronize and distribute platforms to best achieve the effect;

   b. A 'Negate' or 'Command Override' function must be resident within the system so an order may be rescinded if motion policy is not desired at certain levels of automation, when certain assets must return to direct human management for mission-associated reasons or prior to weapon release.

Under today's standard command structure, SEAD or ISR, for instance, may allow for more unmanned-automatic options than DCA or Air Power Contribution to Counter-Maritime Operations (APCMO) due to ID constraints, reactive and proactive profiles, required weaponeering solutions and other issues.

11.2 Computer–Assisted and Synthetic Simulations

This Section will review the different tools and techniques for computer-based and synthetic simulations incorporating the DyAS concept to the current doctrinal Air Power Core Roles. Advanced tactical simulation incorporates hyper-connectivity among cooperative agents, whose performance is scripted and then measured within the environment of the missions.[1]

11.2.1 AFSIM: A Multifunctional Simulation

Advanced Framework for Simulation, Integration and Modelling (AFSIM) is an engagement and mission level simulation environment originally developed by Boeing and now managed by the US Air Force. Modern simulation includes the 'element', 'agent' or 'entity' concept, in order to properly define interactions among each element's functions and skills within a dynamic, evolving tactical context.[2]

In AFSIM, the individual participant is referred to as a platform, which in some simulations is called an entity. Platforms (…) represent things such as aircraft, satellites, missiles, ships, submarines, ground vehicles, structures and life-forms. The platform contains communications, sensors and weapons systems, and information and decision-making systems. These systems are used to gather, process and disseminate information, make command decisions and carry out the commands.

Zeh et al. Advanced Framework for Simulation, Integration and Modeling (AFSIM) 2014
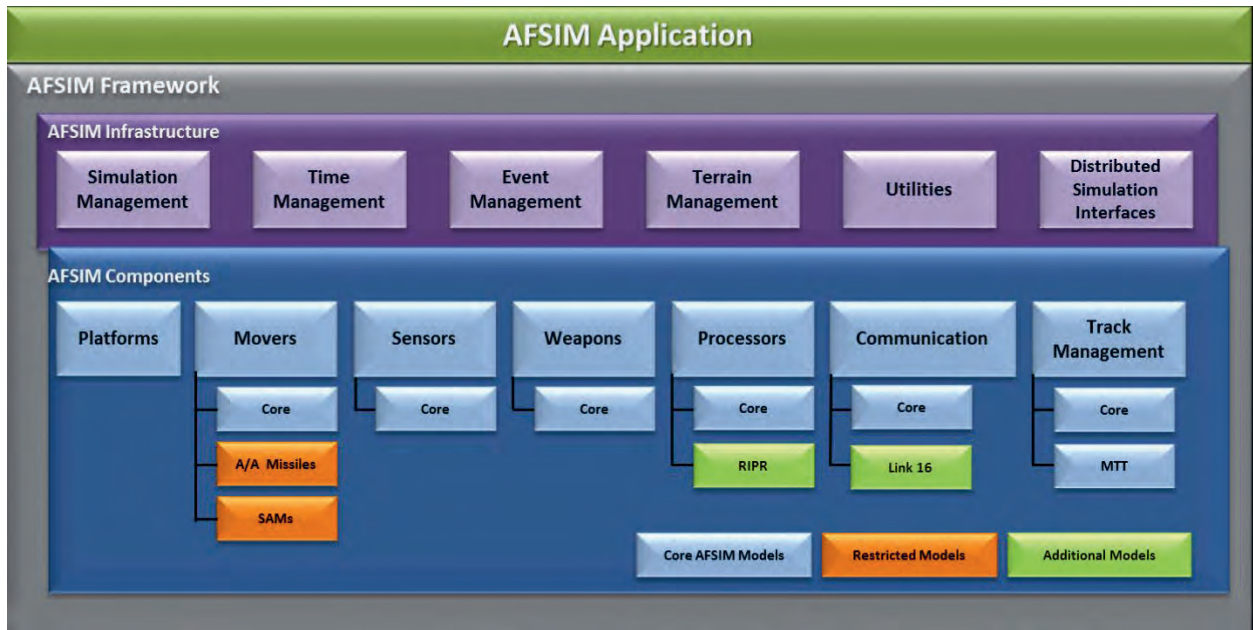
Figure 1: AFSIM Functional Architecture. Explains how platforms with different behavioural profiles may establish cooperative relationships within a synthetic environment simulation through shared perception.

These type of simulation environments may reproduce the DyAS concept, which demand the orchestration of different Core Roles within a fluid, continuous battlespace.

Some simulation solutions are already incorporating collaborative automation regarding platform allocation and task distribution: Multiple agents interacting within unrestricted, continuous battlespace may display complementary, coded behaviours as a result of the combination of their functions and skills (see Figure 1). AFSIM simulation includes behavioural trees connecting these contextual skills in certain ways so the platforms perform in certain orders or subsets. A command chain browser is also available within that specific, contextual cluster. Task generation is then related to task-asset pair evaluation and allocation algorithms. This method of operation allows for higher levels of automation, as cluster formation and sharing of organic resources are a result of the decision support matrixes embedded in the simulation model. A tool to visualize and geo-reference the simulated orchestration and interoperability of the selected

platforms, functions and variables for a given mission is provided in Figure 2.

AFSIM, managed by the US Air Force Research Laboratory[3] defines a functional architecture (Figure 1) whose associated data can be visualized for results in a scenario generator (Figure 2). The multifunctional force can be georeferenced and the potential cluster combinations, motion policies and synchronization options may be analysed and visualized in terms of convergence and continuity for a given threat.

11.3 Robots Experimentation and Spatial Behaviour

A recent Zurich University experiment[4] featured flying robots (quadcopters) executing ground search missions. The quadcopter provided guidance to mobile ground robots whose function was to remove obstacles or navigate around them, like a sort of C2 node and ISR enabler. Another current experiment developed by the SwarmLab at Maastricht University
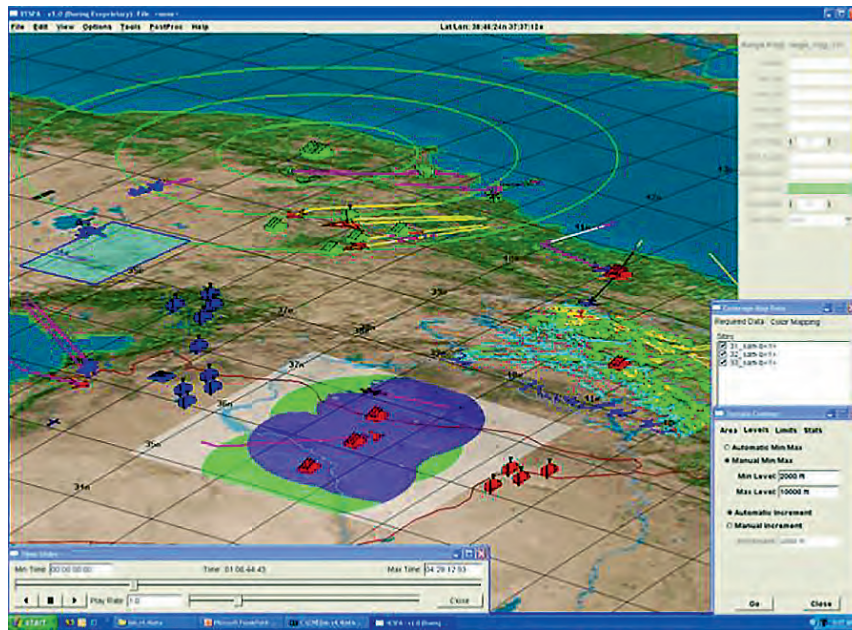
Figure 2: Visualization of objects positional time histories and other event information generated as output from any AFSIM-based application (http://worldcomp-proceedings.com/proc/p2015/CSC7058.pdf).

employs ground-based robots featuring spatially-targeted communication and self-assembly/re-organization capabilities. Once selected for a task, the ground robots would adopt the appropriate formation necessary to comply with the desired motion policy (i.e., complete the task).

Similar experiments have been reproduced to assess different machine-based activities, mainly focused on control for mobile sensor networks, behaviour of multi-agent dynamic systems and options for multi-robot spatial coverages. Multiple functional applications of self-synchronized agents were assessed through computer-assisted engineering simulations before attempting to reproduce those profiles with dissimilar robots accomplishing a multifunctional task.

Following these task-oriented experiments and finding the proper mission design, a computer-generated simulation can reproduce multifunctional tactical clusters and analyse potential self-synchronization among the different Core Roles. This simulation will be expanded upon by basic dissimilar robot experiments and followed by the proper synthetic environment to effectively visualize the concept, Dr. Scharre's approach to the Reconnaissance-Strike Network[5] describes the co-evolution of the ISR and Attack Core Roles in parallel to evolution of battle networks.

This field of laboratory experimentation with robots may already extend to current simulation results or to new concepts. The Alpha AI simulation environment successfully employs language-based algorithms to reach the optimal motion policy of various elements performing air-to-air BFM (Basic Fighter Manoeuvres) 'encompassing hundreds to thousands of variables'.[6] The air-to-air activity reproduced in this synthetic environment may first be extrapolated to diverse types of operations in concert, through further simulation of more complex scenarios; and second, to data linked robots sharing coherent platform conversations through the aforementioned language-based algorithms. The C2 portion, especially in regard to the allocation of human presence in all of the potential cluster's kill chains, must also be addressed through the empiric study of computer-assisted models.
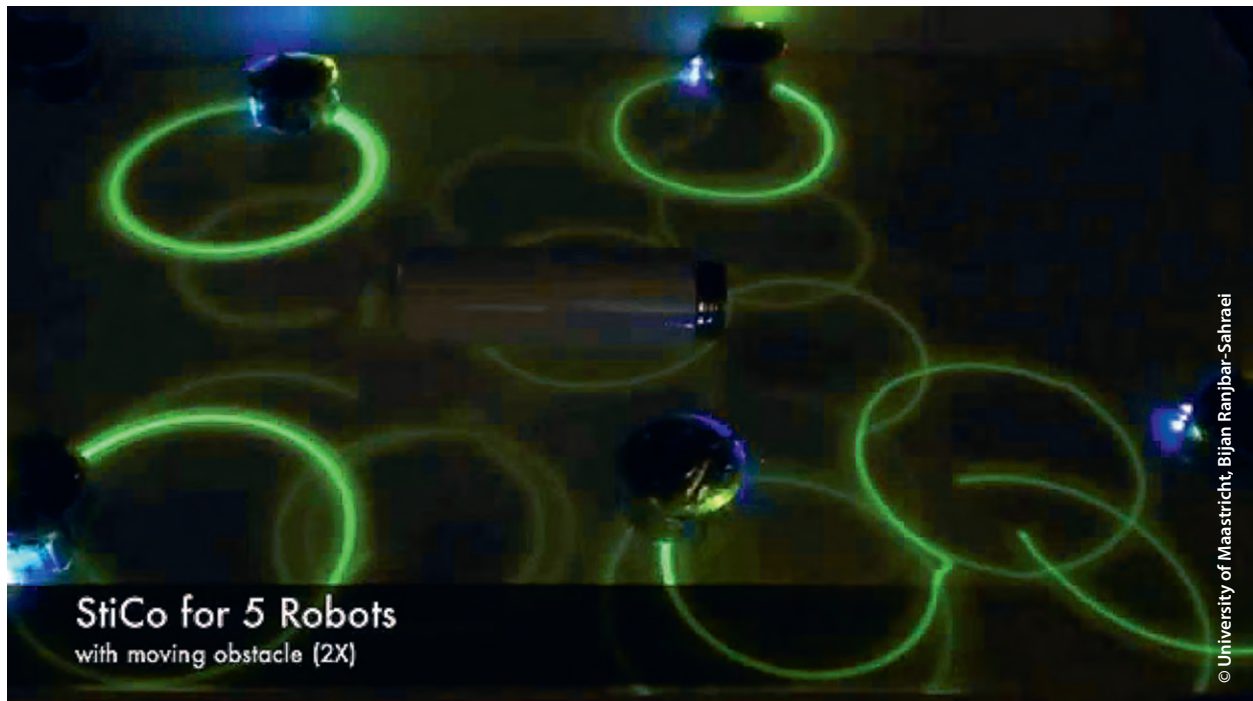
Figure 3: Stigmergic coverage experiment for 5 robots. (StiCo in Practice) Bijan Ranjbar-Sahraei. Swarmlab. University of Maastricht. December 2012. 'The video demonstrates the realization of StiCo approach through stigmergic communication. Neither direct robot-robot communication nor prior information about the environment is needed. The video illustrates robustness, scalability and simplicity of the algorithm.[7]

Computer-assisted or synthetic simulations are a useful step to anticipate and assess the performance of the actual platforms. The stigmergic coverage experiments (Chapter 4) have been successfully recreated (see Figure 3) with robots featuring constant angular speed, including cooperative reactions against intrusions within their spatial boundaries.

11.4 A Tactical, Core Role-Based Simulation

The computer-simulated mission depicted in Figure 4 introduces a functional swarm executing a mission where there is not any function-related spatial segregation among the platforms.

Working from the concept depicted by Figure 2's simulation, the type of operation of choice to exemplify the proposed DyAS simulation methodology is Combat Search and Rescue. CSAR was considered one of the most complex missions within the TLP Syllabus (see Chapter 8), so it permits the analysis of different topologies, hierarchies and supported-supporting schemas within the same mission framework.

11.4.1 The Mission

CSAR consists of missions with a certain degree of competition (in the form of emergent opposition) while performing a recovery. A SAR (no combat, no adversary) mission, like the one depicted in Figures 4 and 5, contains three principle successive tasks: Find, Extract and Recover being the profile of the bees collecting pollen and returning it to the hive. The event chain 'Find' and 'Rescue' is a similar task profile to some foraging options ('Find' and 'Eat') displayed by agents featuring Swarm Intelligence (SI). The SwarmLab at
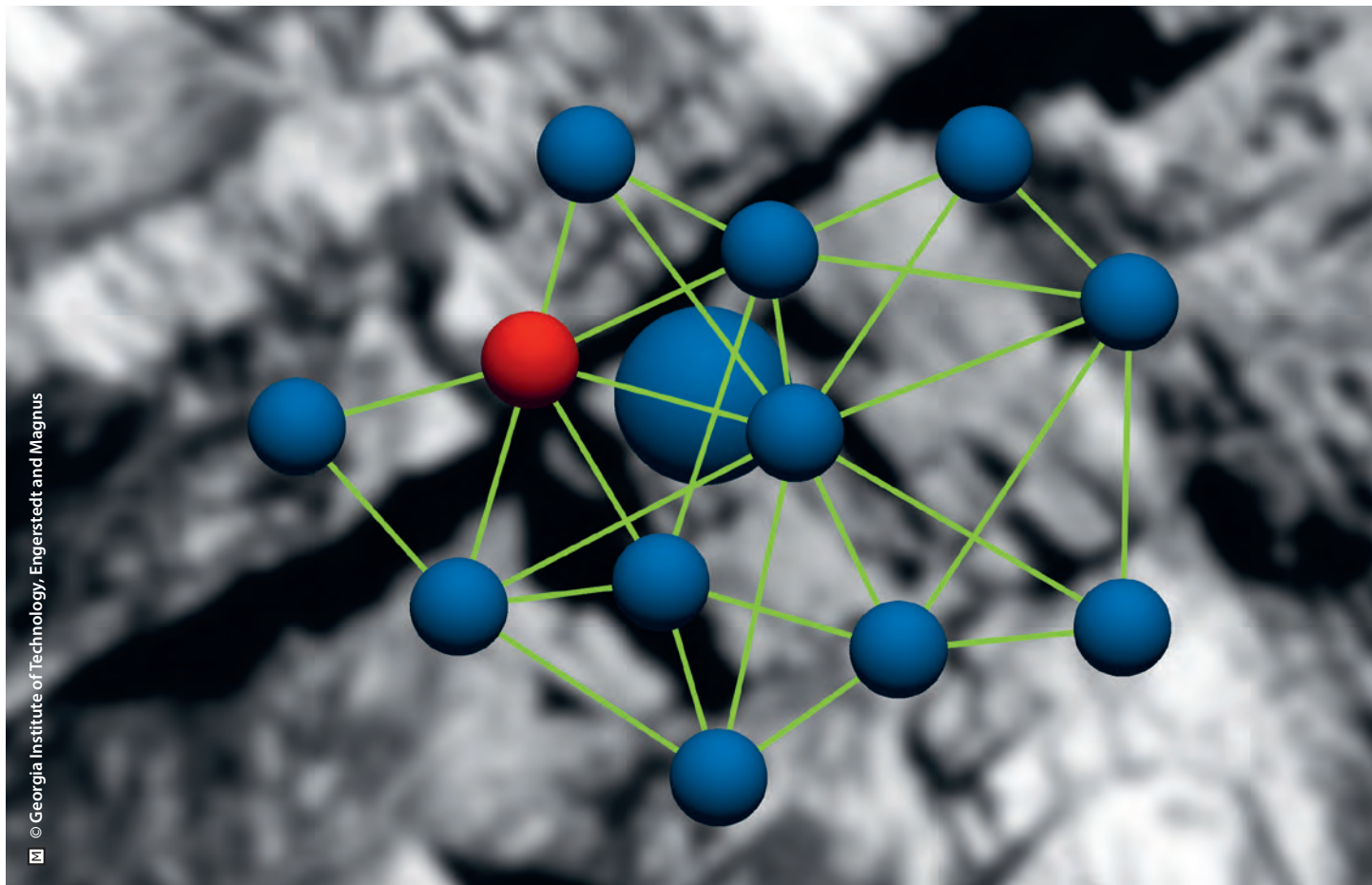
Figure 4: Image represents a computer simulated mesh topology of a functional swarm conducting a Search and Rescue scenario. It is inspired by the Georgia Institute of Technology 'Control of Mobile Robots' series of lectures and experiments (Engerstedt, Magnus), where a reference agent guides the mesh through the search and recovery phases, adapting the common motion policy to different environmental constraints.

Maastricht University is also researching a real-life, robot-based Search and Rescue (SAR) profile involving human detection and support in urban environments. This means self-synchronized, airborne and ground-based robots interacting with humans in distress through different sensors, which nowadays encounters safety problems due to robots certification issues to physically interact with humans in certain environments.

In a CSAR computer-assisted simulation, the simulated platforms would display a limited number of states (FSMs) corresponding to their different functions. These states will change in accordance with a discrete event distribution matching the specific mission context. The platforms will maintain a hierarchy to generate a management element and a finite set of supporting-supported relationships, a finite structured addition of each platform's finite states in the form of contextual variations with repetition. This complementary asymmetry, matching the standard tactical composition of a CSAR mission (ISR, Counter Air, SEAD, EW, C2, Attack and CSAR recovery assets) will be dynamically distributed for each tactical context in all spatial areas of the simulation without any spatial segregation affecting these Roles.

The 'Combat' Search and Rescue mission incorporates a more difficult competitive profile. If threat, intrusion or non-player platforms were present, dynamic decisions would have to be made regarding cluster re-organization and institution of offensive and defensive functions. A non-deterministic element would then be needed in the swarm, in the form of a decision-maker with certain rights allocated, probably with a reach-back command element and certain management tools, some through man-machine interface, some automatic with override features. Algorithms regarding AMR, target kill-loss ratios (based on weapons efficiency, lethality of the threat and defensive capabilities), tactical dispersal and depth, and mutual support should orchestrate how the different platforms, manned and unmanned, would adjust their common motion policies for mission accomplishment.

11.4.2 The Language

As said before, the known part of future operations are the verbs that define the actions related to all types of operations within the current Core Roles included in the AJP 3.3 (B). These verbs will form the proper language-based algorithms through the potential conditional and consecutive clauses that lead to the desired payoff.

The algorithms would then be written in accordance with the cluster hierarchy, while taking into account the non-deterministic condition of the battle manager. A human presence in the loop at different levels of decision to correct, override or cancel undesired evolutions would be retained so the 'Command' function required for NATO Air C2 would not be fundamentally altered. This concept will be explored in detail in the next Chapter.

As explained in the 2 vs. 2 case study in Chapter 8, each tactical manoeuvre may be deconstructed into an orchestrated multifunctional menu that reorganizes the different potential chains of events in accordance with a given syntax. This particular syntax must incorporate subordinate or consecutive clauses, mainly causal but also conditional. In general, and after detecting a condition (if or when), all the 'Wh'

clauses plus quantity (where, when, who, how many, and what) will form part of the consequence that the AI system uses to generate the desired cause-effect messages between machines, and the functions and sub-functions distributed among the cluster by the managers.

In many cases, these match standard behaviours described through brevity words already included in the APP-7. As mentioned in Chapter 8, thesaurus incorporation may be desired when words incorporated to language-based algorithms show contextual polysemy. Self-synchronization of some of these functional behaviours, through automation, may be analysed.

11.4.3 Platforms, Battlespace and Functions

Every platform must be, for simulation purposes, defined in terms of speed (linear and angular), acceleration, climb and descent rate, range, endurance and altitude-associated behaviour, including sensors' and weapons' performance. These will be further defined by their functional behaviour in the different states regarding F2T2EA events, to include search patterns, detection ranges, warning systems, defensive measures, and track, target and engagement ranges.

A CSAR simulation profile requires the following basic functions:

• Navigate;
• Search;
• Mark & Track;
• Neutralize;
• Decoy;
• Pickup;
• Escape (avoid, overfly).

Each CSAR platform will feature a finite number of these seven functions, depending on threat status and resources. The algorithms scripted by the authors during the JAPCC wargame sessions of this model distributed these functions among three different platforms, manned and unmanned, replicating SEAD, ISR and CSAR-C2 platforms operating in concert.
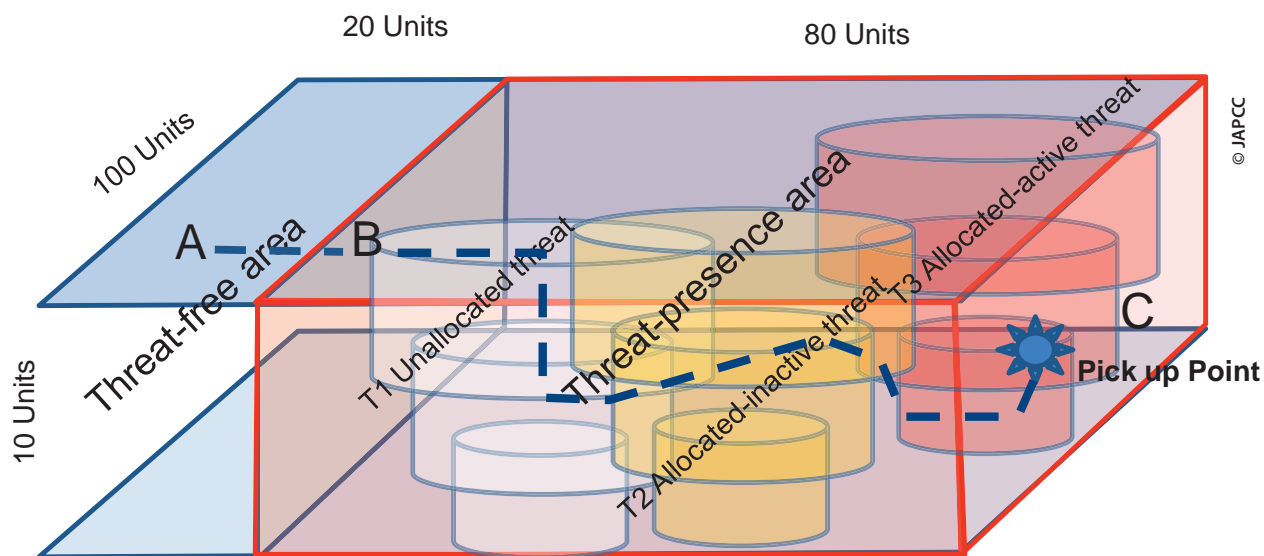
Figure 5: Platform and Battlespace design for a generic Search and Rescue mission.

Each function may be analysed on a different scale in accordance with the intensity dictated by the desired effect, as 'neutralize' may be converted to 'supress' or 'kill.' A colour code may define the different thresholds, so when the supported platform must change state, the supporting platforms act accordingly, again introducing the proper conditional, temporal and consecutive clauses.

To validate improvement of individual motion policies, the global behaviour of the cluster, in terms of an optimal common policy, the different states, actions, state transitions and rewards, will be defined with respect to:

• the cluster's distribution in accordance with a proposed hierarchy and context;
• the pickup point;
• the time available;
• the cluster's status with regard to sensors-weapons-time availability;
• threat position, range, aspect, latency, and threat status.

To illustrate: a 'Kick call' manoeuvre called by the SEAD commander in a CSAR COMAO would comprise two types of motions: the first one, the motion executed by the cluster to avoid a SAM engagement ring; the second one, the commit executed by the platforms with SEAD-DEAD capability, if authorized to engage. These two, together are the dynamic redistribution of a cluster (the COMAO). This would be the common motion policy of the cluster, which will automatically orchestrate the cluster's manoeuvre.

In this computer-assisted simulation, the 'Kick calls' would be written into the different platforms' software in the form of actionable 'Brain-to-Brain' or 'Brain-to-Fin' information (platforms with proper sensors) and in the form of automatic defensive motion policies for those within threat range or for those with the function 'Neutralize' to get the threat within their SEZs-WEZs. Once again, context, channel and message are constant.

Different speeds and altitudes, search sectors, commit ranges and retrograde options may be self-synchronized among the platforms through automated features to redistribute their Voronoi neighbourhoods, while avoiding collision and fratricide. Under a network, unmanned assets will 'learn' to fly along with manned platforms and balance the mission under

human monitoring. All types of dissimilar and asymmetric platforms may be simulated and tested in terms of Convergence and Continuity when networked in a continuous battlespace.

These Core Role-based simulations are also performed at the multiple simulation facilities, such as the Multinational Aviation training Centre (MATC) and the Tactical Leadership Programme (TLP), but at the tactical level. Facilities such as these can feature live, virtual, constructive and / or distributed options. The multiple replay-ability of different scenarios and tactical contests then allows the various training audiences to record and evaluate the best tactics of choice, even though no algorithms are written, nor automated motion policies implemented, as these are Axis 1 and 2-oriented facilities in the Alberts et al. Maturity Model and the technical stage of the participating platforms is still 4th generation and below. The results from each

organization's syllabus may be then used for doctrinal production once tested and analysed.

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Commander Allied Air Command chats with a controller at Decimomannu, Sardinia.

CHAPTER 12

The Role of the Command Function in the Future Network

Leveraging the concepts discussed in the entirety of this study, this chapter will discuss the impacts of the future network capability and the level of C2 maturity on the existing NATO Command Structure. Beginning with an assessment of the Joint Force Commander's role in synchronizing activities across the Joint campaign and following this thread through the Air Component Commander to tactical doctrine, this chapter discusses the potential friction points and challenges that may exist between the Component Commands and the Joint Command in the future. This chapter includes the premise that the proportion of dynamic versus deliberate targeting and Precision-Guided Munitions (PGM) versus non-precision ordnance operations increases steadily (i.e. greater level of dynamic ops and PGM usage). Therefore, it

also discusses the multinational aspect of networked forces and identifies potential options for mitigating these challenges.

12.1 The Commander

Each joint campaign will still need the unique human vision, the formal coherence of a commander lining up all subordinated actions and effects.

Decision support will become even more software-dependent. Strategy-based options will be offered to the commanders in real time by software-based DSSs. Regarding best available weapon and sensor availability during simulation modelling or in real engagements, what if the 'network' was choosing between inter-service, dissimilar platforms operating together in the net? If the network is enabled to choose the best available asset from across the entire networked Joint force, what command structure is capable of dealing with that capability, including

the 'negate' decision, in real time? This discussion challenges today's service and component-oriented command structure.

If the most advanced part of the network is capable of semi-automatic management of certain tactical functions involving real-time orchestration of multi-services' assets, perhaps this command function, related to Tactical Command (TACOM), would then migrate, in part, to a Joint Commander not necessarily coincidental with the JFC.

There might just be one future battle, rather than an Air Battle, a Land Battle, and a Sea Battle. However, this does not mean the entire C2 structure must be hyper-connected. Some parts of the topology may remain at lower maturity levels regarding connectivity, and this concept is valid as long as Concepts of Operations (CONOPS) development and Commander's intent of the JFC are clearly reflected in the network's architecture, force allocation and distribution, as well as in the desired sequence of effects. In this vein, the network itself becomes an augmenter of the decision process (rather than making autonomous decisions on behalf of the commander).

The entire C2 process may never be able to achieve Edge C2 maturity level due to the necessary human presence in the loop; however, there are certain elements of the force that, for certain tactical contexts, can operate at near that level, even while accommodating a human in the loop.

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A Decision Support System (DSS) interface designed to execute tactical management of deployed air combat units.

12.2 The Operational Level

The overall joint milestones and cycles associated with Joint Command will remain, as they are a substantial part of the operational art, which, through a planning method, sustains successful joint action. These milestones in planning and execution, such as stating the Commander's intent, war gaming and selecting a COA (Course of Action), offering continuous guidance, making apportionment decisions, reallocating forces when needed, management of the targeting cycle, info ops options, and setting battle rhythms are already entwined with automated communication and software systems.

Joint target nomination and prioritization will remain a challenge, especially when dynamic targeting options increase due to sensor federation and increased real-time sensor arrays, among other factors. Certain campaign phases may then become more time-compressed in various scenarios, especially when involving Joint A2AD dilemmas.

12.2.1 The Operational Framework

The Operational Framework and its associated graphic design will likely remain relatively unchanged, as the chains of actions and effects along the different Lines Of Operations (LOOs) will still provide the scaffolding of the joint campaign. Nevertheless, the network and its associated effects across the whole spectrum of operational activities must be a primary concern during the Centre of Gravity analysis (both own and adversary's), as well as during the procurement of any related capability to maintain the network functionality, which will become a critical requirement for the commander and the associated staff.

The execution of the range of potentially simultaneous activities across a spectrum of conflict, as outlined in NATO Doctrine AJP 1 (D) and AJP 3.3 (B), will experience shorter timeframes, especially in activities related to certain operations like the principle NATO mission: Collective Defence. In the case of the standing plans providing Collective Defence within NATO's AOR (Area of Responsibility), the topologies are pre-established

and the elements should present strong technical and tactical interrelationships featuring high levels of continuity and connectedness. Standing or Contingency plans related to defence of NATO nations will be based on increased and improved communication features. Recent upgrades within ACCS incorporated some of those activities, but it is inherently limited in the machine-to-machine relationship, as that particular C2 system was designed around a human interface.

12.2.2 (De)Centralized Control, Decentralized Execution

Decentralized execution will likely be augmented by the capabilities of the future network. This network design should prevent duplication of effort and maximize operational effectiveness through automatic deconfliction, prioritization, integration, and synchronization of joint activities. Dynamic reallocation of assets will be suggested by the DSS, as well as some supporting-supported options for the new-born clusters.

12.2.3 Operational Battlespace

Certain high-density areas with increased presence of weapons systems will generate a need for the highest level of integration available. Many operational scenarios played regularly by NATO's Joint Warfare Centre (JWC), through computer-assisted exercises, involve limited battlespace for the allocated Component Commands, generating spatial dilemmas to be solved through coordination, synchronization and integration. As the 'resource battlespace' becomes critical, inter-service platforms will incorporate some sort of DyAS compatibility to make basic emergent cluster formations and swarming behaviour possible and to enable certain levels of orchestrated motion policies through self-synchronization among dissimilar, inter-service platforms.

To achieve this level of spatial integration, the best combination of Core Roles (types of air operations and tactical contexts) must be balanced through computer-assisted and synthetic simulation. Force generation for a given operation may then be determined in order to generate clusters capable of tactical

machine-to-machine execution through certain levels of self-synchronization. The optimal output should match the desired effect and each potential threat.

As an example, the Counter Air and the Attack Core Roles elements, including Surface-Based Air Defence (SBAD) assets, will share timeframe and battlespace through self-synchronization. Today, they already do this at a 'Coordinated' level of maturity through scripted procedures (and even at 'Collaborative' level when fully data-linked) during the COMAO missions. In these COMAOs, aircraft commonly swing roles from (for example) SEAD to OCA or from Air Interdiction to RECCE in a TST (Time Sensitive Targeting) or DT (Dynamic Targeting) environment, when the level of training, capability of the datalink network, and coordination amongst assets permits that level of flexibility. In addition, ISR, DCA and TBMD will experience a significant increase in their detect and engage sequences' speed, especially when federating F2T (Find, Fix and Track) resources.

The capability for NATO to jointly evolve to the 'Collaborative' level or even to some initial stages of the 'Edge' level of maturity may still be achieved, and this concept exported from the Tactical (specific service clusters) to the Operational level and Joint Operations.

12.2.4   A Joint Tactical Commander?

A single Tactical Commander will still retain, exert or delegate decision rights as well as direct the management team that monitors the cluster or clusters. These clusters, controlled by tactical managers acting as on-scene humans in this 'semi-automated loop,' will expand through the continuous battlefield. This will result in a structure similar to a HIDACZ in the form of dynamic sensor and weapons allocation in accordance with the initially allocated ATO roles, the emergent and dynamic allocation needs, ROE, SPINS (Special Instructions) compliance, and a motion policy of reference, arranged dynamically through the network.

A parallel to the HIDACZ is best exhibited by the rules governing its use. Today, if a platform is not in contact with the airspace controller of the HIDACZ, it must remain outside the HIDACZ boundary. In the future, if a platform is not a network participant at a certain level of maturity, it will be unable to effectively integrate with other assets and, therefore, will be a hindrance to the execution of air operations. This might require geographic (or simply graphic and geo-referenced) segregation of that platform, or perhaps the designation of network participant as mandatory (mission essential) for future air operations. This same concept applies to white or green traffic (civilians, non-players or third nation military assets). The network must be able to conduct identification, tracking and graphic segregation functions for white traffic in the airspace as part of both DyAS and the machine-to-machine decision allocation process. Some critical activities, like TBMD, will demand DyAS compatibility for de-confliction when engaging threats and avoiding fratricide through orchestrated motion policy.

The execution of these types of Air Power functions will be orchestrated among different platforms, including surface-based and airborne platforms, manned and unmanned. Different types of escort for parallel strike missions will conceivably be spatially shared by dissimilar, Joint assets, as suggested by the model's Coordinated to Collaborative maturity scale (Chapter 3), as long as they can be dynamically appointed as the best available sensor or weapon. Collaborative ISR will also be available for complementary operations, enriching each other's 'picture', much the way that Chapter 7 explains how the F-35 Distributed Aperture System (AN/AAQ-37 DAS) already interacts with the Ballistic Missile Defence System (BMDS). All participating platforms should be DyAS compatible and incorporate the necessary degree of awareness about each member's status within the cloud.

The challenge for the future Force Command Structure is how to conduct highly centralized control over disparate platforms across the different services fighting in the same airspace, without converting that high situational awareness controller into a single micromanager that might become a human single point of failure. Another challenge is the assurance of C2 continuity upon network degradation.

Note that different portions of the overall Joint C2 structure may be operating at different degrees of maturity, but these must be reflected in the overall BFT for awareness. Tactical hierarchy and communications capabilities within the network will drive the final topology in terms of maturity. This may require re-evaluation of the role of the Component Commander and the subsequent relationship to the JFC in this hyper-connected network. In other words, to form abnormal sets of elements comprised of different services' platforms operating in a mutually supporting role, it will require a different, likely more streamlined and agile, command and tactical management architecture.

12.2.5 Cluster Composition and Net Designs

Force generation processes and Combined Joint Status of Requirements (CJSOR) will likely have to be tailored in accordance with the Joint Force Commander's needs for networked forces, as the JFC will still be responsible for integrating and synchronizing all actions within the JOA and throughout the joint campaign. A likely evolution stemming from advances in today's datalink protocols is that even if self-synchronization of dissimilar combined platforms is desirable, but difficult to achieve, its presence on the battlefield will likely be reflected in future CONOPS and other planning documents, like specific OPLAN annexes.

12.3 The Joint Force Air Component Commander (COM JFAC)

In today's NATO Command Structure, the COM JFAC executes the command function of C2 through the CAOC. Philosophically, this must continue. Even though the network itself may be capable of performing more rapid and more efficient elements of command through AI in the loop, the requirement for a Commander to oversee, direct, and negate certain decisions in the tactical arena must be retained.

As technology develops, and as the future network is realized, the platform hierarchy and human decision maker hierarchy must coexist. That relationship must be codified in doctrine, policy, and machine coding.

This vision of potential real-time combination of types of operations and platforms' semi-automatic re-role and state-changing through automation (as supporting or supported assets) does not necessarily move the command function forward from the CAOC to the airborne platform (even if it may redistribute it). However, it may affect the CAOC/COM JFAC's internal organization.

12.3.1 The Air Plan

As AJP 3.3 identifies, the Air Plan needs to be consistent and match the hierarchy of documents and concepts. Therefore, the Air Operations Directive development team and the Operations Assessment section (two elements within the CAOC) must be prepared to process high tempo operations and translate results into inputs within the Strategy Division, to feed additional and more dynamic Air Operations Directives.

Complexity will increase when the Master Air Operations Plan becomes tied to other inter-service assets (i.e., army or navy surface-based assets) to permit cluster completion once these dissimilar, inter-service platforms recognize each other and interact with each other on the battlefield. The Guidance and Apportionment process will have to align with the JFC's activities in order to maintain a high level of integration throughout the targeting process, as more targeting options will appear when platforms are on station and new tasks become possible through dynamic cluster composition. This process will likely take place in real time, a speed with which the current ATO/AOD development 'cycle' is not capable of operating.

12.3.2 The ATO Cycle

The Air Tasking Order cycle may comprise these new tactical options based on new clusters' composition. The ATO will include, under COM JTF guidance in the OPORD-JCO (Joint Coordination Order) and COM JFAC guidance in the SPINS, the spatial and functional relationships within joint clusters for potential supporting-supported options within a continuous battlespace.

The 'Aegis is my wingman' concept will facilitate transversal support among dissimilar platforms through automation. A weapons allocator, despite his or her position within the force, will have options across the three service components for sensors and weapons to dynamically F2T2EA (and also exploit before engaging, if necessary) airborne or surface-based targets. Transfer of control/options for cueing of manned and unmanned systems to on-scene battlefield managers, in order to orchestrate common motion policies, will also be reflected in the ATO or the SPINs. These documents will reflect potential sensors and weapons configurations for the clusters, similar to today's aircraft Standard Configuration Loads (SCLs) concept. For these reasons, today's dogmatic process of 72-hour ATO feeders and ATO change requests must evolve to a machine-level, fully networked process.

The future battle is likely to be executed at a speed beyond the capacity of today's ATO cycle. Assets will still need to be coordinated from across the Joint Force, but since the tactical decisions regarding platform activity execution will likely be dynamic and managed real time (either by machine or human), future air activity is potentially more similar to a continuous 24 hour problem rather than a deliberate and pre-coordinated series of activities. TST/DT TTPs and associated cells within the CAOC will likely increase their size and volume of effects generated in the resultant CAOC structure.

12.3.3 The ACO

The realization of a highly connected force may result in the achievement of the 'platform of platforms' concept at some degree (Chapter 3). Tasking these assets may inspire new forms of the ATO that permit these levels of integration. As the future battlespace is envisioned to be highly dynamic in nature, it follows that future Airspace Control Order (ACO) structures may include areas of continuous battlespace, where segregation among platforms will be based on the network in accordance with the consideration of the available battlespace as a resource. ACMs will be planned, displayed, and maintained as

a back-up option or as sanctuaries for assets unable to integrate the DyAS capability but desired within the area.

Emergent tactical opportunities will be controlled in real time by the ARS and/or the battle managers onboard certain platforms (5th generation aircraft or any cluster member or members with the capability) with appropriate C2 characteristics. These options will be based on specific (also emergent) new orders of battle through the network-based motion policies and intra-cluster cueing and steering features instead of pre-allocated mission, functions and segregated airspace.

12.3.4 Orchestration: Combat Ops

Because the roles apportioned and the forces made available to the Tactical Commander for the given ATO may include multi-component (and multi-service) DyAS-capable assets, the future ATO must be related to the aforementioned new CONOPS for force execution, as long as the net can support that specific quality/quantity ratio of players. If tactical management is exerted through certain degrees of automation for some of the functions displayed on the battlefield, as described in Chapter 10, dynamic allocation of joint platforms with inter-related motion policies will have to be integrated under a single Tactical Commander with a centralized manned control structure. This is necessary to mitigate mission creep and to prevent gaps in the tactical 'ownership' of the platform.

Other recent studies approach hyper-connectivity as an option for highly decentralized control. However, this study approaches decentralized execution from the perspective that it will involve human decision-making, ruling both manned and unmanned vehicles under a degree of automation. This concept will allow a frigate, a weaponized RPA or other suitable third party asset to offer automatic delousing or supporting options for other airborne vehicles or ground troops under attack. In this example, the 'engage' decision would be centralized under human management for the given battlespace in accordance with the allocated decision rights and the potential delegation to these semi-automatic offensive and defensive actions.

Although a level of this process is achievable today (Coordinated Air Sea Procedures [CASP] under current doctrine), the key difference in the future is the automation. The frigate, the fighters and any other DyAS compatible asset within the cluster would share a motion policy across the net in accordance with the tactical environment, and provide machine speed coordination and cueing. The human would only be involved at the point of engagement or in other command calls (knock-it-off and similar brevity words) or similar options involving a degree of hierarchy.

In many cases during high intensity combat, the choice of weapon will be software-recommended within a joint cluster, resulting in higher tempo variations in its tactical management and in higher levels of efficiency. New DSS's related to the Combat Cloud concept (faster update of the databases to match the speed of this dynamic execution with the ISR collection, analysis and dissemination plan) could address this challenge and link the targeting cycle at the Operational level with real-time targeting options and, simultaneously, with the optimal resources.

12.3.5 Targeting and Target Approval

Deliberate targeting will likely still be present at the initial steps of the Joint Campaign, followed by increasing proportions of dynamic targeting as supported by sufficient bandwidth. As mentioned at the beginning of the current chapter, this stresses the fact that dynamic/deliberate ratio has increased steadily from Allied Force to today's operations, parallel to the increase in the PGM/conventional weapons ratio.

There will be many more engagement options as every platform is a node, and firing platforms and enabling sensors will exchange terms within their pre-programmed, code-written agnostic contracts to allow the force to commit lethal and non-lethal targeting options. The clusters will have embedded ISR options, which will generate more information that is actionable and more commanders' decision demands, either in a reach back configuration or in place, on board a tactical platform within the cluster.

Regardless of the commander's physical location, the command element must have access to the most complete information possible to exert command by negation and/or to trigger lethal engagements, thus maintaining the human in the loop. Even if the tempo is accelerated to higher ratios, national target approval, red cardholders, and even the temptation to use this high bandwidth availability for higher echelons of command's micro-management will still endure, and the OODA loop tempo will be thusly affected in the 'D' portion of the cycle.

12.3.6 Logistical Considerations

Logistic control of available firepower or sensor availability within the clusters of Joint capabilities could also move upwards to a Joint level to avoid tactical imbalances and weapons' dependence on certain assets. The paradox of clusters in which only few platforms are able to deploy weapons or engage targets, but are supported directly by other platforms with national caveats, will have to be solved through the proper processes, like NDPP.

Furthermore, the economic cost of one asset becoming 'best available' weapon more frequently than other cluster's members may have an impact on the nation owning these shooters.

12.3.7 Apportionment Recommendation

The information throughout the battlespace will be completed and passed across the network faster, and new tactical contexts will be offered to the commander for real time decisions regarding engagements. COM JTF's air apportionment and weight of effort may therefore experience faster shifts among types of operations, services, and LOOs as the availability of emergent opportunities allows for quicker sequential engagements, thus affecting further targeting cycles. It is assumed that the 'Assess' portion of the F2T2EA kill chain at the Tactical level, and its expression in the OODA loop, will delay the tempo. In addition, target exploitation before engagement

must be considered in some cases, as information gained can sometimes be more profitable in the medium term if engagement is delayed or sequenced.

Despite the allure of accelerated F2T2EA chains and OODA loops, it is necessary for the Joint Commander to maintain formal coherence of the campaign and avoid mission creep. An excess of dynamic-only Air operations may accelerate the Joint campaign out of the desired operational framework and cause undesired mission creep.

To understand the level of sequential coupling between or among these different air operations (SEAD, CAS, DCA, APCMO, etc.), a valid simulation should be conducted, as described in the previous chapter.

The desired product of these simulations will be an achievable quantity/quality ratio in accordance with the desired risk level per threat (a Pareto optimal cluster where the equilibria are referred to the desired effect).

Once results are convergent and continuous, the Allied Tactical Publications (ATPs) may be reviewed to incorporate new potential cross-platform support options for the different (and constant) types of operations.

12.3.8 Training Options: Exercise Bold Quest

Certain NATO exercises incorporate transformational activities as an approach to concept refinement, doctrine validation and potential C2 changes within the current structure. More specific exercises, such as Bold Quest, focus on interoperability (how to network a coalition), but are still short of the level of integration required to realize the concepts in this study.

In this case, Component Commanders have a wider variety of tactical (airborne, surface-based, EW or cyber, for example) response options by making other service platforms available for effect, addressing kill chain flexibility from sensor to shooter. It also focuses on communication improvements by stand-

ardizing digital CAS procedures and investigating a digital BFT (based on human interfaces), which is an early step toward the DyAS concept envisioned by this study.

12.4 Vulnerabilities

For this study, the authors assumed decision-making will always be human patrimony. The commander, personally and through delegation, will align the decision-making chain with his personal focus, his own comprehensive perception and perspective of the operational or tactical contexts, which will be as different for each human as a fingerprint.

The 2016 JAPCC Conference discussed challenges surrounding 'Preparing NATO for Joint Air Operations in a Degraded Environment'. While much of it centred on physical degradation, the concept of 'political degradation' arose as an equally challenging issue. At the political level, Alliance cohesion cannot be 'automated'. It is associated to that human condition of the decision makers and its impact on the Strategic, Operational and Tactical levels cannot be automated when making engagement decisions. For these reasons, the associated decision rights must remain within the human loop in accordance with the commander's intent, vision, and guidance.

An excess of machine-to-machine communication and a lack of human presence to interpret and intervene as network control assets may distort both the sign-meaning conventions and the tactical context.

Moreover, machines could become a single point of failure without the balanced presence of the human warrior in the net. Similarly, the F2T2EA chain could be affected if a human cannot react to semantic traffic that is not fully aligned with the commander's intent, ROE, social media, weather context, open sources and many other sensorial stimuli. Nevertheless, available, robust, and redundant connectivity will always be an essential enabler for quick and accurate decision-making, which is easily identifiable as one of the Alliance's critical vulnerabilities for two reasons:

Firstly, the Network itself is vulnerable to adversary action. It is an assumption of this study that the network will be robust, resilient, and reliable. This will require a level of engineering and security not currently achieved and may potentially open unknown avenues for adversary exploitation.

Secondly, the network concept itself will remain vulnerable to the will of the nations. As today, future NATO operations likely will be challenged by national caveats and restrictions, ranging from information sharing to platform participation, liability issues, and to the menu of capabilities offered to the Alliance.

If national caveats inhibit the network's capability to conduct machine-to-machine communication for functions and support orchestration, it will potentially result in a self-imposed battlefield firewall, forcing de-evolution to a lower state of C2 maturity.

To address this limitation, the joint synchronization matrix will potentially incorporate these machine-to-machine options to generate certain effects more rapidly and advance the campaign's timeline, thus favouring and improving decision-making speed/operational tempo. The joint synchronization matrix is a key execution document (Operations Plan Annex A, Appendix A-1 per COPD V 2.0) featuring the synchronized Component Commands' tactical execution, the supported and supporting relationships, and their generated effects with regard to the planned timeline.

Force allocation for specific missions will demand higher cluster compatibility, which will be reflected in these new matrixes, and the Joint Operational Planning Group (JOPG) will ultimately solve any conflict, with the assistance of a DSS for simulation and COA war gaming.

5th Generation Fighters must co-exist with legacy platforms in order to efficiently conduct true multinational joint operations.

CHAPTER 13

Findings, Conclusions and Recommendations

'The thing that's scary … is that there's no reason that the processing time and the reaction time from those (artificial intelligences) will not continually speed up beyond the human ability to interface with it …' While the US [and NATO] will insist on human control of lethal weapons, even if that slows the response, others may not. 'There's going to be a whole level of conflict and warfare that takes place before people even understand what's happening.'

William Roper, Director
US Strategic Capabilities Office

13.1 Summary

Over the last decade, many nations have recognized the growing importance of information as a warfighting function and cyberspace as a warfighting domain. The expansion of technology and information networks into today's air forces has highlighted the need for a reliable, robust, and federated information datalink. More accurately, it is a network of networks, capable of integrating information derived from sensors and sharing salient information across aircraft of disparate technological capability.

Effect generation will be increased by platforms that empower one another, in accordance with the 'Combat Cloud' concept. Different technologies will allow for information exchanges and mutualism among dissimilar but complementary platforms.

This study began with the premise that a future network will be developed with certain characteristics of cognitive machine thinking and that, by design, it will facilitate a different level of communication and functional and spatial orchestration between network participants than is currently available today. This increased ability for facile communication will allow a migration up the scale of C2 maturity beyond Collaborative and approaching Edge C2.

Edge C2 will permit certain aspects of the execution of Air Power Core Roles to be delegated to computers operating the air platforms. Platform interaction at machine-to-machine speed will facilitate a re-conceptualization of how airspace is developed, coordinated and employed to achieve effects for the joint force.

13.2 Findings

Future C2 models will support evolutionary C2 architectures based on unrestricted communication. These will incorporate new spatial perspectives, as new clusters of elements (inter-service platforms) will be able to redistribute their roles following an evolved and real-time, adaptable, supported-supporting schema.

These new clusters, comprised of legacy, 5th and 5th+ generation, multi-service, manned and unmanned platforms, will be able to dynamically orchestrate and adapt its tactical performance to emergent contexts through high degrees of automation. This will be done, through compatible code writing, by each platform marking the environment in accordance with the dynamic and emerging tactical context to induce the appropriate state changes in other network participants to achieve the desired Air Power effect.

The resultant system may perform as a single platform for certain activities, even though this platform of platforms is integrated by several third party or off-board elements.

The entire joint set, acting in the third dimension (clusters of Air Power assets), may soon display not only the current and limited brain-to-brain abilities, but also brain-to-fin skills to influence or direct off-board platforms' behaviour while behaving like a single organism. This organism will work as a nervous system to transmit signals to and from different parts of its body through data transfer and is assumed to one day become a reality through technological evolution.

Models are vehicles for learning and represent the organization of a system, and that is the approach of this study in choosing the Alberts et al. maturity model as a roadmap to measure maturity increases. The aspects of Air Power execution which may be automated will permit the clusters to perform in a manner closely approaching that envisioned by the Edge C2 level of maturity. However, those specific functions (kinetic engagement, critical ID requirements [i.e., hostile declaration], negate capability) and considerations regarding the other Axes of the aforementioned model, which require a human decision maker to conform with NATO ROE and potential national caveats, will slow down this decision tempo and result in a C2 stagnated at the Collaborative stage.

Aerial platforms could be considered as complex Finite States Machines, especially when operating in a changing environment that demands a flexible adaptation to a certain supported-supporting combination of functions. This may be reflected in certain characteristic motion policies that solve the 'problem space' and optimize the distribution of roles.

Collateral benefits, in the form of co-evolution, between elements of a system may be boosted when symbiotic relationships appear among multiple biological species in close contact, thus influencing their state changes. This study extrapolates these facts to machine technological evolution through communication and proximity within the Air Power domain.

Three examples based on aerial platforms' performance support this concept:

• The evolution within a single Role (Counter Air) through detailed study of a single intercept manoeuvre.

• A linear study of a four-ship flight performing air-to-air training pre- and post-Link 16.

• A third analysis of the Tactical Leadership Programme's statistics reflecting efficiency increases and motion policy changes pre- and post-Link 16.

The three examples show a uniform and growing impact of improved machine-to-machine communication on the overall force's efficiency and effectiveness. The conclusions drawn from these case studies are

further validated by other projects, research efforts, and doctrinal approaches, such as the US ALPHA research into Artificial Intelligence (AI) control of aircraft and the Australia's Jericho project.

Once the potential competitive and associative options are analysed within the networked environment, a new airspace distribution in the form of Dynamic Airspace Synchronization (DyAS) is proposed to better support the formation of new topologies of Air Power elements. The DyAS concept also provides a visual and haptic support structure to manned aircraft in an effort to reduce operator workload during manned and unmanned teaming events. Platforms will adopt software-based motion policies that could dynamically re-adapt the battlefield topologies. A faster, more flexible response is offered to emergent tactical contexts in accordance with the Commander's intent, ensuring proper human monitoring and control, and thus a faster operational tempo achieved.

Finally, after analysis of biological communication evolution and extrapolation to air platform C2 evolution, (and accepting the self-imposed limitation of a human in the loop for certain functions) this study finds that the target C2 model will be a hybrid between Collaborative and Edge C2.

13.3 Conclusions and Recommendations

This concept of a future Joint Force capability may serve as a factor for transformation if strategic guidance were to be given in this direction. It may ultimately lead to doctrine, organization, training, materiel, leadership and education, personnel, facilities and interoperability and policy changes (DOTMLPF-I). Even though DOTMLPF-I is the most common reference to address impact in the different domains affecting transformation, this study extracted general elements of change and/or conflict that have been identified along the research process.

The following factors, inferred from the previous twelve chapters may affect not only the future evolution, co-evolution and final integration of systems in a continuous airspace, but also the definition of new inter-service, multinational clusters of dissimilar platforms, and the generation of joint effects based on their dynamic adaptation, through communication, to emergent tactical contexts:

• There are three ways to address C2 maturity increases, and out of these three, technology-driven, augmented, robust communication is the only one that is cost-effective and viable for near-term effect in accordance with the 'Combat Cloud' concept. *(Interoperability, Materiel and Training.)*

• The complete C2 topology fitting a certain operation does not have to have a uniform maturity level. The 'Edge' level of maturity is obviously desired if/when integration through self-synchronization is desired, but that might not be the case for certain activities or for network degradation scenarios. *(Doctrine and Organization.)*

• The 'Cloud Concept' may apply even to a two-platform entity forming an Air Power cluster, as long as effect generation is enhanced through communication despite service, generation, or nation of origin. *(Organization, Interoperability, Materiel, and Training.)*

• The operational design process and ROE collection must include the 'network concept' to ensure secure, effective and efficient adaptation of the cloud to the JOA in terms of distribution, effectiveness, efficiency and vulnerabilities. *(Doctrine and Training.)*

• Information flow across the Joint Air assets in the manner described is feasible; however, the Alliance will still need to manage trust issues for information exchange between nations, potentially affecting information flow across the network. Also, the potential negative impact on the Command function of excessive automated communication should be analysed from the combined-joint perspective. *(Interoperability, Organization, Training, and Materiel.)*

• As the capability for machine-to-machine interaction increases, the role of the human in the decision loop for certain types of operations must be main-

tained. The human element must remain as an ethical check on operations even though it will eventually impede the maximum maturity level NATO air platforms can achieve, as humans will be outpaced by the machines' ability to react and anticipate. *(Doctrine, Organization, Training.)*

• Assuming the network and platform allocation manager (whether human or AI) has access to all assets across the Joint Force, dynamic allocation to confront emergent tactical contexts must be balanced with the Joint campaign's apportionment. This may result in a change to the C2 relationship between the Component Commanders and the JFC, potentially leading to single joint TACON cell under centralized direction, or delegated TACON to a single service C2 element, which may cause cultural asymmetry and lack of trust. *(Leadership, Doctrine, and Organization.)*

• A new TACON cell, whether in the CAOC or at the JFC, with a new tactical CONOPS and the necessary C2 tools, should be designed for certain complex scenarios based on a shared complete Common Operational Picture (the future network provides this level of clarity). This should accommodate inclusion of high degrees of automation among the platforms and some form of human command by negation, permitting robust C2 while still allowing the automation function to cross service and component boundaries to select the best available platform at machine speeds. The flexibility achieved in this model should not affect decentralized execution but impact positively in the overall decision-making processes. *(Doctrine, Organization, Training Materiel, and Facilities.)*

• During these highly dynamic events and emergent tactical changes, centralized control and the fastest possible assessment capability remain the primary tool for avoiding mission creep and duplication of effort while increasing operational effectiveness. *(Doctrine, Organization, and Leadership.)*

• Moore's Law and the complexity of these future clusters are tied to each other. There are limits to the processing capacity of MCs, FCCs, and network management computers. It is feasible to overload these computers' capability to process data or make informed decisions if the number of participants or the complexity of the permutations brought about by the scenario exceeds those limits. As technology evolves, these limits will grow but must be part of any conceptual design of the future network, including an optimal quality/quantity distribution. *(Organization, Materiel, and Interoperability.)*

• Convergence (scenarios featuring positive results upon the synergistic combination of certain platforms) through technical development, TTPs, and Training and Exercises should be incorporated to virtual and constructive simulation throughout the Alliance, especially in those activities (DCA, CAS) and platforms (AEGIS community, F-16, Typhoon) that already have a solid, common doctrinal-technical background. *(Doctrine, Training, and Materiel.)*

• Technical upgrades in legacy platforms and new designs will potentially require the review of the NDPP process related to two or more orchestrated platforms with certain degrees of automation incorporated. These new effect-centric combinations would feed different capability codes, especially those linked to the current NATO PSAs (Priority Shortfall Areas). These new combinations might also accommodate the hybrid and multi-role capability of future platforms, and even potentially accommodate machine-to-machine control of third party sensors/weapons. *(Organization, Materiel, and Interoperability.)*

• These new combinations will define a hierarchy, identifying primary, secondary, and further functions within the cluster, and will affect primarily 5th and 5th+ generations of aircraft or vehicles, serving as tactical enablers of a variety of functional platforms, regardless of service, manning and generation as long as connectivity is assured. These clusters will present the opportunity for continuous co-evolution through adaptive code-writing. *(Organization, Materiel, and Interoperability.)*

• National caveats within certain operational contexts may challenge (and even hinder) the concept of self-synchronization, as the aforementioned capability

codes will not be replicated completely by the multifunctional cluster formed. If a specific nation elects to limit or entirely prohibit its forces from networked joint-combined training, or from executing certain Air Power Core Roles in any given NATO operation for political reasons, the network will have to adapt to that reality. *(Training and Leadership.)*

• These prohibitions will limit and inhibit the ability for autonomous self-synchronization even though there is network capability to synchronize. Differing philosophies are the reality of operations within the Alliance, and they will likely hinder future C2 development in a manner similar to retaining a human in the loop. Nevertheless, the Alliance should focus on developing a plug-and-play capability in case new threats demand the highest levels of integration. *(Training and Leadership.)*

• NATO has dealt with similar nationally imposed information or interoperability challenges in the past. One example is air-to-air refuelling. Although one nation's aircraft and another nation's tanker may be technically compatible, national positions on the acceptable and permissible portions of the operation have imposed a significant planning headache on the CAOC when one nation's tanker was not permitted to provide fuel to another nation's fighter because the first nation was not supporting offensive operations being carried out by the second nation. This exact scenario occurred in Operation UNIFIED PROTECTOR and has become part of many NATO air exercises. This scenario also plays out in the information domain with intelligence gathered by one nation and what will or won't be provided to the rest of the Alliance. *(Training and Leadership.)*

• In the engineering of the future network, the scripting and coding necessary for machine-level communication and machine-level decision-making must be scripted and written into code well in advance. When designing the software and hardware to support the network, it must be constructed in such a way to support the required plug-and-play interoperability while still respecting the sovereignty of national caveats and their respective command authority over national assets. *(Training and Leadership.)*

• Cultural Asymmetry (such as service biases) may degrade the effectiveness of Air Power networked environments. The concept of a 'platform of platforms' cluster only works if all platforms are permitted to exploit their inherent capabilities. If national or service restrictions prevent certain platforms from assuming certain hierarchical roles within the battlespace, this will inhibit cluster synchronization in a manner similar to the previous discussion about national caveats. A secondary potential of these types of restrictions might prohibit that nation from being permitted to join the cluster (enter networked the battlespace) due to the fact its presence, while unable to accept operations at these speeds, would reduce the combat capability of the rest of the cluster. *(Doctrine, Organization, and Leadership.)*

• Some platforms may not achieve cluster compatibility without the presence of a higher capability platform enabling the lower to join. Operators (nations) may have to accept the hierarchy in the battlefield based on the capabilities of the platform and its ability to integrate and adopt a 'what's best for us all is what's best for my platform and my nation' mentality. Ideally, the Pareto optimality in the multifunctional cluster must be effect-related, and not a platform-, service-, or nation-related state of allocation. *(Doctrine, Organization, Training, and Leadership.)*

• Future recurrent training among classes of compatible elements must be explored. The NATO Joint Force must actually train as a Joint Force and not be limited to service or component specific events. Cluster development of disparate platforms must be part of the NATO exercise and training regimen through the transformational activities routine. *(Organization, Training, Leadership, Personnel, and Education)* specifically:

– *To achieve and measure a constant tactical output (Continuity) in dynamic scenarios, joint-combined training featuring networked clusters must be planned and executed.*

– *Training objectives for the network itself must be defined, achieved, and measured. Cyber commands must integrate as players and even management elements within these training and exercise routines.*

– Standard clusters' configuration lists must be developed to understand potential doctrinal developments and further training exchanges among compatible assets.

– These unit exchanges must be planned, taking into account software, code compatibility and complementary Core Roles, and types of operations, and not types of platforms or organic origin. These exchanges and training sessions would also contribute to connect forces, and to minimize cultural-national asymmetry and lack of trust while training new cluster-based tactical options.

– NATO should devote effort to high level, advanced, joint training that incorporates Air, Land, and Maritime Components working together to achieve a common aim. The current level of NATO exercises are overly focused on service Component capabilities, and in some cases they actually advance service or component bias against Joint Operations. If a future force is to be constructed using the best available platforms networked in a construct outlined by this study, effort must be made toward training to this level of integration through Bold Quest type exercises.

• Many of the concepts discussed in this paper have potential applicability to the ongoing research into a replacement AWACS capability. The role of the AWACS as a C2 asset, currently under review, may evolve away from sensor and platform organization and be more focused on human decision-making for dynamic platform allocation, motion policy orchestration, and identity and engagements management within the network. Other platforms or platform combinations with potential Surveillance, communications gateway, EW, and C2 capabilities may assume these capabilities through data transfer in certain scenarios. The engagement authority and other non-delegated management functions of the kill chain will remain at the proper level of decision rights. *(Doctrine, Organization and Materiel.)*

• The role of the Tactical Commander may evolve towards that forward element of C2, if present in the cluster, or to a reach-back, more joint and semi-automated

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Participants in the future networked battlespace will consist of agents/platforms from the Maritime, Land and Air domains.

command element. In both cases, the C2 architecture of choice must satisfy the allocation of decision rights for each operation. *(Doctrine and Organization.)*

• Due to the increased ranges of modern weapons and sensors, the entire Airspace Control Plan (ACP), Airspace Control Order (ACO) and Airspace Control Measures (ACM) should evolve to support a DyAS-type construct, but a process must remain in place as a backup architecture for degraded network operations. The airspace will be continuous and with the lowest degree of segregation to allow Convergence among the network and its components. *(Doctrine, Materiel and Interoperability.)*

• Critical battlespace (that associated to weapon and platform trajectory and manoeuvre, sensor and weapons geometry and weapons' effects) may be managed by the network, code-translated, distributed among the force together with steering options and expressed graphically on existing SA systems (HUD etc …). *(Doctrine, Materiel and Interoperability.)*

• A balance among firewalls and an Alliance 'plug and play' concept must be achieved to avoid lack of machine-to-machine communication, which would result in tactical miscommunication and battlefield incompatibility. This speaks directly to a comprehensive, joint (and collaborative) acquisition and software/hardware development program for the Alliance, affecting the NDPP process. Future platforms must be able to integrate with one another at the machine level. *(Training, Materiel, Leadership, Interoperability.)*

• Robots currently replicate automated features that could be extrapolated to Air Power platforms. Robotics laboratories are the toolbox to reproduce and analyse different scenarios with the objective of discovering the human decision allocation schema within the potential cluster, as well as successful options for platform combinations including manned and unmanned teaming. *(Doctrine and Training.)*

• In this early stage of cluster composition development, swarming is a matter of quality of the interactions between different platforms. This results in the hierarchy of platforms based on capability, both of sensors/weapons and of integration. *(Doctrine and Interoperability.)*

• Asymmetry among the members of the cluster is a synergetic feature in the presence of successful, regulated communication. *(Doctrine and Interoperability.)*

A future Airborne C2 capability will allow distributed control of the connected assets.

- The current Core Roles (AJP Doctrine) will likely remain unchanged. New Core Roles might evolve, such as those related to network administration and platform integration. These will be closely tied to the command function and to the tactical presence of Cyber Commands. *(Doctrine and Organization.)*

- Specific platform interactions through data transfer through the different roles and type of operations is yet to be studied (future simulation). Some activities are easier placeholders for automated interaction through communication, whereas others are not as easy to adapt to automated data transfer patterns of interaction. Computer-assisted simulation and further visualization through synthetic environment reconstruction of the concept is the correct tool to research these different levels of compatibility between/among Core Roles. *(Doctrine, Materiel, and Education.)*

13.3.1 Short and Medium Term Options for the Alliance

In light of the previous Conclusions and Recommendations, NATO should:

- Focus on joint exercises that specifically address interoperability in peer-to-peer scenarios, involving all components of Allied Command Operations (ACO), including the Joint Force Commands and Naval Striking and Support Forces (STRIKFORNATO), and leveraging transformation opportunities as identified by Allied Command Transformation (ACT).

- Improve the cohesiveness of the software and hardware acquisition process to ensure future platforms are able to interface from the onset. Incorporate these concepts to the NDPP process once suitable solutions to Priority Shortfalls have been identified. (Nations, SHAPE and ACT)

- Continue to address international and inter-service confidence building. Trust is the foundation for the success of a future network. The network will best operate at machine speeds bypassing the direct human element, but requiring confidence from leadership. (Nations, ACO and ACT)

- As technology evolves and the future network envisioned by this study nears, NATO's command structure should be evaluated to ensure alignment with network potential, component authority, and JFC capability in order to optimally operate and synchronize the joint effort. (ACT, C2 COE)

- Review the execution of Tactical Control once the capability for highly automated functions arrives in the near future, and once these functions have been properly identified through simulation, training, and experimentation. The allocation of decision rights will link to the level of automation, and the capability for command by negation or override must be retained. (ACT)

- Correlate NDPP Capabilities codes with future cluster formations in the machine enabled network. If NDPP capability codes are a source for potential future tactical options, potential clusters fitting certain capability codes may be revealed, especially those codes tied to NATO's PSAs. This could result in increased Continuity (higher and repeated successful outputs) and Convergence (interoperability of forces/successful topologies generating a valid output). (ACO and ACT)

- Explore the relationship between various cyber commands under development, and the operation of this future network. This future network will likely have different support and operational requirements than Link 11 or Link 16 and may require a significantly different level of synchronization with cyber operations. (ACT)

13.4 The Hypothesis, Closing Remarks and Potential Future Challenges

A future model relying heavily on unrestricted communications was framed within this study's hypothesis, which postulated that:

Network-oriented C2 and cyber warfare will dynamically reorganize the current functional and spatial distribution of Roles among aerial/joint platforms and expedite task accomplishment.

A Typhoon, Rafael and Raptor demonstrate the multiple generations of platforms in today's battlespace.

This study began with the premise that eventually a network of information datalinks will be generated. This network would be both capable of providing enhanced clarity to all participants and of having the characteristics of cognitive adaptive machine control based on machine-to-machine interface with each of the network participants. The premise of constant Air Power Core Roles and an unchanged Command function were conceptually framed by a C2 Maturity model, also with the assumption that the network would sustain operations through robustness and redundancy.

From this foundation, the study explored the evolution in C2 maturity of the Air Power platforms resident within the network. These platforms include any asset from across the Joint Force capable of achieving an air effect, and they will self-synchronize to allocate the best available platform to respond to a dynamic and evolving environment.

After conducting a review of C2 levels, which military organizations and campaigns have achieved in the past, the study explored the factors that drive evolution in C2 maturity. As two of the three factors (expressed in axes) are unlikely to be affected by NATO in anything less than generational terms, this study focused on the advancement in of technology to drive evolution in C2 maturity.

Exploring biological examples of stigmergic communication among finite state machines, analysing their spatial behaviour and co-evolution features, and comparing that with statistical analysis of the changes in NATO aircraft performance as Link 16 became available, an extrapolation of air platform behaviour in a future network was generated. Certain Air Power functions could be delegated to machine management, while other elements must remain in human hands. The end result is an advancement in C2 maturity to some extent, which will be realized by NATO's future air platforms.

As network capability improves to the point where platforms can be integrated, leveraging Air, Maritime and Land Component capabilities to achieve an air effect, potential challenges to the current NATO command structure became clear. This may challenge the current role of the COM JFAC. A more agile command position, with the ability to command by negation and the proper tools for centralized control, could be defined.

The resultant C2 architecture must permit the self-synchronization of platforms across the Joint Force in a dynamic and fused battlespace. As NATO evolves past the 'Coordinated' level of maturity and approaches 'Collaborative' and 'Edge' C2, the relationship between the components and the JFC may have to evolve in concert.

Realizing that it is a necessity for a human decision maker to remain imbedded in certain elements of Air Power execution, this study identified a simulation process that would help to depict the functions that could be automated and those that require a semi-autonomous loop linked to a human decision maker.

The evolution in C2 maturity could potentially drive a change in the C2 structure for NATO, likely blending the Air Component Command level decisions with those of the Joint Force Commander (or better to say, of the Commander of a force of integrated joint assets). This is enabled as real time clarity of the entirety of the Joint Force will be available and capable of being managed at machine speeds.

The study then proposed a new concept for airspace management in this new dynamic environment. Dynamic Airspace Synchronization is a radically new method by which airspace may be coordinated for co-use of disparate platforms, managed in real time at machine-to-machine speed and beyond just collision avoidance. New options for common, optimal motion policies would appear once ACMs no longer rule the functional behaviour of the Joint Force. This will fundamentally alter the method by which the NATO CAOCs employ airspace.

Analysis of the role of the command function was also conducted. As the capability for higher levels of machine-to-machine interaction approaches, the human role in certain Air Power roles must be maintained. Although this will eventually impede the maximum maturity level NATO air platforms can achieve, as a human will be outpaced by the machines ability to react and anticipate, the ethical role of the commander must be maintained for kinetic operations.

As the command functions change, the future CAOC will likely change to reflect the radical new approach to airspace management and resource allocation. Furthermore, elements within the CAOC structure itself may need to evolve. The development of airspace, today founded on minimizing fratricide, will need to migrate toward a more dynamic principle. ATO generation will likely morph from a structured hierarchical process to a more fluid and responsive dynamic flow.

A discussion of a simulation, which proves many of the tenets of this study regarding communication was introduced. This simulation will link the concepts proposed by this study in order to provide a foundation for future development of self-synchronization behaviour modelling.

13.4.1 Future Challenges

The future concept of joint-combined networked operations is hampered by several intangible variables, which have to do with politics, anthropology, and social sciences. Lack of trust, lack of political will, or delays in the Alliance's decision process due to human factors, like misinformation or code incompatibility will result in a disadvantage. However, the increasingly faster, more robust networking capabilities that may enable dissimilar platforms to self-synchronize, opens an unexplored field for tactical orchestration.

As per the 'Combat Cloud' concept, future platforms will need software modifications, communications gateways and a new battlespace structure to allow for these new capability combinations. Centralized Tactical Control will have access to each cluster's weapons and sensors management.

These efforts to design more integrated and effective forces are already in place, but mainly at a national level. Australia's 'Jericho' plan is one example of joint concepts that rely on platform connectivity rather than the classic segregated services at a De-conflicted or early-stage Coordinated level.

A potential challenge for NATO is that adversaries may not be limited to the same ethical restrictions regarding machine and man interface. It is feasible that in the near term that fully autonomous swarms of platforms, not slowed down by the ethical requirement for a human decision maker for offensive kinetic operations, could be deployed against NATO, operating well within the Edge C2 stage. As NATO has traditionally enjoyed an advantage in the ability to operate with a higher OODA loop tempo, this might not prove to be the case in the future and may become a future problem for the Joint Force.

ANNEX A

Acronyms and Abbreviations

AAO	Air-to-Air Operations
ACCS	Air Command and Control System (software)
ACM	Airspace Control Mean(s)
ACO	Allied Command Operations
ACT	Allied Command Transformation
AI	Artificial Intelligence
AJP	Allied Joint Publication (Doctrine)
ALI	Air Land Integration
AMDC	Air and Missile Defence Commander (CWC structure)
AMR	Acceptable Merge Ratio
AMTI	Airborne Moving Target Indicator
AOR	Area of Responsibility
APCLO	Air Power Contribution to Counter-Land Operations
APCMO	Air Power Contribution to Counter-Maritime Operations
ATACMS	Army Tactical Missile System
ATC	Air Traffic Control (civilian)
ATO	Air Tasking Order

AWACS	Airborne Early Warning and Control System
BAS	Best Available Sensor
BAW	Best Available Weapon
BENO	Be No further than
BOSS	Battlefield Operations Support System
BVR	Beyond Visual Range
CAF	Clear Avenue of Fire
CAOC	Combined Air Operations Centre
CAS	Close Air Support
CASP	Coordinated Air Sea Procedures
CFI	Connected Forces Initiative
CJSOR	Combined Joint States of Requirements
CODE	Collaborative Operations in Denied Environment (Project)
COMAO	COMposite Air Operation
CONOPS	Concept of Operations
CWC	Composite Warfare Commander
DAC	Dynamic Airspace Configuration
DACT	Dynamic Airspace Collaboration Tool

DAS	Distributed Aperture System (Sensor suite aboard F-35)		**IAMDS**	Integrated Air and Missile Defence System
DCA	Defensive Counter Air		**ID**	Identification
DMA	Dynamic Mobile Areas		**IER**	Information Exchange Requirement
DoD	Department of Defense (USA)		**IFF**	Identification Friend and Foe
DOTMLPF-I	Doctrine, Organization, Training, Materiel, Leadership, and Education Personnel Facilities-Interoperability		**ISR**	Intelligence, Surveillance and Reconnaissance
DSS	Decision Support System		**JADOCS**	Joint Automated Deep Operations Coordination System
DT	Dynamic Targeting		**JCO**	Joint Coordination Order
DyNAMO	Dynamic Network Adaptation for Mission Optimization (Project)		**JEZ**	Joint Engagement Zone
			(COM) JFAC	(Commander) Joint Force Air Component
F2T2EA	Find, Fix, Track, Target, Engage Assess (targeting cycle)		**JTAC**	Joint Terminal Attack Controller
FAOR	Fighter Area of Responsibility		**JOA**	Joint Operations Area
FCAS	Future Combat Air System		**LOO**	Lines of Operation
FCC	Flight Control Computer		**MAIC**	Maritime Air Intercept Controller
FEBA	Forward Edge of Battle Area		**MC**	Mission Computer
FLOT	Forward Line of Own Troops		**MCP**	Mission Capability Package
FSM	Finite State Machine		**MIDS**	Multifunctional Information Distribution System
GBAD	Ground Based Air Defense		**MoE**	Measures of Effectiveness
HIDACZ	Hi-Density Air Control Zone		**MoP**	Measures of Performance
HVAA	High Value Airborne Asset		**MUM-T**	Manned-Unmanned Teaming
HVAAP	HVAA Protection		**NCTR**	Non-Cooperative Target Recognition
IADS	Integrated Air Defense System			

NDPP	Nato Defence Planning Process		**SACC**	Supporting Arms Coordination Centre (Maritime)
NEC	Network-Enabled Capability		**SCL**	Standard Configuration Load
NGO	Non-Governmental Organization		**SD**	Smart Defense (Initiative)
NHTSA	National Highway Traffic Safety Administration (US)		**SEAD**	Suppression of Enemy Air Defences
NIFC-CA	Naval Integrated Fire Control Counter Air Network		**SEZ**	Sensor Employment Zone
			SIGINT	Signals Intelligence
OODA	Observe, Orient, Decide and Act (decision loop)		**TACOM**	Tactical Command
OPLAN	Operational Plan		**TACON**	Tactical Control
OSC	On-Scene Commander		**TAIS**	Tactical Airspace Integration System
PCAS	Persistant Close Air Support		**TBMF**	Tactical Battlefield Management Function
PSA	Priority Shortfall Area (NDPP)		**TDMA**	Time Division Multiple Access
P&S	Pooling and Sharing (initiative)		**TLP**	Tactical Leadership Programme
RECCE	Reconnaissance		**TST**	Time Sensitive Targeting
ROE	Rules of Engagement		**TTP**	Tactics, Techniques and Procedures
RWR	Radar Warning Receiver		**UAS**	Unmanned Aerial System
SAD	Situational Awareness Display		**UAV**	Unmanned Aerial Vehicle
SADL	Situational Awareness Data Link		**WEZ**	Weapons Engagement Zone

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ANNEX B

About the Authors

Lieutenant Colonel Carlos Presa

joined the Spanish Air Force (Ejército del Aire) in September 1987, and he completed an Engineering Degree at the Spanish Air Force Academy, San Javier, in 1992. During these years, he completed Basic Pilot Training in Spain, Undergraduate Pilot Training in the United States, and Fighter Weapons School in the 23rd Wing in Spain.

After nine years flying the Casa 101, the Dornier 27 and the Hornet EF-18 in the 21st Combat Wing (ESPAF), he was assigned as an Instructor to the Spanish Air Force Academy, where he completed two years as Company Officer in the Cadet Battalion, as a Professor and as a Flight Instructor. During this period he also participated in operations over the Former Yugoslavia and attended the Tactical Leadership Programme flying course in Belgium and a Combat Intelligence course in Argentina. He also served in the Balkans CAOC as an Intelligence Analyst for five months during Operation Allied Force.

In 2003, upon promotion to the rank of Major, he was assigned to the Canary Islands Air Force Command Headquarters, as a staff officer. One year later, he reported to Gando AFB to complete a tour first as Logistics, Support and Personnel Officer for the 462 Hornet Squadron and then as Fighter Squadron Commander. After attending the War College in Madrid, he was assigned to the Tactical Leadership Programme at Albacete Air Force Base, working in the Flying Branch (Air-to-Air), responsible for the development and supervision of COMAO missions with integrated operational intelligence play. On several occasions, he also developed and conducted complex scenarios for the Spanish Air Force for the annual Dissimilar Combat Exercise. He also contributed to the development of tactical interfaces and software-based Command and Control applications.

During this period, he served under ISAF in Qala-i-Naw, Afghanistan, as Air DETCO, acting Air Liaison Officer for the Spanish battalion and as Military Airfield Commander and Coordinator, Safety Coordinator and AIP producer. He was then assigned to the Spanish Joint Services War College in 2012 as an Operational Planning Instructor.

Lieutenant Colonel Presa has more than 2,500 flight hours, mainly in combat aircraft. He completed his

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Master's at the Spanish War College with a thesis focused on the Strategic Employment of Literary Discourse. He also holds a second Bachelor's Degree and a Ph.D. in Hispanic Literature and Linguistics. His doctoral thesis is related to the presence of algebraic trends in literary works. Additionally, he has completed several courses in Swedish and Italian.

Captain William A. Perkins

is a native of South Windsor, CT. He graduated from Maine Maritime Academy with an Unlimited Third Mate's Licence, and was commissioned through the Naval Reserve Officer Training Corps program in April 1994. He reported for aviation training in April 1995 and earned his wings in July 1996. After initial training in the P3C Orion airframe, he reported to Patrol Squadron FOUR (VP-4) in January 1997. During this tour, he earned his initial qualifications as a Patrol Plane Instructor Tactical Coordinator and Mission Commander, completing two deployments in support of US FIFTH FLEET operations.

In May 2000, Captain Perkins reported to Tactical Support Center, Sigonella, Italy. While assigned, he earned qualification as a Weapons and Tactics Instructor through the Orion Weapons/Tactics Instructor (WTI)

course in May 2001. Additional duties included combat operations over Kosovo and off the African coast and preparing the groundwork for Intelligence, Surveillance and Reconnaissance (ISR) missions in Iraq from bases in the Mediterranean in support of OPERATION ENDURING FREEDOM. During this tour, he was awarded the Copernicus Award for advances in C4I mission areas. Captain Perkins next reported to USS JOHN F KENNEDY (CV-67) as Operations Administration Officer and Officer of the Deck.

In September 2005, Captain Perkins reported back to VP-4 for his department head tour. He completed a deployment serving as squadron Operations Officer, supporting Joint Special Operations Task Force, South and US SEVENTH FLEET theatre ISR and Anti-Submarine Warfare missions. Captain Perkins next reported to US Strategic Command's Joint Task Force Global Network Operations in November 2007. Initially he served as the Deputy Chief of Staff, finishing this tour as Chief of Plans and Strategy and was selected as the Field Grade Officer of the Year for 2008.

He next served as Commanding Officer of Tactical Air Control Squadron ELEVEN, overseeing detachments assigned to 4 separate Pacific deploying Expeditionary Strike Groups. His command earned both the Naval Unit Citation for performance supporting

classified missions in the Middle East region and also the Golden Anchor award for excellence in retention. Following his command tour, he reported as Navigator, USS GEORGE WASHINGTON forward deployed to Yokosuka Japan, where he planned and executed 4 deployments spanning 85,000 miles of travel in and around the Western Pacific. Additionally, Captain Perkins was the first ever aviator to earn recognition as honor-graduate from the Surface Warfare Officer School (SWOS) Navigators School in Newport, Rhode Island.

Captain Perkins' personal awards include the Defense Meritorious Service Medal, Meritorious Service Medal (2 awards), Navy and Marine Corps Commendation Medals (three awards), Joint Service Achievement medal, Navy and Marine Corps Achievement Medal (four awards) and various unit awards and campaign medals. He has accrued more than 2500 hours in the P-3C Orion.

Captain Perkins is a graduate of the US Joint Forces Staff College and holds a Masters degree in Strategic Foresight from Regent University (2011). He has numerous published works, including articles on naval and maritime affairs published in the US Naval Institute's Proceedings Magazine, Janes International Defense Review, Janes Naval Review, and Janes Defense Weekly, JAPCC's Air and Space Power Journal as well as a Forecast for Maritime Air Anti-Submarine Warfare challenges for NATO.

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