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TRANSFORMING MILITARY AEROSPACE SUSTAINMENT

David Holmes, Andrew Goodwin, Roger Vodicka
Defence Science and Technology Group, Australian Department of Defence

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Abstract

'The RAAF are now looking at how not just to modernise the force; but to transform it.' - *AVM (Retired) John Blackburn. Plan Jericho calls for a fundamental transformation in the way the Royal Australian Air Force (RAAF) acquire and sustain capability. Defence's future sustainment capabilities will exist in an environment characterised by highly dynamic technical, social, economic and environmental forces. This will require people, infrastructure and processes to adapt and innovate in an on-going manner at unprecedented rates. But how might this be achieved? This paper considers this sustainment enterprise architecting question through the lens of complex adaptive system theory and practice.*

1 Introduction

The Royal Australian Air Force (RAAF) is seeking a transformational change to the way it operates. The requirements for this change are reflected in Plan Jericho [1] and have been re-iterated and expanded in the recent Defence White Paper [2]. The goal is to develop a future force that is innovative, agile, adaptive, fully immersed in the information age, and truly joint.

Plan Jericho, released by the Chief of Air Force in 2015, contained three transformation themes:

- Harness the potential of an integrated force
- Develop an innovative and empowered workforce
- Change the way we acquire and sustain capability

With regard to its sustainment capability it further expanded its guidance to state that RAAF requires more agile in-service support arrangements that integrate global supply chains and domestic engineering, maintenance and logistics capabilities.

The Defence White Paper released in 2016 provides a similar commentary. It demands that Defence is a more capable, agile and potent force that is capable of conducting independent combat operations in our immediate region and making contributions to global coalition operations. With regard to Defence posture it specifies a requirement for higher preparedness, greater capacity, agility and sustainability.

These aspirations raise quite a complex system architecting problem: How does the Australian Department of Defence and the RAAF in particular, change the sustainment enterprise to make it more agile, innovative and adaptive? The words agility and adaptation inspire visions of evolutionary biological systems and a consequential link to complexity theory. This paper considers this sustainment enterprise architecting question through the lens of Complex Adaptive System (CAS) theory and practice.

2 Introduction to aircraft sustainment

Sustainment can be considered from a number of interconnected perspectives:

1. As an element of the capability development cycle
2. From the perspective of the Integrated Logistics activities and resources
3. As a part of the capability via the sortie generation process

2.1 Sustainment and the capability development cycle

The capability development cycle as defined by the Defence Capability Handbook [3] consists of five interconnected phases in the notional life-cycle of a military aircraft as shown in Figure 1.

Figure 1: The capability development cycle [3]

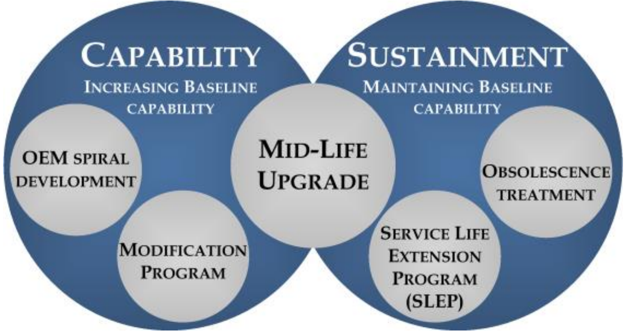
The first step in the process is the articulation of a need. This is achieved through the consideration of strategic guidance, capability goal definition, development of programs and plans that demonstrate how the organisation will be transformed in the future, and assessment of the performance of the planned force against future threats. Capability requirements are then articulated from the previously identified need. This translation occurs via a systems engineering process culminating in three artefacts; an Operation Concept Document, a Functional Performance Specification and a Test Concept Document. These documents form the basis for an approach to market for solutions, and a best value solution is acquired.

During the in-service phase, the selected aircraft is transitioned to service after Operational Test and Evaluation to ensure that it meets the identified need and performs to the agreed operational requirements. Operation and sustainment of the vehicle are considered to be part of the in-service phase, typically the longest and most expensive phase of the capability development cycle (typically around 30 years and 70% of the total cost). During this phase the capability manager undertakes continual needs and requirements analysis to ensure that the acquired capability remains well suited. This process may highlight the need for major capital investment in the form of upgrades. At the end of their useful life, the aircraft is withdrawn from service and disposed of or redeployed depending on the nature of the individual vehicle.

Aircraft upgrades can occur for two purposes: capability and sustainment (Figure 2). A capability upgrade is any modification that increases the baseline capability of the aircraft (such as upgrading the radar to a new type). Upgrades of this type include:

- Original Equipment Manufacturer (OEM) block and spiral programs
- system specific modification programs
- mid-life upgrades

Figure 2: Aircraft upgrade terminology [4]

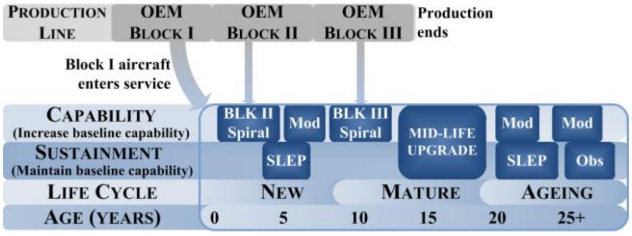


Sustainment upgrades are designed to maintain the baseline capability while decreasing the sustainment burden or extending the service life of the platform (such as structural fatigue life extension). Upgrades of this type include:

- Service Life Extension Programs (SLEP)
- obsolescence treatments
- mid-life upgrades

Timing of these upgrades relative to the life-cycle is illustrated in Figure 3 for a hypothetical Block I aircraft. It can be seen that early in the life-cycle (the 'new' phase) upgrades tend to be capability focused, and as an aircraft ages (the 'mature' phase) both capability and sustainment upgrades are required to maintain system performance and serviceability. At some point in the life-cycle a major mid-life upgrade is often required to ensure the capability remains viable. The later ageing phase is often associated with life extension programs, obsolescence treatment and sustainment changes.

Figure 3: Upgrade timeline for a hypothetical Block 1 aircraft [4]



The move to global sustainment arrangements powered by large global maintenance, repair and overhaul (MRO) organisations has been occurring for decades in the commercial aviation sector and has transformed how and where sustainment services are delivered. Similarly in the military sector, the trend towards leveraging economies of scale across many international military operators has become more common. The RAAF has entered into a number of these agreements including the C-17A Globemaster Integrated Sustainment Program (GISP) which delivers comprehensive sustainment support by Boeing, the C-17A's OEM. These arrangements and other future arrangements such as the Joint Strike Fighter Autonomic Logistics Global Sustainment (ALGS) system are designed to deliver effective and efficient sustainment to a number of international military customers operating under the same arrangement. Managing the assets and outcomes under these arrangements relies heavily on the ability of the operator to understand and leverage the full range of services that are offered. In some sustainment arrangements, the full extent of integrated logistics support can be delivered by a commercial sustainment provider. These arrangements are however typified by a large number of interacting stakeholders that need to work collaboratively in order to deliver effective outcomes.

2.2 Sustainment in terms of the Integrated Logistics Support plan

Sustainment within the In-Service phase of the capability life-cycle can be defined in terms of the Integrated Logistics Support (ILS) plan. This document typically describes the full range of sustainment activities and resources required, some of which are defined briefly below.

Personnel includes the workforce required to support all operations and maintenance of the aircraft. The workforce typically consists of military and civilian (government) personnel, and contractors.

Maintenance Support includes all aircraft maintenance activity and is typically organised into three distinct classes; operational maintenance, intermediate maintenance and deep maintenance.

Operational Level Maintenance is the maintenance that occurs regularly for each aircraft and immediately affects sortie generation. This maintenance is typically carried out by RAAF personnel, although for some weapon systems this function is contracted. The specific maintenance actions may be in common with foreign militaries operating the same aircraft type.

Intermediate Level Maintenance is typically a deeper diagnostic step between the rectification activities of operational maintenance and component deep maintenance. The rise in on-board aircraft built-in-test (BIT) capability has resulted in much of the intermediate maintenance test and diagnostic capability being removed in favour of just operational and deep maintenance.

Component Deep Maintenance includes repairing faulty aircraft components sent from either operational or intermediate maintenance and conducting periodic inspection or overhaul of some sub-systems. This maintenance is often carried out via support contracts or Foreign Military Sales (FMS) cases with the aircraft type's parent military, typically the United States Air Force (USAF) or United States Navy (USN).

Aircraft Deep Maintenance includes whole of aircraft heavy inspection and rectification tasks. Typically these are long periodicity, long duration activities involving major disassembly of the aircraft. Aircraft modification and upgrade activities are often co-located with aircraft deep maintenance because of the time and efficiency benefits that can be gained. RAAF aircraft deep maintenance typically occurs in Australia but can take place overseas at OEM or parent military facilities.

Supply Support includes ongoing procurement of spare parts, supply chain management and modelling, spares accounting and spares contract management. This is typically a mix of local supply chains and overseas support through contractors and FMS cases.

Information Systems includes corporate and maintenance management systems, operational environments, databases and networks. These systems can be owned and managed by the RAAF, the wider Australian Defence Organisation, support contractors, or foreign militaries and governments.

Engineering Support consists of activities to ensure the maintenance of airworthiness, configuration control, aircraft software support, stores clearance and occupational health and safety. This support is provided by a diverse range of organisations much like Information Systems.

Technical Data and Publications constitute the technical documentation that provides instructions to the operators and maintainers. These are typically provided by the OEM and may be common with other militaries or customised due to local operating environments and regulations.

Training Support covers training equipment such as simulators and computer based training devices, syllabus and courseware. It can also include contracted training services up to and including the conduct of flight, mission and maintenance training. Training can be provided by RAAF personnel, Australian government personnel, local contractors or foreign militaries and their contractors.

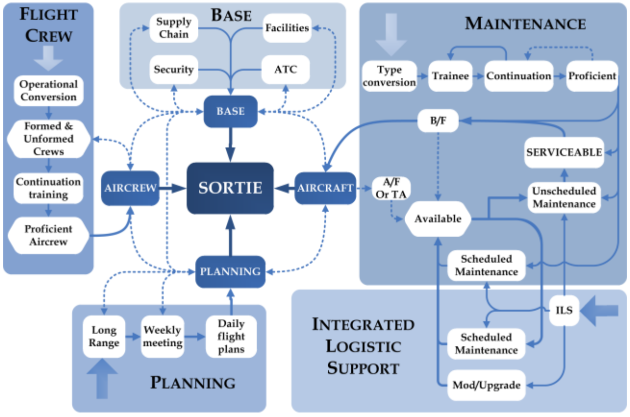
While there are varieties of personnel within many of these activities, individuals frequently spend the majority of their careers associated with particular organisational units, aircraft types or specialisations.

2.3 Sustainment as an element of sortie generation

During the in-service phase of the capability life-cycle, sortie generation is the process through which military aircraft are prepared and launched. This process involves a number of closely interconnected elements interacting at specific times. The elements required are; a mission plan, a suitably trained and briefed aircrew, a suitably configured mission capable aircraft and a series of air base services including air traffic control (ATC), security and emergency services.

A rich picture of the sortie generation process is shown in Figure 4. The elements of the sortie generation process that would be considered aircraft sustainment tasks have previously been discussed and are shown here in the Base, Maintenance and Integrated Logistics Support areas.

Figure 4: The sortie generation system [4]



Sortie generation as a process operates over a short time cycle. The sustainment system can generate up to several sorties per day with sortie durations ranging from less than an hour to over 12 hours, with a rhythm defined by the flying program.

3 Complex Adaptive Systems

The reductionist view of systems requires that system level behaviour can be explained and therefore predicted by the actions of the system's individual components. For many systems, this view provides a lens through which analysis can be conducted. However, the reductionist method is insufficient when systems exhibit behaviour that cannot be explained using decomposition alone. These systems are typically defined as Complex Adaptive Systems.

The Royal Australian Army recognises that military capability can be viewed as a CAS. The following definition of a CAS can be found in the Army's Future Land Operating Concept [5]:

> *".. a complex adaptive system is an open system in constant interaction with its environment. Its capacity to adapt to environmental change emerges from the collective behaviour of all the parts in the system interacting locally in response to local conditions and incomplete information. Complex adaptive systems are proactive, innovative and learning systems that exhibit agility, flexibility and resilience."*

There are many perspectives and nomenclature in the literature on the defining characteristics of a CAS. For our purposes, we turn to those described in the context of the Australian military by Grisogono and Ryan [6], who in turn used the seven properties of a CAS defined by Holland [7].

- Aggregation (often labelled emergence) – system level behaviour emerges from aggregate interactions of components
- Building blocks (often labelled agents) – hierarchical components that are assembled to generate a system level behaviour
- Diversity – diversity must exist across the system elements, the interactions between which provide opportunity for specialisation
- Non-linearity – behaviour of the system is more complicated than a linear combination of the parts (for example due to feedback and temporal mechanisms)
- Tagging – system elements require attributes to allow identification and tailored interaction
- Flows – system elements interacting with each other can be viewed as nodes of a network. These interactions can be represented by flows of information and resources between the nodes.
- Internal models – models for the anticipated behaviours of a system element in response to incentives

4 Is the RAAF's sustainment system a CAS?

As concluded by Grisogono and Ryan [6], a military can be viewed as a CAS. The RAAF's sustainment system can also be viewed as a CAS because it exhibits Holland's seven properties, which are described in more detail below.

One of the goals of the RAAF's sustainment system is to generate serviceable aircraft. The number of serviceable aircraft on any given day is the aggregate result of the intended flying program, size and skill of the maintenance workforce, sparing posture and inherent reliability of the aircraft. The aggregation of the system elements that results in the number of serviceable aircraft is demonstrated by the following example:

The commanders and aircrew have a target number of serviceable aircraft they need in order to, with some level of confidence, complete the flying program. The setting of their target is influenced by their previous experience and understanding of how many aircraft can typically be made serviceable by the maintenance organisation. The maintenance organisation works towards meeting this target and in doing so reinforces the target and/or informs future targets.

Building blocks can be found at multiple levels in the sustainment system. At the highest levels there are personnel, materiel and infrastructure blocks, and these can be broken into smaller components. The personnel block is made up of military, civilian and contractor workforces. These can be further divided by rank, seniority, trade and skillsets through to individual people. These personnel can staff morning and afternoon shifts at the home base and be recombined to concurrently support exercises and overseas deployments.

The sustainment system exhibits diversity across many dimensions. Roles and responsibilities of organisations and people range from maintenance, warehousing, configuration control to engineering services. There is also great diversity across staff experience, qualifications and culture. These dimensions apply to a workforce that is itself made up of a diverse range of organisations, including the RAAF, Australian Public Service, and local contractors, with support from foreign governments and their militaries and contractors. Paradoxically, through increased commonality of aircraft with allied partners the RAAF gain greater diversity in their sustainment system via global support and FMS cases.

Non-linear effects are evident in the sustainment system whenever the system's capacity is saturated, at which point queues begin to form. These queues may contain aircraft or components requiring repair, documents requiring processing, or personnel requiring training. Therefore reducing capacity past a certain point leads to non-linear effects. For common aircraft, integrating the RAAF's sustainment system with allied partners could see RAAF aircraft supported from any number of allied air bases. In this instance, the additional effort associated with integration provides a non-linear effect on deployability.

Tagging can take a visual form in the RAAF through shoulder boards, badges, ribbon bars and role specific attire. Tagging exists for all personnel throughout the sustainment system via job titles, qualifications and pay grades. Tagging is also used for aircraft (tail numbers), materiel (part and serial numbers) and processes that can only be undertaken with a specified combination of tagged personnel and materiel.

Flows of personnel, materiel and information are abundant in the RAAF's sustainment system. The following simplified sortie planning example demonstrates a sample of these flows.

1. A commander describes a desired military effect to aircrew (flow: information)
2. Aircrew plan the mission and generate requests for aircraft in a specific configuration (flow: information)
3. Flight-line and armament personnel work together to configure an aircraft for flight and send demands for parts to the logisticians (flows: personnel, materiel and information)
4. Logisticians convert those demands for parts into new supply (flows: information and materiel)
5. Aircrew accept the aircraft from flight-line personnel (flow: materiel)

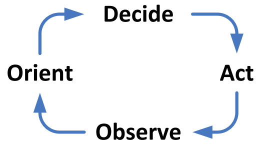
In the real-world sustainment system, the flows between system elements adapt in order to meet changing priorities, failures and parts shortages. Flows may also be redesigned through maintenance productivity reviews or transitioning to contracted support.

An internal model can be seen in the maintenance organisation's response to a serviceability target. The organisation will allocate people and materiel then undertake a set of activities in order to meet the target. The allocations and activities are motivated by the pride in meeting the organisation's expectation and avoiding blame for disrupting the flying program. This internal model will adapt as the maintenance organisation matures or as the aircraft ages and become less reliable.

5 The military viewed through a complexity lens

John Boyd recognised the complexity present in air to air combat and developed the OODA loop [8]. OODA is an acronym for a four stage iterative decision making process, and can be generalised into a process through which an actor interacts with their environment (Figure 5).

Figure 5: The simplified OODA loop [8]

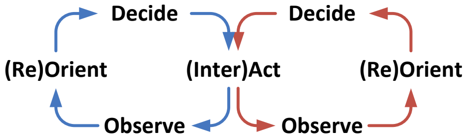


The four stages of the OODA loop are described briefly below:

- Observe: Collection of information about the decision maker’s environment
- Orient: Analysis of the observed information to generate knowledge about the environment
- Decide: Planning a course of action based on the most important knowledge gained in the orient stage
- Act: Realising the course of action (then restarting the loop to observe for possible changes in the environment)

The iterative nature of the OODA loop demonstrates that Boyd appreciated an enemy pilot would also adapt based on the actions of a friendly pilot. Murphy [9] recognised that in the generalised form, the diagram in Figure 5 and in its more detailed representation in Osinga [10] shows how an actor interacts with the environment, but not how the environment interacts with the actor. The environment itself consists of actors also making decisions through an OODA loop, and Murphy offers the interacting OODA loops to explicitly make this point (Figure 6).

Figure 6: Interacting OODA loops [Murphy]



This concept is well known to the RAAF’s aircrew community as it forms the basis for many training and exercise scenarios.

The Australian Army Adaptive Action model (Figure 7) is a similarly recursive decision model but initiates the cycle slightly differently, by specifying that the first step is act, followed by sense, decide and then adapt.

Figure 7: Australian Army Adaptive Action model [5]

a. Act: Initially as a Discovery Action with the aim to test or confirm the understanding of what is happening followed by Decisive Actions having developed sufficient understanding to commit to a course of action.

b. Sense: Initially learning to see what is important about the unfolding situation followed by learning to measure what is important in terms of appropriate Measures of Effectiveness for the situation.

c. Decide: Based on an incomplete understanding of the problem and having acted to stimulate the environment and sense the response, understand what that response means, what the potential ramifications are and decide what should be done.

d. Adapt: Identifying successful approaches in new situations and spreading them to other organisational elements, bearing in mind their possible limits of applicability.

6 Potential interventions in light of the CAS theory

Axelrod and Cohen [11] speak of the balance between exploration, which provides the opportunity to try new approaches and exploitation, which sees incremental improvements and efficiency. Clearly, both are required within a military sustainment system and the challenge for military leaders is to find the right balance. Plan Jericho and the Defence White Paper call for more adaptive and innovative methods of sustainment, and correspondingly a somewhat greater bias toward exploration. If this bias is considered from a CAS perspective, then Plan Jericho requires the sustainment system to be encouraged to grow in a different direction (rather than redesigned).

Axelrod and Cohen's guiding elements for navigating complexity, namely variation, interaction and selection, provide some insights into how an adaptive system might be changed or modified.

- Variation: Identifying and exploring variation provides opportunity for adaptation
- Interaction: The rules governing how system elements relate to one another
- Selection: Selecting and acting upon a new variation or rule to promote adaptation

Rebovich [12] proposes that appreciating the problem space using these elements helps the designer answer the following questions:

1. What is the right balance between variety and uniformity?
2. What should interact with what and when?
3. What should be copied or rejected?

Noting the guiding principles for harnessing complexity from Axelrod and Cohen, how might adjustments be made to variety, interaction and selection to adjust the balance between exploration and exploitation within the RAAF sustainment system?

6.1 Variety

The discussion in Section 2 demonstrates that the sustainment system is very diverse in its activities and that in the current system roles are staffed by either military or civilian defence personnel or contractors. Additionally the current system is highly stove piped by platform types with comparatively small flows of personnel between platforms. In part this is to ensure that activities associated with staffing the sustainment systems are as efficient as possible. An increase in variety at the individual agent level (airmen, officer, civilians and contractors) could be gained by encouraging more movement through roles within the platform sustainment system, particularly early in careers. Additionally, more exposure to other platform sustainment systems should be encouraged to enable greater understanding of how other systems undertake similar activities. Career progression could be linked with the requirement to gain this broader experience, reinforcing that broad experience is desirable. Finally, more formal experimentation could be carried out at various levels in the sustainment system through sustainment wargames and exercises. These could be used to explore the strengths and weaknesses of a variety of approaches to sustainment of wartime scenarios, sustainment concepts and contract structures. This would provide an opportunity for the agents to experience working under greater uncertainty and to become experienced and comfortable with iterative planning approaches (similar to aircrew). These activities would also provide an increase in variety of potential sustainment strategies.

6.2 Interaction

The discussion in Section 2 outlined how the sustainment system is highly heterogeneous and clustered, and consequently interaction is somewhat constrained. This presents an opportunity to tip the balance more toward exploration by increasing interaction within and across the system. Constraint of interaction within a CAS can be considered in terms of proximity (how likely is it that agents will interact) and activation (what is the sequence and timing of an interaction).

Proximity could be addressed at various hierarchical levels within the sustainment system. At the Force Element Group (FEG) or platform level, proximity barriers could be reduced through more joint platform exercising and wargaming such that organisational elements are exposed to the approaches of other groups in a context where they need to work together. At the agent level, exchanging staff in similar roles between FEGs would provide the agents with exposure to alternative strategies.

Activation barriers could be addressed in similar ways. At the platform level, the differing battle rhythms within the sustainment systems of multiple platforms will become clearer when jointly exercising and wargaming. This would help synchronise capabilities and clarify opportunities for adaptation. At the agent level, the posting cycle and positions that personnel are posted into will determine the order, amount and depth of experience gained by the individual actors.

6.3 Selection

Axelrod and Cohen suggest that identification of selection criteria is a very powerful means of adjusting the balance within a CAS and these criteria are important at the agent level (individual airmen, officers, civilians and contractors) and at the strategy level (the individual and organisational approaches used). As discussed previously, to adjust the balance more toward exploration, agents could be encouraged through promotion and other forms of recognition to have a broader experience and to explore novel approaches enabled through analysis, exercising and wargaming. Selection at the strategy level would require systematic development and evaluation strategies in terms of their advantages, disadvantages and limits of applicability.

7 Conclusion

The recent Defence White Paper and Plan Jericho require that the RAAF transform to be more agile, innovative, adaptive and resilient. It’s therefore critical that the RAAF’s sustainment system support these requirements. In order to understand the system and individual level responses required to meet these new requirements, the sustainment system has been viewed through the lens of complex adaptive systems. This view identified several important considerations, particularly the tension between exploration and exploitation. CAS theory suggests that in order to increase bias toward exploration, there needs to be an increase in variety and interaction at the agent level. In the RAAF context, this could be achieved by exposing personnel to more roles throughout the sustainment system and greater rotation between platforms. Additionally, analysis and wargaming of alternative sustainment options and a focus on joint wargaming using recursive planning approaches such as OODA loops and the Australian Army Adaptive Action model will help to enhance agent experience. These recursive approaches will also produce a broader range of strategies to seed adaptation. Finally, selection of agents and strategies needs to be made with a bias more toward exploration to enable adaptation, rather than exploitation and its associated focus on efficiency.

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Contact Author Email Addresses

David.Holmes@dsto.defence.gov.au
Andrew.Goodwin@dsto.defence.gov.au
Roger.Vodicka@dsto.defence.gov.au

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