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Unmanned Tactical Air Vehicles - An Electronic Combat Perspective

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ABSTRACT

This discussion paper, arising from project work at UK DERA, considers UTAVs from an electronic combat perspective. The paper will focus firstly upon their application to Electronic Combat roles, and secondly upon the problems of UTAV self protection by means of Defensive Aids Subsystems (DASS).

UTAVs will find a variety of roles in the military operations of the future, both in conflict, and in operations other than war, such as peace-keeping and humanitarian aid. This paper identifies in general the various roles and scenarios which may become applicable to UTAVs. Current UTAVs are predominantly used for reconnaissance, however their near-term rôle is expanding to encompass communications relay, electronic warfare, environmental monitoring, target designation and the suppression of enemy air defences (SEAD) applications.

The paper addresses the SEAD scenario, sensor payloads, airframe performance requirements and levels of threat faced.

The SEAD rôle presents a particularly high risk for airframe survivability, as the UTAV is challenging the very threats which may be used against it. Such UTAVs are likely to carry advanced payloads, making for a high-value vehicle, requiring some measure of self-protection.

Defensive aids will therefore feature in UTAV system designs. It is important to match the style of defensive aids to the roles and concepts of operation of the various types of vehicle envisaged. The style of self protection may be biased towards threat avoidance, confusion of air defences, or towards the countering of immediate threats. The paper discusses these styles of defensive aids systems, their cost and system drivers, and the types of components needed to realise them.

The defensive aids suites could in most cases have to operate without manual intervention, and in this respect will be rather different to the traditional systems found in manned aircraft. The paper discusses these differences, and their implications in terms of system cost, complexity and effectiveness.

The style of any countermeasure responses proposed for UTAVs may vary considerably according to the type of operation and the rules of engagement. Consideration must be given to the dangers of collateral damage, and even environmental damage, in certain circumstances. The paper discusses these considerations.

1. INTRODUCTION

The term "electronic combat" covers the non-image-forming military use of the electromagnetic spectrum. It includes all aspects denying, confusing or deceiving the enemy's use of the EM spectrum, and the exploitation of his use of the EM spectrum to one's own advantage.

Electronic combat covers passive RF sensing, defensive RF & EO alerting and countermeasure systems, RF and EO stealth, directed energy weapons and all types of jamming system.

It is the defensive aspects of EC which relate to the protection of strike aircraft; SEAD is one element of a layered EC defensive structure.

Long range electronic surveillance measures (ESM), electronic intelligence (ELINT), and reconnaissance, information, surveillance and target acquisition (RISTA) provide the first element of this layered structure. Their deep probing of the hostile territory reveals threats to friendly forces such as air defence units (ADUs). This information can be fed into mission planning which ensures that friendly aircraft can avoid the most lethal of the known threats.

Where mission planning alone is insufficient to protect a raid, non-mobile threats can be suppressed by the use of long range precision stand-off weapons, such as cruise missiles, or by whatever destructive means is most appropriate to the circumstances - attack helicopters, artillery, battle tanks, infantry or dedicated air strikes.

Despite mission planning, a raid is likely to overfly previously unknown defences, or mobile defences which have redeployed. These systems may be engaged by lethal SEAD mechanisms such as the anti-radiation missiles (ARMs), or suppressed by jamming (ECM). It is hoped that in the future, target detection systems will become sufficiently accurate to allow conventional weapons to engage ADUs, rather than the traditional use of ARMs, which are becoming prohibitively expensive. Suitable sensors may well be deployed upon stand-in platforms.

Unmanned tactical air vehicles are well suited to this rôle of target location for SEAD, not only due to the usual "D3" demarcation of Dull, Dirty and Dangerous missions, but in this case a fourth 'D' that the authors propose - *Dollars*. The UTAV based sensor, backed up by conventional weapons is suggested as a more cost effective solution than ARMs for dedicated tactical SEAD missions.

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If the SEAD approach above fails to clear a corridor for a raid, and hostile air defence weapons are launched, then on board DAS is invoked as the final layer of protection for the raiding aircraft. The applicability of DAS to the UTAV platform itself is the subject for the latter part of this paper.

2. TACTICAL SEAD

The term "SEAD" (Suppression of Enemy Air Defences) is applied to the degradation of enemy air defences, broadly speaking, this is defined as the suppression of hostile air defence elements which may engage penetrating friendly aircraft, before an anti-aircraft missile or gun is fired.

Tactical SEAD does not include the pre-strike attack of static air defence assets, such as the destruction of long-range surveillance radars by the use of cruise missiles.

Current capabilities in tactical SEAD rely for the most part upon ARMs, and upon stand-off jamming.

An ARM is launched once a threat is indicated, and flies ahead of the strike aircraft. The missile will search for air defence radar emissions and home onto the highest priority threat. ARMs are capable systems and are combat proven, but there are some drawbacks for the tactical SEAD rôle:

- An ARM can only engage targets which are radiating. If an ADU does not switch on its radar, then an ARM cannot detect it as a target. If the threat of ARMs prevents a radar from switching on, then the radar is considered suppressed, as ADUs are generally unable to engage friendly forces without some radar emission. It is the threat of the radar being switched on to engage friendly aircraft, *after* the passage of an ARM which concerns SEAD effectiveness.

- To maximise the probability that an ADU is suppressed, it is likely that more than one ARM is used against each target. As current ARMs have no battle damage assessment capability, it is not possible to be certain that the engaged threat has been eliminated. The advent of an ADU stopping radiation at the same time as an ARM strikes does not preclude the ADU operators having switched off their radar.

- ARMs are extremely expensive weapons. In a US report (published on the internet) of weapon costs from the Gulf War, unit costs were given for the following weapons. Their warheads are assessed as broadly similar in lethality:
  - AGM-88, HARM, Anti-radiation missile: unit cost $257,000
  - AGM-65E, Maverick air to ground guided missile: unit cost $101,000
  - Mk-82 'iron' bomb: unit cost $498

From the weapon costs stated above, it is apparent that if a cheaper weapon could be delivered to the target area, then the cost-effectiveness of the SEAD operation would improve considerably.

It is the concern that a considerable investment is expended with each launch of an ARM, regardless of the weapon effectiveness, which has prompted research at DERA UK into future SEAD systems.

In its purest form the future concept is to utilise a stand-off sensor to detect hostile ADUs, and then to direct conventional weapons onto the target. If it is considered desirable to reuse this sensor, or at least to utilise its capability against a number of successive targets, then a long endurance sensor platform is required.

This stand-off sensor platform could be a conventional manned aircraft, however the SEAD rôle is traditionally considered the most dangerous of offensive missions, as the SEAD target is specialised at eliminating aerial threats. A natural choice for a platform is the UTAV. An uninhabited air vehicle removes the risk of pilot casualties, and the size reduction brought about by removing the man from the airframe, enhances platform survivability.

3. SEAD OPERATIONS

Target detection is required for all SEAD concepts. Tactical SEAD implies the use of an airborne sensor suite and the provision for some means of attacking threat ADUs. The attack methodology may be either lethal or non-lethal. The definition of a non-lethal strategy is taken as any strategy where there is a reasonable expectation that there will be no loss of human life. An example of a non-lethal attack is stand-off jamming.

An attack platform may be a conventional strike aircraft, or some surface - based system. It could of course be an unmanned combat air vehicle (UCAV), or the sensor platform itself.

In OOTW it is possible that only the target location element of a lethal SEAD system would be compliant with the rules of engagement. This would yield valuable intelligence information, yet would still require some levels of self protection, since the UTAV is likely to be seen as a target of opportunity, or even of high priority, for hostile air-defences.

4. UTAV AIRFRAME

Future tactical SEAD will be operated as a mission support utility. That is to say that it will directly enhance the survivability of specific missions in a timely manner, rather than be used in the 'search and destroy' role.

It may be assumed that fixed ADU sites will be detected ahead of the raid by conventional reconnaissance means. However, it is the mobile ADU threat which is the most significant. Modern mobile ADUs are extremely capable weapons, and any intelligence reports of their position are likely to be stale by the time an offensive mission is launched.

4.1 Range Requirement

The UAV selected must be able to detect threats against friendly aircraft for the whole mission. This may be achieved either by using a static airframe with a long-range sensor, or by use of a long-range airframe with a short(er)-range sensor.

The problems associated with terrain masking at long ranges will almost certainly shift the balance of decision towards a longer range stand -in platform.

4.2 Altitude Requirement

An ESM sensor exists to detect radiation from ADUs, it must be flown at an altitude suitable to intercept such radar energy. This precludes very low flying platforms, as they will be shielded from such radiation by local topography. Equally, platforms which fly too high will be above the area searched by ADUs and would be reliant upon intercepting the very low power sideband emissions, rather than the comparatively high-gain main-beams. This leaves the airframe designer with a medium altitude platform.

4.3 Velocity Requirement

If the SEAD system is to provide timely threat information, and is using a short or medium range sensor, then it can be inferred that the platform must be capable of speeds broadly similar to those of the strike aircraft. A slow flying UAV far ahead of the raid may be unable to detect a mobile threat which has arrived at a point covered by the SEAD sensor an hour ago, but not yet overflown by the raid aircraft.

4.4 Payload Considerations

Payload considerations must also be addressed for the platform. There must be sufficient power and load reserve for the chosen sensor. If the UAV is intended to engage targets with weapons launched from its own airframe, then there must be sufficient scope in airframe design to allow for this.

4.5 Stealth

The airframe design should avoid features which will advertise its presence on the battlefield. A low radar cross section will limit the detection range for radar, whilst a low thermal signature will enhance stealth against thermal imagers.

The sensor suite chosen may avoid active systems to compliment a basic stealthy design. If active sensors are essential for the mission, then stealth of the airframe will fall in importance.

4.6 Performance Summary

In summary the required airframe is likely to have good endurance, fly at high speed (but retain a low speed capability) and at a medium altitude. It may have a low observable profile, and have a reasonable payload capability. One commercially available airframe, which exhibits such features, is the Teledyne Ryan "Scarab" (See Appendix A).

5. UTAV SEAD SENSORS

Sensors technologies applicable to the SEAD field fall into two broad categories; passive and active. If a stealthy airframe is required, then all emissions should be minimised. This suggests the utilisation of a passive sensor. The following section will summarise some of the passive sensor options for a UAV based SEAD sensor.

5.1 Passive sensor technologies

Acoustic

Acoustic signatures have successfully been used in the attack of AFVs. However these are very short range sensors and it is unlikely if current technology can differentiate between an AFV and an ADU based upon the same chassis. It is in doubt whether a motionless ADU will have a sufficient acoustic signature to allow detection.

Passive RF detection

This is the traditional means of sensing used by ARMs, and in ESM and ELINT. Emitted radiation is detected, and the source position calculated. ADUs can only be detected if their radars are switched on; emission control measures (EMCON) will inhibit the performance of such sensors. The utility of these sensors will be greatly enhanced by the use of radar decoys or similar, to encourage the hostile ADUs to illuminate.

Imaging Infra-red

This system obtains a high resolution image of the battlefield and automatically detects likely targets by their thermal contrast and outline. It may prove difficult to differentiate between AFVs and ADUs, but it will produce a near complete set of possible targets. Poor weather will degrade the performance of this sensor significantly.

Optical

Perhaps the best means of differentiating an AFV from an ADU is to have a man in the loop. Both daylight and thermal TV are viable options. An operator cued onto a target can identify the threat and authorise engagement. Again, poor weather degrades performance significantly.

Passive Sensor Summary

The only automated system which will detect all likely threats is the imaging infra-red. This used in conjunction with a passive RF seeker for cueing or differentiation would give the basis for a SEAD sensor suite. However this would not provide an all weather system.

5.2 Active Sensor Technologies

Retro-reflection

A scanning laser detects a reflected flash from an optical lens or camera. This sensor can detect only systems which contain the sensor in their field of view. However any air defence system tracking the sensor platform would give a decisive signature. Again, in common with optical systems, poor weather will significantly degrade performance.

Millimetric Wave Radar

A high-resolution radar system widely employed in the attack of AFVs, this system would be equally effective for the detection of ADUs. It is a comparatively short range system but has all weather capability.

Lidar

A form of high resolution radar using lasers. The high fidelity may allow identification of the targets, but poor weather performance, and short range, are the major disadvantages.

Synthetic Aperture Radar

This is a long-range medium-resolution radar system also used for the detection of armour. It is unlikely that current technology can differentiate between AFVs and ADUs, but a SAR sensor will deliver a complete set of possible threats.

Active Sensor Summary

Active systems can give the required all weather capability, but, in common with passive systems, no one sensor is a robust solution of the detection problem. It is likely that a suite of sensors will be required. SAR offers the best combination of range, detection probability and all weather capability, with the disadvantage of poor differentiation between AFVs and ADUs. Passive RF will show ADUs, as they alone will be searching the sky with radar. Retro-reflection will show EO threats, but only those systems which have the sensor in their field of view. Lidar or mmW offer high resolution signatures which may be used to identify SEAD targets.

6. SEAD SENSOR CONCLUSION

It would appear that the most robust solution is for a sensor suite with at least one active element. It is doubtful whether it is sensible to pursue a highly stealthed airframe if active sensors are to be used.

7. SURVIVABILITY

One of the four key motivations ("D4") for the interest in UTAVs is to have the capability of sending advanced instruments or effectors into hostile or politically sensitive areas, without risk to allied personnel ("Dangerous"). The range of potential UTAV solutions is immense; from the micro-miniature covert surveillance device to the uninhabited large aircraft used to drop relief supplies. The common factor is that the level of risk to the air vehicle, in the desired role, is greater than would be acceptable for a manned equivalent.

The style of UTAV likely to be deployed in an electronic combat role will tend towards the medium sized, but costlier end of the UAV spectrum.

The principal task for an electronic combat UTAV may be one of accurate location of hostile emitters, at long range. The payload would include a high performance, high sensitivity ESM system (the sensitivity may be relaxed somewhat from that of the most advanced manned air systems due to the inherent stealth of the UTAV platform, and the higher level of acceptable risk too the platform). Advanced ESMs are neither cheap nor light weight, however their demands for primary power are not great.

If passive location of emitters is insufficient, then active imaging sensors such as SAR may be required. Alternatively an EC UTAV could be employed as a stand-off RF jammer, supporting a manned raid.

Such active payloads would be technologically advanced, costly, heavy and require considerable power. The high demands for primary power would in turn increase the size and weight of the airframe, or limit the effective range and endurance of the UTAV.

These styles of UTAV will represent high value targets for the enemy air defences, and although more expendable than the equivalent manned asset, they will be too valuable to be regarded as single - use platforms. Thus there will be a requirement for some level of self protection or DAS. The threat environment may be divided into 4 main areas:

- RF threats - short, medium and long range, all weather weapons
- IR threats - short, medium and long range, good weather or clear air weapons
- Laser and Optical threats - short range (line-of-sight), good weather weapons
- Unguided weapon threats - short range only

8. STYLES OF SELF PROTECTION

The traditional concepts of DAS for manned platforms has focused upon detecting and countering immediate threats from missiles and guns - when the platform is under attack, the first priority is survival, and system designs have reflected this imperative. As such, the traditional DAS elements such as radar warners, and the RF countermeasures such as jamming, and the dispensing of chaff, have been of prime importance. More recently, IR countermeasure dispensers, missile approach warners and laser warners have risen in importance, along with IR / optical jamming systems.

A "complete" DAS fit to a UTAV is unlikely to present a cost effective solution except, perhaps, in the case of the most ambitious UTAV concepts such as uninhabited fighter / bombers (i.e. UCAVs) or uninhabited large aircraft.

In order to arrive at the optimum DAS solution for a UTAV it is necessary to take a step back from the traditional concepts, to take a wider view of platform self-protection. We propose here to take a three layered approach toward optimising survivability:

i. The first layer of platform self - protection in any UTAV lies in threat avoidance. Avoidance is achieved by flying outside the detection range, or at least outside the lethal range of the threat. Traditionally this form of protection has been achieved through mission planning and intelligence. In flight, detection by the enemy can be minimised by the use of terrain cover through low flying, and by the stealth of the platform. Cloud may be used against IR and optical detection. Long range passive sensing of un-surveyed threats, permits in-flight re-routing of the mission;

ii. The second layer of platform self - protection lies in minimising the danger that a threat can pose. A SEAD kill (hard or soft) may be invoked from supporting assets or using weapons carried on the platform, if any. The platform can attempt to confuse enemy surveillance and acquisition systems by the use of ECM and decoys. Stealth can be enhanced by flying in the Doppler notch around a threat radar, and by making use of cloud cover against IR and optical seekers. The flight altitude can be chosen to avoid the bulk of short range threat systems. Where it is not possible to avoid or suppress detection, indeed if the mission requires the platform to provoke or attack a threat, then it is feasible to select the most favourable approach geometries, to minimise exposure and to deny engagement opportunities to the enemy.

iii. The third layer of this approach of platform self - protection is the traditional DAS layer, which is invoked only if a threat is engaging the platform. Here the traditional components providing close-in threat warning, such as RWR and MLAW, and more recently LWR, come into play. Countermeasure effectors such as RF and IR jamming, chaff, flares and other expendables are used to break tracking lock or to decoy an incoming missile.

The UTAV concepts of operation may limit the applicability of layers (i) and (ii). This and other issues of self-protection and DAS will now be discussed in more detail. Protection against surface based, and airborne threats will be dealt with separately.

9. SURFACE-BASED THREATS

A wide range of surface-based systems could potentially threaten a UTAV. ADUs may be found in fixed locations, be ground-mobile, ship-borne or man-portable. Missile systems may be guided using active or semiactive RF illumination, laser illumination, command-to-line-of-sight principles, or make use of passive imaging or hot-spot detection. Anti-aircraft guns can derive aim points from radar, laser or passive EO / IR tracking systems, or be aimed by an unassisted human operator.

An enemy's air defences may consist of a haphazard array of individual ADUs, with little or no co-ordination of assets. Such situations are most typical of insurgents, terrorist or criminal groups, and encountered in peace-keeping operations or low - intensity conflict.

Alternatively, the air defences could be well co-ordinated through a clear structure of command and control, making use of early - warning and long range surveillance assets to pass on target vectors to the appropriate ADU networks.

9.1 Threat Avoidance

The avoidance tactic is a basic and obvious one for enhancing the survivability of all types of air platform. The nature of the mission of a UTAV for electronic combat, however, tends to reduce the scope for threat avoidance.

A UTAV employed in long range passive sensing of emitters must have a clear view of them, hence low flying and the use of terrain cover are not compatible with the mission, except when ingressing to, and egressing from, the target area.

Data on the locations of possible threats is likely to be scant, since it is the role of the UTAV to be the instrument of gathering such intelligence. The data collected by the UTAV may, however, be used on board to re-route around the most lethal threats detected, and of course passed back to any manned aircraft that the UTAV may be supporting. Organic support of a manned raid would, however, preclude any re-routing that the raid itself could not follow.

The UTAV is likely to be inherently more stealthy than a manned platform. The airframe will typically be smaller, and engine thrust requirements and power use less. Thus both RF and EO signatures will be simpler to reduce. Advanced stealth will, however, remain difficult and costly to achieve. The role of the UTAV in collecting ELINT could require it not to be over - stealthy in the RF; part of its function would be to provoke silent emitters into action.

RF Stealth

The stealth trade-off in the RF thus becomes a choice between two alternatives:

i) A platform with little or no special stealthing in the lower RF bands used by surveillance and acquisition radars. Such a platform would be vulnerable to attack by RF systems, so require some DAS elements. Some stealthing would enhance DAS effectiveness, particularly in the higher RF bands used by tracking and fire-control radars, and by airborne-intercept radars;

ii) A highly stealthed, hence more costly platform with low vulnerability to threats, but requiring that threats be provoked into action. This provocation could be achieved in either of two ways:

- Deploying some additional UAVs or expendable RF decoys to fly ahead of the UTAV;

- Alternatively the stealthy UTAV could carry an ECM on board, used to present intermittent targets to surveillance radars.

A UTAV carrying an active sensor such as a SAR, or a stand-off RF jamming capability, will be highly detectable when transmitting, so there would seem to be little point in expending great efforts towards passive RF stealth. It will be trackable by enemy ESM and potentially at risk from long range IR-guided missiles, or ARMs.

EO/IR Stealth
EO / IR stealthing will be a key feature in any UTAV optimised for electronic combat. If the UTAV is easily detected and tracked in the visible optical or the IR, then it will fail in its mission of provoking hostile RF emissions, and is more likely to be engaged by IR systems.

Many EO / IR threats, MANPADS in particular, will only be detectable when they launch missiles or fire their guns. To deliberately provoke this would place the UTAV under very great risk. Such a mission would more effectively be undertaken by lower cost expendable platforms, perhaps flying a few minutes ahead of a manned raid.

The bulk of mobile EO / IR systems associated with mechanised infantry or armoured formations, are short range point defence weapons. The UTAV may avoid most of these by flying at a medium altitude. The presence of low cloud would in any case mask the majority of EO / IR threats, and the UTAV could make use of cloud for reduced altitude flying, if cloud were present and reliably detectable. High altitude flight would introduce the risk of leaving a vapour - trail which would severely compromise stealth in the visible wavebands.

9.2 Minimising Danger
If the UTAV platform is detected by a threat radar, it is in danger. This danger could be reduced by avoidance tactics, but assuming that avoidance is not possible or not desirable at some phase of the mission, then there remains the possibility of confusion of the surveillance. The objective is to protect the platform by degrading the threat's ability to hand over from detection to tracking.

This may be achieved by some combination of stealth in the high RF bands typical of tracking and fire-control radars, ECM, and decoys. The optimum point in the cost - performance trade-off will be dependent upon the role of the UTAV.

Stealth can be enhanced against a particular threat radar by flying in its Doppler or MTI notch. If the radar *must* be approached, then stealth can be enhanced by flying slowly, placing the UTAVs Doppler or MTI return closer to that of the ground clutter. If an RF jammer is carried for a raid - support role, then an ECM capability for self protection may be added at minimal cost.

Some styles of UTAV may be required to approach a threat system in order to deliver a lethal payload. In such cases the only remaining option for reducing the risk of engagement is low flying to make the maximum use of terrain screening.

A UTAV flying ahead of a manned raid, will relay threat locations back to the manned aircraft. Pilots may then choose to respond with some form of hard kill, to clear a path for themselves, and of course for the UTAV.

9.3 Countermeasures
DAS countermeasures represent the final layer of platform self - protection, invoked only if a threat is engaging the platform.

The major threat systems challenging UTAVs used in ELINT or stand-off jamming will employ RF guided medium to long range missiles. The principal RF alerting device in traditional aircraft DAS is the radar warning receiver (RWR), giving both the type of threat and its direction of arrival. Now the EC - UTAV will be equipped with an advanced ESM as part of its primary sensor suite, and RWR functionality can be added to ESM at marginal cost. Certainly it would neither be necessary nor cost effective to propose a stand-alone RWR.

Once alerted to a locked on tracking threat or to an incoming active missile seeker, the simplest countermeasure is to turn to place the threat on the beam. This has the effect of placing the platform in the Doppler or MTI notch of the threat radar, and combined with the platform's low inherent signature may have some success in breaking lock.

Manoeuvre is a simple and cost effective countermeasure. More robust countermeasures are feasible but introduce additional cost and weight penalties.

Chaff has been used as a counter to radar systems since the second world war. The use of chaff for *self screening* can be effective in the case of slow moving assets, such as air-ship-type UTAVs. The principal self-protection use of chaff from a UTAV would, however, be as a decoy target, in conjunction with UTAV manoeuvre, to break the lock of a tracking radar. Chaff is not costly, but it is expendable, implying a weight and volume a trade-off in the number of shots of chaff which are to be carried on a mission.

RF Jamming or ECM offers a wide range of techniques to counter RF threats. Systems are costly, but if restricted to the role of self-protection jamming, weight and power use can be contained within reasonable limits. ECM has the advantage over chaff of being re-usable, it also offers additional functionality in support of the UTAVs primary ELINT role.

The problems associated with protection against EO, IR and laser-guided threats are considerable. The bulk of such threats will not alert the UTAV in any way until a missile is launched or a gun fired. Thus a missile launch and approach warner becomes highly desirable, particularly in protecting a costly UTAV such as one carrying both ESM and SAR.

Flares of some sort would be the most practical countermeasure reaction to a missile alert. Flares, like chaff cartridges are expendable, implying a weight and volume a trade-off in the number of shots to be carried.

If anti-air ARMs are considered a threat then EMCON (i.e. switch off of all active RF devices) plus manoeuvre must be invoked along with flare deployment - an MLAW cannot distinguish between an IR guided missile and an ARM.

IR jammers tend to be costly and bulky, however there is one style of jammer which does not require the addition of a missile approach warner to cue its operation. Such un-cued jammers compromise stealth in the IR bands, and, without the presence of a MAW, there would be no warning of nor protection against ARMs.

Laser Warning Receivers are practical, and need not be particularly bulky. They can effectively alert the UTAV to the presence of laser threats of all types.

In summary, the favoured solution against surface-based EO, IR and laser-guided threats is avoidance wherever possible. DAS - style warners and countermeasures impose penalties in terms of cost, weight and volume, however in the case of UTAVs carrying costly active RF payloads, these penalties are likely to have to be borne.

10. AIRBORNE THREATS

The prospect of an electronic combat UTAV encountering fighter aircraft is realistic only when facing a sophisticated enemy possessing a well co-ordinated air defence network, and an efficient airforce. In such circumstances, however, the threat from manned aircraft is a considerable one. Enemy airborne interceptors are likely to carry a mix of medium to long range air to air missiles both RF and IR guided, and possibly air-to-air ARMs. Additionally they may carry cannon for close combat, and can make use of their jet-wakes to disrupt light air vehicles.

Anti-air helicopters would pose little threat to any UTAV flying at medium altitude, unless equipped with an advanced "look - up -shoot - up" capability.

UTAVs employed in organic support of raids will be followed by manned aircraft. We can assume that the raid's strike aircraft will represent the highest priority targets for the enemy interceptors. A raid likely to encounter such opposition will typically include fighter aircraft to deal with enemy interceptors.

10.1 Threat Avoidance

The typical UTAV will not be able to out run or out fly a fixed wing interceptor aircraft. Consequently, any avoidance strategy must rest upon avoiding detection by the long-range systems used to vector the fighters to their target, and upon detection by the fighters' airborne intercept radar and IR search and track systems. Ultra high altitude operation is a possible strategy, but largely outside the scope of UTAVs for electronic combat.

These considerations push toward the more stealthy UTAV options, making use of off-board decoys or on-board ECM for the prime task of provoking the air defences into action. If the UTAV cannot be detected by long range systems, then fighters cannot be vectored against it . If there is a significant risk of fighters being vectored towards the UTAV, then we can consider reducing the tracking accuracy of detecting system, with some mix of stealth, low speed flying, manoeuvre and ECM. Enemy airborne early warning radars are likely to have the ability to form high quality tracks, hence ECM efforts should be directed towards them.

10.2 Minimising Danger

Assuming that the UTAV can successfully deny high accuracy tracking to the enemy, then incoming fighters will have to search for the UTAV using AI radar, and IR. Against these threats, stealth in the high radar bands, and in the IR, become most important.

The SEAD or ELINT UTAV will carry ESM / RWR to warn of the presence of hostile Airborne Interceptor radars. The danger they present may be reduced by presenting the AI radar with the minimum radial velocity. This may be achieved by turning to place the threat on the beam, and by flying the UTAV at its minimum air speed. Some forms of ECM may also be appropriate.

At close quarters the enemy pilot will try to acquire the UTAV visually, the stealth emphasis here must be in the visible and IR bands, ensuring minimum observability.

10.3 Countermeasures

The responses to a locked on RF tracker, or an incoming RF missile, have been discussed above, and are really no different with regard to air-to-air threats. The platform must, however, face the possibility of a medium or long range shot using an IR missile. It was argued above that a suite of IR warners and countermeasures is unlikely to be cost effective, except for a high value UTAV carrying active SAR.

Short range cannon may be effective against a UTAV, but typically it will present a small and difficult target. The jet wake of a fighter, particularly using an afterburner, is potentially destructive over a large volume. There is no DAS countermeasure to this type of attack, but some hardening of the airframe and its aerodynamics may be possible.

Some forms of UTAV will carry lethal payloads for deployment against their ground targets, and in some cases these may be usable against fighter aircraft. The problem lies in the targeting and fire control associated with such a weapon; the solution, if any, is likely to depend upon the presence of remote manual control of the UTAV.

11. AUTOMATED RESPONSES

A UTAV will be required to derive its own defensive responses to the situation it finds itself in. A totally manual style of decision making and control, through remote piloting, is an option, but not an attractive one. Practically, a great deal of autonomy will be required. Key to decision making is knowledge of the environment or "situation awareness".

11.1 Situation Awareness

Situation Awareness is a much used term with a variety of meanings. In the context of an EC UTAV, this paper suggests a definition that

> "Situation awareness comprises an up to date mission library (or database) of own forces, neutrals, targets and threats, in terms of their positions and headings; their identities, their capabilities and technical parameters; their groupings and intentions (as far as can be deduced) and of the priority of each threat."

Situation awareness exists against the background of the UTAV's own position, own mission objectives, the local terrain and local conditions.

In most current manned air platforms situation awareness exists almost entirely in the pilot's mind. Some elements of it exist within the various sensor and effector subsystems, but the pilot alone must perform the overall data fusion task; filtering, summarising and prioritising what he sees. In an UTAV, situation awareness must be implemented as a subsystem, performing data fusion at all levels.

11.2 Data Fusion

Data fusion represents a family of tools and approaches to the problem of forming situation awareness. The term embraces a variety of levels, or areas of interest; for example:

- image fusion at pixel level;
- association of new measurements with each other and with currently tracked entities;
- fusion of measurements and current tracks to form updated kinematic tracks;
- classification of entities by track analysis, and clutter removal;
- fusion of declared identities of entities;
- association of entities into groupings, forming an air-picture;
- fusion of evidence or assumptions of intent, forming threat priorities;
- responses, tactical advice, and reactions

A variety of methods and algorithms exist for the implementation of each level of data fusion. The table below summarises these against the JDL four-layer model of data fusion processes - OODR (Observe, Orient, Decide, React):

Level	Function // Techniques
1 (Observe)	Association (of plots or tracks) // Mathematical techniques e.g. nearest neighbour.
1 (Observe)	Fusion of plots or tracks to form entities // Mathematical techniques e.g. Kalman filters, winning sensor.
1 (Observe)	Classify entities, de-clutter // Pseudo - sensor analysis of track dynamics.
1 (Observe)	Identify entities // Probabilistic techniques e.g. Baysian (STANAG 4162), Dempster - Shafer; Rule - based.
2 (Orient)	Picture formation (entities >> groups) // Rule - based, reasoning tools.
3 (Decide)	Threat Prioritisation // Rule - based, game - playing.
4 (React)	Reactions // Rule - based, hill-climbing, optimal control, database lookup.

11.3 Responses

The end product of data fusion at levels 1 to 3 is a machine held situation awareness. This exists only to be used by the routines which will control the UTAV's responses.

The principal response packages will be:

- Mission re-planning, re-routing to avoid threats whilst fulfilling the mission requirements of data collection, coverage of areas, time on station, and recoverability.
- Tactical manoeuvre control.
- Allocation, timing and control of DAS countermeasures.
- Targeting, allocation, firing and control of any lethal systems carried.
- Moding and tasking of EC and other sensor assets.
- Reporting back of the situation to the command centre responsible for the UTAV mission, and to other interested allied assets.

An overall response control function will be needed to allocate classes of response and resources to each response package. Manual overrides may be allowed if there is remote piloting or decision making.

12. RULES OF ENGAGEMENT

The difficulties associated with the application of rules of engagement to UTAV missions affect both the concepts of operation and the self protection strategy.

12.1 Operations Other Than War

The rules of engagement associated with peace keeping and humanitarian aid operations tend to be the most restrictive, precluding lethal responses in almost all circumstances. A non-lethal UTAV involved in electronic combat is most likely to fulfil a surveillance (ELINT) role. Threats may be faced, so countermeasure strategies must be considered. Threats are likely to be isolated, uncoordinated and, mostly, unsophisticated.
In order to safeguard life and property, any use of DAS expendables must be carefully regulated. Flares pose obvious hazards should they hit the ground burning. At low level, flares would not be an option, although at medium or high altitudes they could be quite safe.

These considerations push the countermeasure strategy towards stealth and threat avoidance. Flying at medium altitude will avoid the bulk of small arms, AAA and IR guided threats. Sophisticated air-defence surveillance networks are most unlikely to be encountered in these operations, but the occasional mobile SAM could be present; indeed locating these will be one of the main objectives of the UTAV mission. The favoured countermeasure against RF systems is ECM. Jamming offers a non-lethal (soft) kill of the launcher (by disrupting the engagement sequence) or of a missile in flight. The missile or its debris will fall to earth somewhere: this is unavoidable.

The use of ECM in operations other than war may be almost unrestricted. The only exception is where it could pose a hazard to civil air traffic. Such hazards should be minimised at the mission planning stage - avoiding civil air lanes. The presence of the UTAV itself in a civil air lane would pose a risk of collision far greater than any risk from its ECM.

12.2 Intense Conflict

War scenarios are not without rules of engagement. The control of UTAVs carrying any sort of lethal payload is problematic, and in the foreseeable future the solution will lie in remote manual intervention.

Parallels may be drawn with cruise missiles and stand-off weapons dispensing submunitions, however there is an essential difference. Stand off weapons are dispatched against a specific target or target area, implying that the surveillance, identification and acquisition tasks have already been carried out and confirmed, and that the mission has been judged safe in terms of its potential for endangering civilians or allied assets. The lethal UTAV electronic combat mission, in contrast, is one of surveying an unknown area, identifying and locating targets (mobile ADUs for example), then attacking. It is most likely that visual confirmation will be required, if, for example, an ADU is located within a built up area, or close to known positions of allied forces.

The lethal UTAV must, therefore, carry two way communications links passing sensor data to a controlling location, and receiving command instructions. It is also likely that IFF and some EO / IR imaging must be carried. Imaging would also allow the lethal UTAV to collect some battle damage information after its attack.

The problems of controlling non-lethal UTAVs are less severe, however DAS countermeasure responses could, in some cases, endanger allies or civilians. Flare and chaff deployments present the same problems in intense conflict as in they do operations other than war, but the level of acceptable risk will be higher. Non lethal countermeasures such as manoeuvre, ECM and IR jamming will be preferred over other forms, as these present the least risk to allies and to civilians.

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14. STATEMENT OF RESPONSIBILITY

Any views expressed in this paper are those of the authors and do not necessarily represent those of the UK DERA, nor of H.M. Government of the United Kingdom.

GLOSSARY

ADU	Air Defence Unit
AFV	Armoured Fighting Vehicle
AI	Airborne Interceptor
ARM	Anti-Radiation Missile
D3	Dull, Dirty and Dangerous
D4	Dull, Dirty, Dangerous, and Dollars
DAS	Defensive Aids Suite(s)
DASS	Defensive Aids Sub-System(s)
DERA	Defence Evaluation and Research Agency
EC	Electronic Combat
ECM	Electronic Counter-Measures
ELINT	Electronic Intelligence
EM	Electro-Magnetic
EMCON	Emission Control
EO	Electro Optic
ESM	Electronic Surveillance (or Support) Measures
IR	Infra Red
JDL	Joint Directors of Laboratories
LWR	Laser Warning Receiver
MANPADS	Man Portable Air Defence Systems
MLAW	Missile Launch and Approach Warner
mmW	millimetric wave (radar)
MTI	Moving Target Indication
OODR	Observe, Orient, Decide, React
RF	Radio Frequency
RISTA	Reconnaissance, Information Surveillance and Target Acquisition
RWR	Radar Warning Receiver
SAR	Synthetic Aperture Radar
SEAD	Suppression of Enemy Air Defences
TV	Television
UAV	Uninhabited Air Vehicle
UCAV	Unmanned Combat Air Vehicle
UTAV	Unmanned Tactical Air Vehicle

APPENDIX A - Example Platform

Name: Scarab
Company: Teledyne Ryan, USA
Status: In service (Egypt 1988)

PERFORMANCE & DIMENSIONS

Range: 1000 km
Altitude ceiling: 13100m (42900 ft)
Maximum speed: 235 m/s (460 Knots, 530 Mph, 850 kph)

Length: 6.15m
Wingspan: 3.35m
Height: 0.86m
Maximum weight: 1077 Kg

Launch: Rocket assisted take-off (RATO)
Recovery: Parachute and airbag
Propulsion: 1 x Teledyne CAE 373-8c Turbojet
Guidance: Inertial and GPS navigation, pre-programmed or by remote control

PAYLOAD

Payload weight: 131.5 Kg
Payload: Storage daylight camera / TV / infrared line scanner