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The operational effectiveness of UCAVs in mobile target attack

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1 SUMMARY

This paper addresses a high-level approach to the analysis of uninhabited combat air vehicle (UCAV) effectiveness. The need for effectiveness analysis to take place in a range of realistic operational contexts is established, and the utility of effectiveness analysis is addressed. It is argued that it is necessary to take a 'system of systems' view in assessing UCAV effectiveness due to the diversity of impacts such systems will have on military operations. Relationships between some areas of UCAV performance, and their impacts on UCAV effectiveness, are presented as examples of the complexity of UCAV operations and to demonstrate the need for effectiveness analysis to assist in system definition.

2 INTRODUCTION

Recent years have seen an explosion in the attention paid to uninhabited air vehicle (UAV) concepts and technologies. Three main drivers can be identified for this explosion:

- improvements in technology;
- the escalating cost of manned aircraft coupled with a general reduction in military budgets;
- the changing political environment.

Through recent advances in the fields of sensors, communications, and computing technology, UAVs offer the potential of high levels of military effectiveness at low levels of cost. At the same time, UAVs offer interesting challenges to scientists and engineers, allowing them to push back the boundaries of contemporary aviation technology. Finally, with the end of the cold war, and the establishment of 'the new world disorder', the relative importance of 'operations other than war' has increased, bringing with it a range of problems that have not been widely addressed in the past.

Against this background, it is necessary for political and military decision makers to be able to strike an objective balance between conventional inhabited air vehicles and the revolutionary possibilities offered by new UAVs. This balance must be struck so as to provide optimal military cost-effectiveness across the range of operational situations that may occur. Cost-effectiveness analysis of potential systems is used to inform decision making within the procurement process (e.g. the UK's combined operational effectiveness and investment appraisal (COEIA)).

In addition to its utility in informing procurement decisions, cost-effectiveness analysis can also be used to explore system trade-offs and the prioritisation of system capabilities against defined operational requirements. This allows for the early focusing of resources on those elements of system capability that offer the greatest potential for pay-off in terms of military effectiveness. It is often the case that the true drivers of military effectiveness are not obvious. Cost-effectiveness analysis can also be used to investigate military concepts of operation, and technology balance of investment.

This paper has been prepared with the specific focus of offensive operations against mobile targets. While this is often seen as a problem of 'sensor to shooter' connectivity, this ignores many other problem areas such as target detection, target identification, avoidance of collateral damage, and the integration of attack assets with other air operations. The introduction of UAV concepts into this role provides many new challenges. UAV operations against mobile targets need to be evaluated in the light of all of their potential impacts on the problem, and not only those which get the most attention in the press.

3 DEFINITION OF TERMS

Several phrases used in this paper could be considered 'buzz-words' and therefore need more formal definition. The definitions given are for the purposes of this paper, and should not be considered as being generally 'definitive'.

3.1 UCAV

Paper presented at the AGARD MSP Symposium on "System Design Considerations for Unmanned Tactical Aircraft (UTA)", held in Athens, Greece, 7-9 October 1997, and published in CP-594.

An uninhabited combat air vehicle. This is an uninhabited air vehicle that functions as part of a combat system (that is, one whose end goal is the delivery of weapons to targets). This definition means that a UAV carrying a sensor system that provides targeting data to a weapons platform is considered a UCAV. This definition is used to emphasise the holistic view that should be taken in the analysis of UCAV mobile target attack.

3.2 Effectiveness

Effectiveness is defined as being the level of impact of the performance of a system on a defined operational context, and is measured in terms of defined military goals (e.g. the destruction of tanks) rather than physical values (e.g. penetration of armour in mm). That is, effectiveness is the level of 'military worth' of the system.

Effectiveness can be viewed as arising from the interaction between technology, tactics and environment.

3.3 Mobile target

A target which is not fixed in space. Since virtually any target can be moved in some timescale this means that a time threshold must be set. For the purposes of this paper a mobile target will be considered to be one which can relocate within the timescale of the operation of an Air Tasking Order (ATO).

It should be noted that a mobile target is not necessarily a moving target. The target may well be stationary for significant periods of time (e.g. mobile strategic surface-to-air missile batteries).

4 OPERATIONAL CONTEXTS

UK defence doctrine (as a consequence of wider national policy) recognises that the UK armed forces may be required to act in many different roles and geographic locations. This gives rise to a wide range of potential environments in which military systems may be required to operate (the word environment is taken to include the military context of an operation as well as its geographic location). It is important to understand that the impact of a particular military system (and hence its effectiveness) will vary depending upon the environment in which it is deployed. For example, arctic survival clothing is highly effective in arctic conditions, but if deployed in the Persian Gulf region during summer, it would not only be completely useless, but actually counter-productive.

For this reason it is necessary to postulate a number of operational contexts (or 'scenarios') in which the capabilities of systems can be evaluated. This ensures that the system or systems procured can deliver an acceptable degree of military effectiveness across the range of contexts that might be required by national policy.

In postulating scenarios it is necessary to address the range of scenario-driven factors that will significantly impact on the problem at hand. These factors are termed scenario characteristics. For many problems there are likely to be a large number of such characteristics, all of which can take multiple values. In theory this requires a large number of scenarios to fully analyse the impact of differing operational contexts on system effectiveness. There is a balance to be struck between completeness and cost. DERA has developed a method for scenario selection based on coverage of relevant scenario characteristics and their distinct values, so as to get the optimum level of problem coverage for the least number of scenarios.

An example of a scenario characteristic might be the 'level' of an operation. This might range from general war, involving the full resources of a nation or nations, to peace support operations using perhaps only a handful of personnel. This characteristic would significantly impact on the range of possible military goals in the scenarios selected. In addition, where similar military goals might exist in different levels of operations (e.g. suppression of enemy air defences, or suppression of ground force movements), the balance of importance between them may alter. Furthermore the methods that could be used in different operations may also differ (e.g. jamming as opposed to destruction of air defence sites).

Some scenario characteristics of particular relevance to UCAV operations and technology, insofar as they may impact on the desirability of using a UCAV as opposed to an inhabited combat air vehicle, or a particular UCAV solution as opposed to another (e.g. autonomous operation versus a remotely piloted vehicle (RPV)) are:

- rules of engagement - these may have a strong influence on the permitted degree of autonomy of a UCAV system;
- sophistication and density of enemy air defences - these are of particular relevance to the issue of risk to aircrew (when comparing inhabited with uninhabited air vehicles);
- size of geographic area of interest - can impact on required levels of air platform endurance and range (which is relevant to inhabited versus

uninhabited operations), and communications infrastructure requirements based on line-of-sight restrictions (which is particularly relevant when considering the degree of autonomy of UCAV systems).

5 EFFECTIVENESS ANALYSIS

As defined earlier, military effectiveness relates to the impact of systems in realistic operational contexts. Taking the 'system level view' in measuring effectiveness is widely accepted as being necessary in most situations. However there is often a question of how far 'the system' actually extends. Furthermore, most military systems depend on other systems to provide them with the environment in which they can operate, e.g. the most potent air superiority fighter in the world is not effective without the support systems that get it airborne (fuel delivery, maintenance, command and control etc). For the attainment for military goals in realistic contexts, it is almost always the case that many systems have to work together. Thus military effectiveness is often not a system-level attribute, but arises from the interactions between many systems. This is the basis for taking a system of systems level view of military effectiveness.

In practice, this is not always done. This is justifiable when the impact of a particular system type is well understood, and where the functions of the supporting systems in the system of systems do not substantially alter as a consequence of the system under study. However, UCAVs as a concept are still immature and it is widely felt that they will have multiple impacts in many areas of military operations. This would suggest that the system of systems level view is the appropriate one to take.

But what specifically is meant by the effectiveness of the system of systems? Effectiveness is measured in terms of parameters known as Measures of Effectiveness (MoEs). These MoEs vary depending on the nature of the system being studied and the purposes for which it is intended. However it is often the case in combat modelling that military effectiveness is measured in terms of some combination of the following three factors:

targets destroyed (or targets suppressed);

own force losses;

collateral damage inflicted.

The first two factors reflect traditional approaches to the measurement of military effectiveness (e.g. Lanchesterian type analysis). The third factor has risen in importance in recent years, and in some types of operation may actually be of greater importance than the other two (e.g. peace support operations). Other measures are also used, but in almost all cases are constructed in some fashion from those listed above (a measure of the position of the forward line of own troops (FLOT) against time will often depend on the remaining enemy strength at that time related to that of friendly forces).

Political effectiveness, or the impact of military effectiveness on the political context of a particular operation, is much harder to quantify. It may be that a high degree of military effectiveness in terms of targets destroyed for example, may actually be politically counter-productive. For this reason effectiveness analysis often steers clear of these muddy waters. Nevertheless DERA is sometimes required to generate non-traditional measures for situations such as peace-support operations.

In situations where procurement or investment advice is being generated, system costs must also be taken into account. In procurement support, cost-effectiveness analysis is required as effectiveness analysis alone can lead to the 'gold-plated silver bullet' solution. UCAV cost analysis is of as much importance as effectiveness analysis. It is however beyond the scope of this paper to consider cost further.

The approach used to address the question of UCAV effectiveness in the attack of mobile targets is first to consider the problem from a generic viewpoint, i.e. not specifically as a UCAV problem. After this, the specific effects of UCAV operations on the generic problem can be considered. The effectiveness analysis is carried out by considering the measures of effectiveness, the factors that impact upon them, how those factors interact, which factors impact on them, how they interact and so on. This leads to the production of a 'structure' which illustrates the scope of the problem.

The structure developed can be used in a number of ways. For example, it can be converted into a 'model' through the use of a systems dynamics type approach, or it could be used as the basis for a specification for a conventional computer simulation (or more likely a series of simulations) and how the outputs of those simulations should be integrated. A useful initial output from such an activity is the ability to use such structures to form the basis for discussion, to point out interactions which may otherwise be missed, and to identify areas where feedback may occur (positive feedback between factors may identify potentially useful synergies whereas negative feedback may suggest areas where variations in performance may have little impact).

6 UCAV EFFECTIVENESS

6.1 GENERAL DISCUSSION

So far this paper has addressed why UCAVs should be considered as part of a system of systems, and why effectiveness analysis is a vital tool in system development. One element of this is the comparison of conflicting requirements, or concepts of operation e.g. comparing the trade between expensive sophisticated defensive aids to allow high altitude operation, versus the performance penalties due to low altitude operation without those aids, for example in a penetrating reconnaissance system.

Having followed the 'structural' approach suggested above we can begin to pull out areas of particular relevance to UCAV operations. Not surprisingly these are areas which are already known of and are being worked upon, e.g. the issue of automatic target recognition, which if reliable could lead to autonomous UCAVs with good enough target identification capabilities to be allowed to attack those targets without human intervention. What are not always apparent are the multiple impacts that some factors can have on system effectiveness, e.g. 'Risk to crew'. The main impact of this factor is often seen as being on weapon types used (stand-off or short ranged). However, this also impacts on the routeing options useable and therefore the system's transit time to its weapon release point, therefore the timeliness of its attack, therefore the required trade-off between target location accuracy and the timeliness of the target location data, the required sensor coverage and quality, the numbers of platforms required and so on. Some factors are likely to have non-obvious, non-linear impacts on system effectiveness due to having complex interactions with other factors, and due to the potential for feedback between them. The ability to identify these interactions explicitly is a strength of this 'structural' approach to the analysis of UCAV system effectiveness.

6.2 SYSTEM AUTONOMY

One issue which is often discussed in the UCAV arena is system autonomy for attack platforms. In essence, the main problem that is perceived is whether an autonomous system would have the capability to detect and identify its targets without human intervention, and particularly in low-intensity conflict settings, whether it would be able to reject false targets such as civilian traffic. The degree of human/machine intelligence of the system, combined with the timeliness and accuracy of the targeting data with which it is provided, contribute to the correct identification of targets. This combines with several other factors to drive target destruction, the level of collateral damage inflicted, and hence system effectiveness. Another factor impacting on this area is the location of the human/machine intelligence. This issue of 'where is the intelligence in the system?' is one that is likely to be critical for future UCAV systems, in particular in the attack of mobile targets.

In attacking mobile targets there will be a premium in correctly locating targets in a background environment where both target position and the nature of the environment may have changed since the last targeting update. The location of the intelligence in the system is likely to be an effectiveness driver. An inhabited combat air vehicle will have human decision making capabilities on the scene, but will suffer the limitations imposed by the requirement to carry crew. Alternatively a remotely piloted vehicle will have human decision making capabilities but will rely upon communication links to allow them to be used. Those communication links could be jammed, malfunction, or be limited by line-of-sight, or satellite usage restrictions. Further they could make the system more vulnerable to detection and hence less survivable. A fully autonomous UCAV would have no need for human decision making, thus it could enjoy all of the benefits of being designed without the need for a crew, and at the same time not suffer from the limitations of requiring the communications support that characterises the RPV. However, how reliable would the autonomous system be, and given its limitations (if any), in what circumstances and therefore how often could it be used? These issues can be addressed through effectiveness analysis, in particular the mix of such capabilities which may be required.

6.3 SURVEILLANCE, TARGET ACQUISITION AND RECONNAISSANCE (STAR)

An area in which UCAVs are seen as being of particular use is in providing STAR coverage. In the main this is due to the potential for very long endurance, allowing for substantial coverage with limited assets, and the lack of risk to crew (which has already been discussed). Unfortunately there is a tendency to overstate the impact of such systems, with images of constellations of UAVs freely wandering the skies providing instant intelligence on any target of interest in enemy territory being not uncommon in the open literature. It would be very dangerous to design a mobile target attack system based purely on such an image. Consideration must be given to countermeasures which could be applied by an enemy to protect his assets, particularly those which could be considered to be 'high value' e.g. tactical ballistic missiles, mobile SAMs, mobile command and control.

One countermeasure that could be employed would be to operate high value mobile assets in areas with substantial surface-to-air missile defences as well as radar sites, electronic intelligence (ELINT) systems etc. Aggressive fighter sweeps over such areas could also be envisaged with radar, infra-red, radio frequency and optical sensors all playing a role in the detection of surveillance platforms. Considering the ballistic missile target, by the time such defences could be suppressed to a level allowing effective operation of friendly sensor assets, it may be the case that the enemy may have already had sufficient time to launch most of his stocks. Of course, the level of effort required by the enemy to mount such a defence may either be beyond him, or may adversely impact on his other operations. In this second case it could be argued that the friendly system was still effective through the threat of its use requiring the enemy to act in a sub-optimal manner. The evaluation of enemy countermeasures and their effects both on the UCAV system in question, and the wider operational context as a whole, is an area in which effectiveness analysis can provide value to decision makers and system designers.

7 CONCLUSION

The impact of UCAVs on military operations will be far more wide ranging than would be suggested by simply considering them to be 'aircraft without pilots'. Because their impacts will be so wide ranging it is necessary for rigorous cost-effectiveness analysis of UCAV systems in a wide range of operational contexts to be carried out. This will be fundamental to the successful integration of UCAVs into military operations in such a way as to meet future national objectives. However, cost-effectiveness analysis should not be seen as simply an aid to procurement decision making. It should be integrated into the design process of future UCAV systems as a means of focusing effort on key system effectiveness drivers, and of avoiding unnecessary or inappropriate effort in areas of marginal impact on system cost-effectiveness.

8 CLASSIFICATION

UNCLASSIFIED

This paper represents the views of the author, it does not necessarily represent the official views of the Defence Evaluation and Research Agency nor the UK MOD.