Miniature UAV's & Future Electronic Warfare

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Abstract

A capable adversary will use a combination of SAR, ISAR, early warning, and MTI radars, as well as EO, IR, and ESM sensors networked together using tactical data links to provide a complete situational awareness picture. For a small defence force such as the ADF, which has historically depended upon a few high value assets to act as force multipliers, this means that its platforms will be difficult to conceal and commensurately easy to target. In order to protect against this we are undertaking a research project aimed at prosecuting an EW campaign through the use of small, inexpensive, autonomous, cooperative air vehicles. This combination of attributes provides a capability that, even if it is possible for an adversary to target the individual vehicles, due to the distributed, autonomous, adaptive, and robust nature of the system it is difficult to counter effectively.

The current program focuses on the location and suppression of targets such as radars through the use of a geographically distributed and heterogenous mix of sensors that are autonomous and capable of cooperative behaviour. The individual sensors are relatively unsophisticated, however, the observation system that is created through the cooperation and adaptive networking of these sensors provides sufficient process gain to achieve results similar to those of significantly more expensive centralised systems, but with the added advantage of achieving robustness to an adversary's countermeasures whilst simultaneously maintaining operational capability at a reduced cost.

The program comprises a trials program that uses the Australian-made Aerosonde UAV, the study of team formation, distributed sensing, data fusion, sensor resource and energy management, and communication link control based on the concept of cooperating machines, the development of intelligent agent algorithms based on the self-organising behaviour observed in ant colonies, and the implementation of these algorithms within a simulation environment.

UAV's can contribute in all aspects of Electronic Warfare, from jamming and Suppression of Enemy Air Defence (SEAD) to Electronic Support Measures (ESM), and Signals Intelligence (SIGINT). The inherent range advantages enjoyed by EW/ES payloads make them the natural sensor of choice for cross-cueing payloads with shorter ranges and/or more restricted fields of view such as SAR or EO/IR sensors. EW fits for UAVs can also include SIGINT payloads, or defensive sensors that can perform a SIGINT role. For example, a Radar Warning Receiver (RWR) can be a source of vital information, particularly when related to imagery information to form a more complete or accurate Situational Awareness picture or when updating the Electronic Order of Battle. The key is the integration of the inputs from all of the vehicle's sensors or all of the sensors on all of the vehicles, in the case of smaller more distributed systems that use a heterogenous mix of sensors.

1. Introduction

Electronic Warfare (EW) is vital to all types of military operation. The ADF's capacity to identify, characterise, locate, exploit, and suppress the electromagnetic emissions of an adversary is crucial to this objective as it allows for the establishment and mapping of the adversary's electronic order of battle. In particular, integrating EW information (which often includes ID and intent) with surveillance and imagery data (which does not) provides a very much more complete situational awareness (SA) picture. Unfortunately, all too often EW is overlooked - until the shooting starts.

Unmanned Aerial Vehicles (UAV's) have a vital role to play in the prosecution of EW campaigns. Similarly, EW has a vital role to play in the protection of UAV's. To exploit this synergistic relationship we need to make use of the latest miniaturised EW equipment. For example, a communications jammer or an Electronic Surveillance (ES) receiver can supplement or even replace a UAV's main payload. An EW module such as a Radar Warning Receiver (RWR) can also be used to provide the UAV with some advance threat warning. Alternatively, the UAV and its payload can form some part of a higher-level total capability.

This paper discusses:

a) Issues relevant to the physical and electromagnetic vulnerabilities of UAV's,
b) The potential for EW payloads to simultaneously enhance the capabilities and reduce the vulnerabilities of these UAV's,
c) The potential applications of smaller UAV's in an EW campaign.

The paper also describes a DSTO program of work that is exploring the trade-offs between the larger, more sophisticated, platform-centric UAV/payload options and the smaller, cheaper, distributed, network centric options that are available.

2. UAV Vulnerabilities

In Afghanistan the UAV's appear to have achieved excellent results for few losses. However ...

Our adversaries are not blind to this,

The opposition in Afghanistan do/did not have access to sophisticated air defences;

When the ADF goes up against a more capable adversary the UAV's will attract a great deal of unwelcome attention;

Shoot-downs may not result in loss-of-life or hostages, but they do represent loss of opportunity and expenditure of resources;

There are very few political ramifications for an adversary destroying one of these UAV's should the level of hostilities be less than open conflict;

EO/IR payloads are effectively blinkered by their narrow fields of view;

The cost of the airframe is relatively high, slow and relatively easy to target, but not sufficiently expensive enough to merit the inclusion of capable EW self-protection systems;

This leaves the UAV's vulnerable to 30-40 year old SAM technologies (UAV losses during the Kosovo campaign are thought to be approximately one every 3 days – in part due to an air defence that was typical of the Soviet pattern from the 1960's era [1]);

Put an emitter such as a SAR on board and, from an EW perspective, the UAV becomes a slow moving, highly luminous sitting duck.

Another problem for the larger UAV's is that their development process parallels that of larger (manned) aircraft, which stresses longer life, a high level of maintainability, a multi-role capability, and high reliability. The resulting systems are expensive with life-cycle costs and logistic complexities approaching those of manned aircraft.

3. Miniature UAV's

UAV platform technologies (eg. guidance, airframes, control, etc.) are now sufficiently mature in the small-to-medium sized range to be considered as part of the ADF's experimental force mix options. Moreover, because UAV's of this size are now being fielded, and a range of technologies for new and advanced payloads is readily available, we can expect a rapid evolution in the available platform and sensor mix. The mission characteristics expected of these UAV's and their associated concepts of operations are also likely to change accordingly.

These *Affordably Expendable* alternatives [2] offer the prospect of a capability that allows the warfighter to conduct the high value, high risk missions that are beyond the capability (or justifiability) of other systems. It relies upon the notion that the useful life of the capability is a function of its constituent payloads and technologies rather than the physical life of the airframe.

The situation is similar to that of the modern computer. Early computers were physically large, essentially stand-alone devices that were expensive to produce and maintain. Today's computers, on the other hand, are small and inexpensive platforms that are extensively networked and, when they outlive their usefulness due to advances in technology, are discarded even though they still function.

There is, of course, no free lunch: smaller, less expensive, lighter UAV's are generally less capable than their larger, more strategic counterparts. Moreover, they also carry less capable payloads. However, this may be offset by the increased affordability of the systems, our ability to network the UAV's and sensors to derive process gain¹, and our capacity to withstand losses due to conflict and malfunction.

Given the recent advances in sensor miniaturisation, data links, and fusion technologies, it may well be that a combination of several smaller UAV's standing in at lower altitudes with a few manned platforms (or larger UAV's) standing off and at higher altitudes provides the optimal mix for the largest range of applications. Whatever the eventual solutions, it is clear that the full breadth of payloads and CONOPS is only just beginning to be explored.

In addition to the exploration/evaluation of operational concepts either in their own right or (appropriately scaled) for their larger counterparts, as mini-UAV's and their associated payloads can be acquired or developed at a fraction of the cost of the larger systems, they can also be used as a framework to explore more experimental concepts such as Network Centric Warfare (NCW).

4. AVATAR Key Initiative

NCW exploits concepts such as information superiority to provide a competitive edge in warfare. NCW emcompasses "the ability to collect, process, and disseminate an uninterrupted flow of information while exploiting and/or denying an adversary's ability to do the same" [3]. Under the Autonomous Vehicle Advanced Tactical Applications Research (AVATAR) Key Initiative, DSTO plans to use formations of networked, autonomous vehicles as a model to explore the capability edge obtained when networking multiple platforms and sensors.

AVATAR is aimed at developing a multidisciplinary, cross-environmental framework for demonstrating the advanced applications of autonomous, uninhabited vehicles [4]. Its focus is on experimentation

¹ A simple example of "process gain" is depth perception from stereo-scopic vision.

in the hands of the warfighter. The aim is to investigate the potential for advanced capabilities through the exploitation of new technologies and novel concepts of operation for networked, multi-platform, autonomous vehicles, sensors, and effectors.

To develop the airborne aspect of this experimental capability and to explore the capability edge as a function of technology innovation and application innovation, we required the development of a flexible and accessible autonomous aerial vehicle infrastructure. The Electronic Warfare Division (EWRD) of the Defence Science and Technology Organisation (DSTO) recently signed a contract with Aerosonde Ltd to provide this infrastructure through the use of their mini-UAVs. The capabilities of the Aerosonde UAV are shown in Table 1 (for more details on the UAV, readers are advised to see the website www.aerosonde.com.au).

The six Aerosonde UAV's purchased under the contract will be used to conduct a series of trials over a two-year experimental program. In addition to funding purchase of the airframes, the contract makes provision for the trials program, some experimental payloads, a ground control/support element, and a launch and recovery system.

It is important to note that AVATAR is aimed at experimentation and fielding proof-of-concept systems in order to inform future capability analysis, acquisition or upgrade. It is not aimed at defining "final" capability solutions. The significant restrictions associated with limited payload and power can be viewed as either a technology challenge or simply as factors that limit the scale of the experiment (eg data link range or data rate). Clearly, some CONOPS and payloads will not scale down to enable sensible experimentation.

Specification	
Weight	13 - 15 kg
Wing span	2.9 m
Engine	24 cc, Avgas, 1kw
Fuel Consump	180g/hr level flight
Full Fuel Load	5 kg
Navigation	GPS/DGPS
Communication	200 km depending on
Range via UHF	height and terrain
On board power	40 Watt continuous
generation	60 Watt peak
Payload	Supports Serial
Computer	Interface Input
Main Payload	100mm Length
Bay Area (can	120mm Width
be adapted)	180mm Depth
Performance	
Speed, Climb	$18 - 32 \text{ ms}^{-1}$
	$Climb > 2.5 ms^{-1}$
Endurance,	No Payload > 30 hrs
Range	Clear air >3000km
Altitude Range	100 m to > 6000 m
Payload	Maximum 5 kg (gives
T 1: 0 / 1	approx 10-hour flight)
Landing & take off distance	Less than 300 m
Take off speed	Average 90 km/hr
Operation	
Staff for	$3 \sim \text{Controller},$
Launch and	Engineer,
Recovery	Pilot/Maintenance
Staff for Flight Command	1 Person for several aircraft
Ground	
Equipment	Proprietary Staging Box, 2 PC's, GPS
Flight	Fully autonomous, or
	under Base Command.
Launch and	Launch from car roof
Recovery	rack, land on belly
Max speed	31 m/s (110 km/hr)
Ground & air	UHF or Satcomms
comms	to/from Aerosonde
Table 1: Agrosonda UAV Specifications	

Table 1: Aerosonde UAV Specifications

Nevertheless, the opportunities offered by the miniaturisation of the UAV's and their payloads mean that there is considerable potential for new approaches to old problems and that we must explore very different cost-capability equations.

The overall AVATAR program goal is to analyse, develop, and field - in conjunction with all that wish to participate - a varied range of baseline operational concepts, flight and sensor algorithms, and payloads suitable for small, tactical UAVs. A crucial part of this research will be the demonstration of combined platform-UAV operations at a relatively sophisticated level (i.e. UAV experimentation in conjunction with ADF assets).

5. Mini EW Payloads

There are a variety of potential payloads suitable for mini-UAVs. These include: communications & electronic intelligence (SIGINT) payloads, communications and radar jammers, electro-optic, infra-red, and MAW sensors, MTI and SAR radars, BDA sensors, comms relays, EW self-protection suites, chemical, biological, & nuclear detectors, target designators, and "horizon extenders". Only a selection of the EW payloads is discussed here.

Electronic Surveillance (ES) Payloads

ES and SIGINT sensors can be a source of vital information, particularly when related to imagery information to form a more complete or accurate Situational Awareness picture or when updating the Electronic Order of Battle. The key is the integration of the inputs from all of the sensors on all of the platforms. Moreover, as the sensor only has to receive and process signals it does not require large amounts of power to operate it. Consequently, ES payloads scale well to the power constraints of mini-UAVs.

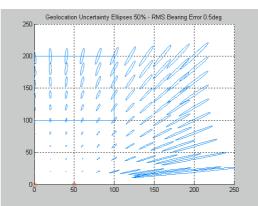


Figure 1: Geolocation error ellipses for 0.5 deg. rms DF sensors onboard 2 platforms with stand-off range of 100km. AOI (100km x 100km) is bounded by blue line.

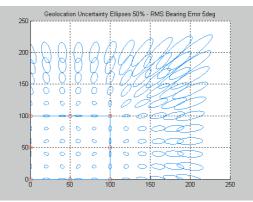


Figure 2: Geolocation error ellipses for 5 deg. rms DF sensors onboard 8 platforms with stand-in capability. AOI (100km x 100km) is bounded by blue line.

Mini-UAVs are not considered a practical replacement for the larger strategic UAV's, although by networking their sensors we may derive greater capability. As an example, Figure 1 and Figure 2 show a comparison between the 50% uncertainty bounds for geolocating² emissions of interest from two platforms with 0.5degree rms Direction Finding (DF) capability and eight platforms with 5degree rms DF capability, respectively. The more accurate sensors are nominally placed on board

² Geolocation is the process of determining, either directly or indirectly (eg. through DF), the location of an emitter of interest.

high-value assets and must therefore standoff at a range of 100km, whereas the less capable sensors, which are significantly smaller and cheaper, are placed on more expendable platforms and may therefore stand-in (their cost means that we are also able to afford more of them). Analysis of the figures shows that system using the less accurate sensors has errors around 50% less than those of the more expensive system.

As another example, Figure 3 shows the trade-off between geolocation error and range for a variety of Direction Finding (DF) sensor accuracies. The figure clearly shows that situational awareness and even targeting level accuracies are achievable using ES/ELINT sensors with very modest DF capabilities, if stand-in capability can be achieved.

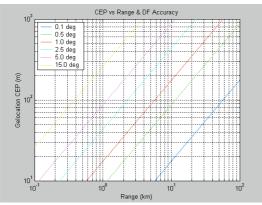


Figure 3: Geolocation Error (m) versus Range for 0.1-15 degree rms DF sensors enjoying optimum geometry.

Geolocation may be achieved in a number of ways other than using DF techniques and the reader is referred to [5] & [6] for more details on these techniques. By and large, however, the accuracy of the techniques is heavily dependent upon the separation distance between the sensors and their geometry relative to the emitter.

Clearly, if geometry is a major component of the geolocation problem then, for a single platform, the time that it takes to obtain a given level of accuracy is dependent upon the time taken to manoeuvre to obtain this geometry. These manoeuvres can be very time-consuming and the emitter may move some considerable distance in the intervening periods. Using multiple platforms geolocation can be performed in near real time. Moreover, the distribution of the payloads means that the system geometry can be adapted more quickly to favour a small geolocation error. This provides a "double" incentive to obtain geolocation using multiple platforms.

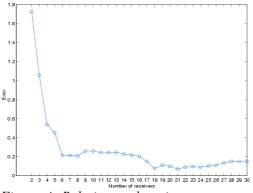


Figure 4: Relative geolocation error versus the number of DF sensors located around an emitter [6].

Electronic Attack (EA) Payloads

A jamming platform must stand off at a considerable range from a target to allow for its own protection. Because it must stand off, it requires a large amount of power. By reducing the size of the platform and the need to protect it, we are able to stand in, which means that we need significantly less power to jam a given target. In addition to this, because the stand-in jammer is closer to its target its transmissions cover a smaller area and the potential for electro-magnetic fratricide is also significantly reduced.

Figure 5 shows the Jammer-to-Signal Ratio (JSR) as a function of range for a 100W jammer and 10kW radar transmitting into a 20dB directional antenna. The radar returns

are based on the detection of a target with a radar cross-section roughly the size of a (non-stealth) strike fighter.

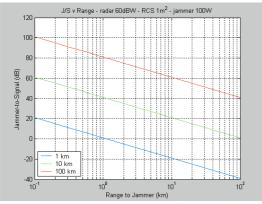


Figure 5: Jammer-to Signal Ratio versus Range for a 100Watt noise jammer against 10kW radar with 20dB antenna gain attempting to detect a target of $1m^2$ RCS. The red, green, and blue lines are for target ranges of 1, 10, and 100km.

The figure shows that the achievable JSR from a 100W jammer located 10km from the radar and protecting the target at a range of 10km is equivalent to a 10kW jammer located 100km from the radar attempting to protect the same target. When one considers that many modern weapons systems have ranges in excess of 100km and that miniature UAV's are also hard to detect (and hence target) it makes the technologies a very attractive potential alternative. In addition to this, even if the mini-UAVs are detected, targeted, and engaged, the UAVs have such small IR signatures and RCS there is still no guarantee that the weapons will fuse correctly and destroy the UAVs.

Horizon Extenders

In addition to placing the sensor/processing capabilities onboard the UAV, it can be treated as a "flying antenna". In this case, the UAV is effectively an electromagnetic "bent pipe" – comprising a receive antenna, a modest amount of processing capacity, some time stamping & signal amplification, and a (directional) transmit antenna. Combined with knowledge of the UAV's location and a high gain antenna on the ground (and considerably more processing power than is available onboard the UAV) we have the capacity for significant horizon extension.

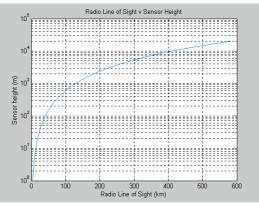


Figure 6: Radio line of sight vs. altitude.

Figure 6 shows the rapid increase in the potential line of sight (LOS) as a function of UAV height. It can be seen that even for very modest altitudes of about 500m, LOS of around 100km are achievable.

Operational Issues



Figure 7: Endurance capabilities of the Aerosonde UAV in geographic perspective for a 2kg payload (12 hrs on station ~ black continuous circle to 0 hrs on station ~ red dotted circle)

Figure 7 and Figure 8 show the typical endurance capabilities and coverage that could be achieved using the ES payloads referred to above when flown on the Aerosonde mini-UAV. Control of the UAV in the area of operations could then be undertaken either by a commander at the launch site or by one based further forward (eg. onboard a ship or tactically deployed).



Figure 8: Typical ES sensor coverage for two areas of interest - the range estimates assume a launch from Darwin, a 2kg payload, and an altitude of 3.5km. The time on station is estimated as 15 hours.

6. DSTO Trials

In February and June of this year, DSTO conducted a series of trials to demonstrate potential operational concepts for miniature UAVs involved in maritime EW operations. The mini-UAVs were designed, built, and operated by Aerosonde Ltd. The payloads were designed, built, and operated by DSTO. The payloads tested were:

EA ~ 100MHz bandwidth noise jammer,

RF repeater \sim a test target of controlled radar cross-section used with EA payload,

 $ES \sim 2-18$ GHz superheterodyne receiver

The combined objectives of the trials were: 1. Demonstrate successful launch of the Aerosonde UAV carrying the EW payloads, 2. Demonstrate hand-over of control of the UAV to a surface combatant and back again to the land-based launch/recovery crew, 3. Determine detectability of the Aerosonde UAV using the ship's radars and ES,

4. Determine the effectiveness of the EA payload installed on an Aerosonde UAV,

5. Determine the effectiveness of the ES payload onboard an Aerosonde UAV,

6. Demonstrate the surface combatant's "extended horizon" capability by enabling it to control the UAV-based ES payload and receive/process surface emissions detected over the horizon from the ship,

7. Demonstrate injection of the ES data collected by the payload onboard the UAV into DSTO's EXC3ITE network,

8. Demonstrate the TECHINT "value-add" of the ELINT/ES product within EXC3ITE,

9. Demonstrate the dissemination of this product to the Joint Command Support Environment (JCSE) in near real time.

10.Demonstrate successful landing back at Jervis Bay carrying the EW payloads.

Figure 9 shows a schematic of the DSTO trials conducted in June and February.

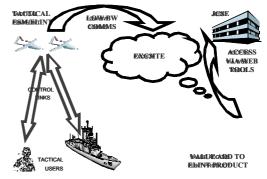


Figure 9: Schematic of mini-UAV trials

The trials are reported in detail elsewhere [7] & [8]. The February trial comprised EA and a "shake-down" of the ES payloads. The June trial may be summarised as:

At launch, a pilot at the Aerosonde Launch and Recovery Site (ALRS) manually flew the UAV before switching it to its autonomous mode. Control of the UAV and its payload was then passed to another landbased control site or to the ship, depending upon the trial. A DSTO controlled emitter was located, as were a number of other marine radars. The radars and transmitter were used as test signals for the ES payload. Signals information received at the UAV was passed to the ship and the landbased control sites. On being received at the land-based control site, the information was injected into DSTO's EXC3ITE network for TECHINT value-add and dissemination to the JCSE in near real time.

One of the navigation radars was used as a test-radar for the EA payload. A second UAV, with an RF repeater payload, was used as a controlled radar cross-section and flown in conjunction with the UAV with the EA payload. The navigation radar was successfully jammed (Figure 10).



Figure 10: Navigation radar display showing jamming strobe due to EA payload onboard mini-UAV

All of the objectives referred to above were achieved successfully.

7. Future EW

The ADF's current approach to EW is platform-centric in nature and requires each platform to rely upon its own sensors. This approach requires extremely fast responses. It does, however, allow those responses to be tailored to the relevant threat. Achieving that response requires rapid detection and classification of the emitters and is typically obtained from an onboard ESM receiver loaded with the appropriate threat libraries. Unlike platform-based EW, which is tactical, short-range, reactive, requires very fast responses to the threats, and is often the last defence option, Force Level EW³ can be operational, pre-emptive, and long range in nature, requires more modest response times and is an early defence option.

For the ADF, the areas in which FLEW is likely to make a impact include [9]:

The surveillance and monitoring of a region of interest (including the detection, identification, geolocation, recording, and analysis of electromagnetic signals that are potentially linked to an adversary's sensors or C3I systems),

EA for counter-surveillance or counteracquisition of radars, imaging, or C3I systems in both a strike context and a defensive role,

The use of anti-radiation missiles (ARM's) to destroy hardware and suppress enemy air defences,

The development of operational concepts, doctrine, and tactics (for the use of FLEW),

The assessment and allocation of priorities to requirements for equipment acquisitions,

Through-life-support to maintain, sustain, and enhance EW-capable datalinks and applications that exploit shared EW data (such as situational awareness, geolocation, and remote/third-party targeting of EA and ARM's),

The development and maintenance of databases for EA techniques for counter-C4ISR and the provision of ES and EA reprogramming data, tactics, advice, and

³ Force Level EW is defined as the offensive or defensive application of EW in such a manner as to have effects beyond the immediate self-protection of a platform. In other words, where EW is used to attack or protect a group of assets or individuals within a group, excluding the act of self-protection. It is achieved by networking sensors, data fusion centres, command and control systems, and weapons systems.

analysis via secure communications from support areas to forward areas,

The assessment of derived sensor and C3 arrangements of potential adversaries for vulnerability to EA,

The investigation of the vulnerability to EA of the ADF's C4ISR arrangements and the implementation of appropriate protective measures,

The research, development, and application of both hardware and software technologies to produce and enhance integrated EW situational awareness and EA capabilities, and

Liaison with civilian authorities on matters relating to an operational EW capability.

The implementation of FLEW is more complex than simply widening the communications bandwidth and linking the platforms. It includes the interpretation and application of information of uneven quality and timeliness, the purification of information to preserve the quality of the network and prevent error propagation, and the coordination of assets to obtain a synchronised response. In addition to this, it must be achieved within a framework of finite resources [10].

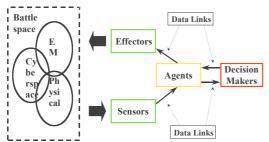


Figure 11: Relationship between Force Level EW entities and elctromagnetic conflict.

The coordination and synchronisation of assets has the potential for improving EW operations. However, it also increases the matrix of options available to the ADF. The study of Complex Adaptive Systems (CAS) shows that the most striking benefits come not from the direct linkages and connections between the entities, but from the vastly larger number of indirect connections that are established [11].

The requirements for FLEW transcend the traditional environmental boundaries of air, land, and sea and also the operational boundaries of tactical and strategic. In both cases, this is because the sub-systems involved in delivering the EW product occupy multiple domains. Consequently, it will be necessary to analyse the use and integration of these entities within a joint operations framework that spans both the tactical and strategic environments. For these reasons, it is instructive to break the battlespace into three overlapping domains: physical space, cyberspace, and electromagnetic space. For each of these domains the means by which the ADF may affect an outcome may be broken into four blocks (Figure 11):

a) Sensors, which provide information to form the basis of situational awareness,
b) Agents, which perform selected tasks delegated by the effectors/decision-makers,
c) Decision-makers, which exercise C2, and
d) Effectors, which execute the plans and prosecute the engagements.

These are the standard entities referred to in NCW texts, and FLEW draws heavily from some of the concepts in this area. The architecture that supports FLEW is heavily dependent upon the nature and capabilities of the datalinks used to support the sensor-processing, value-adding, and C2 processes.

In the FLEW concept of operations the participants are heavily dependent upon a network of continuously adapting systems that are capable of making strategic choices about how to survive and achieve their goals in a dynamic environment. The agents are enabled to perform a range of selected tasks delegated by other participants, decision makers, or controllers. The power of the networked force is thus derived from the strong networking of a well informed, but geographically dispersed force.

To visualise the potential benefits of FLEW and UAV networks it is instructive to analyse the Reactive EW⁴ and Geolocation problems. In a platform-centric engagement the ESM receiver is co-located with its EA assets and radar sensors and the receiver is allocated only a limited duty cycle because of the look-through problem⁵. Clearly, the probability of intercepting the threat signals is a function of the duty cycle (amongst other things). Moreover, the response delay of the platform's countermeasures is a function of the sensor and processing latencies. Achieving a response to multiple threats within a limited duty cycle is therefore extremely challenging, as rapid detection and classification of the emitters is needed. Geolocation is similarly affected. First, if DF techniques are used the level of accuracy that can be achieved within a given time frame is restricted, as the platform must spend time manoeuvring to obtain the necessary geometry. Second, the probability of intercepting certain types of signals is obviously affected by the lookthrough problem. If, instead of DF, TDOA techniques are used to geolocate the signals, the geometry is similarly unfavourable as the sensor's antennas are limited in their distribution to the extremes of the platform.

Let us now consider the situation where the ES sensors are distributed across a number of geographically dispersed platforms. By placing dedicated sensors on the platforms and combining the information available from each of them we are able to improve (if not completely remove) the look-through problem. Similarly, we are able to improve the likely detection of signals through the cumulative probability of intercept of multiple sensors. On the other hand, the information must be passed over finite bandwidth communications links and can be expected to experience network delays. Thus, the multi-platform case offers reductions in the response delay to a threat, but only if the gains in sensor and processing latency are not overwhelmed by network latencies. This may require new datalinks and more intelligent ways of passing information.

Clearly, in terms of achieving specific levels of geolocation accuracy within a given time frame, for any fixed level of payload capability, the multi-platform case provides superior results because of the distributed geometry. That is, in the case of DF techniques, multiple "cuts" or "fixes" are available simultaneously and in the case of TDOA techniques, the dispersal of the sesnors' antennas is no longer restricted to location on a single platform (which means that longer baselines may be used).

In addition to the above, in the Force Level EW environment it is possible to use a heterogenous mix of sensors to exploit both the diversity of the available information as well as its geographic distribution. For instance, we can use a wideband IFM⁶ receiver to cross-cue one or more narrowband superheterodyne⁷ receivers. As before, combining the signal time-of-arrival information with the UAV locations provides a geolocation capability. This time, however, the Probability of Intercept (POI) is enhanced and the description of the

⁴ Reactive EW is the deployment of electronic countermeasures in response to an EW threat (eg. jamming a seeker on an incoming missile).

⁵ Look-through is the inability to receive and transmit at the same time due to the co-location of the ESM and jammer/radar.

⁶ Instantaneous Frequency Measurement (IFM) receivers can typically monitor a wide band of frequencies continuously (eg all spectrum from 2-18GHz), but they provide poor information on the signals received.

⁷ Superhetrodyne receivers monitor only a narrow band of frequencies (eg 1GHz segment), but provide more accurate signal information.

signal likely to be more accurate (and the commensurate signal ID).

If we now combine the control of these payloads with the autonomous control of the UAV's through the use of Intelligent Agents⁸ and provide these agents with a communications architecture that allows the information to be passed from agent to agent we have a system that is potentially able to adapt to its dynamic environment.

Depending upon the nature of the corporate and individual goals of the UAVs and their payloads the structure of the network may vary greatly, but it allows the strengths of the individual agents to be combined into a single cohesive team [11]. This intelligent, autonomous, adaptive, and co-operative behaviour is an important component of the NCW and FLEW concepts and DSTO has a program of work that is exploring a range of options pertinent to their development. Currently, these concepts are implemented in simulation environments, such as the FLEWSE (Force Level EW Simulation Environment ~ pronounced "floozy" [12]).

8. Conclusions

EW needs UAV's and UAV's need EW. The synergistic relationship can provide the ADF with enhanced Situational Awareness, a significantly superior capacity to conduct EW operations, and much better protected UAV's.

Miniature UAV's are of particular interest to EW operations as these UAV's are likely to undertake some of the most dull, dirty, dangerous, and impossible missions (D3I). The affordability of these smaller UAV's also provides us with the opportunity to acquire or develop suitable payloads for these missions. In addition, it allows for the development, experimentation with, and evaluation of (scaled) operational concepts for the larger UAV's and more advanced concepts, such as NCW.

DSTO has embarked on the AVATAR Key Initiative. The initiative is aimed at developing a multi-disciplinary, crossenvironmental framework for demonstrating the advanced applications of autonomous, uninhabited vehicles. The aim is to investigate the potential for advanced capabilities through the exploitation of new technologies and novel concepts of operation for networked, multi-platform, autonomous vehicles, sensors, and effectors. Its focus is on "experimentation in the hands of the warfighter".

Ackowledgements

The authors would like to thank Dr Don Koks and Mr Richard Bowyer of EWRD for their helpful contributions to this paper.

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⁸ An Intelligent Agent is an autonomous algorithm that, having been provided with some over-arching mission objective, senses, reasons, and acts upon its environment independent of any external command structures. A typical deployment philosophy might be "go over there, fix the problem, and don't do any harm".

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