Air Defence Systems Development – The Systems Engineering Challenge

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ABSTRACT

The range of threats facing an Air Defence System, and the nature of the system itself (integrating a number of different sub-systems each of which could operate in its own right and which are possibly physically dispersed) puts such systems into the class called a 'System of Systems'. Many of the traditional Systems Engineering methods, used for systems on any scale, are equally applicable to Air Defence Systems. However, the nature of the Air Defence System means that there are a number of special considerations to be made during design and development, some of which affect the Systems Engineering process and methods. In this paper these considerations will be outlined and their influence on the design and development methods illustrated, using the example of an Air Defence System.

1.0 INTRODUCTION

Effective Air Defence requires the integration of a number of sub-systems. Each sub-system will be developed under its own programme, and each will probably be at different stages of their life-cycle. The subsystems are also likely to be physically dispersed about the area to be defended.

Such a system can be classed as a 'System of Systems', and although most of the traditional methods used in Systems Engineering for any other class of system will be applicable, there are special considerations for this class of system. A phased, incremental acquisition process is required, and systems should have adaptable architectures, capable of growing to accommodate new threats or technologies. Sub-systems will be developed at different times to each other, and operational and training issues as important as technology issues.

Failing to consider these issues in the development of an Air Defence system will, at best, result in an inefficient system and excessive system cost. At worst the Air Defence System will be ineffective and may result in inadequate defence.

In order to develop effective Air Defence Systems within an efficient project process it is necessary to take the issues relating to System of Systems development into consideration and to adapt the traditional Systems Engineering process accordingly. To achieve this an understanding of the nature of Air Defence Systems and of the evolving threat faced must be developed, and an awareness of the special considerations for this system class must be attained.

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2.0 THE NATURE OF AIR DEFENCE SYSTEMS

Current air defence doctrine employed by a number of NATO member countries consider air defence to consist of three aspects:

Active Defensive Counter Air (A-DCA)

Active Defensive Counter Air tasks are performed in response to a direct, immediate threat from enemy air assets. An incoming attack must be detected, the nature of the threat identified and understood, an appropriate counter planned, and the relevant action taken. This is the traditional view of air defence, long range sensors detecting an incoming bomber raid or the approach of missiles, and controllers vectoring fighter aircraft to intercept or allocating Surface to Air Missile batteries to engage.

Passive Defensive Counter Air (P-DCA)

Active air defence measures are unlikely to be 100% effective (unless overwhelming air supremacy has already been attained), so some attacks by enemy air assets will be successful. Passive Defensive Counter Air measures are used to minimise the effects these enemy raids might have. Key facilities are hardened and protected, and may be duplicated or otherwise backed up by use of redundancy. Camouflage, Concealment and Deception may be used to prevent direct attacks on likely targets, supported by an effective civil defence organisation to provide fire-fighting, medical, rescue and recovery services.

Offensive Counter Air (OCA)

The third element of air defence, Offensive Counter Air, involves removal or degradation of the enemy's air strike capability through direct action. Offensive air attacks are made against enemy air assets over their own territory or at their own operating bases. The bases themselves, as well as supporting facilities such as repair, spares and fuel, or even the aircraft industry may also be targeted. Whereas the DCA elements are essentially reactive in nature and possibly involve the use of defensive weapons, OCA operations are pre-emptive and involve the use of offensive, strike weapons.

When an Integrated Air Defence System is considered, it is usually the elements of an Active Defensive Counter Air capability that are actually included. For a truly Integrated Air Defence capability the Passive DCA and OCA aspects must also be included.

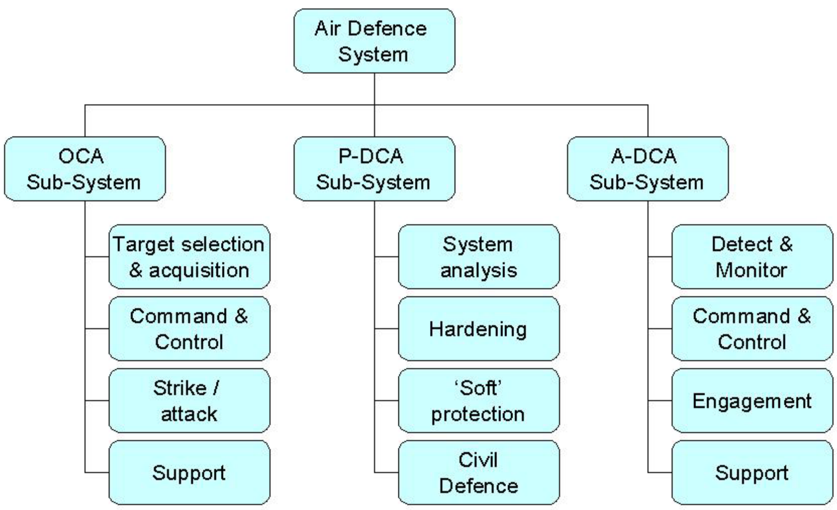

Figure 1: Components of a Truly Integrated Air Defence System.

Integration implies that the elements of the overall air defence system must be co-ordinated to achieve the desired capability. Just as the elements of a 'branch' of the air defence system must be integrated, so must the elements within each branch be integrated to the other branches to achieve full effect. Notice that in Figure 1 Support is considered to be a key element of both the offensive and defensive branches. Support would include logistics, spares, maintenance and staff training, all of which are essential to sustain air defence capability and should be an integral part of an Integrated Air Defence System.

An Active Defensive Counter Air system will consist of sensor systems to detect and monitor the airspace of interest. Command and Control elements will direct the operations of the weapon systems in response to the observations made by the sensor systems (and, indeed, co-ordinate the operation and deployment of the sensors). The defences themselves will also be layered, providing 'Defence in Depth', longer range detection and engagement systems being backed up by mid-range systems, themselves supported by Short-range Air Defence (SHORAD) assets (Figure 2). The operations and hand over of targets between these layers must also be co-ordinated, by the Command and Control function.

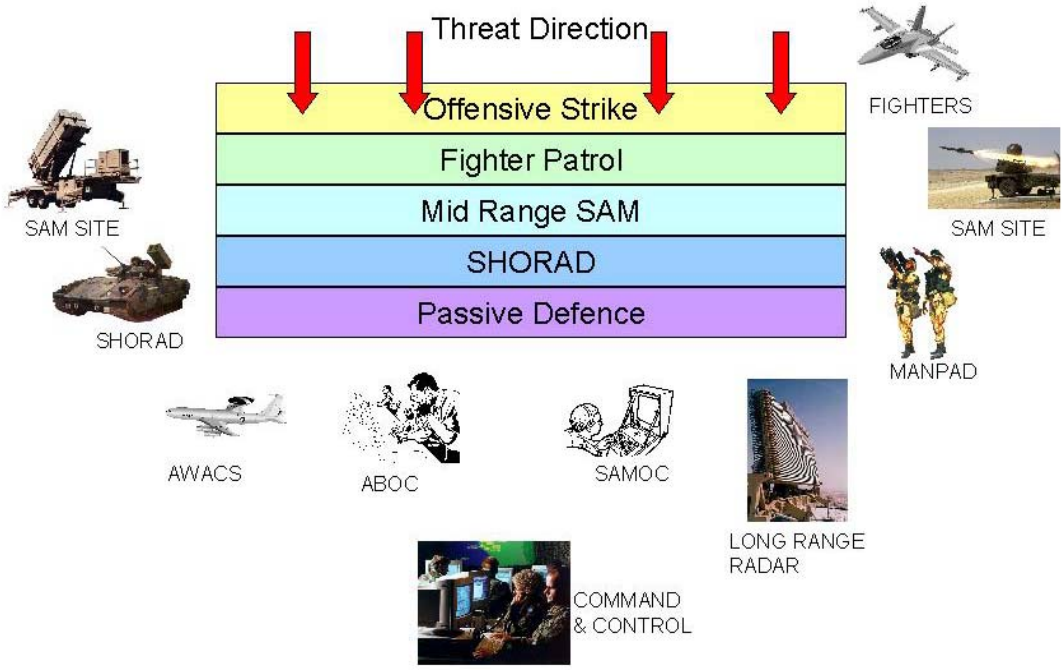

Figure 2: Layered Defence, Requiring Integration Within and Between the Different Layers.

The A-DCA elements must also be integrated with the efforts of the OCA and P-DCA elements. Operations undertaken by the offensive systems must be notified to the A-DCA systems, to ensure own forces are not engaged. The threats posing greatest problem to the active defences might be identified as targets to the Offensive Counter Air system. Civil defence organisations must be informed of impending attacks, as detected by the active defence sensor systems.

In summary, an air defence system consists of a number of individual elements, including sensors, weapon systems, communications networks, Command and Control and support. The elements must be co-ordinated to provide a sustainable and layered defence system, and must provide active defensive, passive defensive and offensive operations, with the intent of restricting, if not removing, the enemy's ability to hinder our own operations through the employment of their air assets.

3.0 EVOLVING AIR THREATS

3.1 Traditional Threats

The traditional threats facing air defence systems have included manned, air-breathing platforms and ballistic or cruise missiles. A combination of Defensive and Offensive Counter Air operations countered the manned aircraft. Operations against missiles were somewhat restricted, both due to the nature of the technologies that would be required to detect, track and engage high-speed targets and due to limitations imposed by various nuclear control treaties. Anti-missile systems were developed for naval platforms, in the form of missile systems capable of engaging anti-shipping missiles such as Sea Wolf, or Close In Weapon Systems such as Phalanx.

3.2 Emerging Threats

Over recent years the nature of the threat facing an air defence system has evolved from the conventional bomber aircraft and the ballistic or cruise missile. Whilst these threats still exist, additional threats and changes to the nature of the threats make the air defence task more demanding.

Low Observability or 'stealth' technologies have now become established, and whilst true stealth capability remains expensive and, hence, the realm of super-powers, the techniques are being applied to more and more platforms to create lower observability, if not low observability. Stealth techniques and technologies are being introduced to new aircraft designs, but are also applied to platforms such as cruise missiles, which already had small signatures.

Ballistic and cruise missile technologies are becoming more prolific, with a number of nations actively pursuing longer-range missile capabilities. Availability of such platforms as the Scud-B has allowed their deployment with a range of warheads, and has led to development of the missiles in a quest for greater range or payload capability. Possession and development of ballisic missiles remains relatively expensive, though, and a potentially greater threat is posed by the much cheaper cruise missile. Missiles may be based on current missile bodies, such as anti-shipping missiles, or may even be developed from scratch (possibly including low observability techniques) with small gas-turbine engines providing power. Low-cost GPS, inertial navigation and even digital map based terrain following systems can be developed and incorporated to produce effective, affordable cruise missiles.

Similar techniques are making Unmanned Air Vehicles available for reconnaissance or even weapon delivery. UAVs range in size from the large, highly sophisticated Global Hawk strategic reconnaissance platform through to small observation or armed 'toy' aircraft.

The events of 11th September 2001, where scheduled passenger aircraft were hijacked and used as weapons in attacks within the United States, have shown how much the air defence threat has changed. An earlier indication that non-conventional threats might require consideration came in May 1987 when Mathias Rust, a West German citizen, flew a light aircraft across Soviet territory and landed in Red Square.

In recent years the major powers have concentrated on development of sophisticated, but very expensive, weapon delivery and reconnaissance platforms, epitomised by the F-117A and B-2 stealth aircraft. Although highly capable as a weapon platform, and very difficult to detect and engage, the sheer cost of these platforms means that they will be deployed in limited numbers. Offensive capabilities are supplemented by cruise and ballistic missile developments, and the effectiveness of platforms enhanced by the use of precision guided munitions.

More recent trends, though, have shown the development of missile technologies in greater numbers, the employment of chemical, biological or nuclear warheads in theatre missiles, and the use of unconventional platforms, including hijacked airliners, for attack. A much greater range of threats, using large numbers of delivery platforms, capable of approaching from any direction, characterise the evolving threat faced by air defence systems. Unless these developments are accommodated in the development of future air defence capabilities, the defences could readily become overwhelmed or saturated.

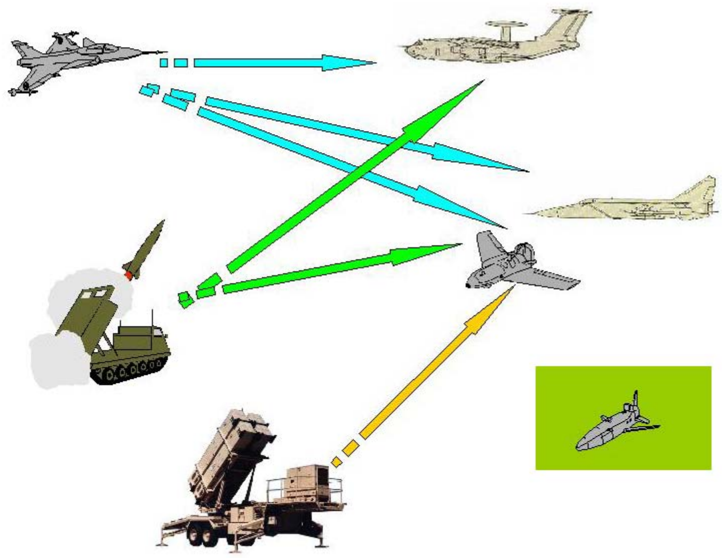

Figure 3: Example of Saturation – Duplication of Engagement and Leakage with the Highlighted Target not Being Engaged.

As a result a diverse range of sensor types, covering a large geographic area, is required to detect the threat. The sensors must be networked and the resulting compiled air picture available to controllers and weapon system operators alike to ensure timely engagement. System architectures must be flexible, to allow future growth and the introduction of new technologies.

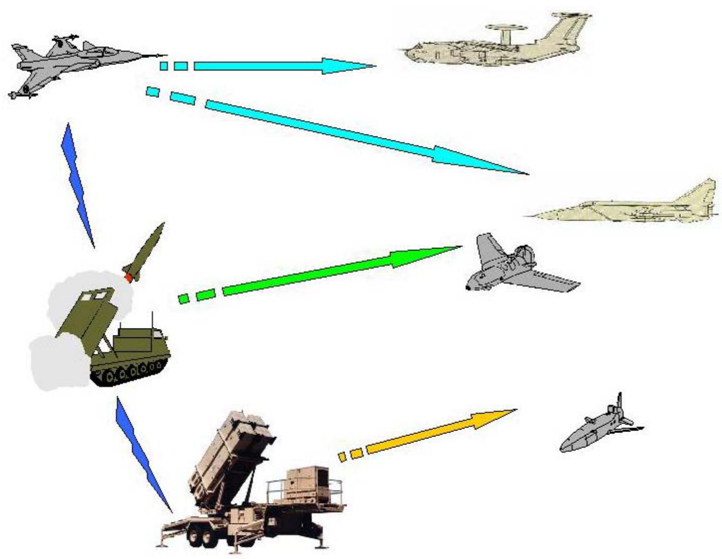

Figure 4: Example of Co-ordination of Effort – Minimise Leakage and More Efficient Engagement.

4.0 ISSUES FOR AIR DEFENCE SYSTEMS ENGINEERING

We have already seen that modern, integrated air defence systems involve the co-ordination of activities of a wide variety of different systems and organisations that could act independently. Such a system can be classed as a 'system of systems', for which the general Systems Engineering methods are applicable, but which require attention to four particular system architecting principles [Ben-Asher, 2004; Maier, 1998]:

1) Stable Intermediate Forms of the system allow a more rapid evolution of the overall system. Full operation of the air defence system is not necessarily a sensible first step, and it is likely to be more cost-effective and efficient in the long run to allow elements or sub-systems to be developed and to commence operation independently of the rest of the system.

2) It is not possible for the teams developing one aspect of the overall air defence system to exert influence over all aspects of the overall system. A Responsibility Sharing Policy should clearly identify those aspects of development that are the responsibility of a particular team or organisation, and those aspects for which there is a collective responsibility.

3) Whilst the air defence system is composed of a number of sub-systems that could operate independently of each other if required, the air defence effect comes from the sub-systems operating collaboratively. In order to achieve this careful attention must be given to the interfaces (physical as well as functional) between the diverse elements.

4) There should be incentives to allow co-operation between the elements of the overall air defence system. Whilst co-operation can be enforced when all of the elements of the system fall under the same command authority, where this is not the case there should be clear benefits for both parties to ensure that collaboration takes place. (This principle is more of an issue for civil systems of systems such as the Internet or public transport. The consequences of failure of an air defence system should be sufficient incentive to co-operate.)

The overall systems architect for the air defence system (or, for that matter, any system of systems) is responsible for ensuring a number of different, geographically dispersed systems, each capable of operating in isolation, can collaborate to produce the required effect for the total system.

Overall, an air defence system would tend to be large and expensive, which presents the first issue affecting Systems Engineering for this class of systems:

No nation would be likely to afford to develop an entire Integrated Air Defence System that would meet their requirements, and so a phased, incremental upgrade to existing systems would be followed.

This results in constraints being imposed on any system development activities (or non-functional requirements, in Systems Engineering terminology). New requirements or capabilities must be met whilst ensuring the existing systems and organisations can still operate and provide the services previously available. Developments tend to be incremental in nature, with new requirements being met through additional capabilities or modifications to existing systems, rather than a 'clean sweep' and introduction of radical new technologies. For example, the threat from stealth aircraft was countered by the addition of new surveillance methods and radar frequencies and modes, rather than the complete abandonment of radar and a move to an alternative technology.

It is still necessary to introduce changes to air defence systems, though. We have seen that the nature of the threat has changed, and is likely to continue to change. More widely dispersed and heavily networked systems are required to counter the threat from diverse, numerous small platforms including ballistic and cruise missiles, UAVs, and unconventional air threats. Further changes may be expected in the future when new threats or new operating environments are devised. An incremental or evolutionary acquisition approach should be followed, and reflected in the project organisation and contracting arrangements.

Air Defence System architectures must be 'open' sufficiently to allow adaptation and the introduction of new elements, as threats and operational doctrine change. An incremental acquisition process should be followed.

Changes to the physical architecture of the air defence system must be supported by changes in operating methods and to support systems such as logistics and training to ensure the integrated system is capable of defending against evolving air threats.

Changes may also be introduced because existing elements of the air defence system, though perfectly capable of fulfilling their current and expected future roles, become obsolete or reach the end of their useful life. Modifications to elements of the system may be entirely self contained (such as the addition of new radar modes in an interceptor aircraft), or may require the insertion of a new system (introduction of air defence artillery for SHORAD at key civil landmarks, for example). With the high integration levels involved in modern air defence systems, though, many changes would require mutual development within a number of systems, such as the introduction of a tactical datalink to aid data transfer.

The incremental approach to system development means that different sub-systems within the integrated air defence system will be at different stages of their life-cycle, at any particular moment in time.

Individual sub-systems within the Integrated Air Defence System will be at different parts of their life-cycle, at any point in time. Configuration control for the overall system is crucial.

Because the systems are highly integrated, it is vital that control over system configuration is maintained. Traceability of system configuration back to operational requirements is needed to ensure that upgrades are co-ordinated, duplication of role is minimised, and all requirements have been achieved by some element of the IADS.

Finally, consideration must be given to the likely operational use of the IADS, and in particular the political environment within which it will be deployed. It may be the case that the system will be 'stand-alone', providing air defence cover for a single nation entirely in isolation. It is more likely, though, that joint force or coalition operations must be included, according to the operational doctrine.

Integrated Air Defence System requirements must take into consideration operational doctrine and operator organisations, as well as technical characteristics, to achieve operational capability and not simply system performance.

Interoperability involves more than the capability to transfer data from one entity to another. For interoperability between the diverse elements of the IADS, all of which contribute to overall air defence, understanding of processes and organisations is required.

5.0 AIR DEFENCE AND THE SYSTEMS ENGINEERING PROCESS

5.1 Introduction

The Systems Engineering lifecycle has been presented, in a number of forms, in a variety of books and it is not intended to provide an SE 'teach in' within this paper. In this section, though, some of the Systems Engineering stages will be briefly described and illustrated in their use for air defence systems development.

Although air defence systems fall within the class of systems referred to as ‘Systems of Systems’ (SoS) or ‘Family of Systems’ (FoS), the basic approach to Systems Engineering can be the same as that followed for any system. Initially an understanding of the requirements must be developed, and then analysis of these requirements undertaken. Concepts that will fulfil the requirements are devised, and a suitable design developed and implemented. Finally the completed system must be verified to show that the initial requirements have been achieved.

There are specific aspects of a System of Systems that will affect the development of systems in this class, as discussed earlier. Within this section the influence of this class of system on the design and development process will be described. The stages of the lifecycle will be illustrated by means of an example, introduced in the following section.

5.2 Illustrative Example

In this example, it is assumed that an air defence force operates legacy equipment which is currently providing air defence coverage but which is in need of modernisation. Weapon systems are operating adequately at present and a well-established Command and Control organisation exists, but legacy surveillance equipment is ageing, and is becoming unreliable. It is also becoming increasingly difficult to obtain spares for the radar equipment, leading to a gradual need to cannibalise some units to keep an ever reducing number of radar system operative. The radar units were once mobile, but the ageing equipment is now too delicate to transport and must operate from fixed bases. Combination of radar plots and tracks is performed automatically on a local basis, using two or three radar types, but overall air picture combination at the Air Operations Centre is still performed manually, using ‘voice told’ information from the various surveillance sites.

5.3 Requirements Elicitation

As for any system development project, the initial task must involve definition of the need for the air defence system. The air defence system itself already exists in some shape or form, and it is probably only part of this system that will actually require development. To understand exactly what part to develop, it is first vital to determine what the system is intended to achieve.

At the initial stage of the project, although an idea of the aspect requiring development may be held, it is important to identify the requirements of the whole system. When completed the systems that constitute the overall air defence system must operate together in the most efficient and effective manner possible. Unless the overall requirements are understood then sub-systems will be developed in isolation from each other, and duplication of effort or gaps in capability are likely to result. This approach also supports incremental acquisition methods, where an idea of the overall system requirements provides focus to each increment.

Requirements are best identified at a group workshop, as teamwork is likely to result in a more complete set. Figure 5 shows the Viewpoint Structure Charts for the Active Defensive Counter Air aspects of an air defence system.

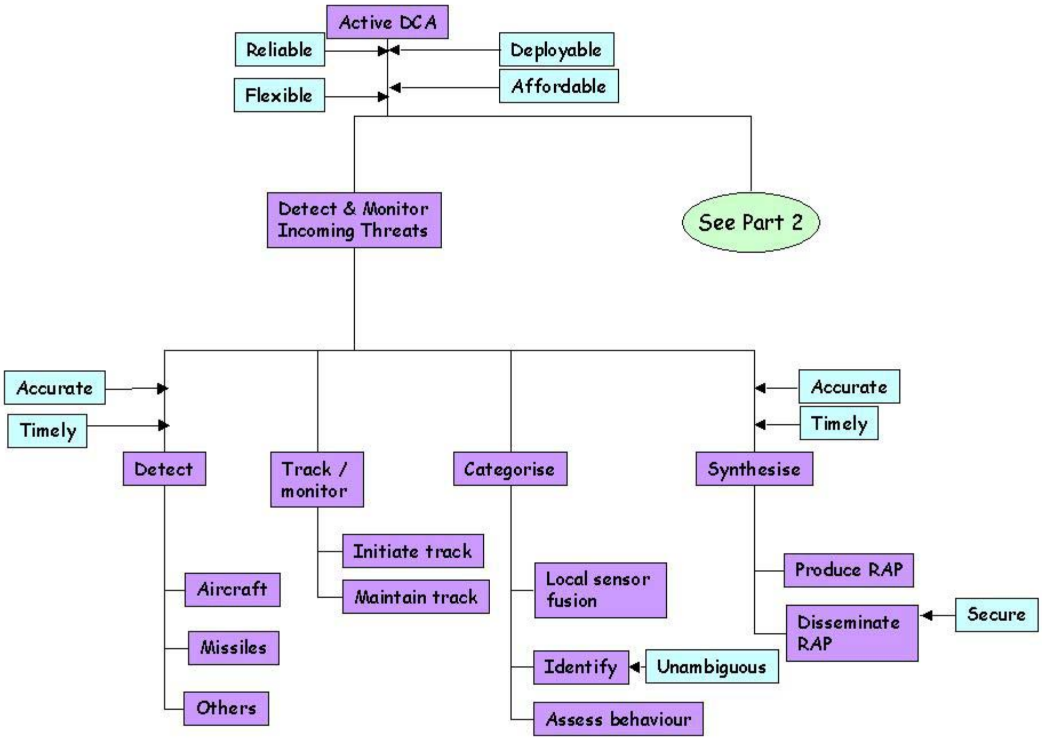

Figure 5 (Part 1): Viewpoint Structure Charts for the Active Defensive Counter Air Sub-System.

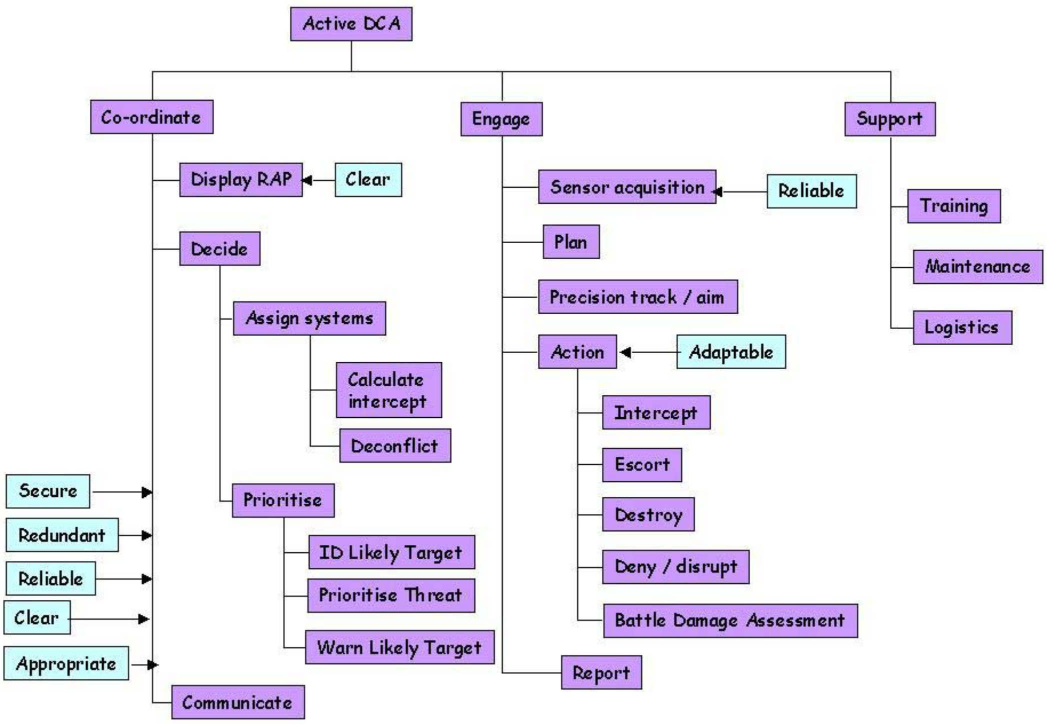

Figure 5 (Part 2): Viewpoint Structure Charts for the Active Defensive Counter Air Sub-System.

The Viewpoint Charts show the functions that must be performed by the air defence system as branches of the 'tree' structure, and non-functional requirements indicated as attachments to the functions or branches they constrain. The complete set of these diagrams will show the range of functions to be performed by the overall air defence system, and not just the tasks allocated to the parts intended for replacement.

With respect to the illustrative example considered in this paper, the current arrangement would not meet general requirements for Reliability and Deployability, or the lower level requirement for Timeliness in synthesis of the Recognised Air Picture.

5.4 Functional Modelling

Following identification of the functions that the overall air defence system must perform, it is then necessary to develop an understanding of the inter-relationships between these functions. A useful tool for achieving this is Functional Modelling. Again working as a team, including experts from a number of operational areas such as engineering, support and customer operations, a series of functional flow diagrams can be produced. These show the relationships between functions and the flow of data between them.

Figure 6 shows the top-level diagram for the Functional Flow Diagrams of the Active-DCA system. A number of additional diagrams would sit in the hierarchy below this diagram to provide a complete description of the system functionality.

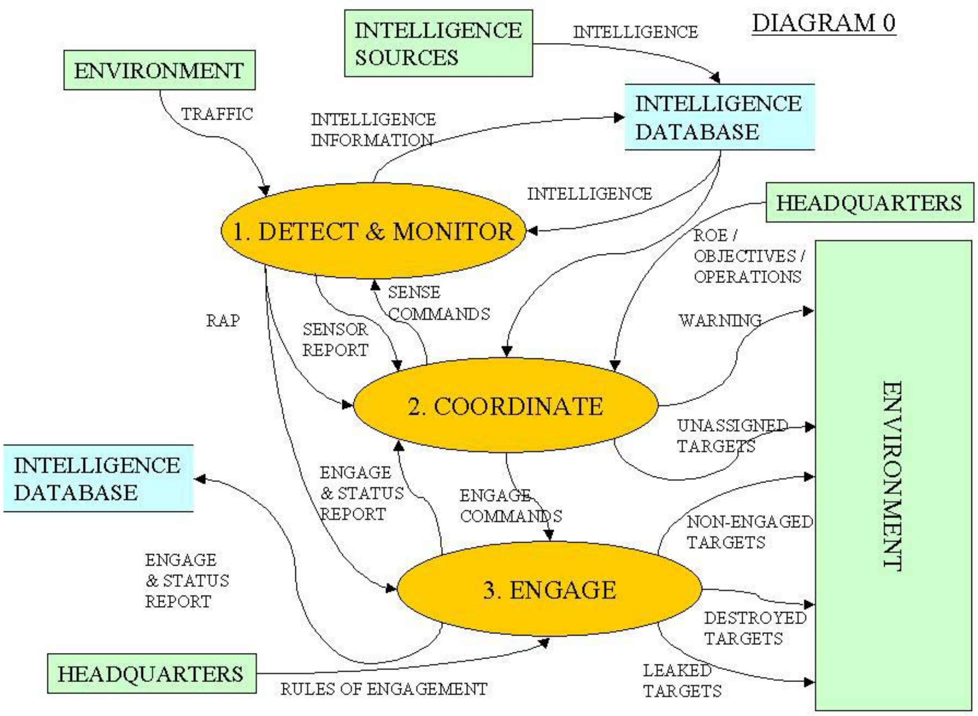

Figure 6: Top-Level Function Flow Diagram for the Active Defensive Counter Air Sub-System.

The top-level functions are:

1) Detect and Monitor – involving the search for air targets and development of the integrated picture of the airspace.

2) Co-ordinate – involving the command and control functions of analysing the air picture, assessing priorities and allocating resources (surveillance and engagement) as appropriate.
3) Engage – involving action taken against hostile targets by the weapons systems.

The functions have interconnections between themselves, requiring the flow of information to achieve their own tasks, and interact with the outside world which includes higher level command organisations, traffic (friendly, hostile and neutral) and intelligence sources.

In understanding the associations between functions it is necessary to deviate somewhat from classical Systems Engineering and consider the physical entities that would operate certain functions. Generally this is considered a taboo in Systems Engineering organisations, but is necessary in this case for two reasons. First, the air defence system is likely to exist already and functions have already been allocated to particular physical entities. The operation of this existing network must be taken into consideration in devising future developments. Second, the air defence system is so heavily integrated that organisational relationships and operating doctrine influence the functions themselves. For example, a basic function of the system is to perform surveillance, and a non-functional requirement may be that the surveillance sub-system must be able to deploy to remote sites within a specified time. In understanding the functional flows, though, it is important to understand whether the surveillance function will deploy freely when its operators see fit or whether they are constrained to only deploy when commanded by a higher authority.

The function flow diagram would be decomposed to lower levels of detail, until a sufficient level of fidelity has been achieved for the system being considered. This would be done for all of the functions, but to illustrate the method using the example considered in this paper only the appropriate levels of the 'Detect and Monitor' function are presented here.

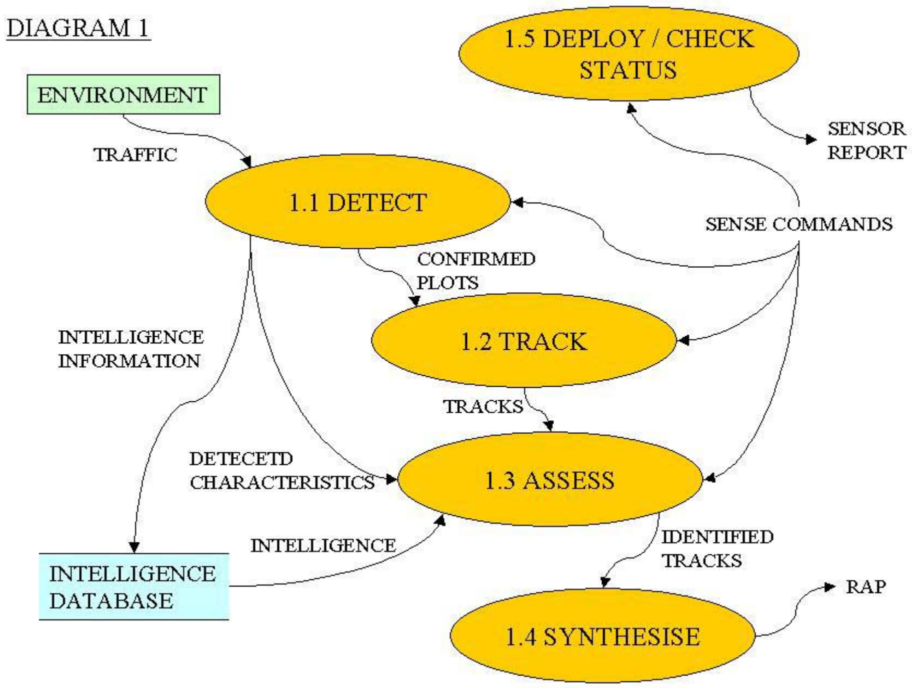

Figure 7: Decomposition of the 'Detect and Monitor' Function.

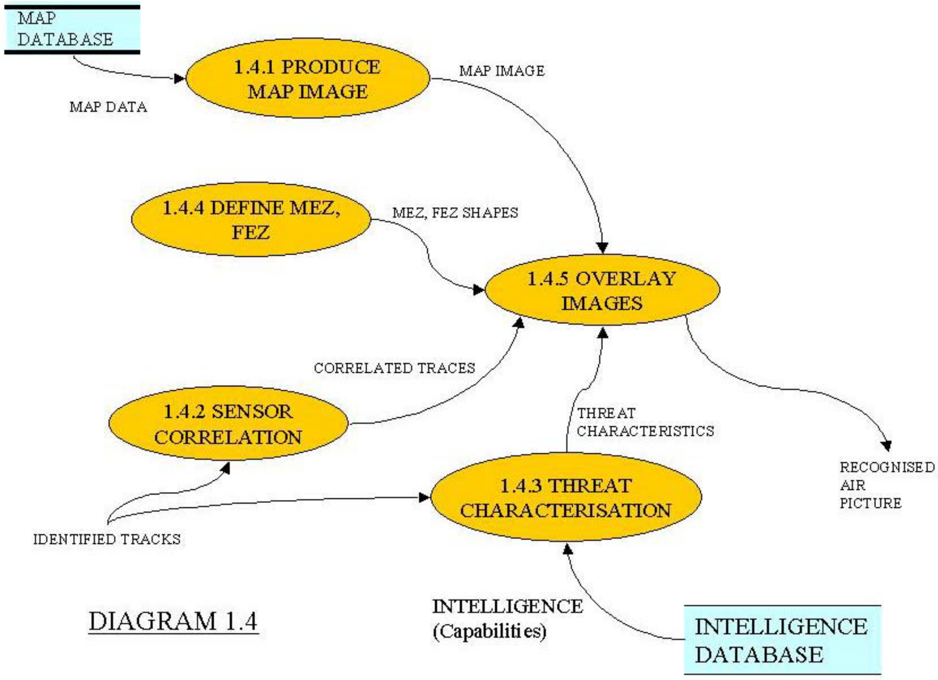

Figure 8: Decomposition of the 'Synthesise' Function.

5.5 'Gap' Analysis

After identification and analysis of the system functions, a traditional Systems Engineering lifecycle would now require the identification of concepts that achieve all of the required functions. For a System of Systems, however, there is an additional analysis stage required first.

Because the air defence system is a System of Systems, much of the functionality is likely to already exist, embodied within physical entities. The existing system will not be scrapped and a complete, fresh system brought in to replace it, so the current capabilities will need to be determined. A traditional method of achieving this is Operational Analysis (OA).

Operational Analysis uses a model of the existing system, including performance models of the physical sub-systems and communications and organisational networks. The model of the system can then be used to assess performance against a series of potential operational scenarios.

The analysis is used to defines 'gaps' in capability, or an inability of the current system architecture to achieve all of the functional and non-functional requirements. There are three types of gaps that could be identified.

The gaps may be produced if functionality can not be achieved adequately at present. For example, the analysis may indicate that engagement of a large number of small targets, during an attack using mass-produced, simple cruise missiles, may result in an unacceptably high leakage rate. In this case it would be necessary to enhance existing functions such as surveillance or engagement to reduce the leakage rate.

The capability gaps may also be due to an inability to achieve a particular function. An example of this may be found in current systems with an inability to engage high-speed, high-altitude targets such as ballistic missiles. Here, the gap may be filled by the addition of new facilities such as an alternative weapon system.

The third type of gap in capability may result from planned future changes to the current system. The current system may perform a function adequately, but a pending change such as retirement of a sub-system due to age or obsolescence issues may result in the function not being adequately performed in the future. A suitable replacement for the system to be retired, or re-allocation of the function to other sub-systems, would fill this type of gap.

Without the benefit of Operational Analysis to determine the extent of any deficiencies in the example case, assessment of the Function Flow Diagrams shows that the 'Deploy / Check Status' function would be inadequately achieved, whilst the entire 'Synthesise' function cannot be achieved by automated means.

5.6 Concept Definition

Having identified the gaps in current or projected capability, it is possible to identify methods to achieve the functions that need to be allocated. Although the functionality of the entire air defence system had been considered at earlier stages in the lifecycle, most of the functions will already have been allocated to physical sub-systems, and it is only necessary to define means to fulfil 'missing' functionality. Allocating a method to each unfulfilled function provides a concept for the capability gap fulfilment, which can provide the basis for a Request for Tender from the prospective customer or a proposal from a potential supplier.

For each function to be performed a list of suitable methods is produced. This list is organised in a 'Function Means' chart, showing the means by which each function can be achieved. An illustrative example is shown in Figure 9, where a number of methods of achieving some of the sub-functions of the 'Detect and Monitor' function are given (note that this list is by no means exhaustive, but was produced to illustrate the method). From the range of means a set can be selected that will produce a concept for achieving the system requirements. A possible selection is highlighted, providing a concept of new radar units feeding a central, computer automated combiner and Recognised Air Picture generation suite.

Function	Sub-function		Means		
Detect and Monitor	Deploy / Check Status		Replace mobilisers	New mobile radar	New surveillance UAV
	Synthesise	Produce Map Image	Paper info	Reverse write board	Computer generated
		Sensor Correlation	Voice telling	Conversion box / current system	New combiner
		Threat characterisation	IFF	Flight Plan correlation	Human observer
		Define MEZ/FEZ	Paper info	Reverse write board	Computer generated
		Overlay Images	Paper info	Reverse write board	Computer generated
Training	Operator Training		Exercise	Discrete Simulator	Synthetic Environment

Figure 9: Function Means Chart for Part of the 'Detect and Monitor' Function.

An example of function allocation for one of the 'soft' functions (Operator Training) is also indicated in Figure 8, where the selected concept involves the use of built-in synthetic environment generation capabilities. Such facilities could be built into an automated Command and Control system providing benefits for both training and trials.

The earlier efforts in assessing the functionality of the complete air defence system will now begin to provide real benefits. An air defence system is highly integrated, with much overlap between physical elements performing the same basic function or inter-dependency between sub-systems providing supporting functions. For example the engagement function may be performed by a variety of fighter aircraft, long-range Surface to Air Missiles and Short Range Air Defence (SHORAD) systems. The efforts of these systems must be co-ordinated and any new engagement sub-system (filling a gap in anti-ballistic missile defence, for example) must also be able to co-ordinate operations with the existing systems. Similarly new sensor systems must be able to provide data in a format that can be integrated with other sensor data to produce an overall air picture.

New capabilities being introduced cannot be developed in isolation and consideration must be given to the environment they will operate within and the existing (or even prospective) sub-systems with which they must collaborate, including those operated by potential coalition partners. Traceability of requirements through to physical instantiation is important in a large, physically and operationally diverse system such as an air defence system, to ensure no functions are neglected and to minimise duplication of effort.

5.7 System Design and Development

The additions or changes to system elements are designed and produced as any other sub-system might be, with requirements flowing down through to element level, the system components being designed, integrated and proven in their own right. Where the development of the system elements overlaps with other developments or impact on inter-system interfaces, then care must be taken in specifying interoperability or interface requirements. The overall air defence system can then be integrated, starting with individual elements and building to the complete system.

5.8 Acceptance and Verification

The final stage in the air defence system development program will involve verification that the original system requirements have been achieved. Having established the requirements for the system at the onset of the project, and attaining agreement between customer and contractor, a demonstration of level of compliance with the requirements must be given. The individual system elements will be tested to prove compliance with their own, individual requirements, such as the Factory Acceptance Tests and Operational Acceptance Test normally conducted for a radar system. However, the overall air defence system must also be tested to ensure compliance with the top-level requirements, and in particular to prove that all of the elements can operate together to produce an air defence capability.

Verification on this scale is usually proven by trials. An air exercise will be planned, either within the customer air force's organisation or even involving other nations, to test the air defence system. Whilst such trials are visible and involve the customer actively using the system in an operational scenario, the trials are not generally all encompassing and assessment of satisfactory outcome can be very subjective. Whilst raids by bomber aircraft can be simulated by using an air force's offensive resources, it is unlikely that the system's ability to handle attacks by large numbers of cruise and ballistic missiles would be fully tested in such an exercise.

A more structured approach, which would also provide the ability to test the system against a wider range and larger number of threats, involves the use of Synthetic Environments. Having networked the air defence system it is possible to introduce synthetic targets that can be shared between the defensive elements to provide a consistent picture of the air space, suitable for trials and evaluation purposes. The ability of the discrete, physically dispersed elements of the system to co-operate effectively and provide air defence protection against the range of threat scenarios envisaged can then be demonstrated in a controlled manner.

6.0 CONCLUSIONS

Air Defence Systems fall into the class of systems often referred to as a 'System of Systems'. Whilst many of the traditional Systems Engineering methods used for any other system development programme are applicable, there are a number of considerations affecting this class of system. The nature of the Air Defence system is such that a number of separate sub-systems will be included, usually at different stages of their development life-cycle. To be effective the various sub-systems, which are often physically dispersed, must collaborate with one another to create an overall air defence. Different elements of air defence must be included, within the groupings of Active Defensive Counter Air, Passive Defensive Counter Air and Offensive Counter Air. Within these groupings a range of sub-systems will provide surveillance and detection, communications, information display, warning and engagement functions.

The threat faced by a modern Air Defence System has become very diverse. Traditional threats of bomber and fighter-bomber aircraft remain, but more nations (and even organisations without a national alignment) are obtaining access to ballistic missiles and cruise missiles, which could attack from unexpected directions and in large numbers, saturating defences. Advanced technologies for stealth and navigation are making the threat from conventional weapon systems even greater. Unconventional weapon systems, such as hijacked airliners, add another dimension to the threat facing Air Defences.

This all makes the development of an Air Defence System extremely complex. Unless proper consideration is given to the special issues affecting a System of Systems, and the development programme adapted to reflect Systems Engineering practices applicable to this class of system, then at best the development programme will be inefficient and costs will escalate. At worst the system will be ineffective and gaps in the air defence capability will remain.

7.0 REFERENCES

[1] MW Maier, Architecting Principles for Systems-of-systems, Systems Engineering 1(4) (1998); 267-284.

[2] JZ Ben-Asher, Systems Engineering Aspects in Theatre Missile Defence – Design Principles and a Case Study, Systems Engineering 7(2) (2004); 186-193.

GLOSSARY

ABOC	Air Base Operating Centre
A-DCA	Active Defensive Counter Air
AWACS	Airborne Warning and Control System
FEZ	Fighter Engagement Zone
FoS	Family of Systems
MANPAD	Man Potable Air Defence
MEZ	Missile Engagement Zone
NATO	North Atlantic Treaty Organisation
OA	Operational Analysis
OCA	Offensive Counter Air
P-DCA	Passive Defensive Counter Air
SAM	Surface to Air Missile
SAMOC	SAM Operating Centre
SE	Systems Engineering
SHORAD	Short Range Air Defence
SoS	System of Systems
UAV	Unmanned Air Vehicle