Electronic Warfare in the Fifth Dimension: Human Factors Automation Policies and Strategies for Enhanced Situational Awareness and SEAD Performance

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> *"The offense created a radically new vehicle to delivers its message of shock and fire, the aerial bomber. As a response to this new means of communicating destruction, the fortified walls mutated again, in effect dematerialising to become the electronic curtain of radar." De La Macha (1998: p. 77)*

SUMMARY

The process of supporting human operators in the very difficult task of electronic warfare is considered because it is representative of the need to flexibly operate systems and equipment from one conflict to another. It is argued that the weak element of the partnership is often the system and not the human, as it is normally portrayed. It is proposed that the design of future systems enable effective representations of operation to create transparent operation of the equipment. It is argued that the functional capability of the EW system should be universal or as close to universal in operation, to facilitate learning, operation and error recovery. Transparency and universality of operation are required to aid the development of an effective user mental-model of system operation, to enhance trust, increase authority and facilitate collaborative process management. Finally, the pace and demands of the system must create synergy between the operator and the task demands, balancing workload across time in a multi-tasking environment.

OUTLINE

Electronic warfare (EW) has become a critical part of modern air warfare with the advent of increasingly sophisticated systems for Integrated Air Defence Systems (IADS) (Mason, 1999; Price, 2001; Schleher, 1999). At the same time the projected development of ancillary communication and computer systems is likely to show only moderate growth and provide limited improvements in protection against IADS, which will increase the drive towards Unmanned Air Vehicles (UAVs) (O'Hanlon, 2000). Increasingly sophisticated IADS capable of detection, tracking and interception of aircraft, even stealthy aircraft, means that the role of jamming and other specialist EW assets has assumed critical importance (Price, 2001). In the past specialist Wild Weasel units, and more recently multi-crew assets such as EF-111 Ravens or EA-6B

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Prowlers, would manage the electronic warfare with the information captured by specialist Electronic Intelligence (ELINT) aircraft. This meant that a wide range of cognitive assets, in the form of expert and specialist electronics intelligence officers, was tasked with interpreting emissions from hostile forces. It would be easy to assume that automatic electronic warfare via an integrated Defensive Aids Suite (DAS) would be an obvious choice to replace this function with reduced manning. Given the criticality of the response characteristics and the potential destructive interference between concurrent tasks in the single-seat cockpit of future fighter aircraft a DAS is an obvious necessity. Opting for such an automated system could be used to argue for a less important role for Tactical Surface-to-air Missile Defence Situational Awareness Displays (TSD-SAD). In addition, it could be argued that automated defence systems using combined Miniature Air Launched Decoys (MALDs), Towed Radar Decoys (TRD), and Active Jamming Pods, in combination with more conventional systems such as multi-spectral flares and chaff would be better managed by an automated system. An automated system would ensure comprehensive, responsive and economical counters to critical event signals indicating missile launches, early detection radars, tracking radars, lasers, and other types of missile guidance systems. However, the operators input to the system in terms of aggressive aircraft manoeuvres, strategic use of on-board assets in relation to mission goals and cooperative engagement of assets by multiple platforms with both hard and soft kill capability may rely upon cognitive engagement in the defensive task (Cook, 2001). It is clear that electronic warfare should embrace the general principles of war in using speed, surprise, and deception (Munro, 1991). While it is not impossible to embody all of these principles of warfare in on-board automation it may be the critical principles of deception and surprise that are less effectively represented, limiting the operational effectiveness of a highly automated electronic warfare system. The development of a dynamic automation policy and an effective situational awareness display for enabling a less predictable and more resilient suppression of enemy air defence is considered.

> *Clausewitz wrote, "War is the province of uncertainty; three quarters of the factors on which action is based are wrapped in a fog of greater or lesser uncertainty. A sensitive and discriminating judgement is called for; a skilled intelligence to scent out the truth. That was in the comparatively straightforward days of warfare, before airmen added a new dimension and the fog became electronic." Mason (p.271, 2001).*

The complexity of modern electronic warfare (Adamy, 2001; Vakin, Shustov, and Dunwell, 2001) makes it unlikely that single-seat operation will truly manage the task effectively and the only sensible response is that envisaged for the two-seat EA-18 (Quigley, 2001). It is proposed that such a system could increase the Electronic Intelligence (ELINT) capacity on the battlefield to ensure fast and confident responses to changing enemy air defence strategy. The aim would be to achieve cognitive dominance of the battlefield to increase capability and not simply to expedite decision making on a case-by-case basis. This would represent a policy of Integrated Airborne - Suppression of Enemy Air Defence (IA-SEAD) through automation enabled situational awareness, facilitation of confident signal interpretation and cooperative engagement of threats with jamming assets, Anti-Radiation Missiles (ARM) and stand-off GPS guided munitions. This type of approach is in harmony with the complexity of electronic warfare on the digitised battlefield (Frater and Ryan, 2001) and the necessity for network centric warfare to manage weapons and sensor assets. Thus, it is argued that retaining operator involvement and using integrated communications and computer technologies to enable suppression of enemy air defence is a more appropriate goal for a DAS, than simple agent substitution with an automated process replacing human cognition. It suggests that technology should enable sharing and processing of ELINT information across platforms to detect anomalies (due to deception), making use of correlations to give confidence target identification and enhance position fixes for prosecution of active hostile air defence systems via cooperative engagement. This would mimic the tactics developed with such great success in the Vietnam War but exploit the advanced technology capacity for information sharing across platforms. In this way it would increase operator situational awareness, increase confidence of targeting and reduce the effort to detect target emitters. Space and time provide four of the dimensions of the electronic warfare environment and information or cognitive dominance is the fifth dimension. It is the fifth dimension that is critical in ensuring that the operator retains confidence in self-protection systems and the ability to integrate their use into achieving mission goals. Recent conflicts suggest that it may be impossible to ensure that IADS are totally destroyed and as a consequence they will remain a threat throughout a conflict that is subject to changes that would make an inflexible DAS a liability. Recent conflicts and historical analysis indicate that flexibility is an asset and it can be argued that this cannot be easily obtained from a highly automated approach to EW.

The choice is clearly between representative technology and assistant technology. The risks posed by relying too heavily on assistant technology are clear but the practical justification of keeping the human-in-the-loop is perceived as vague and imprecise. As a result the insistence on human intervention and control is seen as irrational and weak, it is clearly an area where crews are reluctant to cede control to automated systems completely.

> *"New technologies are paradoxical, as well as equivocal. These descriptions are not intended to be merely clever phrases. Instead, they speak to the core issues we need to resolve if we want to understand technologies in which mental representation plays a central role." Wieck (p. 172, 2001).*

INTRODUCTION

The traditional physical science, engineering, and computer science models aim to develop systems that occupy a finite space of possibilities and for which behaviour can be verified under appropriate test conditions. It can be argued that this simplistic approach, necessitated by cost, underlies some of the failures observed in modern automated systems and constrains designs to a limited performance envelope. The focus on the ideal closed system, with a well defined set of operating conditions is exaggerated by training systems that emphasise the development of routine procedures for managing expected failure conditions. Thus, in the event of an unusual, unexpected or unfamiliar condition the operator is poorly prepared to manage the exception encountered. Klein (2000) has suggested that automation may make us effectively stupid in additional ways that compound the limited support from automation and some of the issues raised by that paper are addressed in this analysis. The phrase "Stupid is stupid does…" was attached to the sub-title of this paper to emphasise the dangers in slavishly following instruction and treating automation with a high degree of trust.

It is unrealistic to expect that the operator has not been prepared from every condition or that the automation could be design from every condition, as the cost of extended training or the probationary period would be too long. However, the operator of complex equipment is rarely prepared to identify the cues that indicate that their ability to manage events is likely to be challenged, at least until it is too late. In addition, emergency procedures rarely consider the flexible management of catastrophic event sequences and the operator is unable to review their coping behaviour. This paper explores these issues in the realm of self-protection systems for airborne systems against surface and air launched missiles. The air warfare environment is particularly challenging because it is an environment where there is rapid change. The methods and strategies used in the last war are rarely applicable to the next because the lessons learnt are used to generate new methods of operation or equipment. Portions of this paper were presented to the 3rd Conference on Engineering Psychology and Cognitive Ergonomics in Edinburgh November 2000.

The execution of air warfare is an extremely complex process because of the sophistication of the avionics and weapons systems used in aircraft (Bacon et al., 1990; Clancy, 1996; Rendall, 1998; Spick, 1995, 2000a, 2000b; Thornborough, 1995; Walker, 1989) and this is a continuous process of change. The complexity of warfare is largely a result of the heterogeneous nature of the threat environment that generates a high degree of unpredictability that is the greatest threat in all warfare because these sits cannot be managed. The complexity of air warfare can best be judged by accounts of Desert Storm (Clancy and Horner, 1999) and by government documents like the description of RAF doctrine in AP3000 (Ministry of Defence, 1999). Although the complexity of the on-board systems has increased, in response to increasing threats from enemy forces in the air and on the ground, no system can ever manage all the threats. There have been repeated statements concerning the need for more effective cockpits that meet the needs of an increasingly reduced crew complement (Penney, 2000b) and the only way to achieve this is by improving the automation. There is an increasing recognition of the need for a balance of power between the technology and the human (Dudfield, 2000; see Penney, 2000b) to ensure that effective control is maintained. The critical issue is how that balance is to be managed and whether it can be dynamically changed during the course of a mission. The role of the combat ready fighter pilot has already changed significantly from that appropriate to the two-seat Tornado, and if current training requirements are a guide (Mason, 1999) it may take even longer to produce combat ready pilots. In the single seat multi-role and swing role aircraft of the future the pilot will be required to manage both offensive and defensive functions simultaneously. In addition, the move towards beyond visual range (BVR) air-to-air and air-to-ground will place greater emphasis on projection capability of the pilot to envisage future outcomes.

Concerns have already been expressed about the potential effects of the poor quality of training for highly automated systems, which have occurred in the civil domain, and it is likely that the same problems will occur in the military domain. In military aircraft the gaps between generations of new aircraft are larger (Cook, Angus, Brearley and Drummond, 1998) and mid-life updates may represent compromised design choices, creating opportunities for under-estimating the training requirement in fully automated systems. In recent engagements the forces of NATO, and Coalition Forces in the Gulf War, were not required to engage a sophisticated air force but they were required to defeat a hostile air defence system (Hewson, 1999). While there is some doubt about the exact nature of the true facts, it seems clear that the air campaign in Kosovo was not as effective as one might hope and much needs to be done to improve performance. Thus, there have been recent requests for proposals for new self-defence systems for installation on Harrier, Tornado, and Jaguar to deal with potential threats of Surface to Air Missiles (SAMs). Even though the airborne threat has not been strong in recent conflicts the designers must consider the possibility of air engagements in future aircraft. As the pilot’s role in air warfare has currently become more demanding psychological design factors play an increasing role in effective use of both weapon systems and counter measures. For example, the three factors of Trust, Confidence and Uncertainty are likely to play a significant role and measures developed to measure such factors are likely to assume greater importance.

- Trust – in the automation or weapons to successfully accomplish the required task.
- Confidence – in predicting the outcome of planned use of systems.
- Uncertainty – surrounding the behaviour of the weapon or system.

A critical aspect of the systems interface for EW is the boundary layer between the responsibilities of the human and the machine intelligence. The interface is critical to development of a representation of this boundary. If the system interface is opaque this may prevent the operator relinquishing control, when it is wholly appropriate. Or, in some cases over optimistic beliefs about the system capability may be catastrophically proved otherwise by experience. This interpretation of human-machine collaboration indicates that a system that lacks universality will need an effective interface to demonstrate cues that identify automation capability and its limits.

There is in many systems a clear difference between the perceived capability of the system and the actual capability that is itself dynamic in a rapidly evolving environment such as electronic warfare. Sometimes the operator will underestimate capability and monitor the system unnecessarily. In other cases the operator will fail to monitor the system and the limits of the system will enable an effective attack. For many system designers the operator's appreciation of the system is often that last consideration in the design process and it is largely driven by a remaindering of process, according to the expected capability of the system and automation. Often the gold standard for capability is not met and even the bronze standard is weak, leaving a system that is limited and ineffective at representing its functional frailty.

The psychological concerns may be exacerbated by the limited opportunity to exercise the systems and to gain appropriate knowledge in peacetime exercises. It is not a good idea to reveal the defensive strategy of a system in an exercise because the countermeasure may be countered, by modifications to the weapon system, prior to the deployment of the aircraft in an operational role. Much was made of the Coalition Forces testing of the Iraqi defences prior to the air assault in Desert Storm because this allowed the attacking forces to gain important knowledge about the Integrated Air Defence System protecting Iraqi positions. The role of Signals Intelligence has been defined as one of the most important in future air warfare (Isby, 2000) and any advantage can begin at a relatively small scale.

For electronic warfare systems to be truly effective and usable it can be argued that they should have key properties that should be present in all automated systems. Thus, an automated electronic warfare system should have the properties of universality, transparency, criticality and pace. Clearly the speed or pace of the system should be responsive to the demands put upon it and the need to represent information to the operator. The level of support provided by the system should match the criticality of the response required and the quality of the response set at a level appropriate to the criticality of function. Finally, the system should be transparent to the user and the response as universal as is appropriate for the tasks attempted. Electronic warfare systems should ideally manage all the relevant threat categories with equal effectiveness and the effectiveness of their operation should be apparent to the user.

Examining systems with the different properties of transparency and universality one finds that the optimal system is both transparent and universal in its responses. This system is rarely achieved in practice and many of the operational automated systems are either low in transparency or universality, or both. Thus, many of the systems in operation paradoxically increase the workload, increase specific types of catastrophic errors and are difficult to learn or acquire a mental model for. The problems with automated systems are well documented by Wood, Johannesen, Cook, and Sarter (1996) and Dekker and Woods (1999), Dekker and Orasanu (1999) and Hollnagel (1999). This concern is well demonstrated in many other observers of the automation enterprise with regard to aerospace systems and avionics and electronic warfare.

It is possible to trace the interaction between the user and the system via use-cases laid out in UML. These use-cases are individual examples or tasks where the user interacts with the system to achieve a goal in a specific way. Use-cases can be used to estimate interface complexity, situational awareness, cognitive demands, user information requirements, and to estimate the core characteristics of the system interface, such as universality, transparency and criticality based on the use-cases identified.

It is clear that many partnerships of human operator and automation are asymmetric in understanding and communication. Human-human dialogues adapt and shift over time and with experience they are refined into brief skilled exchanges between sympathetic operators, with a common shared mental-model. This can be envisaged as the human-human relationship climbing the Rasmussen (1983, 1986) skill ladder. Over time the exchanges transition from verbose knowledge-based dialogue to terse and implicit message passing dependent on latent knowledge. Even in modern automated systems the only sentience is on the human side of the equation and exchanges rarely progress beyond the rule-based appreciation of performance, as they automation cannot appreciate the operator's true intent. Thus, the burden of work is largely left with the operator and it is only in very simple universally applicable automated systems that one finds release of the operator's cognitive resources for other tasks. This asymmetry is the underlying weakness of human-machine collaboration and not the weakness of the human, as many system designers would suggest. Indeed, system design largely incorporates that which is possible and easy to automate, leaving more difficult tasks to the user, along with the blame when things go awry.

AIR-TO-AIR ENGAGEMENTS

In the air, the pilot has a range of weapon systems at their disposal ranging from short-range infra-red missiles to long-range semi-active and active radar homing missiles. The missiles vary in the degree to which they are autonomous with most short-range missiles using infra-red seekers, which are effectively live-off-the-rail. Live-off-the-rail, autonomous weapon systems are extremely dangerous because once they are launched the pilot cannot exert further control over the weapon. However, in close in engagements the pilot should be able to visually identify the aircraft they are shooting at and only launch against identified targets. Some of the Beyond Visual Range (BVR) missiles are autonomous and the pilot must rely on the aircraft sensors or a data-link picture for identification of potential targets in the engagement area.

From a psychological point of view there is considerable antagonism between the capability of the weapon and the concern over fratricide, which is exemplified in the shooting of Black Hawk Helicopters in the Northern Iraq No-Fly Zone. Beyond visual range missiles allow the pilot to engage targets well before they present a strong threat and once engaged the high Probability of Kill (PK) allows the operator to ease of their mental workload and stress. After firing a BVR missile the pilot can lower the demand on mental resources or re-allocate resources to other threats, and they can feel more secure having dispatched one threat. The use of electronic information to identify threats presents a threat if the system can produce false positives because even if the pilot approaches to visual identification distance an earlier indication by on-board systems may undermine the effort to identify the threat positively. It is obvious that in many situations those hostile targets will frequent need identification in a non-cooperative manner because uncertainty is an advantage, as it delays prosecution of targets with weaponry.

Any willingness to accept the early indication as proof positive may be underscored by the fear of the opponents close in weapons systems that may be difficult to defeat. One major fear for pilots flying against Russian built aircraft was the capability of the missiles at close ranges because of the use of the Helmet Mounted Sight (HMS), available to their pilots, which allows for off-axis engagement of aircraft. Off-axis engagement is a grave concern because the direction of flight of the aircraft is no longer a good predictor of threat status of the attacking aircraft and the missile envelope opens up a whole new volume within the Missile Engagement Zone.

The detection of threatening aircraft and the guidance of air-to-air missiles (AAMs) requires the use of an active on-board emitter in the form of radar, even BVR missiles may require the strength of the aircraft radar to gain a lock initially. The problem is that the radar emission from the aircraft is detected, by both air and ground forces, and this can be used to triangulate the position of the aircraft passively prior to launching a Surface to Air Missile (SAM). This allows both air and ground forces of the opponent to prepare a response to the detected aircraft and in the case of swing-role aircraft to encourage the jettison of stores and abort of missions.

Thus, the very thing that allows the pilot to operate the weapon system and detect threats increases the degree of threat to the pilot. The Russian response to the detection threat has been the use of infra-red search and track in their aircraft and the co-ordination of forces by the use of ground based radar. The U.S. response to the threat of detection was the creation of elite aircraft like the F117 and B2 that use stealth to escape detection to allow air-to-ground assaults to take place. Another strategy was the use of off-board sensing by airborne early warning aircraft to reduce the time needed for active tracking of enemy aircraft. Recent evidence suggests that the stealthy option may not be foolproof and the resurgent interest in Electronic Jamming forces suggests that pilots may require support from other aircraft. O' Hanlon (2000) has identified a number of weaknesses in the stealth argument and suggests that even if further development of technology will result in reductions in radar cross section the use of multi-spectral tracking and specific radars will enable detection and tracking of stealthy aircraft.

The threat status of an enemy aircraft, at long range, can be judged by a combination of radar emissions, from their on-board radar, and their spatial location. A nearby aircraft is far away then it may not pose a threat and the threat is further reduced if the radar is not locked onto the aircraft in receipt of the emitted signals. The lock is usually necessary to allow the missile seeker to track towards the aircraft. However, it is possible that aircraft are using the hunter-killer approach proposed by U.S. forces where an aircraft is identified and tracked by one actively emitting aircraft while another fires the missile at close range. The onset of stealthy aircraft and small Unmanned Air Combat Vehicles (UCAVs) makes this mode of attack even more likely. For the pilot of the aircraft the increasing complexity of the attack scenarios makes it increasingly difficult to categorically identify threats.

According to psychological models of decision-making the increasing complexity and uncertainty of the air warfare environment should slow down the decision making process. For example, according to Klein (1993a; 1993b; 1997a; 1997b) cues are identified in the environment and these are used to identify the type of events taking place, and the expectancies generated from prior experience in combination with available information result in selection of appropriate actions. The increasing uncertainty of the air warfare environment is likely to undermine the identification of cues from the environment with any degree of confidence. The wide variety of interpretations possible from the same set of cues is likely to potentially generate a high degree of workload from the maintenance of a large number of potential interpretations or action solutions and leave the operator less able to manage multiple tasks required by a swing-role aircraft. Even multi-role operators may find it difficult to master the complexity of the air-to-air role because of the subtle variations in the patterns of information.

It is possible to interpret the same material with regard to Endsley's model of Situational Awareness (1995, 1996, 1997, 2000) and to reach broadly similar conclusions to that with Klein's model of decision-making. The increasing complexity of the cues in the environment and the variety of interpretations possible makes level 1 SA (perception) and level 2 SA (comprehension) more problematic. The weakness of the first two stages of situational awareness in turn prevents adequate development of level 3 SA (projection) and this is likely to leave the operator less effectively prepared to counter the responses of their combatants.

Two issues concerning automation flow from this analysis. An automated threat detection system for airborne threats may fail to detect all the potential threats or their axis of attack. Given the complexity and the ambiguity of the cues it may be impossible to create a rule set capable of classifying the threats in the environment or providing effective advisories. This may be analogous to the problems with Traffic Collision Avoidance Software (TCAS) where operators know that all aircraft are not fitted with the system but fail to act appropriately. In TCAS trials pilots fail to scan the outside world for non-TCAS threats and spend disproportionate amounts of time heads-down observing the TCAS display, undermining their response to non-TCAS equipped or failed TCAS aircraft. Failure to respond to threats, in the air warfare environment, could mean life or death decisions for pilots and the fact that pilots seems to ignore knowledge of equipment limits suggests that they may not benefit from extensive training to reduce these errors. Indeed, it may be argued that pilots are simply trying to adopt a simple model of the mediating software and ignoring the exceptional cases, where it does not work in a form that is consistent with the Schneider and Schiffrin's (1977) automatic-controlled distinction.

The use of passive sensing creates further problems because it introduces more exceptions into the pattern of events. Enemy aircraft using passive sensing and stealth, or the absence of radar in attacking aircraft would track the aircraft without emissions so the pilot and the on-board systems would not know they had been engaged, or were under threat. Sensors and the digital signal processing in threat protection systems are largely designed to identify more frequent threats and less adapted to signalling the exceptions when identification failures. In a sense there is a bias in design of many systems towards the confirmation of identity and neglect of signalling uncertainty. The human operator is more familiar with the frequent events and is doubly disadvantaged by presence of the automation that does not assist with the unexpected events. The failure to address exception management in many systems has been recently addressed by Cook (2001) with regard to memory demands during familiar and unfamiliar event management. Cook (2001) suggests that despite suggestions to the contrary, the critical and exceptional events, where training does not prepare the operator to identify the cues using a naturalistic decision making strategy Klein (1993a; 1993b; 1997a; 1997b), are not managed by knowledge held in skilled memory or long-term working memory. Indeed, the failure of expert operators to manage unfamiliar and unexpected events can be explained by the reliance on more basic information processing strategies.

SAM THREATS

> *"The overwhelming electronic combat achievement laid the basis for all subsequent Coalition military success. Stand-off, barrage, and escort jamming of Iraqi radar and fighter control communications…..blinded and paralysed Iraq's air defence system." Mason (1994)*

Awareness of the enemy on the ground will be provided by a number of information sources. In its most rudimentary form the current GPS position and intelligence will indicate the potential threat axes, with knowledge of terrain giving an indication of the effects of shielding, in medium and low level flight. However, mobile launchers and the double digit SAMs, SAM-10, SAM-11, and SAM-13, in particular present a very great threat (Zaloga, 2001). Although man portable systems can be lethal and a significant threat to pilots who do not effectively monitor their height during aggressive manoeuvring or in air-to-air engagements. It is possible that the first thing the pilot will be aware of is a missile launch warning, from IR and UV sensors, and recent reports suggest that ballistic missile launches have been used in conflicts to protect against SEAD aircraft and weapons (Kromhout, 2000). In some cases it was likely that Serbs used early warning radar to predict the arrival of Allied forces and they would fire SAMs blind (Brookes, 2000). However, it would normally be expected that on-board sensors on the aircraft would detect the emissions of either radar systems or laser beams prior to launch, where the latter represents the potent threat of tracking from a beam riding missile system. The detection of tracking signals is usually suggestive of threatening intent but it can be used to provoke release of stores or fuel, in an effort to sabotage missions by swing-role aircraft.

Radar emissions are detected by Radar Heading and Warning Receivers (RHWR), commonly pronounced RAW. Once detected the signal gives an indication of direction but as the power levels of radar can vary the distance to the emitter is only an estimate of distance. However, triangulation of the emitter by multiple receivers can locate the emitter by simple physics and consequently reveal distance of the threat. By interpreting the emitter type it is possible to detect the degree of threat posed and the likely type of weapons system posing the threat. Hence, once the threat is known the kinds of countermeasures appropriate can be deduced and action taken. Long-range weapon systems take time to reach the pilot's aircraft and there is significant time to deploy immediate countermeasures such as chaff or miniature air launched decoys. However, a towed decoy can be used to produce a deceptive position indicator to the receiving radar and this can result in mis-location of the missile threat away from the aircraft, increasing the chance of survival.

The problem is that future detection may rely on indirect or passive methods of sensing by ground threats, such as reflections off aircraft from mobile phone site signals (Penney, 2000a). Recently, it has been suggested that mobile phones signals may be used to passively detect even stealthy aircraft and give the multiplicity of mobile phone sites it would be difficult to bring SEAD forces to bear upon all the potential emitter sites. Thus, it may be difficult to provide adequate signals and protection to future aircraft based on emission detection as a pre-emptive indicator of a threat location.

AUTOMATION POLICY

Automated systems are normally designed with a pre-programmed rule-set of some description that allows the identification of specific cues in the environment in a fixed or determined pattern that would indicate the occurrence of an event. The significant event usually requires action by the operator triggered by an alarm or immediate action by the on-board systems. Thus, automation manages those situations in which there is likely to be a routine response to a well-defined set of cues but leaves the operator to detect and manage the non-routine events. The assignment of exception management to the human operator by highly automated systems has drawn significant amounts of criticism and the area of airborne self-protection systems is not unique in creating potential problems through the application of automation. Automation can undermine level 1 SA, termed perception by Endsley (2000) because the operator is less aware of the events that are managed by the automation. The reduced perceptual experience can create less effective comprehension and even though the frequent events are less well managed it is likely to be the exceptions that create the greatest comprehension problems. It is well known that positive and affirmative decisions are easier and quicker to take than negative decisions making the detection of anomalous events cognitively and emotionally more challenging.

It is clear that coalition operations where both sides may share the use of the same types of equipment may increase the levels of uncertainty and diminish confidence in automated systems. This makes IFF systems more vital but no less immune to failure, with the attendant issues of non-cooperative identification.

As a consequence of the repeated changes in threat pattern, from both air and surface threats, it is almost impossible to predict from the previous war what the strategy of the air and surface threats will be in the next war. It is generally agreed that SAM radar operators were more alert to the dangers of anti-radiation missiles in Kosovo (Lake, 2001) and the balance of power in such operations is always subject to change. It is clear that layered Integrated Air Defence Systems (IADS) will provide a significant challenge with electronic warfare against radar the most sophisticated and the most expensive in technological development (Dawes, 1999a; Dawes, 1999b).

The traditional engineering models used to verify system operation and performance would be fruitless. Once used in combat the automation and the mode of operation would be obsolescent, or at least the tactics would be. A large part of the preparations for the Gulf War concerned detailed signal intelligence and electronic intelligence on the electronic defences (Clancy and Horner, 1999). Obsolescence could be further avoided by using a flexible rule set for the self-defence capability and this would have further advantages in that it would engage the operator in developing the model of system behaviour, increasing the effectiveness of their mental model of the system operation. The recent involvement in setting the system mode of operation may help to ensure selective operator vigilance in the monitoring role, when required, and ensure an accurate mental model of predicted system performance as they were actively involved in the rule development. The disadvantage is that the system would not enable complete operator disengagement, freeing cognitive resources totally, and automaticity of human performance would not necessarily occur. The operator may be able to select a number of strategies for automated self-protection system deployment that make their behaviour less predictable by the opposition. The alternatives are contained in the table below.

Table 1: Automation Strategies and their Strengths and Weaknesses

Automation Strategy	Strengths and Weaknesses
Identify some of the required conditions and respond automatically.	Good for high threat environments with rapid onset e.g. low-level flying and MAN Portable Air Defence Systems (MANPADS).
Identify some of the required conditions and notify the operator.	Good for high level engagement e.g. where the missile system will take time to reach aircraft.
Identify some of the required conditions and notify the operator.	Where the offensive response may violate airspace and neutrality of emitters e.g. to prevent attacks on non-hostile systems.
Identify all of the required conditions and respond entirely automatically.	Good for high air-threat environments e.g. where stealthy approach reduces time to contact of air launched missile.
Identify all of the required conditions, prepare a response and notify the operator	Good for high threat coalition force environments e.g. where hostile and friendly aircraft may use the same emitter frequencies or deception is in use.
Identify all of the conditions and notify the operator.	Good for medium and low threat coalition environments.

A major concern in all of these strategies is the possibility of reduced situational awareness where the operator relies heavily on the automation to detect and in some cases prosecute target threats. Over-reliance on the system may generate errors of commission in response to false positives and incorrect rejections, or misses. A key issue is the operator's model of the system in use and the more flexible system will paradoxically result in a higher level of workload than a simple automated system. However, the retained operator involvement may ensure that their SA is good enough to prepare a logical response and trapping of exceptions, where the protection assets are not managed by the automation.

It should be remembered that a number of response alternatives exist in the event of a threat. Thus, with an airborne threat the pilot may pull to the notch to momentarily disturb the radar lock from Doppler pulse radars of the opposing aircraft and not use aggressive responses (Spick, 2000b). Or, the pilot may use jamming or a towed decoy to disable the radar system lock used to track their aircraft. Where the aircraft continues an aggressive posture the pilot can attempt to step around the threat and if this fails they may decide to engage the threat.

Care has to be taken in the use of automated systems because in many cases the pilot must make the final and the most aggressive response against SAM sites, using ALARM and HARM missiles (Lake, 2001). To take effective decisions the pilot must have good situational awareness and that means processing the information about threats. However, processing all of the threat information in a high threat environment would be overwhelming for a single seat pilot and this was one of the reasons why the two and four seat Wild Weasel aircraft were so highly valued. Wild Weasel pilots were dedicated to the role of SEAD and the modern F-16CJs or EF-18 Super Hornet is unlikely to achieve the same levels of performance with a reduced crew-complement and single seat multi-role aircraft. There is an increasing potential for smarter automation to be a mind-suck where the pilot is distracted from other tasks, much as is the case for TCAS, where the civil pilots are likely to neglect out-of-window scanning. When the automation works well it is likely to induce complacency and dependence, with reversion to more basic modes of operation impossible as a result of pilot de-skilling. Mosier has described the effects of automation in detail and Skitka (1996) who warned about the dangers of divided responsibility, automation induced complacency and skill erosion.

It has been suggested that triangulation of emitter location is one type of cooperative engagement of enemy forces and hunter-killer operation of aircraft is another form of cooperation. In the future UAVs and manned aircraft may operate together with the weapon platform and the sensor-control located elsewhere. It is likely that automation could be very effective in aiding this cooperative or network centric aspect of warfare in a manner that is largely not considered. The only major aspect of network centric warfare currently used is the used of AWACS aircraft to provide distributed real-time information on targets via data-links and it is likely that this will be a major issue in future coalition forces. The U.S. JSTARS is the other type of network centric system but there are no aircraft currently fitted with real-time data link to enable cooperative prosecution of targets. Thus, the JSTARS network is vulnerable to jamming, even if some networks are supposed to be jamming free. There are key issues in cooperative management of data-linked information that is not supported by voice validation of target identification and action that are yet to be resolved. It is equally uncertain what role automation may play in the mediation process.

Currently, one of the most sophisticated network centric systems is operated in the Saab Grippen that allows the capability to hand-off targets between aircraft but the operator does this manually, not automatically (English, 2000). There is no reason why a computer intelligence might not be capable of this it may generate a predictable response and that allows for countermeasures to be deployed to defeat the system. It has been argued that there are many problems with using high-speed secure communication networks to allow for more centralised command that is more rigid and prone to deception (Cook, 1999). It is not impossible to sustain distributed management of tasks in real-time environments but it is clear that it requires a high level of training and planning beforehand (Cook, Elder, and Ward, 1997; Cook, Angus, and Campbell, 1999). Training to operate in a highly cooperative manner in such an environment may be prohibitively expensive and many of the systems developed for current and future aircraft are woefully inadequate in sharing information in a readily digestible manner, given that the single-seat cockpit is already a very busy multi-task environment.

MODELS OF SKILLED BEHAVIOUR AND AUTOMATION

If one accepts the revised model of Rasmussen's Skill Levels, which incorporates cognitive resource gradients and affective gradients (Cook, 2000) it is easy to imagine the automation can be seductive in its operation when training occurs. The automation could enable operation at the highly automatic skill-based level and relatively quickly if the automation model is relatively simple. At the same time the low-cost of the simple automation strategy would have to be balanced against false positives, and incorrect rejections, which would result in erroneous performance or reduced performance as a result of the need to cross-check the system operation. The simple model of automation would be cheaper to validate and more easily justified by demonstration than a complex model. However, the use of a simple automation model would clearly be a false economy.

The operator will rarely experience multiple SAM threats of the appropriate types and they will never have to manage the multiple air threats using different modes of attack. To enable effective use of the automation the pilot must be trained and exposed to threats in a manner that simulates as effectively as possible the use of the equipment in situ. The simple automation system would not present a training challenge because it would take a limited amount of learning to master. This might reduce the quality of the mediated threat environment and the mental model of the potential threats in the mind of the operator. Thus, a more complicated system would require more training and increase the quality of the mental model of the air threat environment. This underscores the falsehood in assuming that lower workload will always equate to a better operational system because more difficult systems may result in longer training and better mental models of the operational environment.

In conclusion, it can be argued that the use of automation in Airborne Self Protection Systems (ASPS) requires careful consideration to avoid the pitfalls of aiming for low cost, low workload, and simple-minded automation design. It is arguable that such a policy may result in a system that will be obsolescent before it is deployed.

> *"Technological advantages may swing from ground-to-air and back again, but the aircraft will retain the advantages of exploiting the third dimension by concealment, deception, variable height, speed and direction." Mason (p. 277, 2001).*

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