MINISTRY OF DEFENCE

Joint Doctrine Note 2/11

# The UK Approach to Unmanned Aircraft Systems

# JOINT DOCTRINE NOTE 2/11

# THE UK APPROACH TO UNMANNED AIRCRAFT SYSTEMS

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# PREFACE

1. **Context**. Unmanned aircraft have been around since the early days of aviation, exemplified by such systems as the World War II German *Fritz X* Glide Bomb and the proliferation of US systems such as the *Firebee* that played a major role during the conflict in Vietnam. In the last 5 years, the packaging of satellite positioning systems with advanced sensors, communication links and computer processors, have given Unmanned Aircraft Systems (UAS) a capability that previously existed only in the realm of science fiction. As General Schwartz noted recently,

> '*technology and explosive computing power are creating conditions for change at an unprecedented rate*'.[1]

Unmanned aircraft now hold a central role in modern warfare and there is a real possibility that, after many false starts and broken promises, a technological tipping point is approaching that may well deliver a genuine revolution in military affairs.[2] However, despite the growing ubiquity of unmanned aircraft, key questions remain over how to best procure, employ and support them.

2. **Purpose**. Joint Doctrine Note (JDN) 2/11 *The UK Approach to Unmanned Aircraft Systems* considers how UAS may contribute to the UK's future defence and security needs between now and 2030.[3] Its purpose is to identify and discuss policy, conceptual, doctrinal and technology issues that will need to be addressed if such systems are to be successfully developed and integrated into future operations. Although broad agreement has been achieved amongst contributors, the JDN does not describe a position of consensus. It does, however, seek to energise debate within the UK and move UAS-related thinking forward.

3. **Structure**. This JDN comprises 7 chapters and a conclusion. Following the introduction in Chapter 1, Chapter 2 revisits the terminology and classification issues that were first introduced in JDN 3/10 *Unmanned Aircraft Systems: Terminology, Definitions and Classification* which is now superseded by this JDN and will be withdrawn. Chapter 3, which discusses 'Why Unmanned Aircraft?', is a key element of the document, together with Chapter 5, which covers legal, moral and ethical issues. Chapter 4 outlines the current

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[1] Comment made by General Norton Schwartz, Chief of Staff US Air Force, during a presentation to the National Defence University, 15 December 2010.

[2] Similar effects are occurring in the Land and Maritime environments. Many of the principles discussed in the document will have applicability and direct read across from the Air to the Land and Maritime environments.

[3] For concepts, time is considered in 5 year epochs. For this document, Epoch 1 covers the period 2011 – 2015 inclusive.

unmanned aircraft situation from a UK perspective. Chapter 6 discusses, for the non-technology specialist, the main technology and science issues related to UAS and Chapter 7 provides, from wider Development, Concept and Doctrine Centre (DCDC) work, an outline of how the future character of conflict will impact on air operations and hence on unmanned aircraft. The document ends with a separate conclusion that lists key issues and a summary presented in the form of a Strengths, Weaknesses, Opportunities and Threats (SWOT) diagram.

4. **Consultation**. JDN 2/11 has been written following a wide consultation across Defence, including Warfare Centres, Central Staff, UAS operators and the Military Aviation Authority.

## LINKAGES

5. This JDN is written to inform and prompt wider debate on UAS-related issues in the UK and follows on from the initial work conducted for JDN 3/10. The concepts will feed into the development of the *Air Interim Environmental Operating Concept*, due end 2011, which will replace the *Future Air and Space Operational Concept* published in 2009. It will also contribute to the rewrite of *Air Publication 3000* (*AP3000*) and inform UK input to future NATO publication updates.

# CONTENTS

## THE UK APPROACH TO UNMANNED AIRCRAFT SYSTEMS

# CHAPTER 1 – INTRODUCTION

101. In the absence of any higher level policy, all Unmanned Aircraft Systems (UAS) currently used by UK armed forces have been procured or leased under the Urgent Operational Requirement (UOR) process. As such, these systems were brought into service to meet an immediate operational need rather than any long-term endorsed capability requirement. Post Afghanistan, it remains unclear what will happen to these systems following the withdrawal of forces and who will act as lead to formulate an overarching UAS development and governance policy for the 3 services. Regardless, as defence moves to regularise some UOR procurement into core, there will be a need to identify what future capability could be delivered by unmanned aircraft and the consequences for those organisations that use them.

**British Army Desert Hawk 3**

102. There is a general expectation across defence, academia and industry that unmanned aircraft will become more prevalent, eventually taking over most or all of the tasks currently undertaken by manned systems. This view is strongly reflected in current government policy. In the foreword to *Securing Britain in an Age of Uncertainty: The Strategic Defence and Security Review*, the Prime Minister and Deputy Prime Minister noted that '*by the 2020's….. The fast jet fleet will be complemented by a growing fleet of Unmanned Air Vehicles in both combat and reconnaissance roles*.'[1] The Strategic Defence and Security Review further stated as one of its principles that, '*we will invest in programmes that will provide flexibility and advanced capabilities, and reduce legacy capabilities which we are less likely to need in a world of precision weaponry, and where the battlespace increasingly involves unmanned and cyber operations'.*[2] Later, in the section on 'Alliances and Partnerships', it notes the intention to intensify the UK's security and defence relationship with France and to seek closer co-operation in several key areas, including: '*extending bilateral co-operation on the acquisition of equipment and technologies, for example in the areas of complex weapons, and increasing*

[1] *Securing Britain in an Age of Uncertainty: The Strategic Defence and Security Review,* HM Government, page 5, 2010 available at http://www.official-documents.gov.uk/ accessed on 17 February 2011.
[2] *Ibid*, page 17.

*significantly our investment in joint projects, including unmanned aerial systems'*.[3]

103. The over-riding motivation for moving to unmanned systems is a desire to deliver new or enhanced capability by embracing new technology while reducing costs and the threat to personnel. In particular, it is expected that UAS may offer an opportunity to reduce force structure size due to decreasing buy-to-deploy ratios. There will be a reduced requirement for airframes to conduct pilot and sensor operator training, which could be largely synthetic, although airframes will still be required for collective training with end users. Further work is required to investigate how far we can move towards a *boxed rounds* concept, where unmanned aircraft would only be used on operations. Manning ratios reduce considerably when aircraft are operated remotely from a Main Operating Base (MOB) rather than a Deployed (DOB) or Forward (FOB) Operating Base. This removes the normal 4:1 or 5:1 manning ratio required to achieve deployment harmony rules, although the intensity and duration of operations may require a significantly higher domestic manning ratio than for peacetime operations[4]. While the UK is at the forefront of technological development in many areas, it has only limited experience of operating modern, capable, unmanned aircraft and relevant operational analysis is scarce. The paucity of long-term data means that accurate through-life cost analysis to either support or counter force-structure arguments will be difficult.

104. Mirroring a long standing manned aircraft trend, and perhaps partly as a result of a strong defence industrial lobby, discussions on UAS remain largely fixated on platforms, rather than the wider capability these systems provide. UAS truly are a system of systems, with the aircraft forming only one part of the overall system from which capability is derived.[5] A platform-centric analysis inevitably pushes capability development towards a high complexity/high cost aircraft solution – an area of the cost versus complexity curve that has already been shown, in the UK at least, to be unaffordable for manned systems.[6] If current trends continue, it is likely that the cost of complex unmanned aircraft will increase to converge rapidly with those of manned aircraft. This is particularly the case as we move toward full

[3] *Ibid,* page 60.
[4] Although operating from a deployed or forward base will increase the in-theatre footprint, there are some advantages to such an arrangement. These may include greater mission flexibility, reduced tasking timescales, greater situational awareness and better integration with the supported formation. The extra cost may be partially mitigated by the reduced use of expensive satellite links.
[5] Generally it is the exploitation of the data provided by the payload which provides the capability.
[6] As examples, the requirement to minimise cost has reduced the original order for Typhoon from 232 aircraft to around 110 (or fewer) and the original requirement for 24 MRA4 reduced to 21, then 18, then 12, then 9 before the project was cancelled altogether.

airworthiness certification of unmanned aircraft, rather than the limited clearances upon which we rely at present. This upward cost trend for military systems is unlikely to be mitigated by sales to the civilian market until long-standing issues related to integration of unmanned aircraft into non-segregated airspace[7] are resolved; this is not expected to happen until 2015-2020 at the earliest.[8] There is, thus, a concern that 2 of the principle advantages of unmanned systems, simplicity and low cost, will be lost.

105. As an example, the US RQ-4 *Global Hawk* is listed as costing from $38M to $103M per aircraft,[9] although true cost is hard to determine as it varies with the actual specification of each platform and how development costs are allocated. Analysis further shows that today's UAS can carry a manpower bill equal to or greater than a manned system.[10] As the US and the UK now consider their future *unmanned combat aircraft system* requirement, there is a realistic possibility that platform costs will be on a par with those of fifth generation fighters.[11] As a counter balance to this view, relatively cheap and simple unmanned aircraft are already capable of providing situational awareness at a tactical level that simply could not be afforded by manned means.


**RQ-4 *Global Hawk***

[7] Segregated airspace is that airspace which is reserved for specific users, which may include unmanned aircraft. Non-segregated is everything else.
[8] Information as briefed at various industry presentations and derived from the ASTRAEA Programme Roadmap; see Annex B for more detail.
[9] General Brady, Commander US Air Forces in Europe, speech to the Joint Air Power Competence Centre conference 12 October 2010. Some estimates now place the cost as high as $120M per aircraft.
[10] Although less manpower may have to be deployed forward.
[11] General Brady, *op cit*.

106. If an unmanned system is to be considered to meet a capability requirement, then there is a need to establish, early in the process, the utility and challenges provided by an unmanned solution. The principle issue will remain through-life cost. Can unmanned systems provide the same effect as manned ones, for less money?[12] Other drivers might be a reduced threat to aircrew, reduced manpower footprint in-theatre, or a need for greater persistence. It is also important to consider the maturity of the technology and whether it can deliver the promised capability in the expected timescales. Currently, unmanned aircraft often deliver only niche capabilities compared with the multi-role flexibility offered by manned systems; additionally aircraft losses have been high. If the move towards a greater proportion of unmanned aircraft in the force structure is to be a success, the technological, legal, ethical and moral issues required to ensure a successful transition must be addressed. As unmanned aircraft become more capable and automated, complex issues emerge. What governance and supervisory systems will be required to authorise and control weapon release or, in peacetime, to ensure privacy? How will such systems be integrated with manned air operations and civilian air traffic structures? How will the data generated by different sensors, and analysed by specialists in different locations around the world, be fused into a final product.[13] Is a common ground control station, interoperable with any national or allied unmanned aircraft, feasible? This Joint Doctrine Note (JDN) raises and discusses a number of these key issues to provide baseline knowledge of UAS and to provoke thinking that will ease the transition to an increasingly unmanned future.

**High Loss Rate of Unmanned Aircraft**

During NATO's engagement in Operation ALLIED FORCE in the former Yugoslavia in 1999, 2 manned aircraft were lost (F-117 and F-16CJ). Additionally, 15 unmanned aircraft were lost to the Serbian air defence system which, though capable, was not as advanced as many fielded today. Even in the uncontested airspace of Afghanistan and Iraq, significant numbers of unmanned aircraft have been lost. The Los Angeles Times, in its 6 July 2010 report *War Zone Drone Crashes Add Up* reported that 38 MQ-9 *Reaper* and MQ-1 *Predator* had been lost in Iraq and Afghanistan and 9 more during training on bases in the US. Altogether, it reported that the total number of accidents was 79.[14]

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[12] This is actually harder to determine than it sounds. Most unmanned aircraft provide only a subset of the functionality of a manned aircraft and so care must be taken to compare like with like.
[13] Although this problem will apply equally to manned systems.
[14] Analysis shows loss rates per thousand flying hours are similar for manned and unmanned aircraft. It is the larger number of hours flown by unmanned systems that leads to the comparably high number of losses.

# CHAPTER 2 – CURRENT TERMINOLOGY, DOCTRINE, AND CLASSIFICATION

## DEFINITIONS

201. In order to standardise UK unmanned aircraft military terminology, the DCDC published Joint Doctrine Note (JDN) 3/10 *Unmanned Aircraft Systems: Terminology, Definitions and Classification* in May 2010. This is now accepted doctrine within the UK defence community and its use widespread. The following terminology has been agreed by the 3 services and should be used when discussing unmanned aircraft in a military context.

202. Unmanned Aircraft and Unmanned Aircraft System (UAS) can be defined as:

| | |
|---|---|
| **Unmanned Aircraft** | An Unmanned Aircraft (sometimes abbreviated to UA) is defined as an aircraft that does not carry a human operator, is operated remotely using varying levels of automated functions, is normally recoverable, and can carry a lethal or non-lethal payload.<br><br>Note: In the UK, cruise and ballistic missiles are not considered to be unmanned aircraft.[1] |
| **Unmanned Aircraft System** | An unmanned aircraft system is defined as a system, whose components include the unmanned aircraft and all equipment, network and personnel necessary to control the unmanned aircraft. |

203. **Remotely Piloted Aircraft and Remotely Piloted Air(craft) System**. While *unmanned aircraft* is the preferred term in the joint environment, there are occasions when such a generic term can be unhelpful, particularly when working with an uninformed audience. Confusion can arise over the actual level of human control over the system, which may lead to concerns being raised, particularly with regard to the employment of weapons and flight in non-segregated airspace. Consequently, for example when talking to the media, it may be appropriate to use the term *Remotely Piloted Aircraft* (RPA) to describe the actual aircraft, and *Remotely Piloted Air (or Aircraft) System*

[1] *Smart* weapons, such as *Paveway* IV and SLAM, are not considered to be unmanned aircraft. The guiding rule is that if a system is designed principally for warhead delivery and is not designed to be recoverable, then it is not an unmanned aircraft. Each new UK weapon system undergoes a legal review as part of its introduction to service and its status will be determined at an appropriate point in the procurement cycle.

(RPAS) to describe the entirety of that which it takes to deliver the overall capability. RPA and RPAS[2] are defined as follows:

| | |
|---|---|
| **Remotely Piloted Aircraft** | A remotely piloted aircraft is defined as an aircraft that, whilst it does not carry a human operator, is flown remotely by a pilot, is normally recoverable, and can carry a lethal or non-lethal payload. |
| **Remotely Piloted Aircraft System** | A remotely piloted aircraft system is the sum of the components required to deliver the overall capability and includes the pilot, sensor operators (if applicable), remotely piloted aircraft, ground control station, associated manpower and support systems, satellite communication links and data links. |

204. **Pilot and Piloted**. The use of the terms *pilot* and *piloted* can cause confusion when trying to equate unmanned with manned aircraft operations. Some unmanned aircraft are required to be controlled by personnel who are already qualified to pilot manned aircraft, while most are not. Guidance on unmanned aircraft pilot qualification is given in Civil Aviation Publication 722 *Unmanned Aircraft System Operations in UK Airspace*, Section 2, Chapter 5. An alternative description of *operator* may be used instead, if appropriate.[3] The JSP 550 Series *The Military Aviation Regulatory Document Set* (MARDS) contains additional terms such as *UAV Cdr* and *UAV-p* (UAV pilot). Over time, staff action will be initiated to align terms between this document and the MARDS. As with manned aircraft, where pilots will be qualified to different standards, unmanned aircraft pilots may be qualified to fly only certain classes of unmanned aircraft or to undertake certain mission types. Qualification to act as an unmanned aircraft pilot or operator does not imply qualification as a manned aircraft pilot.[4]

205. **Automation and Autonomy**. There are many different industry and academic descriptions of what comprises an automatic or autonomous unmanned aircraft. Confusingly, the 2 terms are often used interchangeably even when referring to the same platform; consequently, companies may describe their systems to be autonomous even though they would not be considered as such under the military definition. It would be impossible to produce definitions that every community would agree to – the following

[2] RPA and RPAS are used in preference to unmanned aircraft and UAS by the RAF.
[3] The alternative term, *operator*, may cause confusion and should be used with care. In civilian unmanned aircraft usage the term *operator* specifically refers to *the legal entity (organisation) operating a civil UAS.* By this reasoning, the operator of a military unmanned aircraft is the MOD. Additionally, the term gives no clear indication as to which aircraft functions are controlled by an operator and which are automated.
[4] Nor do manned aircraft pilot qualifications imply qualification as an unmanned aircraft operator/pilot.

definitions have been chosen to be as simple as possible, while making clear the essential differences in meaning between them:

| | |
|---|---|
| **Automated System** | In the unmanned aircraft context, an automated or automatic system is one that, in response to inputs from one or more sensors, is programmed to logically follow a pre-defined set of rules in order to provide an outcome. Knowing the set of rules under which it is operating means that its output is predictable. |
| **Autonomous System** | An autonomous system is capable of understanding higher level intent and direction. From this understanding and its perception of its environment, such a system is able to take appropriate action to bring about a desired state. It is capable of deciding a course of action, from a number of alternatives, without depending on human oversight and control, although these may still be present. Although the overall activity of an autonomous unmanned aircraft will be predictable, individual actions may not be. |

206. An analysis of automated and autonomous UAS issues provides the following deductions:

a. Any or none of the functions involved in the operation of an unmanned aircraft may be automated. Examples include: take-off and landing; navigation/route following; pre-programmed response to events such as loss of a command and communication link; and automated target detection and recognition.[5] Unmanned aircraft which execute some elements of their operation without relying on human intervention or control may be described as partially automated.[6] Those which carry out their entire mission from take-off to landing without human intervention may be said to be fully automated. At the moment, all but the very simplest unmanned aircraft missions will be partially automated with a human overseeing most aspects of the mission.

b. Autonomous systems will, in effect, be self-aware and their response to inputs indistinguishable from, or even superior to, that of a manned aircraft. As such, they must be capable of achieving the same level of situational understanding as a human. This level of technology

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[5] For major functions such as target detection, only some of the sub-functions may be automated, requiring human input to deliver the overall function.

[6] When describing a system as *partially automated* it is useful to describe which functions are automated (and by implication, which are not).

is not yet achievable and so, by the definition of autonomy in this JDN, none of the currently fielded or in-development unmanned aircraft platforms can be correctly described as autonomous. As computing and sensor capability increases, it is likely that many systems, using very complex sets of control rules, will appear and be described as autonomous systems, but as long as it can be shown that the system logically follows a set of rules or instructions and is not capable of human levels of situational understanding, then they should only be considered to be automated.

c. The distinction between autonomous and automated is important as there are moral, ethical and legal implications regarding the use of autonomous unmanned aircraft. These issues are discussed in Chapter 5.

d. It is an over-arching principle that, whatever the degree of automation, an unmanned aircraft should provide at least the same, or better, safety standard as a manned platform carrying out the same task.[7]

## UNMANNED AIRCRAFT CLASSIFICATION

207. A classification system is required to progress doctrine, tactics and techniques development and to ensure, for example, appropriate crew training and medical employment standards if required, for each class or sub-class. Similarly, further progress on integration of unmanned aircraft into controlled airspace is likely to stall until a standardised classification and licensing system can be agreed. Given the diversity of unmanned aircraft and their capabilities, there is no easy *one-size-fits-all* classification system. For example, small unmanned aircraft, that might be expected to operate only in lower airspace and have short ranges, have already demonstrated transatlantic capability[8] and operational or even strategic effect is often exerted by what may be considered primarily tactical unmanned aircraft. Whichever system is adopted, it is inevitable that there will be some unmanned aircraft that do not fit neatly within a single class or sub-class.

208. The following classification system[9] has been proposed and endorsed by NATO's Joint Unmanned Aerial Vehicle Panel and the Joint Capability Group on Unmanned Aerial Vehicles. Since it is UK policy to implement NATO

[7] CAP 722, Section 2, Chapter 2, paragraph 5.1.1
[8] For example, in 1998 Aerosonde Limited flew its 30lb *Laima* unmanned aircraft from Newfoundland to Benbecula on a 2031 nautical mile flight using only 1.25 gallons of fuel.
[9] Further details of the classification system can be found in the Joint Air Power Competence Centre *Strategic Concept of Employment for Unmanned Aircraft Systems in NATO* which is available for download at www.japcc.org.

doctrine where possible, it is intended that the UK will agree to formally ratify and implement this system as UK doctrine. The UK is adopting this doctrine now, while acknowledging that a minor update may be required in the future.

209. This classification model, shown at Table 2.1, follows a simple system, similar to that for manned aircraft, which is based on a platform's maximum gross take-off weight. This creates 3 separate classes, each of which may be subdivided, if required, depending on normal operating altitude. The latter is for convenience and helps to bridge between this system and legacy classification systems which partially used a task/capability model. The 3 classes are as follows:

a. **Class I**. Less than 150kg.

b. **Class II**. 150kg to 600kg.

c. **Class III**. More than 600kg.

## GENERAL CAPABILITIES AND LIMITATIONS OF UNMANNED AIRCRAFT BY CLASS

210. A general description by class follows.[10] It is acknowledged that many platforms may well share characteristics across classes.

211. **Class I**. These are typically hand-launched, self contained, portable systems employed at the small unit level or for force protection/base security. They are capable of providing *over the hill* or *around the corner* type reconnaissance and surveillance and would have utility for the RN in, for example, boarding operations. Payloads are generally fixed Electro-optical/Infrared (EO/IR), and the system has a negligible logistics footprint. A Class I unmanned aircraft typically operates within line of sight at low altitudes, generally less than 5,000 feet Above Ground Level (AGL) and has a limited range/endurance.

212. **Class II**. These unmanned aircraft are typically medium-sized, often catapult-launched, mobile systems that usually support brigade-level, and below, Intelligence, Surveillance, Target Acquisition and Reconnaissance requirements. These systems generally operate at altitudes below 10,000 feet AGL with a medium range. They do not usually require an improved runway surface. The payload may include a sensor ball with EO/IR, a LASER range finding or designation capability, SAR/GMTI[11] radar and SIGINT. A Class II

[10] See Joint Air Power Competence Centre *Strategic Concept of Employment for Unmanned Aircraft Systems in NATO.*
[11] Synthetic Aperture Radar (SAR) and Ground Moving Target Indicator (GMTI).

unmanned aircraft is typically employed within tactical formations and usually has a small logistics footprint. It is likely, however, to require a high degree of coordination and integration into military and civilian airspace.

213. **Class III**. These are typically the largest and most complex unmanned aircraft, operating at high altitude with, typically, the greatest range, endurance and transit speeds of all unmanned aircraft platforms. They can perform specialised missions including broad area surveillance and penetrating attacks. Payloads may include sensor ball(s) with EO/IR, multi-role radars, lasers, synthetic aperture radar, communications relay, Signals Intelligence, Automatic Identification System, and weapons. Most Class III unmanned aircraft will require improved areas for launch and recovery and may be piloted from outside the joint operations area via a satellite control link; lack of satellite communications may prevent use when being operated Beyond Line of Sight (BLOS).[12] The logistics footprint may approach that of manned aircraft of similar size and they typically have the most stringent airspace coordination requirements. Endurance, which may be measured in days, may be reduced when carrying weapons due to a decrease in fuel load capability and increased aerodynamic drag from external hard points



[12] While most Class III systems will be operated BLOS via SATCOM, not all will be. Lack of SATCOM can be mitigated by using pre-programmed missions, comms relay and hand-off from one ground control station to another.

| Class | Category | Normal Employment | Normal Operating Altitude | Normal Mission Radius | Civil Category (UK CAA) | Example Platform |
|---|---|---|---|---|---|---|
| **Class I <150 kg** | MICRO < 2 kg | Tactical Platoon, Section, Individual (single operator) | Up to 200ft AGL | 5 km (Line of Sight (LOS)) | Weight Classification Group (WCG) 1 Small Unmanned Aircraft (<20 kg) | Black Widow |
| | MINI 2-20[13] kg | Tactical Sub-Unit (manual launch) | Up to 3000ft AGL | 25 km (LOS) | | Scan Eagle, Skylark, Raven, DH3 |
| | SMALL > 20 kg | Tactical Unit (employs launch system) | Up to 5000ft AGL | 50 km (LOS) | WCG 2 Light Unmanned Aircraft (20><150 kg) | Luna, Hermes 90 |
| **Class II 150–600kg** | TACTICAL | Tactical Formation | Up to 10,000ft AGL | 200 km (LOS) | WCG 3 UAV (>150 kg) | Sperwer, Iview 250, Aerostar, Watchkeeper |
| **Class III >600 kg** | Medium Altitude, Long Endurance (MALE)[14] | Operational/ Theatre | Up to 45,000ft AGL | Unlimited (BLOS) | | Reaper, Heron, Hermes 900 |
| | High Altitude, Long Endurance (HALE) | Strategic/ National | Up to 65,000ft AGL | Unlimited (BLOS) | | Global Hawk |
| | Strike/ Combat | Strategic/ National | Up to 65,000ft AGL | Unlimited (BLOS) | | |

**Table 2.1 – Unmanned Aircraft Classification Guide**



[13] NATO is considering a break- point between mini and small of 15 Kg.
[14] Although endurance is not generally a discriminator for determining which category an unmanned aircraft is in, MALE and HALE remain in common usage in the unmanned aircraft community (particularly in the US) and provide useful sub-category breakpoints within Class III.

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# CHAPTER 3 – WHY UNMANNED AIRCRAFT?

## HIGHER LEVEL ISSUES

301. There is a vast range of unmanned aircraft, both in service and in development. Systems vary from palm-sized micro-platforms to very large wingspan aircraft with global reach. Recent UK operational deployments have been of unmanned aircraft bought as off-the-shelf finished products, or as simple evolutionary developments of existing platforms; all have been procured under the urgent operational requirements process. No unmanned aircraft currently in service have been procured through the regular equipment procurement process, although the British Army *Watchkeeper* system will do so later this year. Another major programme, *Scavenger*, is planned to deliver systems later this decade. The process of deciding on whether an unmanned system may fulfil a capability requirement is thus still relatively immature.

302. When initially deciding whether a requirement could be addressed by an Unmanned Aircraft System (UAS), it may be simpler to consider unmanned aircraft as belonging to one of three groups, all of which require different consideration. Firstly, there are those unmanned aircraft, generally medium to large in size and fairly complex, that share the attributes and capabilities of manned aircraft. These are usually so clearly similar to manned aircraft that it is obvious as to how they would be employed and on what tasks. The decision between such an unmanned system and an equivalent manned solution would simply be based on a cost/benefit analysis to establish which solution would have the lowest through-life cost followed by consideration of a range of operational factors, discussed later in this chapter. This process may entail a significant amount of operational analysis, but there is likely to be a significant read-across from the wealth of detail already amassed on manned systems. The second group, characterised by mini, or very large unmanned aircraft, may have the same capabilities as manned aircraft but could also provide very different capabilities or be able to operate in a very different way. For this group, new thinking may be required and there will probably be little relevant operational analysis to draw on. Finally, at the micro unmanned aircraft scale, comparisons with manned aircraft break down. The aircraft are

**Prototype Micro Unmanned Aircraft**

just so different that use of existing manned aircraft data and analysis will be difficult. It is likely that, at this scale, the capabilities provided by unmanned aircraft will be more akin to those provided by ground assets than manned aircraft. For micro and mini systems, there are few commercial barriers to entry, with hundreds of firms and research laboratories competing for business, many with innovative ideas. Such systems can provide excellent tactical utility and may be cheap enough to be considered as single-use items, an approach that is used already with some US systems. With some caveats (operation below 400ft, remaining clear of controlled airspace and within 500m and line of sight of the operator) unmanned aircraft below 20kg in weight are largely unregulated by the Civil Aviation Authority and it may not be cost effective, or necessary, for the Military Aviation Authority to subject such small military systems to the full airworthiness process.

303. Regardless of the class, future procurement must be broadly focussed on overall system capabilities rather than concentrating on just the aircraft; this includes sensors, weapons, common ground control stations and supporting data networks, as well as provision for the analysis and dissemination of acquired data. As more unmanned aircraft join the force structure, thought will be required to consider how unmanned aircraft could operate alongside manned systems in a complementary force mix. Some work has already been carried out to define optimal manned/unmanned ratio, particularly in support of unmanned combat aircraft systems, but further thought will be required as the technology continues to mature.

304. The US is ahead of the UK on the specification, development and procurement of unmanned aircraft systems. In 2009, the United States Air Force (USAF) produced a detailed roadmap for the technology – *The United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047*,[1] which seeks to:

> *describe a family of unmanned aircraft consisting of small man-portable vehicles, including micro and nano-sized vehicles, medium 'fighter sized' vehicles, large 'tanker-sized' vehicles, and special vehicles with unique capabilities, all including autonomous-capable operations. The concept is to build a common set of airframes within a family of systems with interoperable, modular 'plug and play' payloads, with standard interfaces, that can be tailored to fit one or more USAF Core Functions in support of the Joint Force's priorities.*
>
> The United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047

[1] *United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047*, Headquarters USAF, 18 May 2009.

Crucially, the flight plan provides recommendations as to how the individual DOTMLPF[2] supporting lines of development will need to be synchronised and sequenced in order to deliver the roadmap vision. Each of the US services is undertaking a similar process, while the Joint UAS Centre of Excellence in Creech, provides a joint perspective.[3]

305. A UK MOD roadmap for UAS was produced in 2005, but has not been updated since. As the UK military plans for a period of post Afghanistan rationalisation and regeneration, in preparation for Future Force 2020, the UK roadmap could be usefully refreshed to provide the detail of how UK UAS will be developed, tri-service with joint oversight, over the next 20 years. A lack of unity of joint purpose in UK UAS thinking will likely continue until an over-arching body is set up that takes ownership of the roadmap and that is empowered to oversee and co-ordinate UK UAS and supporting lines of development. To gain credible traction across the MOD, this would probably have to be championed by a formally appointed 2* or higher Senior Responsible Owner or become part of the core work of the joint capability area. A roadmap could also help tackle the many stove-piping issues that arise as a function of how capability areas are organised and help deal equitably with any inter-service issues. The concept of a UAS Research and Technology Pipeline, that would provide higher level overview of, and direction to, the UK's UAS research and technology effort over the next 5 years, has been approved in principle by the Defence Research and Development Board. It's precise scope and level of resource need to be confirmed but it is likely to form the basis of a longer term research plan that underpins, and helps deliver, the UK roadmap.

***Hermes* 450**

[2] DOTMLPF list: Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities.

[3] The Joint UAS Centre of Excellence, based in Creech Air Force Base, will close later this year as part of the reorganisation of US force responsibilities following the closure of US Joint Forces Command.

306. While commentators speak of a time when air power will be completely delivered by unmanned aircraft, it is not exactly clear when the transition will be complete. It is increasingly common to hear Joint Strike Fighter referred to as the last manned fighter platform and, given its in-service date of early 2020's and a 20+ year life, this may well be true. How soon we will see the air power roles of attack and mobility and lift conducted by unmanned systems, will be reliant on advances in technology, cost effectiveness and in public acceptance. We may be some time away from asking soldiers to trust unmanned aircraft to move them around the battlefield, although some countries are already developing unmanned medical evacuation system concepts.

## FACTORS FOR CONSIDERATION

307. Approximately 10 years ago, at an early stage of the latest unmanned aircraft development cycle, it became commonly accepted that unmanned aircraft were most useful doing 'dull, dirty or dangerous' tasks and this phrase will often still be heard in discussions on UAS utility. Examples of dull, dirty and dangerous tasks may include repetitive Intelligence, Surveillance and Reconnaissance (ISR) patrols, Chemical, Biological, Radiological and Nuclear (CBRN) detection, or simply those tasks considered too dangerous or politically challenging for manned aircraft to undertake. While useful, these three descriptors are but a sub-set of the wider argument and the following, more expansive list, should be considered.

### Tasks for Unmanned Aircraft

308. **Dull**. Low workload, low intensity tasks are ideally suited to unmanned aircraft. Such tasks can be simply automated, often only requiring human oversight rather than direct and continuous control. There is a long list of tasks that could be included in this category such as: pattern of life surveillance tasks over fixed locations or in support of littoral manoeuvre; maintenance of standing anti-submarine warfare or anti-surface warfare radar barriers, including counter-piracy tasks; monitoring of arrays of sonobuoys or other sensors; a range of electronic warfare tasks, acting as a communications relay; and as an air-to-air refuelling tanker. However, some of these tasks may themselves generate more complex or time-sensitive tasks (such as the identification of a fleeting high value target) that may not easily be prosecuted by a simple, single task platform.

309. **Dirty**. Unmanned aircraft are an ideal choice when operations are required in environments that would be hostile to a manned aircraft or its crew. For instance, airborne sampling or observation missions related to CBRN would be ideally suited to unmanned aircraft. Sensors could be fitted to a

range of types; for example, a small man-portable system for local tactical use, or large aircraft-sized systems for global monitoring. Such systems could be sacrificed in a safe area once data was gathered rather than having to recover to an airfield where it would have to be decontaminated, or risk contaminating personnel and other equipment. In the civilian sector, small unmanned aircraft are already used by some fire brigades for reconnoitring fires in inaccessible locations or where smoke and flame would make human presence hazardous.

310. **Dangerous**. The level of risk of a particular operation may be too high to merit the involvement of human aircrew or soldiers on the ground. This may be because of a high ground-to-air threat and there are a number of tasks where unmanned aircraft may participate in the suppression of an integrated air defence system. In such a scenario, multiple, cheap unmanned aircraft can be used sacrificially to swamp enemy detection and command and control systems or to force an enemy to expend large numbers of missiles. Alternatively, as seen with the use of *Firebee* drones by the USAF in the early 1960's,[4] or more recently by Israel in operations against Syria, unmanned aircraft may be used to penetrate enemy missile engagement zones to gather electronic guidance and fusing data, observing enemy engagement tactics and transmitting data back to intelligence collators before they are destroyed. There are 2 approaches to the use of unmanned aircraft in dangerous situations that require differing investment philosophies; aircraft can be cheap, simple and expendable or complex, and therefore probably expensive, but with high survivability. The latter would probably entail incorporation of stealth technology and defensive aid suites If regular sacrificial use is planned for unmanned aircraft, then it is essential that aircraft cost is kept low. Future tasks for unmanned aircraft that may fall under this heading also include tactical resupply to troops in contact or the combat recovery of personnel or casualties where it is simply too dangerous to

**Firebee drone shot down over Vietnam**

[4] Thomas Ehrhard, *Air Force UAVs: A Secret History*, Mitchell Institute Study, page 8, 2010, http://www.afa.org/mitchell/reports/MS_UAV_0710.pdf last accessed 28 February 2010.

send in manned aircraft.[5] Dangerous can also increasingly relate to the dangers faced by troops on the ground. Unmanned aircraft can potentially replace several dangerous ground tasks, such as convoying of tactical supplies and sweeping for improvised explosive devices.

311. **Deep**. Deep operations are formally defined *as operations conducted against forces or resources not engaged in close operations*.[6] Often, the term deep targets is used interchangeably with the term strategic targets which may or may not be correct, depending on the context of the specific operation. For unmanned aircraft, the use of the term, *deep* often goes beyond the classic definition to generally indicate operations carried out at long range inside enemy territory. In today's battlespace, which increasingly reflects the notion of 'wars amongst the people', such phraseology may be a little outdated, although clearly aircraft may need to move long distances between target areas in the same mission within a joint operations area. Notwithstanding the above, and when operating in uncontested airspace, deep targets could be ideally suited to observation or attack by unmanned aircraft; this removes the risk to aircrew of operating at range inside enemy territory. In the short-to-medium term, when operating in contested airspace or a restricted communications environment, legal constraints[7] and the low readiness levels of appropriate technologies, may mean other assets are better suited to servicing these targets. For static, well researched and understood targets, weapons such as *Storm Shadow* or *Tomahawk* already provide much of the required capability. For mobile or time-sensitive-targets, which will require a man-in-the-loop to make targeting decisions, the recent move to *the Lightning II* Carrier Variant (CV) instead of the *STOVL*[8] variant will provide a stealthy manned aircraft with the range to provide such a capability through to 2040. Inevitably, unmanned aircraft will eventually have the ability to independently locate and attack mobile targets, with appropriate proportionality and discrimination, but probably not much before 2030.

[5] Accepting the fact that for many cases, it is treatment by the manned aircraft medical evacuation team working on a casualty *en route* to a medical facility that saves lives.

[6] Joint Doctrine Publication 0-01.1 *UK Glossary of Joint and Multinational Terms and Definitions*. Close operations are defined as operations conducted at short range, in close contact and in the immediate timescale. Since there is no formal national or NATO definition of short range, both deep and close are open to a degree of interpretation.

[7] See Chapter 5.

[8] Short take-off and vertical landing

### Exploitation of Captured Personnel

312. Associated with the dangerous label, the capture and exploitation of downed aircrew by an enemy may have a considerable effect on the morale of one's own forces and, particularly in today's wars-of-choice, may affect the support given to the campaign by a nation's domestic population. The capture and parading of downed aircrew in the media has long been used to influence home and enemy audiences[9] and, in addition, efforts to rescue such personnel under combat conditions have often been costly in lives and materiel.[10] Conversely, an opponent that succeeds in shooting down an unmanned aircraft has little to show for it but some wreckage – which they can easily be accused of fabricating, or for which ownership can simply be denied.

### Performance

313. The provision of sufficient space, controls, displays and life support equipment for on-board aircrew can have a significant effect on the design and performance of a manned aircraft. Removal of these design limitations enables significant potential performance improvements, particularly for less complex and smaller unmanned aircraft. The space created by removing the cockpit can be used to carry extra fuel, weapons or equipment. However, highly complex and high performance systems will still tend toward a similar size and weight as their manned equivalents, as engine size, defensive aids equipment, datalinks, additional sensors or computers and stealth technology may become the dominant factors. More innovatively, the lack of a cockpit enables novel shapes or more efficient aerodynamic design, although this possibility has yet to be realised in many of the unmanned aircraft designs seen today. Performance becomes limited only by the aircraft structure rather than the human, with no human-imposed G-force (particularly in the x and y planes), or environmental limits. Increased manoeuvrability can be particularly useful for self-defence or when operating in the urban canyon.[11] Additionally, the aircraft can be manoeuvred with no physical effect on the human operator, whereas manned aircraft performance will degrade during a sortie as the pilot becomes fatigued. Long duration unmanned operations may, though, lead to operator fatigue that affects performance.

[9] The parading and subsequent trial of CIA U2 pilot, Francis Gary Powers, after he was shot down over the USSR in 1960 derailed Eisenhower's attempts to win over Khrushchev and led to a significant worsening of cold war tension.

[10] During the Vietnam War, a 17 day operation began to rescue Lieutenant Colonel 'Gene' Hambleton, an electronic warfare specialist who was shot down behind enemy lines. By the time the rescue mission finished, 24 sorties had been flown and 13 people had died.

[11] Urban Canyon is the term used to describe the environment encountered by an aircraft operating in a city or built up area. It is envisaged that, in future, unmanned aircraft will be able to fly through, rather than over, such environments.

**Persistence/Endurance**

314. Another advantage of removing the human from the air platform, but such a major characteristic of unmanned aircraft that it merits a discussion in its own right, is that of persistence. Indeed, this is often quoted as the unique selling point of an unmanned aircraft. Without the need to provide space for aircrew, and without a human crew to become tired, unmanned aircraft can be designed to have extremely long endurance. *Reaper* has an endurance of 18 hours+ for normal tasking and more novel designs such as hybrid air vehicles have an endurance of weeks. High altitude solar powered aircraft such as QinetiQ's *Zephyr* or, in future, aircraft powered by ground-based lasers or that use air-to-air refuelling, may be able to remain airborne indefinitely. It is this ability of unmanned aircraft to persist over the battlespace that has proved to be so effective in Iraq and Afghanistan.

**QinetiQ's Zephyr can remain airborne for several weeks**

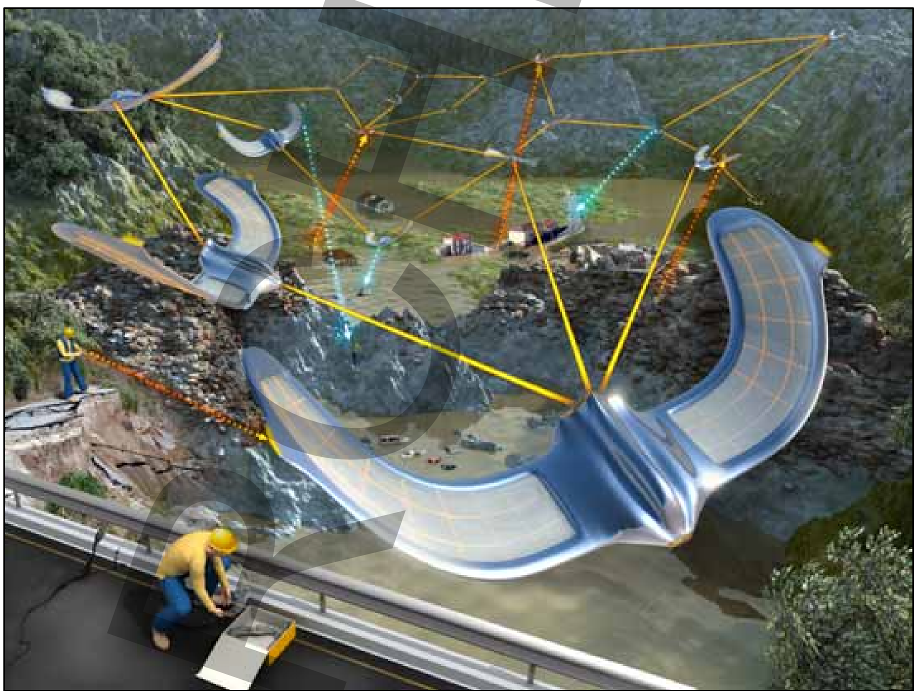
315. There is a caveat to the above: persistence comes at a price. With today's relatively simple systems, long duration sorties require multiple shifts of operators,[12] thus increasing the manpower bill, and, if missions require weapon delivery, an unmanned aircraft persists only until its weapons are exhausted.[13] If all weapons are expended in the first 4 hours of a sortie, it may well take considerable time, at the relatively slow transit speeds of some current unmanned aircraft, to return to base, re-arm, and resume patrol. Furthermore, prolonged air weapons carriage will require a re-think of the way such items are currently managed, or weapons stocks could be used at an alarming rate. Much work on an unmanned weapons programme may be required to either extend the life of existing weapons, design future unmanned aircraft for internal weapons carriage,[14] or design future weapon systems specifically to have more resilient components than at

[12] Although these may be rear, rather than forward, based.
[13] In current operations, the use of weapons is infrequent enough for this not to be a major issue; this may not be the case during future conflicts. Other sources of kinetic effect, such as Joint Fires, may also be utilised.
[14] On its own, this may not solve the problem. The problem with weapon life is often not just caused by aerodynamic forces, but rather the effect of vibration on warheads and rocket motors. Internally carried weapons could still have a limited life due to the vibration regime present.

present. Additionally, long endurance sorties will require improved systems reliability, with possibly a different approach required to what constitutes acceptable mean-time-between-failure in aircraft that have not, historically, been built to manned standards.

**Cost versus Mass versus Capability**

316. As Stalin allegedly said, "quantity has a quality all of its own". Modern military manned aircraft, though more capable than any in history, are now affordable in only small numbers and can take a very long time to bring into service; once procured, each platform, however capable, can only be in one place at a time. Similarly, in the attempt to get the most out of each platform, as well as reducing the overall aircrew requirement, complexity has been increased (and hence cost) to allow aircraft to execute many different tasks. This can mean that when employed on simple tasks, much of the inherent capability is under-utilised.[15] Low cost, single or dual-role, unmanned aircraft could be procured in large numbers and used in novel ways. In the maritime environment, swarm tactics by small fast boats have proved very effective against surface ships and are difficult to counter.



**In future, swarm tactics may be used to overwhelm enemy systems or to provide localised communications/wifi capability**

[15] This is not an argument against the level of capability of current and expected manned systems; future conflicts may well require all the capability we have, and more.

Similarly, swarms of unmanned aircraft may be used to quickly provide unprecedented amounts of surveillance data on a particular problem, to provide wide-area internet or telecoms access, or to overwhelm even modern air defence systems (if only due to the fact that such systems have a finite number of rounds). However, caution must be applied when considering this approach as practical methods to control swarming systems have yet to be fully developed and demonstrated, and unless development costs are not controlled more carefully than we have seen with manned systems, they may eventually provide little cost saving. Air worthiness is another cost driver; in-service UAS have not been built to a defined manned air worthiness standard and so can only operate in-theatre under a specific theatre clearance.[16] Experience from projects such as *Watchkeeper* has shown that transitioning the industry to full air worthiness standards is more challenging than expected and may add significantly to system costs.[17] This could negate low cost as one of the key advantages of unmanned aircraft. The situation is improving as industry adjusts to the requirement and some smaller companies are taken over by more traditional aircraft manufacturers.

**Simplicity and Availability**

317. Smaller unmanned aircraft can be provided very cheaply and with high levels of availability, albeit often with a single task focus. The advantages to a platoon commander of having the ability to produce imagery from over a wall or just around the corner, on demand, should not be underestimated.[18] For these missions, the unmanned aircraft is literally a pair of flying binoculars, but with increased capability. The key to gaining the most from these smaller systems is to be flexible in their procurement. New innovations appear daily, providing a real challenge to those responsible for acquisition; how is the warfighter to be provided with relevant capability while minimising the re-training and logistical support burden? As an example, the US Army is currently exploring

**AeroVironment RQ-11 *Raven***

[16] Air worthiness issues are discussed further in Chapter 5.
[17] For unmanned systems, airworthiness will apply much more to the entire system than it tends to for manned systems.
[18] Although the troop commander will need to balance the value derived from such imagery against the burden carrying/operating the system imposes on the individual soldier.

phased procurement processes to allow rapid infusion of new technologies as units rotate into theatre.[19] The concept is to buy systems in blocks just large enough to equip troops as they train and deploy. The system is then upgraded by industry, which provides the next block in time for the next rotation period and so on. There are obvious difficulties with this approach; industry needs to generate enough follow-on sales to make continued development worthwhile and the user needs to deliver updated training and logistics. To be effective, the systems need to be made cheaply enough that they can be used in service for the period of a rotation and then, if necessary, disposed of. Currently, manned platforms are increasingly expected to be multi-role capable and can conduct a number of widely differing tasks either separately or simultaneously. While such flexibility is possible with unmanned aircraft, complexity, and hence cost, would inevitably rise. If low cost is a principal driver, simple unmanned aircraft, dedicated to single tasks and possibly weaponised, will remain the norm.

Systems such as this Flying Robots unmanned aircraft can take-off and land on minimally prepared surfaces. It can be programmed to fly routes automatically, can be remotely operated, or even optionally manned. It can deliver 250kg (scaleable to 1000kg) of supplies that can be air dropped or landed at destination. Once unloaded, it can return automatically to its origin. Such systems have wide use in both military and civilian applications.

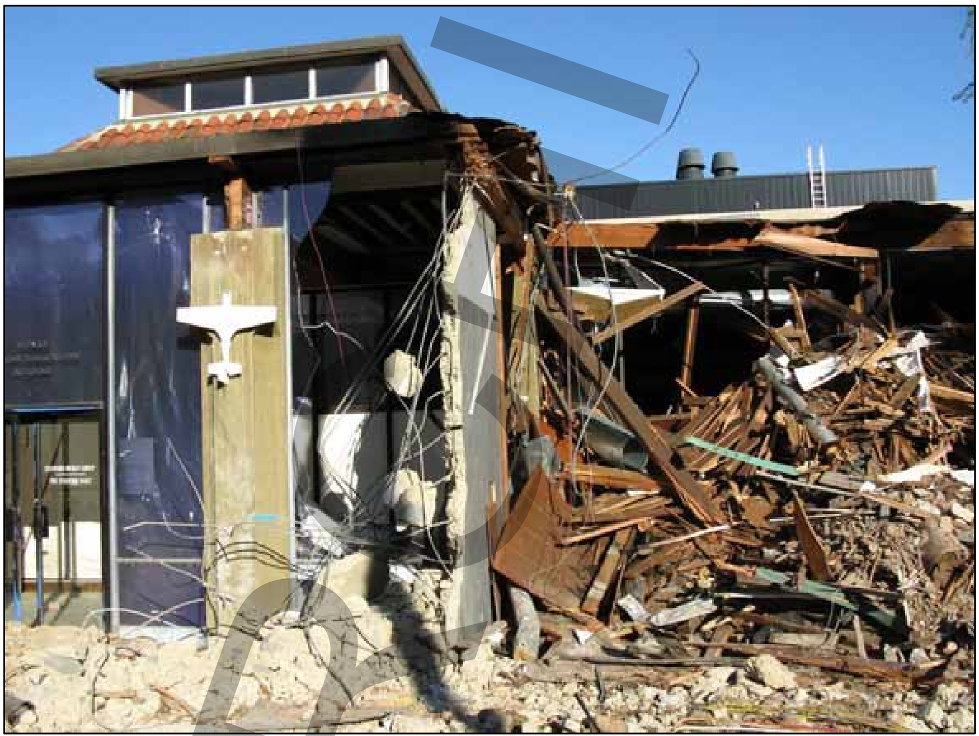
318. Some simple rotary and flying-wing based systems also require a minimum of supporting infrastructure and would have considerable dual-use potential in military re-supply tasks or providing support to civilian humanitarian and disaster relief operations.



[19] Reported in *Aviation Week* at http://www.aviationweek.com/aw/generic/story.jsp?id=news/asd/2011/02/03/02.xml&channel=misc accessed on 11 February 2011.

**Access**

319. Either by virtue of manoeuvrability or small size, unmanned aircraft may be able to operate in areas inaccessible to manned aircraft. They could be used to reconnoitre the inside of buildings or a cluttered urban landscape and would provide invaluable support to operations in such environments. Small systems may fly to a destination then transform to crawl inside buildings or through windows, hiding their presence where possible. Flying in the previously described *Urban Canyon* environment, systems could employ small precision kinetic or non-kinetic weapons, including directed energy weapons. Micro-unmanned aircraft, such as those optimised for *perch and stare*[20] surveillance have attracted considerable interest from intelligence and law enforcement agencies. These would navigate through urban areas before perching on walls or roofs, sometimes for days, collecting audio and visual data. Some, after re-charging in the sun, would move on to secondary or tertiary targets for further information gathering.



**Small unmanned aircraft can navigate through urban environments and perch on vertical walls or on roofs. They can observe the local environment for several days before moving on to another task.**

[20] The term *perch and stare* is used to describe the ability of an aircraft to land on, or attach to, an object such as a building. From this *perch* position it can *stare* at its surroundings with an array of sensors, without having to expend energy in remaining airborne.

320. Figure 3.1 shows a methodology adapted from a US Navy N81 Assessment Division model that helps thinking on whether unmanned systems may be suitable for any particular application. Where the logic flow ends in a shaded *manned* box, an unmanned solution may be applicable but the technology is too immature to go unmanned. This model is not intended to supplant or replicate the normal capability area acquisition process.

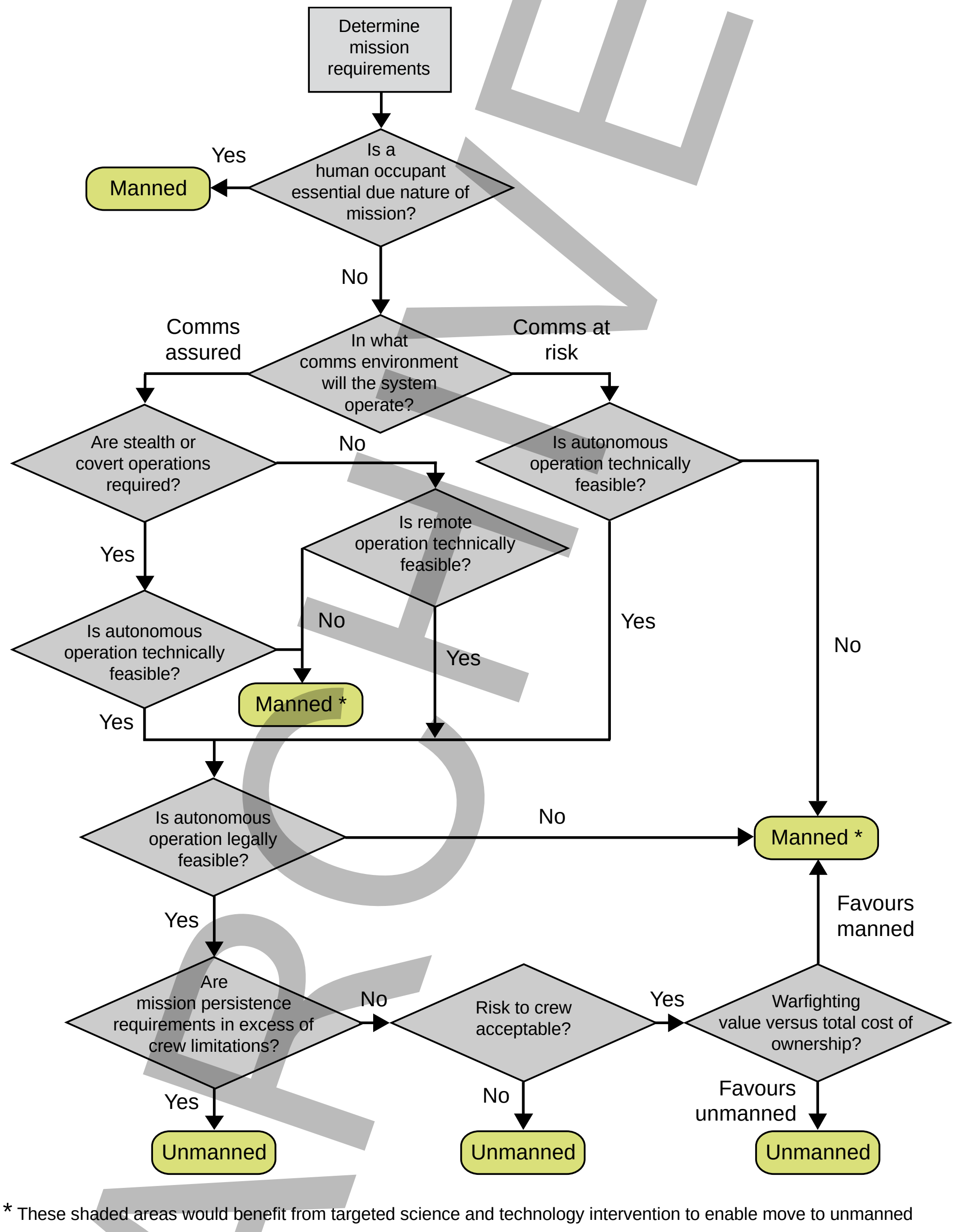



**Figure 3.1 – Decision Flowchart to Aid Unmanned/Manned Thinking**

321. **Summary**. UAS have both advantages and disadvantages when compared to manned aircraft. Regardless, it is certain that they will be ubiquitous on the battlefield of the future. Manned aircraft can still provide wide utility and may, in some circumstances, be cheaper, more acceptable or more technologically feasible than an unmanned solution.

# CHAPTER 4 – THE CURRENT SITUATION AND A UK PERSPECTIVE

401. The demanding requirements of the on-going Iraq and Afghanistan campaigns have been a prominent driver of the current western military Unmanned Aircraft System (UAS) order of battle. In platform-terms, the high-end sector is dominated by US manufactured systems such as the General Atomics Aeronautical Systems Inc MQ-1 *Predator* and MQ-9 *Reaper* and the Northrop Grumman RQ-4 *Global Hawk*. Israel, an early entrant, is particularly strong in the medium and small UAS market with impressive worldwide export sales. At the less complex and smaller end of the market, there are many aspiring UAS manufacturers producing aircraft that range from little more than radio control toys to quite sophisticated and capable platforms. Most of the major national manned aircraft manufacturers are either already producing unmanned aircraft, are planning to do so in the near future, or are actively looking for partners with which to team. The industry and military consensus view is confident that the worldwide military UAS market will continue to grow at a considerable rate, with increasing civil sector applications following on, particularly once airspace integration issues are resolved. As technology and the associated regulatory processes mature, it is likely that there will be consolidation within the industry, in a similar manner to that which occurred in manned aviation in the 1960's and 1970's. For high end systems, it is likely that apart from the US, even major western countries will need to collaborate on UAS development.[1] The strategic importance to the UK of the various UAS related technologies must be determined soon, if scarce resources are to be directed to those areas where sovereign capability needs to be retained or recovered, or where UK industry can add most value.

***Zephyr* – QinetiQ's Experimental High Altitude, Long Endurance Unmanned Aircraft**

402. In contemporary operations, UAS' most obvious contribution has been to revolutionise the delivery of the core air power role of intelligence and

[1] The recently announced Government Green Paper *Equipment, Support and Technology for UK Defence and Security* points towards increased bi-lateral, rather than multi-lateral, collaboration. In light of the recent accord signed between the UK and France, there is scope for a collaborative effort between the UK's *Taranis* and the French *Neuron* programmes if affordable economies of scale and shared risk are to be achieved. Italy is also keen to work with the UK on UAS development.

situational awareness. This has largely been achieved through the ability of unmanned aircraft to persist for long periods in the battlespace. Indeed, it is persistence that has become one of the unmanned aircraft's unique selling points in current operations as, although manned aircraft may often have better sensors, greater speed and a better developed all-weather capability, they generally have less endurance and are available in smaller numbers.

403. Unmanned aircraft have become a key enabler of ground manoeuvre. In particular, the United States Air Force (USAF) has been at the forefront of UAS operation, with a 200% increase in demand for unmanned aircraft orbits in the last 2 years and an overall 1200% increase over the last 6 years. USAF unmanned aircraft now provide well over 30,000 unmanned hours per month and the US Department of Defense aims to have 68 Motion Imagery (MI) capable orbits established by 2015.[2] The US Army's growth is similarly remarkable, growing from a handful of platforms in 2001, to approximately 1,000 by 2010. Having taken 13 years to achieve its first 100,000 hours and a year for the next 100,000, the US Army is currently achieving around 25,000 per month using a range of platforms. The one millionth US Army unmanned aircraft flying hour milestone was reached in April 2010.[3]

**GA-ASI MQ-9 Reaper**

[2] Each orbit typically requires 168 airmen to support, of which 52 are analytical posts (dependent on type). The RAF MQ-9 requires 152 personnel, of which 112 are servicemen, with 49 at the FOB/DOB.
[3] http://www.army.mil/-news/2010/04/29/38236-army-surpasses-1-million-unmanned-flight-hours/ accessed 10 January 2011.

Serious concerns are now being raised as to whether there is a physical limit to the number of orbits that can be supported. The main concerns include aircraft co-ordination and de-confliction, competition for radio-frequency bandwidth and the ability to analyse the flood of collected data. Commentators note that the only approach in future may be to limit commitment and make more effective use of what is already available.[4]

404. The UK has only a limited ability to independently deploy and operate unmanned aircraft. However, as alluded to earlier, the 2010 Strategic Defence and Security Review (SDSR) identified UAS as one of the few capability areas to receive increased funding over the next decade. On 11 March 2010, the Royal Air Force reported that it had achieved 20,000 MQ-9 *Reaper* hours since October 2007 and it is now providing over 1200 hours per month in support of the Afghanistan operation. The British Army operates 3 tactical unmanned aircraft systems in theatre, the *Class II Hermes 450*, an interim solution until *Watchkeeper* enters service in late 2011, and the mini-size *Class I Desert Hawk 3* and *T-Hawk*. The *Hermes 450* has achieved good results, with the Army passing 30,000 operating hours by mid-2010. Further details of the UK's current unmanned aircraft order of battle are at Annex A.

## FUTURE UK PROGRAMMES, TECHNOLOGY DEMONSTRATORS AND INDUSTRY INITIATIVES

### The *Watchkeeper* Programme

405. *Watchkeeper*, a derivative of Elbit's *Hermes 450*, is an advanced Class II tactical unmanned aircraft that will be operated by the Royal Artillery.[5] The circa £800M contract for *Watchkeeper* development, manufacture and initial support was awarded to Thales UK in August 2005, with the programme providing 54 aircraft and associated equipment.[6] It is due to enter service in late 2011 and the system will be built in the UK by UAV Tactical Systems Ltd (U-TacS), a joint venture between Thales UK and Elbit.

406. *Watchkeeper* will be the first UK military unmanned aircraft certified to airworthiness standards. It is capable of limited all-weather operation and can carry a range of sensors, including day and night cameras and the Viper surveillance radar that provides a ground moving target indicator and synthetic aperture radar imaging capability. Endurance is typically in the order of 16 hours and the aircraft can be operated out to a range of 150km, flying at a

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[4] Broadly reflects a sentiment noted several times during different briefings received during a Development, Concepts and Doctrine Centre (DCDC) visit to the Pentagon in November 2010.
[5] *Watchkeeper* will be operated by 32 and 47 Regiment Royal Artillery (RA), with augmentation from 104 Regiment RA (V).
[6] House of Commons Hansard Debate for 22 February 2010.

cruise speed of 70kt. The ground control station, housed within a 20ft ISO container provides space for a pilot, payload operator/Unmanned Aerial Vehicle (UAV) commander,[7] a mission commander, image analyst and a signaller. Each ground control station can control up to 2 aircraft and, once set up in theatre, will be able to share *Watchkeeper* derived information with other aircraft and ground headquarters via data link. In addition to remote human operation, the aircraft can be pre-programmed on the ground to automatically carry out a mission from take-off to landing.

407. Following first flight in Israel in April 2008, trials were conducted to demonstrate the automatic take-off and landing system as well as sensor integration and performance. Flight testing moved to West Wales Airport and the adjoining Aberporth Range in late 2009, in preparation for its introduction to service with the British Army, at the end of 2011. On 1 July 2010, after a lengthy period of public consultation, an airspace change proposal was approved to allow *Watchkeeper* training flights to transit from either Boscombe Down or Upavon to training areas over Salisbury Plain. A further Airspace Change Proposal (ACP) is currently being considered by the Civil Aviation Authority that will permit unmanned aircraft operations between West Wales Airport and the Sennybridge Range.

***Watchkeeper***

### The *Scavenger* Programme

408. The *Scavenger* programme is designed to provide UK forces with a theatre-wide, persistent Intelligence, Surveillance and Reconnaissance (ISR) capability and an ability to attack land and maritime time-sensitive targets. Currently in the advanced stages of the concept phase, the assessment phase is expected to begin later this year; the capability is expected to enter service at the end of the decade. Extensive operational analysis, and decisions made at the Anglo-French Summit of November 2010, have narrowed the solution to a Class III Medium Altitude Long Endurance (MALE) UAS – although the UK will consider if other complementary components are needed to fully satisfy the UK capability requirement. The Anglo-French agreement announced a

[7] A legacy term used in the *Watchkeeper* programme.

jointly funded, competitive assessment phase. While the UK is not yet formally committed to a joint programme, this proposal will enable the sharing of development, support and training costs, and will enhance future interoperability.

409. There is some debate as to whether *Scavenger* could also mitigate some of the capability gaps created by the early withdrawal of *Sentinel* and the cancellation of *Nimrod* MRA4, following decisions taken in the recent SDSR. Likely limitations on payload size and radar performance, however, mean that an unmanned aircraft solution, of the size currently envisaged, may only partially alleviate the loss of these capabilities. In particular, *Scavenger* is unlikely to be in the same class as *Sentinel* in terms of its ability to monitor a very wide area or to provide radar imagery at equivalent stand-off ranges. Similarly, although *Scavenger* may have some utility in maritime reconnaissance, it is unlikely to be able to make more than a limited contribution to anti-surface warfare. Additionally it will have little or no utility in Anti-Submarine Warfare (ASW), unless the requirement is substantially re-written to include a specialist anti-submarine radar mode and the ability to carry considerable numbers of sonobuoys. Furthermore, the requirement to relay extensive amounts of sensor data and to develop a remote ground control station that could control the sensors and allow operator analysis, would inject considerable technical risk and hence cost into the programme. Additionally, for both tasks, the airspace requirements of overland and maritime reconnaissance and current restrictions on the operations of unmanned aircraft in non-segregated airspace, are likely to present significant obstacles in the short to medium term.

410. **Procurement**. The finer system requirements and scale of the *Scavenger* capability are, as yet, undetermined at this stage of the planning process. Further analysis will be required to determine, in particular, the number of unmanned aircraft required. However, the aspiration is for a system to support 6 deployable task lines, which implies around 20 aircraft available for operational tasking and to support training. To cover an operational life of 15 years, it is likely that somewhere in the region of 30 airframes would be required, assuming an appropriate level of risk regarding likelihood of repetitive sustained operations throughout the service life. The whole life programme cost is expected to be around £2 billion, which would include development, demonstration, manufacture, in-service and disposal costs and personnel. Note that the in-service life of UAS such as *Scavenger* is likely to be considerably shorter than that historically seen for manned aircraft. This occurs for 2 reasons. Firstly, ISR-tasked unmanned systems tend to fly very long duration sortie profiles and airframe life can be consumed at a high rate. To maintain such a system in service for several decades would require a very

large number of platforms to be procured. Secondly, UAS technology is a fast moving area of development. By the time *Scavenger* comes into service later in this decade, it will have been studied, developed and manufactured over a period of at least 8 years. Even though this is a compressed timeframe compared to that for manned aircraft procurement, some elements of the system will inevitably be obsolete on introduction to service and many others shortly thereafter. As an example, the MQ-1 *Predator* has been in operation for 15 years, but the Royal Air Force operated them for only 5 years before moving on to the MQ-9 *Reaper*. It would be sensible, therefore, to keep the initial buy of new systems small, so that they can be spirally developed once in-service, or replaced fairly quickly.

411. **Adaptive Procurement**. More specifically, the geo-political environment is expected to change considerably over the period 2020 – 2030[8] and any system delivered in the *Scavenger* timeframe, unless it can be easily updated or replaced, may well become less relevant as the threat and operating environment changes. The indication, therefore, is that UAS is a key area where a new approach to capability acquisition may be required. In particular, a change of philosophy to late freezing of final specification, followed by in-service spiral development, or even limited buys that can be replaced at regular intervals with updated systems. Given the potential use of unmanned aircraft by other government departments, a cross governmental collaborative approach might be fruitful.

412. **Sovereignty Issues**. In this document, sovereignty means the ability to deploy and operate a system at a time and place of the UK's choosing, together with the ability to upkeep, update and upgrade the capability. It may well be an important strategic requirement which will need to be balanced with the associated through-life cost and risk. Although there is, inevitably, a desire for full sovereignty, the practicalities of retaining sovereignty for key enablers, such as communications and navigation systems, are already unrealistic. For example, it is likely that any unmanned aircraft navigation system would make use of United States International Traffic-in-Arms Regulation controlled global positioning system equipment. Similarly, the Missile Technology Control Regime may well, in its present form, place restrictions on a UK/FR *Scavenger* solution. These issues are dealt with in more detail in the legal section of Chapter 5 and Annex C.

[8] DCDC, *Future Character of Conflict*, February 2010 and DCDC's Global Strategic Trends Programme, *Global Strategic Trends – Out to 2040*, February 2010.

## TECHNOLOGY DEMONSTRATOR PROGRAMMES

### The *Mantis* Advanced Concept and Technology Demonstrator Programme

413. The BAE Systems *Mantis* concept demonstrator is a twin-engined, 22m wingspan, Class III MALE unmanned aircraft that has been designed to investigate the design, engineering and integration issues associated with the provision of an unmanned air system to fill the intelligence and situational awareness core air power role and which could also carry a range of weapons. The 2-year Industry/MOD jointly funded demonstrator programme began in 2007 and concluded in November 2009. *Mantis* conducted its maiden flight on 21 October 2009 in Woomera, South Australia. An operational Mantis system is envisaged to have an operating altitude of 55,000 ft and an endurance exceeding 24 hours, dependent on payload. Normal cruise speed would be around 200kt, with a dash speed of around 300kt. It would provide an all-weather, night and day capability carrying a comprehensive range of sensors including electro-optical/infra-red, synthetic aperture radar, signals intelligence and communications intelligence capabilities. It would be controlled by a human operator via a satellite link, with extensive on-board automation.

***Mantis***

**The *Taranis* Technology Demonstrator Programme**

414. The *Taranis* programme will result in a one-off flying Technology Demonstration Vehicle (TDV) comparable in size to a Hawk trainer aircraft. The programme aims to develop UK industry's ability to integrate advanced Low Observable (LO) technologies into an unmanned aircraft, as well as developing design and manufacturing capability and understanding of how to manage future LO systems, in-service. The TDV, which was first shown publicly in July 2010, will demonstrate the integration of off-the-shelf technologies, including, automation, command and control sub-systems, sensors and payloads. The TDV is not designed to release weapons, but will include emulated release as part of a mission representative scenario. The programme contract award was for £124M, with the industry team contributing approximately 25% of the funding. The team, led by BAE Systems, also comprises Rolls Royce, QinetiQ and GE Aviation.

***Taranis***

415. Technology Demonstrator Programmes (TDPs) by their very nature are demanding and high risk and Taranis is no exception; it is the first of its kind in the UK and places the UK at the forefront of such technological development. Successful completion of this programme would demonstrate to potential collaborative partners that the UK has the industrial capability to design, develop and manufacture a combat unmanned aircraft.[9]

## UK INDUSTRY INITIATIVES

**Hybrid Air Vehicles**

416. A Hybrid Air Vehicle (HAV) derives some lift from the aerodynamic shaping of the balloon envelope and the rest from the aerostatic forces created by the lighter-than-air helium gas inside the envelope. A UK Company, Hybrid Air Vehicles Limited, won a contract through Northrop Grumman in June 2010, to provide a platform for the US Army that would provide a persistent intelligence, surveillance, target acquisition and

[9] In the UK MOD, a combat unmanned aircraft is known by the term Unmanned Combat Air System (UCAS).

reconnaissance capability in Afghanistan and after. The US Army calls this the *Long Endurance Multi-intelligence Vehicle* (LEMV) and first delivery is expected toward the end of 2011. The cost of LEMV aircraft is expected to be in the order of £4M each and it is hoped that operating costs may be lower than for conventional platforms.

417. LEMV can fly at 20,000ft for up to 3 weeks and, in its optionally manned mode, can operate within national and international airspace. This could allow, for example, an aircraft to deploy to a remote theatre with a pilot and other crew on board, removing the requirement to negotiate and set up segregated airspace across national borders for the deployment. Once in theatre, the aircraft could operate in an unmanned mode, either remotely piloted from home via a satellite link, or following a pre-programmed flight path. The aircraft can be operated from a variety of prepared and un-prepared surfaces, including water, marsh and snow.

418. The HAV's long range and high endurance would allow a persistent presence of several weeks, reducing the number of platforms required, by necessitating fewer transits to an operating area. An ability to hold station for a prolonged time could allow the platform to offer a localised service akin to a geostationary satellite. Its primary role, though, would probably be as an ISR platform, although it is flexible enough to be adapted easily to other roles such as in-theatre tactical re-supply, airborne early warning and maritime reconnaissance and patrol. The HAV's large size means that there is little difficulty in finding space for antennas, a common problem on conventional aircraft. A large antenna could be integrated inside the envelope or even become part of the envelope as intelligent textiles and printable antenna technology matures. This capability could make HAVs a potent signals intelligence platform.

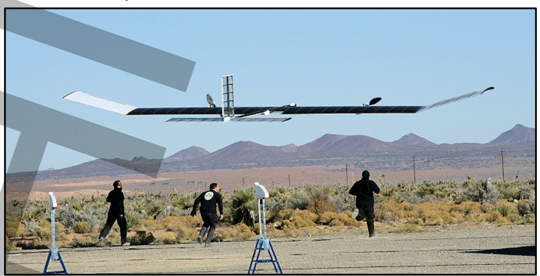
**Long Endurance Multi-Intelligence Vehicle (LEMV)**

419. There are some disadvantages to the HAV concept, mainly related to their relatively slow speed and some uncertainty over their utility in bad weather, especially strong winds. These issues have been studied before,

when considering military use of conventional airships, so there should be good read across from previous operational analysis. Slow transit speed might also limit patrol area size due to re-visit times, although this might be mitigated by the ability to carry heavier, more capable sensors. Transit time between widely separated operating areas would be problematic, although, sensibly, HAVs would probably be one of a range of conventional and unconventional air platforms providing a complementary platform mix. It is uncertain whether the large size and visual signature of the vehicle is an issue, although indications are that HAVs may have similar survivability to other large ISTAR[10] aircraft. Although it could be fitted with a defensive aids suite, it is probably more suited to employment in benign airspace.

### *Zephyr* Experimental Unmanned Aircraft

420. *Zephyr* is an experimental high altitude, long endurance unmanned aircraft developed by QinetiQ. It is powered by rechargeable batteries that are kept charged by amorphous silicon arrays that cover the wings. Although the aircraft is quite large, with a wingspan of 22.5m, its carbon fibre construction means that it is very lightweight. The aircraft is hand-launched by a small team of people and in July 2010 set a world record for the longest duration unmanned flight of 14 days and 22 minutes. During this flight it reached an altitude of 70,000 ft. The programme aims to continue to extend flight endurance, possibly to as much as 3 months. The platform is ideal for extended earth observation and communications relay tasks, although it is limited by the fairly small payload that it can carry and its low speed. The former is likely to be increased over time by continued reduction in the size of electronic components and more efficient power usage.



***Zephyr***

## THE MARITIME REQUIREMENT

421. For the last 5 years, the UK's main effort has been the Afghanistan campaign and it has been difficult for the Royal Navy to gain traction for procuring unmanned aircraft to fill maritime surveillance gaps.[11] Currently the Royal Navy has no funded procurement programme for a maritime UAS. However, there is a strong case to be made for both organic and land-based maritime unmanned aircraft programmes, particularly in the ISR role. As

[10] ISTAR: Intelligence, Surveillance, Target Acquisition and Reconnaissance.

[11] For example the deletion of Nimrod MR2 in March 2010 and subsequent cancellation of the MRA4 in SDSR.

surface ship numbers decrease, post SDSR, the requirement for remaining ships to cover larger operating areas increases. Capability audits have already shown that unmanned aircraft could be a cost effective way of extending sensor coverage, and hence situational awareness, whether in the littoral or for blue water operations.[12] Operating unmanned aircraft from ships at sea is demanding, but entirely feasible, with most tactical systems being catapult-launched/net-recovered, or vertical take-off and landing. While there are no Royal Navy unmanned aircraft currently in service, deployed ships are already fitted with the capability to receive video feeds from unmanned and manned aircraft via a downlink terminal.

422. The Royal Navy successfully trialled the *ScanEagle* system in 2005/6, as part of the Joint UAV Experimentation Programme (JUEP)[13] but was subsequently unable to secure funding to take a programme forward. It is now planned to demonstrate a medium size vertical take-off and landing unmanned aircraft in late 2011 as part of the Tactical Maritime UAS Concept Capability Demonstrator. Since such systems are generally optimised for ISR tasks they will likely complement, rather than replace, manned helicopters over the next 2 epochs as manned helicopters will still be required to perform the myriad of other support and attack tasks.

**Boeing/Insitu *ScanEagle***

[12] Such as counter-piracy in the Indian Ocean (joint operations area of 2000nm x 1600nm) or counter-narcotics in the Gulf of Mexico.
[13] As part of JUEP, the Royal Navy flew *ScanEagle* from the Type 23 Frigate HMS SUTHERLAND in the Hebrides Range.

Navy Command is also actively engaged in supporting the *Scavenger* requirement in order to ensure that units, Task Groups and future embarked battle-staff will be able to exploit its product in future operations. The US is already running programmes that aim to deliver the entire spectrum of maritime aviation tasks, probably in epochs 3 and 4; at some stage, capability planners will have to test the cost effectiveness of such systems for UK use.

423. For larger unmanned aircraft, the QUEEN ELIZABETH Class (QEC) aircraft carrier is due to enter service around 2016 with a service life of at least 30 years. Subject to evolving concepts, the QEC could operate unmanned aircraft and exploit data from other national or coalition unmanned aircraft. It could also, given incorporation of the appropriate support and communication systems, operate unmanned combat aircraft using the same Advanced Launch and Arresting Equipment[14] as that required for *Lightning II*. Indeed, the closer integration with the French Navy we expect to result from recent accords could see the ability to operate mixed fleets of manned and unmanned coalition aircraft from the QEC.

**US Maritime UAS Capability**

424. The US Navy (USN) is currently the world leader in the exploitation of maritime unmanned aircraft. In April 2008, the USN awarded a contract to Northrop Grumman for 40 marinised *RQ-4 Global Hawk*, to be designated the *MQ-4C*. These aircraft will be deployed to 5 bases around the world and are expected to be in service by the end of the decade. The system, known as *Broad Area Maritime Surveillance* (BAMS) will work alongside the new *P-8A Poseidon* Maritime Patrol Aircraft and the EP-3 Electronic Intelligence platform. BAMS is already deployed in support of US Central Command, where its considerable range and persistence permits it to be launched and recovered from land. *Saber Focus* is a deployed USN system of MQ-9 Reaper B, operated in support of missions off Somalia and integrated with

**Northrop Grumman MQ-8 *Fire Scout***

[14] Electromagnetic catapult and arrestor gear which can scale outputs and forces to match any size of platform and required launch speed.

USN manned air, surface ships and submarines. The USN has also deployed a range of tactical ship-based unmanned aircraft, including *ScanEagle* and *Fire Scout* and have funding for a carrier-based *Unmanned Combat Aircraft System Demonstration (UCAS-D)* system, based on the Northrop Grumman *X-47B.* The extent of *UCAS-D* development and success will shape USN manned aircraft replacement requirements; *UCAS-D*'s first test flight took place in Feb 2011 and deck trials are planned for 2013. In due course, the USN seeks to integrate unmanned air vehicles to a carrier wing by 2018 with a view to replacing Super Hornets from 2025.

**Other Nations' Maritime UAS Capability**

425. The Indian Navy stood up its second land based UAV Squadron in January 2011, equipped with Israeli *Heron* and *Searcher II* aircraft which will patrol the North Arabian Sea. Many other countries have also either already bought, or are in the process of buying, systems to support maritime operations. Since unmanned aircraft can support air, land and maritime tasks alike, maritime based unmanned aircraft can support air and land operations and vice versa. Indeed, for ISR tasks, this is already the norm. While operational analysis will determine the optimal future force mix, and where it is based or operated from, it is likely that maritime use of organic and non-organic unmanned aircraft systems will increase considerably between Epochs 3 and 4.

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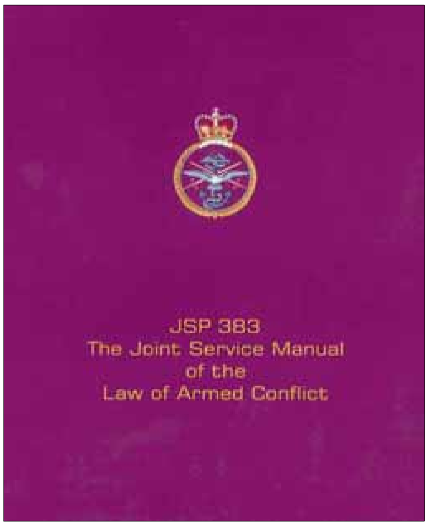
# CHAPTER 5 – MORAL, LEGAL AND ETHICAL ISSUES

501. Current debate on unmanned aircraft related moral, legal and ethical issues is mostly centred on the use of weaponised systems, but there are other, wider issues that will affect future development and employment of unmanned aircraft. Inevitably, some unmanned aircraft activities will face legal challenge, or create moral and ethical dilemmas; although where these activities mirror those conducted by manned aircraft, useful analogies can be drawn when deciding what is acceptable. Future novel systems may, however, have characteristics or capabilities that do not easily correlate to manned aircraft activity and hence require new thinking. In the civil and public service sectors in particular, privacy of the individual and organisations will be increasingly threatened by the presence of surveillance platforms and regulation to control this may also limit state and military activities, particularly when conducting training. This is more a matter of scale, rather than anything new, so there should be good read across from current regulations.

## LEGAL ISSUES

502. Most of the legal issues surrounding the use of existing and planned systems are well understood and are simply a variation of those associated with manned systems.[1] An aircraft, whether manned or unmanned, is commanded and therefore its use is governed by the Law of Armed Conflict (LOAC) in 2 ways. Firstly, weapons law guides whether a weapon and its generic uses are lawful; secondly, targeting law determines whether the use of a particular weapon is lawful on a specific mission or in specific circumstances. This also defines the framework for the Rules of Engagement (ROE).[2] The LOAC is based largely on the Geneva Conventions of 1949 and the 1997 Additional Protocol 1, of which the UK is a signatory. Further guidance on the LOAC is contained in Joint Service Publication (JSP) 383 *The Joint Service Manual of the Law of Armed Conflict,* and guidance on ROE in JSP 398 *Rules of Engagement.*






[1] For a more complete discussion, see *Requirements for Autonomous Unmanned Air Systems set by Legal Issues*, Tony Gillespie and Robin West (Defence Science and Technology Laboratories, UK), available from http://www.dodccrp.org/html4/journal_v4n2.html last accessed 25 February 2011.

[2] UK *Reaper* uses the same ROE and targeting directive as manned aircraft in Afghanistan but they have the persistence to check and re-check, possibly via legal advisers, that they are compliant.

503. Signatories to the Geneva treaties are required to review all new weapons, methods and means of warfare to determine their compliance with applicable law. In the UK this process is conducted by the legal team at the Development, Concepts and Doctrine Centre. There are elements of the LOAC that have specific consequences for unmanned aircraft, as compliance will become increasingly challenging as systems become more automated. In particular, if we wish to allow systems to make independent decisions without human intervention, some considerable work will be required to show how such systems will operate legally. Additional Protocal 1, in particular, requires that constant care is taken in the conduct of military operations to spare civilians and civilian objects. This means that any system, before an attack is made, must verify that targets are military entities, take all feasible precautions to minimise civilian losses and ensure that attacks do not cause disproportionate incidental losses. Where the unmanned aircraft is remotely piloted, this process can be undertaken in exactly the same way as it would by the pilot of a manned aircraft, although it will have to be shown that the remote pilot is capable of making reasoned judgements based on the level of data passed by the remote sensors and other networked information that may be available. For automated systems, operating in anything other than the simplest of scenarios, this process will provide a severe technological challenge for some years to come.

504. Some fully automated weapon systems have already entered service, following legal review, and contributing factors – such as required timeliness of response – can make compliance with LOAC easier to demonstrate. For example, with the Phalanx and Counter-Rocket, Artillery and Mortar (C-RAM) systems that are already employed in Afghanistan it can be clearly shown that that there is insufficient time for a human initiated response to counter incoming fire. The potential damage caused by not using C-RAM in its automatic mode justifies the level of any anticipated collateral damage.

505. In order to ensure that new unmanned aircraft systems adhere to present and future legal requirements, it is likely that a systems engineering approach will be the best model for developing the requirement and specification. Using such an approach, the legal framework for operating the platform would simply form a list of capability requirements that would sit alongside the usual technical and operational requirements. This would then inform the specification and design of various sub-systems, as well as informing the concept of employment. Additionally, future civilian airspace regulations will generate further capability requirements that must be met, if the system is to be used in non-segregated civilian airspace.

506. **Situational Awareness**. In order to normalise the legal review process, work will be required to further standardise ground station displays and more fully define the level and quantity of information that must be presented to an operator (NATO STANAG 4586 Edition 2). Although the air platform mission system may *know* exactly what state the platform is in and, to some degree, what is happening around it, the remote pilot relies entirely on the output of the on-board sensors[3] to achieve his or her own local situational awareness. Legal review will need clear information on what information is, or is not, presented to the remote pilot, in order to understand the level of situational awareness that can be achieved. Similarly, although an unmanned aircraft will respond to commands in the same way as any manned aircraft, system induced delays between control input, aircraft response and feedback to the pilot will need to be quantified and understood. An unmanned aircraft with an automated control system that is designed to reduce pilot workload, so that it is monitored[4] rather than directly controlled, may well react rapidly to self generated inputs, but the remote operator will be less aware of what the platform is doing on a real time basis. Thus there are trade-offs to be made between acceptable workload and the level of aircraft control and system management required. This will vary the amount of real-time feedback to a remote operator. The pilot may even be in another manned aircraft, as pilot or crew, instead of on the ground or, if ground-based, may be overseeing several unmanned aircraft. These factors will further constrain design, operation and real-time awareness of an individual platform's activity.

**Ground Control Station**

[3] Advanced systems may have access to Link 16, *Chat messaging* and *blue force tracker*.
[4] So called on-the-loop rather than in-the-loop.

507. **Increasing Automation**. As systems become increasingly automated, they will require decreasing human intervention between the issuing of mission-level orders and their execution. For example, a mission may require an unmanned aircraft to carry out surveillance or monitoring of a given area, looking for a particular target type, before reporting contacts to a supervisor when found. A human-authorised subsequent attack would be no different to that by a manned aircraft and would be fully compliant with the LOAC, provided the human believed that, based on the information available, the attack met LOAC requirements and extant ROE. From this position, it would be only a small technical step to enable an unmanned aircraft to fire a weapon based solely on its own sensors, or shared information, and without recourse to higher, human authority. Provided it could be shown that the controlling system appropriately assessed the LOAC principles (military necessity; humanity; distinction and proportionality) and that ROE were satisfied, this would be entirely legal.

508. **Increasing Autonomy**. In practice, such operations would present a considerable technological challenge and the software testing and certification for such a system would be extremely expensive as well as time consuming. Meeting the requirement for proportionality and distinction would be particularly problematic, as both of these areas are likely to contain elements of ambiguity requiring sophisticated judgement. Such problems are particularly difficult for a machine to solve and would likely require some form of artificial intelligence to be successful. Estimates of when artificial intelligence will be achieved (as opposed to complex and clever automated systems) vary, but the consensus seems to lie between more than 5 years and less than 15 years, with some outliers far later than this. Artificial intelligence and autonomous systems are discussed further in Chapter 6. Until such a capability is achieved it is likely that, apart from some niche tasks, human intervention will continue to be required at key stages of an unmanned aircraft's mission if it involves weapon-delivery. For operating environments with easily distinguished targets in low clutter environments, a degree of autonomous operation is probably achievable now and data from programmes such as *Brimstone* and ALARM, for example, would have direct read-across. However, this is unlikely to be of much help to unmanned systems that we expect will have to operate in the future cluttered urban and littoral environments on long endurance missions. It should be noted that the MOD currently has no intention to develop systems that operate without human intervention in the weapon command and control chain, but it is looking to increase levels of automation where this will make systems more effective. As technology matures and new capabilities appear, policy-makers will need to be aware of the potential legal issues and take advice at a very early stage of any new system's procurement cycle.

509. **Survivability**. In contested airspace, unmanned aircraft may be subjected to either ground-to-air or air-to-air attack. Remotely piloted aircraft may not provide sufficient situational awareness to the remote pilot to either determine the source of an attack, or to respond in a proportionate manner. Similarly, automated aircraft may lack the level of intelligence required to respond in accordance with the LOAC, without further human direction. It is likely that unmanned aircraft, however operated, may be more susceptible to attack, because of their increased reliance on sensors and communication links for normal operations, than their manned counterparts.

510. **Accountability**. Legal responsibility for any military activity remains with the last person to issue the command authorising a specific activity. This assumes that a system's basic principles of operation have, as part of its release to service, already been shown to be lawful, but that the individual giving orders for use will ensure its continued lawful employment throughout any task. This process has an implicit assumption that a system will continue to behave in a predictable manner after commands are issued; clearly this becomes problematical as systems become more complex and operate for extended periods. In reality, predictability is likely to be inversely proportional to mission and environmental complexity. For long-endurance missions engaged in complex scenarios, the authorised entity that holds legal responsibility will be required to exercise some level of supervision throughout. If so, this implies that any fielded system employing weapons will have to maintain a 2-way data link[5] between the aircraft and its controlling authority.

***RAF Reaper***

[5] Although this link may not need to be continuous.

A complex weapon system is also likely to require an authorisation and decisions log, to provide an audit trail for any subsequent legal enquiry. It has been proposed[6] that situations can arise where it is unclear whether the legal liability for inappropriate weapon release lies with the pilot, the design authority or the regulatory authority. However, if the logic of the current manned process is maintained, then the responsibilities of the designers will have been discharged once the Unmanned Aircraft System (UAS) has been certified by the relevant national military or civilian air authorities. The safety case will, however, have to address the additional risks in an autonomous system as any clearance will only consider safety in terms of air platform safety and integrity. For example, it will ensure that a weapon does not damage the weapon-carrying platform on release, rather than address how the weapon is used.

511. **Civil Airspace Regulation Considerations**. The airspace regulatory regime for operation of unmanned aircraft in civilian airspace is the same as that for manned aircraft. As discussed at Annex B, it is not currently permitted for unmanned aircraft to operate alongside manned aircraft, as approved systems that will ensure safe operation and separation have not yet been agreed; currently, unmanned aircraft can only operate in segregated airspace. Separately, there are additional regulatory constraints that will need to be satisfied. These include ensuring that any unmanned aircraft will have a predictable response in the event of loss of the controlling data link and, potentially, require a human representative to be available in the event of in flight emergencies. Current guidance is laid down in CAP 722[7] *Unmanned Aircraft System Operations in UK Airspace – Guidance*, but this can be expected to change, over time, to reflect technological developments, particularly as sense and avoid systems approach maturity. MOD capability areas and integrated project teams need to ensure that the specification for new systems remains flexible enough to accommodate such changes.

512. **Airworthiness Standards**. Manned aircraft are built to well-defined UK and, in-future, European Aviation Safety Agency airworthiness standards. This is to both protect the crew/passengers of the aircraft and minimise third-party risk to people on the ground. Few unmanned aircraft to date[8] have been built to any defined airworthiness standard, mostly being operated under a limited clearance. This has been exacerbated by the fact that many UAS manufacturers have no manned aerospace background and are unaware of

[6] There are 2 useful articles that discuss this proposal. Myers A, *Unmanned Aerial Vehicles – The Legal and Moral Challenges Facing the 21st Century Air Commander*, RAF Air Power Review, Volume 10, Edition 1, 2007, pages 79-96. Mardell A, *Unmanned Aerial Vehicles: the Legal Perspective* in *Air Power: UAVs the Wider Context,* RAF Directorate of Defence Studies, pages 68-85 2009.
[7] CAP: Civil Aviation Publication produced by the UK Civil Aviation Authority.
[8] *Watchkeeper* is the first UK system to be fully airworthiness certified to the same standards as a military manned aircraft. In the US, *Global Hawk* is the only system so certified.

the airworthiness strictures placed on manufacturers and the proof that is required to ensure certification.[9] If unmanned aircraft are to be integrated into civil, unsegregated, airspace then it must be proven that they are at least as safe as manned aircraft, and that the third party risk is mitigated as much as possible. As an aside, it should be noted that adherence to strict airworthiness standards is likely to significantly increase costs of unmanned platforms – negating their current *selling point* of relative cheapness.

513. **Safety Critical Versus Mission Critical**. UAS, with their currently limited level of autonomy are even more reliant on a *system of systems* approach than manned aircraft. Each element of the system that delivers the end unmanned aircraft capability has to work before, during, and after, a mission if the aircraft is to be controlled effectively. There are, therefore, many more safety critical elements relevant to the operation of an unmanned aircraft.[10] For example, a communications link that was only mission-critical for a manned system, may well be a safety critical issue for an unmanned platform as may be provision of a legally acceptable fail-safe mechanism.

514. **Export of UAS Technology**. There are a number of legal restraints on the export of UAS technology, the most significant of which is the Missile Technology Control Regime (MTCR). Although missile focused, the MTCR also limits the export of unmanned aircraft and associated technologies and includes 'complete unmanned aerial vehicle systems (together with cruise missile systems, target drones and reconnaissance drones) capable of delivering at least a 500kg payload[11] to a range of at least 300km'.[12] It is not clear how the MTCR would affect the export of UK built systems or the import of foreign ones but it would affect the scope of a defence industrial strategy aimed to support UK manufacturers and the export of unmanned aircraft systems. The MTCR has already influenced, and is reflected in, European Community and national law. This creates legal obligations which are enforceable and affects which particular equipment, technologies and related items must be licensed. A more detailed discussion of the legal situation regarding export is at Annex C.

515. **The Remote Warrior**. With kinetic operations being controlled from several thousand miles away, such as those in Afghanistan currently being

[9] The *Watchkeeper* programme has been heavily delayed, in part because of the lack of provision of proof, by the manufacturer, that the system meets airworthiness requirements. This does not mean that the proof does not exist, rather that it may not be available in the format or detail required by the MOD.
[10] Although this view could be considered over-simplistic when comparisons are made with some modern aircraft that require inputs from ground-based planning and maintenance systems if they are to be effective.
[11] MTCR defines payload as *the total mass that can be carried or delivered by the specified rocket system or unmanned aerial vehicle system that is not used to maintain flight*. It includes munitions, countermeasures, recording equipment and recovery equipment (e.g. parachutes) amongst others.
[12] *Missile Technology Control Regime Equipment, Software and Technology* Annex dated 11 June 2010, page 16.

conducted from the continental US, LOAC issues are further complicated. The concept of *fighting from barracks* as it has been termed raises a number of interesting areas for debate. Is the *Reaper* operator walking the streets of his home town after a shift a legitimate target as a combatant? Would an attack by a Taliban sympathiser be an act of war under international law or murder under the statutes of the home state? Does a person who has the right to kill as a combatant while in the control cabin cease to be a combatant that evening on his way home? More broadly, do we fully understand the psychological effects on remote operators of conducting war at a distance?

## MORAL AND ETHICAL ISSUES

516. Unmanned systems pose more than just legal dilemmas. The ethics- and morals-related questions of when, where, and how automated or autonomous unmanned systems may be used, have been tentatively explored in academia (and in popular science fiction), but we are only now starting to require real-world answers. Many of the dilemmas apply to the use of unmanned systems in any environment, not just in the air. Beyond the question of whether an action is legal there is now the concern of whether an action is morally justified. Will the advent of increasing autonomy raise complex dilemmas centred on the moral and ethical justification of our actions? For instance, will future wars be fought remotely, at least initially, with little or no loss of friendly human life? Is human nature such that the next arms race will seek to pitch increasingly complex unmanned systems against other unmanned systems or humans?

517. The first area for consideration involves the removal of risk to ones own forces in warfare. This raises a number of interesting areas for debate, not the least being the school of thought that suggests that for war to be moral (as opposed to just legal) it must link the killing of enemies with an element of self-sacrifice, or at least risk to oneself.[13] This raises 2 interesting issues. Firstly, does it follow that the ability to use unmanned systems, without risk to an operator's life, will lead to the rapid escalation of what would previously have been

***RAF Reaper – 20,000 Hours, Mar 11***

[13] See discussion in Singer P W, *Wired for War,* Penguin: London, 2009, page 432.

considered a simple diplomatic problem, to full-on technological warfare? In 1862, after the Battle of Fredericksberg, General Robert E Lee said:

> *"It is well that war is so terrible – otherwise we would grow too fond of it."*[14]

If we remove the risk of loss from the decision-makers' calculations when considering crisis management options, do we make the use of armed force more attractive? Will decision-makers resort to war as a policy option far sooner than previously? Clausewitz himself suggests that it is policy that prevents the escalation of the brutality of war to its absolute form via a diabolical escalatory feedback loop[15] – one of the contributory factors in controlling and limiting aggressive policy is the risk to one's own forces. It is essential that, before unmanned systems become ubiquitous (if it is not already too late) that we consider this issue and ensure that, by removing some of the horror, or at least keeping it at a distance, that we do not risk losing our controlling humanity and make war more likely. For example, the recent extensive use of unmanned aircraft over Pakistan and Yemen may already herald a new era. That these activities are exclusively carried out by unmanned aircraft, even though very capable manned aircraft are available, and that the use of ground troops in harm's way has been avoided, suggests that the use of force is totally a function of the existence of an unmanned capability – it is unlikely a similar scale of force would be used if this capability were not available. The discussion in this paragraph must be tempered however, by the fact that the moral responsibility on every commander to reduce loss of life – *on both sides* – is clear. The use of unmanned aircraft prevents the potential loss of aircrew lives and is thus in itself morally justified. (There is no objection in the popular press, for instance, to the use of bomb disposal robots). What is needed is a clear understanding of the issues involved so that informed decisions can be made.

518. The second area for consideration is that use, by the western nations, of high technology unmanned platforms, offering no risk to their own personnel, may directly impact on the apparent legitimacy of their actions. While notions of fairness are not necessarily appropriate in war, the UK, as a democratic nation '*cannot achieve long-term security and prosperity unless we uphold our values*'.[16] We must consider the war of ideas inherent in all modern warfare, particularly counter-insurgency operations.[17] Legitimacy

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[14] McPherson J, *Battle Cry of Freedom,* Oxford University Press, 1988, page 551.
[15] Clausewitz, *On War,* translated and edited by Howard M and Paret P, Princeton University Press, 1989, page 606.
[16] Hague W, Foreign Secretary, *Britain's Values in a Networked World*, Speech at Lincoln's Inn, London, 15 September 2010.
[17] Singer P W, *Attack of the Military Drones,* in Brookings, June 2009. http://www.brookings.edu/opinions/2009/0627_drones_singer.aspz?p=1 accessed 10 January 2011.

becomes a key battleground in this type of environment and, as David Whetham says:

> '*winning the narrative of the situation is just as significant as winning any tactical engagement*'.[18]

519. In such operations, which tend to be enduring, the onus is on the counter-insurgent to maintain his legitimacy; the insurgent gains every time a mistake is made, be it a bomb landing in the wrong place or a potential war crime. The counter-insurgency operation must be perceived as ethically sound, above reproach, and the ill-considered use of armed unmanned aircraft offers an adversary a potent propaganda weapon. This enables the insurgent to cast himself in the role of underdog and the West as a cowardly bully – that is unwilling to risk his own troops, but is happy to kill remotely. This argument must be balanced against the greater situational awareness provided by the sensors on a persistent unmanned aircraft that observes the battlespace for long, uninterrupted, periods which enables better decision making and more appropriate use of force. This is enhanced by the fact that the decision-maker is in the relatively stress-free environment of an air-conditioned cabin instead of in a fast jet cockpit. Whichever philosophical viewpoint is taken, the use of armed unmanned systems in such a war of ideas will need to be carefully managed.

520. **Autonomy**. Increasing autonomy in unmanned systems brings an even more extensive portfolio of moral and ethical issues. As has been seen by reports in the press of *killer drones* in Afghanistan,[19] feelings are likely to run high as armed systems acquire more autonomy. Increasing autonomy is likely to be driven by both a desire to make systems more effective in performing increasingly complex tasks, and by the requirement to make manpower savings – enabling one operator to oversee a number of unmanned systems simultaneously. Increasing autonomy also provides back-up options should control data links be disrupted. There is also an increasing body of discussion that suggests that the increasing speed, confusion and information overload of modern war may make human response inadequate and that the environment will be '*too complex for a human to direct*'[20] and this has already been exemplified by the adoption (described above in the legal section) of autonomous weapon systems such as C-RAM.[21] The role of the human in the loop has, before now, been a legal requirement which we now see being

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[18] Whetham (Ed) D, *Ethics, Law and Military Operations*, Palgrave Macmillan, 2011, page 19.
[19] For instance see the following http://www.guardian.co.uk/uk/2011/jan/16/drones-unmanned-aircraft last accessed 21 February 2011
[20] Singer P W, *Robots at War: The New Battlefield* in The Wilson Quarterly, Winter 2009. http://wilsonquarterly.com/article.cfm?aid+1313 accessed 10 January 2011.
[21] Counter- Rocket, Artillery and Mortar.

eroded, what is the role of the human from a moral and ethical standpoint in automatic systems? Most work on this area focuses on the unique (at the moment) ability that a human being has to bring empathy and morality to complex decision-making. To a robotic system, a school bus and a tank are the same – merely algorithms in a programme – and the engagement of a target is a singular action; the robot has no sense of ends, ways and means,[22] no need to know **why** it is engaging a target. There is no recourse to human judgement in an engagement, no sense of a higher purpose on which to make decisions, and no ability to imagine (and therefore take responsibility for) repercussions of action taken. This raises a number of questions that will need to be addressed before fully autonomous armed systems are fielded. As Christopher Coker says:

> '*We enter a new century knowing all too well that our ethical imagination is still failing to catch up with the fast expanding realm of our ethical responsibilities. Robots are taking us even further away from the responsibilities we owe our fellow human beings.*'[23]

521. The other side of the autonomy argument is more positive. Robots cannot be emotive, cannot hate. A target is a series of ones and zeros, and once the decision is made, by whatever means, that the target is legitimate, then prosecution of that target is made mechanically. The robot does not care that the target is human or inanimate, terrorist or freedom fighter, savage or barbarian. A robot cannot be driven by anger to carry out illegal actions such as those at My Lai.[24] In theory, therefore, autonomy should enable more ethical and legal warfare. However, we must be sure that clear accountability for robotic thought exists and this in itself raises a number of difficult debates. Is a programmer guilty of a war crime if a system error leads to an illegal act? Where is the intent required for an accident to become a crime? The pace of technological development is accelerating and the UK must establish quickly a clear policy on what will constitute acceptable machine behaviour in future; there is already a significant body of scientific opinion that believes in banning autonomous weapons outright,[25] countered by an acceptance in other areas that autonomy is inevitable.[26] There is a danger that time is running out – is

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[22] See discussion in Coker C, *Ethics and War in the 21st Century*, Routledge, 2008, page 151.
[23] *Ibid*, page 152.
[24] The My Lai Massacre was carried out by US troops in South Vietnam on 16 March 1968. An unknown number (estimates range from 347-504) of unarmed civilians, the majority women and children, were killed. For a discussion see Tripodi P, *Understanding Atrocities* in Whetham D (Editor) *Ethics, Law and Military Operations*, Palgrave Macmillan 2011 pages 173-188.
[25] For instance, The International Committee for Robot Arms Control, www.icrac.co.cc.
[26] Jane's Defence Weekly reported on 23 February 2010, that the *US Air Force Science and Technology Strategy*, published in December 2010, called for more autonomy and that the development of autonomous systems should be a top priority.

debate and development of policy even still possible, or is the technological genie already out of the ethical bottle, embarking us all on an incremental and involuntary journey towards a *Terminator*-like reality?

# CHAPTER 6 – SCIENCE AND TECHNOLOGY

## INTRODUCTION

601. This chapter examines science and technology issues of particular relevance to Unmanned Aircraft Systems (UAS). Key technologies that may have the most impact on future UAS development are identified. This is followed by a short section on *Black Swans*, those areas where unexpected breakthroughs or rapid success could act as the catalyst to step-changes in capability.[1] The chapter finishes by briefly discussing defence industrial issues. It may be useful to consider this chapter in conjunction with Chapter 3, particularly Figure 3.1.

602. A key future capability requirement of unmanned aircraft will be the automated acquisition of objects of interest. This will require capable automatic detection, recognition and classification sub-systems. While some capability for this already exists for simple objects, it is expected that this will become achievable for difficult objects[2] over the next 2 epochs.[3] This may be mostly driven by developments in the civilian photographic and augmented reality markets. Considerable advances in on-board processing capability will be required though, for this to be successfully implemented. Secondary beneficial effects may include a reduced bandwidth requirement, as the amount of data passed off-board for analysis decreases, and a reduction in the requirement to transmit data in high threat environments. Satellite-based communications are currently essential for *beyond line of sight* operation of unmanned aircraft and this capability is

***ScanEagle* Sensor Head**

[1] *Black Swan* is a term coined by Massim Taleb in his book *The Black Swan: The Impact of the Highly Improbable* (Penguin: London 2008). Taleb describes *Black Swan* events as those that are outside the realm of regular expectations that have extreme impact. They often give rise to unexpected and considerable societal or technological change.
[2] Given the range of possible objects, it is impossible to give a definitive definition of what constitutes simple and difficult recognition objects. However, examples of simple objects may be a particular class of military ship, or a tank in a non-cluttered environment. Difficult objects may be an individual in a crowd, or a particular vehicle in a queue of traffic.
[3] For this document, epochs are considered in 5 year periods, with Epoch 1 equating to 2011 – 2015 inclusive.

likely to be increasingly provided by unmanned aircraft acting as *stratellites*. These systems may also, by Epoch 3, provide localised laser-based communication networks, greatly reducing the burden on the radio frequency spectrum. While sensor performance will continue to increase incrementally, it is anticipated that most value will be gained by continuing to drive down sensor size and cost to allow them to be more widely deployed in cheaper and smaller systems. Military systems are likely to exploit developments in the commercial collection, manipulation and exploitation of data, allowing much greater access to, and real-time exploitation of, data collected by unmanned aircraft. These advances, along with developments in smart materials, novel power sources and the application of nanotechnology are expected to deliver ever more capable UAS. Military system advances will increasingly be driven by developments in the commercial sector due to their respective economies of scale, rather than uniquely military research.

603. Infrequent acquisitions of small numbers of airframes create significant difficulties for industry in maintaining continuity of design and build teams. This problem, which exists equally for manned aircraft, is one of the issues being addressed by the Government in its Green and White Papers on Defence Technology, (discussed at paragraph 626). Unmanned aircraft acquisition teams could be presented with an opportunity to move to a new procurement model that relies on a trickle feed of orders to sustain industry and to allow continuous insertion of new technology. This approach may also allow the MOD to better manage design risk to ensure that new systems are still up-to-date and relevant on introduction to service. The UK does, however, have to match its excellence in high technology research and design of air systems, to production and provision of in-service capability, if future UAS acquisition programmes are to be successful.

604. Similarly, the UK's inability to nationally fund research and procurement across the full range of UAS sub-systems means that key technologies and opportunities are increasingly being denied to UK industry. Increasingly, *International Traffic in Arms Restrictions* means that many common sub-systems are only available from US suppliers, while at the same time, multinational, US-based, companies are increasingly becoming the parent to formerly British companies. Without a coherent UK industrial strategy for UAS, our ability to develop and build the entire range of unmanned aircraft types may be lost.

## KEY TECHNOLOGIES

### Airframe

605. **Miniaturisation**. There is a rapid increase in the development and production of Class I micro (<2kg) and mini (2-20kg) UAS. Largely driven by advances in the commercial sector,[4] these will have considerable utility for tactical Intelligence, Surveillance and Reconnaissance (ISR) in urban environments. Even though small, such systems are very capable and will have increasingly higher degrees of automation; they may include Global Positioning System (GPS) navigation and video downlink capability. Very small solid-state attitude sensors and inertial systems will increasingly provide the ability to self-orientate and navigate without a permanent GPS signal – useful for automated operation inside buildings. At an even smaller scale, biological mimicry will be a key factor for developing Nano Air Vehicles (NAV).[5] These vehicles, which may weigh less than 25g, will be highly specialised and in addition to having miniaturised sensors for ISR tasks, may be weaponised to act as anti-personnel devices. Low cost for such devices will be critical as they are, effectively, disposable. Detecting and countering such systems will be difficult, particularly if they are deployed in large numbers. However, such systems are likely to have some major operating limitations; adequate power sources will be a particular challenge, and operation in adverse environmental conditions such as rain, wind, dust, etc will be problematic.

606. **Design Factors**. Removing aircrew and associated support systems enables the design of unmanned aircraft that are smaller and lighter than their manned equivalent, although a potential need to duplicate mission-critical systems may reduce some of the space savings generated. The use of novel shapes or materials may also allow designers greater opportunity to incorporate concealment and deception camouflage features into the structure. These may include elements such as shielding of hot spots, or the application of surface treatments to change the airframe signature, as well as using design and colour to provide a false perception of what is being observed. Small systems can be particularly hard to detect visually and adaptive surface coatings that change in response to different stimuli such as light or heat may enable effective camouflage at all wavebands, not just the visible. Unmanned aircraft design also provides an exciting opportunity to implement modular payload planning to the way such platforms are operated. Standardised sensor and payload interfaces and sizes would allow rapid changes of each to meet different mission requirements, throughout the phases of a campaign. Thermal and power management will become

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[4] Not necessarily UAS related. The mobile phone and computer industries are key drivers of software and hardware development that have dual use in military UAS.
[5] NAV is not a formally defined term, but is in common usage.

increasingly important for such aircraft, particularly when stealth and Directed Energy Weapons (DEW) technology is employed. Discussions on such issues are outside the scope of this paper, but suffice to note that many of the resultant design requirements will be challenging.

### Propulsion

607. **Propulsion and Powerplants**. Propulsion systems for unmanned aircraft range from battery powered electric motors through to high-end gas turbines. As unmanned aircraft carry increasing numbers of sensors and, in future, DEW, the energy requirement of on-board sensors and weapons may well become the critical factor in power source selection. Figure 6.1 provides a breakdown, by type, of propulsion systems currently used in unmanned aircraft.

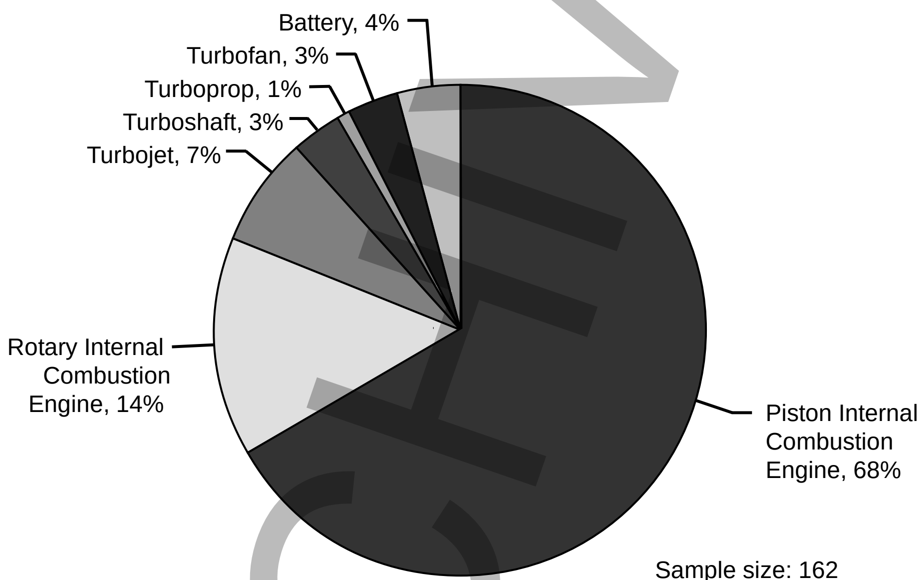



**Figure 6.1 – Propulsion Systems in Use on UAS Aircraft**

This shows that internal combustion engines are the predominant type, used in over 80% of the surveyed aircraft. Turbine engine based systems are the next most significant type with 14%, with battery systems making up the remainder. For small lightweight platforms, a popular choice has been micro turbojets and turbofans, often derived from the model aircraft industry. These have also been useful for development systems built to validate flight controls and design concepts, before platform scale-up and integration of high value sensors or weapons. Small and medium sized unmanned aircraft often use internal combustion engines from ground applications that are not built to airworthiness standards. As we move to regularise unmanned aircraft away from the urgent operational requirement system, use of such engines may no longer be permitted. Development, if required, of new airworthy internal combustion engines is likely to increase programme costs significantly. Larger unmanned aircraft tend to use gas turbine engines originally developed for smaller manned trainers or business jets.

608. **Propulsion System Selection**. ISR missions, operating in permissive environments, typically require high propulsive efficiency for endurance and low specific power. Armed unmanned aircraft, such as *Reaper*, operating in low threat environments, may require increased specific power to cope with an increased weapons payload. Attack unmanned aircraft are likely to require the highest power density systems, to enable large weapon payloads while operating at high speed and altitude. The key characteristics of different propulsion systems and their typical applications are shown in Figure 6.2.

| Key: Low High | Gas Turbine | Piston Internal Combustion | Rotary (Wankel) Internal Combustion | Battery | Fuel Cell/Hybrid |
|---|---|---|---|---|---|
| Propulsive Efficiency | | | | | |
| Altitude/Flight Speed | | | | | |
| Vibration | | | | | |
| Endurance | | | | | |
| Typical Applications | High power density – fast jet, UCAV | Long endurance, low flight speed, low-med altitude | Med endurance & flight speed, low-med altitude | Short endurance, low power density, low altitude | Long endurance |
| Specific Applications | *Reaper* *Global Hawk, UCAS*[6] | *Predator* | *Watchkeeper* *Shadow* | *Desert Hawk* | |

**Figure 6.2 – Propulsion System Characteristics and Applications**

609. **Attack Unmanned Aircraft Propulsion**. For attack unmanned aircraft, designed to operate in high threat environments that require stealth technology, air vehicle signature becomes a dominant design driver and this directly impacts the choice of propulsion system. With currently available technology, the high power requirement largely dictates the use of gas turbines, probably in a turbofan arrangement. Compromises are inevitable, as a low bypass ratio would give best speed and power,[7] while a high bypass ratio gives better fuel consumption and stealth performance. While there has been research in other countries into variable bypass ratio engines, such systems are likely to be prohibitively expensive to design and build. Since the development cost, from scratch, of a new complex gas turbine engine is likely

[6] Unmanned Combat Air System.
[7] Additionally, since for stealth the required intake duct length is proportional to the diameter of the engine intake, a low bypass ratio is preferred as this will minimise the engine diameter.

to exceed £1B, it is very likely that any gas turbine chosen for a future attack unmanned aircraft will be from an existing design, or minimal modification of the same. Integration of an existing engine into a stealth airframe, while achieving acceptable engine signature control, presents a considerable challenge and is likely to be the main driver of resultant aircraft size, weight and configuration.


***Taranis* Under Construction**

610. **High Speed UAS and Future Propulsion Systems**. Potential high speed UAS propulsion systems include ramjet, scramjet and high speed gas turbines, although the majority of these systems are currently at low technology readiness levels. For future systems that require high energy densities, it is unlikely that there will be a credible alternative to the gas turbine in the next 6 epochs. Since the technology is already mature, improvements in gas turbine performance are likely to be incremental rather than revolutionary, although an early crisis in fossil fuel availability would help spur alternative developments. For lower power density applications, there is scope to use more novel power sources. These include stand-alone fuel cells and hybrid systems consisting of a mix of fuel cells, internal combustion engines and batteries. These systems require greater management, but potentially offer higher propulsive efficiency, that can deliver greater responsiveness and endurance than at present. Developments in conventional batteries such as lithium cells will be incremental, with slow reductions in size and increases in power density. Fuel cells are likely to have most utility in high altitude, long endurance applications – probably ISR and communication tasks. Fuel cells have relatively high efficiency, with low

emissions and good stealth characteristics. Conversely, the relatively low energy density of hydrogen means that the overall power density of a fuel cell system will remain low. This can be mitigated by incorporating battery or capacitive systems that can store energy for use in short term peaks to power certain sensors or weapons. Advances in this area are likely to be led initially by the development of hybrid systems for the car industry, where the underpinning technologies of intelligent power and thermal management are becoming increasingly important. Such technologies are considered to be the enablers for automation/autonomy within unmanned propulsion systems, particularly novel hybrid systems with multiple power sources (fuel cell/internal combustion engine/battery) and multiple loads (propellers, flight controls and mission systems).

**Avionics**

611. **Sensing**. The sophistication of instrumentation and sensor systems will increase, providing data levels similar to, or greater than, manned aircraft. Improvements in sensor performance are likely to be incremental, rather than revolutionary, with the greatest effect on unmanned aircraft likely being decreases in sensor size and associated packaging. Research effort for sensors is likely, therefore, best expended on sensor integration, fusion and on board analysis. Timely distribution of analysed data is a key issue and work is required to determine the best mix of on-board versus off-board analysis.

612. **Automation and Autonomy**. The terms automated and autonomous with respect to UAS are defined in Chapter 2. Most systems available today already have a high degree of automated functionality that is designed to reduce operator workload and allow the aircraft to be operated rather than continuously piloted. Examples of automatic functionality may include take-off and landing, height keeping, and route following/planning. Over time, additional capability is expected to further reduce operator workload and facilitate better operator decision-making. This also has the potential to significantly reduce the requirement for operator training as well as standardisation and hence operating cost. Libraries of automation programmes have been, or are being, developed that can be mixed and matched across platforms. These programmes, often referred to as intelligent software agents, will be aware of, and respond to, the output of agents in other air and ground platforms and work collaboratively to produce increasingly complex systems.[8] The more complex agents can already cope with abstract concepts to some extent and these will increasingly mimic human behaviour. As these systems mature, it is likely that automated systems will be developed

[8] While the term *smart systems* is often encountered, it should be used with care as it remains undefined and can be twisted to suit the user.

that are broadly capable of the same levels of functionality as self-aware autonomous systems, while being easier to certify and operate. For the latter, it is likely that the civilian sector will provide any early breakthroughs,[9] probably within the next 2 epochs.

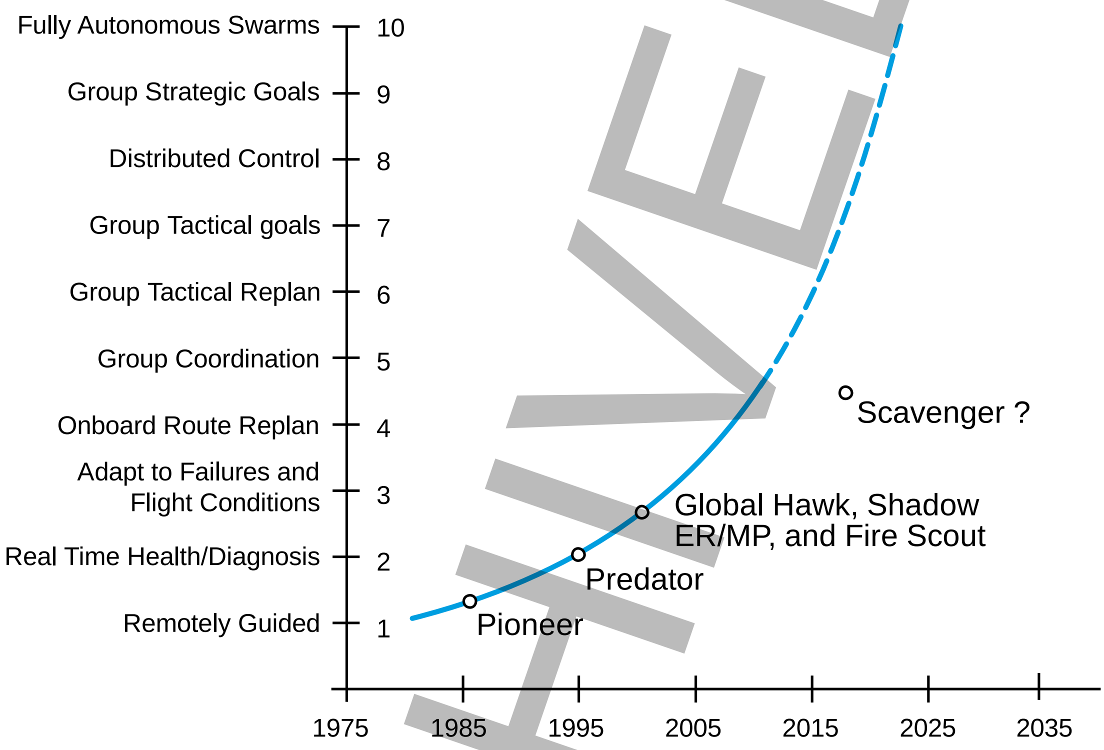



**Figure 6.3 – Autonomy levels for unmanned systems**[10]

## System Issues

613. **Electromagnetic Spectrum Management**. Effective electromagnetic spectrum management will be critical to the operation of UAS for both command and control and the exploitation of data. Secure and assured access to sufficient bandwidth is vital. While system automation, data compression and on-board processing will reduce the bandwidth requirement at the individual platform level, the high number of systems fielded will mean that providing sufficient bandwidth remains a challenge for the foreseeable future. Current data-link requirements range from a few kilobytes per second

[9] For example, considerable research is underway in Japan to provide artificial intelligence in care systems for the elderly. There is some argument that artificial intelligence (or machine intelligence) has already arrived, but it is not widely recognised because it is different to human intelligence.

[10] Figure 6.3 categorises the various autonomy levels for unmanned systems, developed by the Air Force Research Laboratory, and adopted by the National Institute of Standards and Technology Working Group – Autonomy Levels for Unmanned Systems. This system uses a different definition of autonomy than the one used in this document.

for launch and recovery to in excess of 250 Megabits per second (Mbps) for the transmission of sophisticated sensor data. Dissemination of imagery requires in the region of 3Mbps, or 6Mbps for high definition motion imagery feeds. Interoperability is another key problem area, with different regions of the electromagnetic spectrum allocated to different users in different countries. Worse, the radio-frequency spectrum is already particularly congested at current in-theatre main operating bases and there are Electromagnetic Compatibility (EMC) issues with other users that require constant monitoring and management. While spread spectrum systems may provide a partial solution to the security issue, further work is required to develop and standardise such systems and to better understand the bandwidth issues.

614. **Networks and Swarming**. Swarming technologies will allow vehicles to operate as intelligent individuals or as part of a larger collaborative networked group, working toward common mission goals. Information available to one unit will be available to all, allowing data such as target information, obstacle information, or hostile unit positions to be shared. Intelligent software agents that control the swarm may be run at platform or system level, allowing for redundancy as aircraft are lost.

**Operations**

615. **Self Protection and System Integrity**. As already noted, secure, robust data links will be essential to system integrity and security. Preventing the compromise of these links, either from electronic or cyber attack will be crucial and appropriate countermeasures, provided by system hardening or reversionary modes, will be required. Fail-safe modes such as orbiting in position while re-establishing communications, or returning to base, are already enabled in most systems and development of the ability to operate in non-segregated airspace will ensure that these modes become more robust over time. For self-defence against kinetic attack, Class I micro and mini unmanned aircraft can be almost invisible and inaudible from the surface and will provide significant detection challenges for air, ground and maritime defence systems. Larger Class II and III aircraft may need to be low observable, fitted with defensive aids, or capable of high g-force response manoeuvres to avoid hostile action.[11] These aircraft may also be able to use height to avoid the small arms threat, which can never be completely mitigated and, depending on performance, also operate above all but the most advanced hand-held and ground-to-air threats. The temptation to add increasingly complex self-defence aids should be considered carefully; development and provision of such systems will inevitably drive the cost and complexity of unmanned aircraft towards that of manned systems, while still

[11] Low observable, unmanned aircraft may have very limited manoeuvrability due to the design constraints imposed by current stealth technology. Such systems rely on not being detected in the first instance.

providing a less capable and flexible air platform. Current ISR optimised unmanned aircraft may have little utility in contested airspace and it is likely that manned aircraft and other systems would have to be used to establish appropriate control of the air in any such aircraft's operating area. This would be a useful further study area for operational analysis and make a practical contribution to future discussion on the appropriate ratio of unmanned to manned aircraft for the future force mix. High value unmanned aircraft carrying sensitive on-board technologies will also need built-in anti-tamper systems that render the vehicle and technologies inoperable if captured.

616. **Sense and Avoid**. Development of certified sense and avoid systems is crucial to the future operation of unmanned aircraft in non-segregated airspace, both at home and on operations overseas. Increasingly, as future operations are conducted in the littoral and urban spaces, it will become impractical to expect large volumes of segregated airspace to be set aside for exclusive unmanned airspace use. A more detailed discussion of current initiatives to solve the sense and avoid problem is at Annex B.

617. **Air-to-Air Refuelling**. Air-to-air refuelling is likely to remain an enduring requirement for short to medium endurance hydrocarbon fuelled platforms. Two systems are proposed to meet this requirement; one based on the use of differential GPS has already been trialled, although man-in-the-loop authority was applied at key stages during the manoeuvre. An alternative approach suggests a vision based system with conventional drogue and probe that has light or infrared emitting diodes installed in the basket for visual reference. Laboratory tests of the latter system, that included light turbulence, indicated such a system could be viable. In practice, a mix of both approaches is likely to be most successful and unmanned tanker, manned-receiver, or *vice versa*, is a likely first step.

**Unmanned air-to-air trials are being funded in the US**

618. **Synthetic Environment**. Operating costs, capability and interoperability with other manned and unmanned systems will be key factors for future unmanned fleets. High quality synthetic training will be essential and potentially easier to provide successfully than for manned aircraft. The operating environment for pilots and sensor operators would be unchanged

from the actual system. The live flying requirement for training could, potentially, be reduced considerably by comparison with manned systems, although some form of collective training with the end users of unmanned aircraft products will still have to be provided. In the short term, given unmanned operating restrictions in UK airspace, collective training may be more easily provided by providing a video downlink and communications relay from a small (*Cessna* sized) manned aircraft, equipped with representative sensors and radios than from unmanned aircraft.

619. **Operational Analysis**. Determining whether a particular capability should be delivered manned or unmanned requires an uneasy mix of military judgement and operational analysis. As noted, this is a new field and for many potential unmanned aircraft applications, there is little broadly based operational analysis on which to draw. Similarly, military judgement will be based on limited experience of a small number of niche systems. Since it is easy for operational analysis to be used selectively to reinforce desired outcomes that support existing agenda or ideas, it is vital to protect the independence of the operational analysis function and to extend its reach beyond currently fielded systems. One area that would benefit considerably from further operational analysis is an examination of the future manned/unmanned force mix across a range of capabilities. The Defence Science and Technology Laboratories' studies into unmanned combat aircraft systems indicate a 70:30 manned/unmanned split may be the preferred solution. However, this work still requires deeper consideration of the consequences for supporting defence lines of development.

### Weapon Systems

620. Small, agile and armed unmanned aircraft will be difficult to detect. If costs remain low, swarms of such aircraft could be used to quickly overwhelm and disable even the most advanced air defence systems. Suitable small weapon systems have yet to be developed and the cost of doing so may be prohibitive in current economic conditions.[12] Even large Class II and Class III unmanned aircraft may have a lower payload capacity, or smaller bomb bays, than manned aircraft. Consequently new, smaller and lighter, precise weapons may need to be developed otherwise compromises will have to be made on the number of weapons that can be carried. Additionally, externally carried weapons also need to be designed that have a longer carriage-life than existing systems. Although it is possible for unmanned aircraft to carry and employ air-to-air weapons, little work has been done in this area in the UK. Specific advances, and considerable investment, in many unmanned aircraft

[12] Although similar effect may be achieved by the use of such systems as the Tactical Air Launched Decoy (TALD), which was used successfully in Operation DESERT STORM to confuse and saturate the Iraqi air defence system.

sub-systems would be required to make the use of such systems as capable as those of manned aircraft. With no specific plans to provide this capability, this task is likely to remain dominated by manned aircraft for at least the next 3 epochs.

621. Non-kinetic systems offer the potential for unmanned aircraft in the attack role to suppress or destroy radar, communication and other computer systems. Power requirements for such attack capability will be high if used from appropriate stand-off ranges and meeting the power requirement of such systems would be a considerable challenge. Electromagnetic pulse and DEW, if made small enough, may be ideally suited to use in unmanned aircraft, although the system hardening required to prevent harm to the host aircraft will add weight and hence reduce performance. DEW may have equal utility for attack or self defence and the energy source could be high power microwaves or a chemical laser. As well as the large power requirement for radio frequency systems, chemical laser systems require large volumes of special fuels, further reducing aircraft performance and endurance.

## BLACK SWANS, FUTURE DEVELOPMENT AND DEFENCE INDUSTRIAL ISSUES

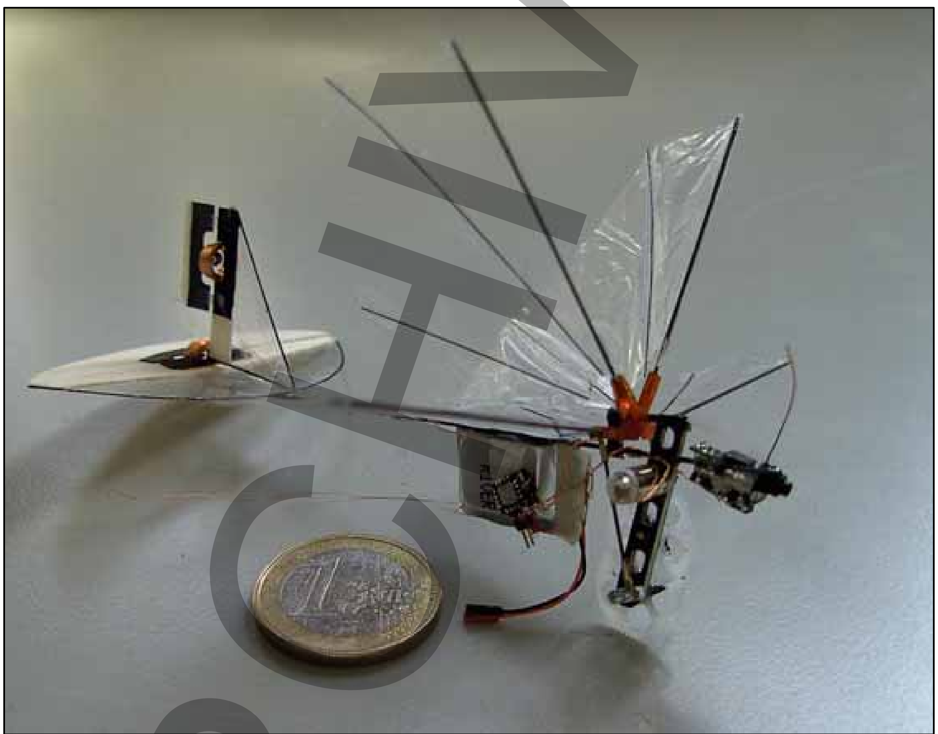
622. Notwithstanding the slowness of the current procurement process, UAS offer an opportunity to capitalise on commercial sector developments and offer rapid technology insertion. Breakthroughs in the civil sector could be rapidly transferred to military use. Novel aircraft configurations such as blended wing bodies and laminar and active flow controls may enable very responsive and manoeuvrable aircraft that can operate in areas not accessible to manned aircraft, while wing warping and thrust vectoring are further examples of systems that could add performance to stealthy vehicle configurations. The use of self-healing systems and re-configurable control schemes may be used to overcome battle damage.

623. **Artificial Intelligence**. True artificial intelligence, whereby a machine has a similar or greater capacity to think like a human will undoubtedly be a complete game changer, not only in the military environment, but in all aspects of modern life. A paradigm shift in artificial intelligence technologies would have a major impact on the future of autonomous vehicles and be disruptive in their military application. The development of artificial intelligence is uncertain and unlikely before the next 2 epochs, though any breakthrough would have significant and immediate implications.

624. **Energy Sources**. From the section on propulsion, it can be seen that developments in this area are expected to be incremental rather than

revolutionary. Sudden and unexpected delivery of new high power sources would, by their nature, be disruptive and allow the development of long range, high speed, and persistent systems.

625. **Commercial Sector**. The changes in world economies over the last 2 decades mean that the military sector is now dwarfed by the economic size and power of the commercial sector. Except perhaps for space, new developments in military systems are therefore likely to come from specialised development of commercial systems rather than *vice versa*. It is to the commercial sector that we must look for the delivery of future disruptive technology. It is vital that the UK maintains the ability to conduct horizon scanning of commercial technology developments



**Nano and micro systems have the potential to revolutionise the conduct of warfare**

### Defence Industrial Issues

626. In an environment of increasing globalisation, western nations face significant challenges to their economic and industrial supremacy from the emerging Asian economies. Against the backdrop of unprecedented economic problems, the UK will need to address fundamental questions about its defence technological and industrial base. Failure to invest adequately in

relevant technologies will only accelerate a decline in strategic national capabilities. The Government issued its Green Paper, *Equipment, Support, and Technology for UK Defence and Security: A Consultation Paper* in December 2010 and this will be followed by a Defence White Paper in 2011. The Green Paper, while too broad to deal specifically with unmanned systems, does note the November 2010 agreement to collaborate more closely with France on UAS and also the challenges of bringing unmanned systems into core procurement activity. It is not within the remit of this Joint Doctrine Note to argue the case for or against any particular strategy, except to note that decisions will be required on where to focus research and development effort.

627. UK industry, from large corporate primes to small entrepreneurial businesses, believes that unmanned aircraft and associated UAS capability is a future growth industry and a key source of future business, both for UK and overseas sales. For the majority, small and medium size unmanned aircraft will be the most important, and although this may represent only a small portion of total market value, a nationally produced aircraft is seen as vital to support and generate sales in associated mission systems and systems integration.

# CHAPTER 7 – THE FUTURE BATTLESPACE

**Epochs 3 to 4 – The Future Battlespace?**[1]

The UK is part of a coalition force deployed in support of a failed state. Much of the country has been stabilised, but some areas remain under hostile control. While humanitarian and stabilisation operations continue throughout the country, enabled and supported by the UK Unmanned Aircraft System (UAS) contingent, an operation to search for prohibited weapons within the contested area is being mounted.

Ground forces are deployed predominantly within one of the contested regions of the country. To avoid the risks inherent in overland resupply, forward operating bases are routinely re-supplied from the air by airdrop or airland, in many cases using hybrid air vehicles and rotary wing mobility unmanned aircraft. These same unmanned aircraft are also employed in delivering humanitarian aid (mostly food, water and some medical supplies), particularly in those parts of the country where road access is considered too dangerous or where the poor transport infrastructure hinders the movement of large logistic vehicles. A significant proportion of strategic re-supply is now provided by unmanned aircraft. Routine bulk re-supply is flown into theatre by conventional manned strategic lift but is supplemented by hybrid air vehicles operating in the optionally manned mode to ease airspace and overflight issues.

Civilian and military communications, both voice and data are enhanced by a constellation of UAS *stratellites*.[2] Civilian use of these networks enables the commercial sector of the economy to start rebuilding quickly after the destruction of much of the mobile and fixed telephone infrastructure during the civil war. Military use supports the building of situational awareness and a robust independent command and control capability. It also reduces the loading on the limited Satellite Communications (SATCOM) bandwidth; by routing tactical long haul voice communications through this network, the limited available SATCOM capacity can be prioritised to supporting communications back to the UK and for essential UAS control and data links. These *stratellites* also provide the backbone for the indigenous government's ability to communicate with its population; of particular value is the ability of the national communications media to be able to broadcast on a number of voice channels through a network that lacks the fixed infrastructure that might attract an insurgent attack.

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[1] This vignette is designed to promote thinking about how UAS may be used in the future and does not represent a real location nor represent any particular MOD view.

[2] The *Stratellite* concept is one of high altitude UA that provide persistent satellite type communications, wifi or mobile phone capability above fixed geographic locations at a fraction of the cost associated with such services via satellite. They will be of particular use during humanitarian relief and stabilisation operations.

UK ground forces within their area of operations work intimately with UAS on a routine basis. In addition to their own organic systems, the support provided by land based UAS is fundamental to their success. The broadcast of a recognised land picture, fused from information collected by a wide range of sensors (including electro-optical, synthetic aperture radar, electronic warfare) mounted on several manned and unmanned ground and air platforms enables operations to be undertaken at high tempo in an agile manner. When in contact, ground troops have come to expect information and a range of kinetic and non-kinetic effects to be available to them at high levels of guarantee and at low levels of latency; an asymmetric advantage that could not be delivered without unmanned aircraft. Pervasive collection capabilities, allied with change detection algorithms, have reduced the likelihood that friendly troops can be successfully targeted with Improvised Explosive Devises (IEDs) and enabled a more detailed understanding of the insurgent IED network itself.

A deliberate operation, aimed at finding prohibited weapons, requires close co-operation between ground forces and unmanned aircraft. Small calibre weapons pose a credible air threat below 1000ft and intelligence indicates that there are likely to be a small number of shoulder-launched anti-air weapons in the operating area. Unmanned aircraft are tasked to conduct a 'pattern of life' Intelligence Surveillance and Reconnaissance (ISR) soak, to build understanding of activity in the area of operations; this focuses attention on a single village where insurgents are observed moving and transporting prohibited weapons. Ground troops, supported by combat-ISTAR[3] unmanned aircraft respond quickly and with surgical precision; a legacy of the high levels of situational understanding, resulting from air Intelligence and Situational Awareness (ISA) mission results and other intelligence that has been fused in the preceding days. Air-derived real-time intelligence is used to guide many of the ground forces to the exact location of weapon caches. As insurgents attempt to withdraw, they are destroyed from the air by the same unmanned aircraft that provided the intelligence feeds. Once post-strike battle damage assessment confirms that the operation had been successful, force elements held at readiness for a possible re-strike can be allocated to other tasks within the area of operations, while unmanned aircraft continue to monitor the area.

701. The conceptual model for how the UK will deliver air power over the next 20 years is described in the Development, Concept and Doctrine Centre's (DCDC) *Future Air and Space Operational Concept*.[4] This was last published in 2009 and is due to be updated in 2011 as part of the conceptual force development process. Since the 2009 edition, much work has been

[3] ISTAR – intelligence, surveillance and target acquisition.
[4] The DCDC *Future Air and Space Operational Concept* published August 2009 aims to articulate the operational concept for UK air and space power, in order to inform concept, force and capability development.

conducted by the DCDC to examine global strategic trends and provide further insight into the future character of conflict. These areas are explored in *Global Strategic Trends – Out to 2040* and *Future Character of Conflict* (FCOC).[5] The conceptual force development process will examine how new strategic guidance will further change our expectations of the future air battlespace and, crucially, what will the contribution of UK air power be to future joint operations.

702. An early conclusion from the FCOC work, supported in the Strategic Defence and Security Review (SDSR), is that the UK will choose to achieve a deterrent and coercive effect through continuous engagement and focused intervention upstream of any conflict. Additionally, the UK will mainly seek to work within alliances or partnerships. Consequently, UK air assets will be required to bring a range of effects to bear across the mosaic of likely activities before, during and after combat operations. The speed with which air power can be tasked, deployed, and if necessary re-tasked, is in stark contrast to the time taken to build up or draw-down land and maritime forces in remote locations, although its effect will usually be limited by the small number of platforms available in the force structure. The often-demonstrated ability of western air forces to quickly and easily dominate the battlespace is the single most important factor in enabling land and maritime surface manoeuvre. Some tasks, particularly urgent ones, can only be conducted by air, such as homeland air defence, *blue-water* and littoral anti-surface warfare conducted at range, rapid medical evacuation and some signals intelligence, reconnaissance and time-sensitive targeting tasks. The ability to deliver timely precision effects to the deep battlespace is a unique attribute of air power, while recent experience from Afghanistan indicates that the ubiquity of air power can considerably constrain the freedom of action of non-state, as well as state, actors. In addition, as the UK moves towards smaller and more agile expeditionary forces, the importance of highly capable enabling air mobility platforms will continue to increase.

## CHARACTER OF THE BATTLESPACE

703. FCOC describes a complex future dominated by the *5Cs*: congested, cluttered, contested, connected and constrained. These describe the character of the battlespace that will shape how operations are conducted. The *5Cs* create military problems, some of which are best addressed by air and the implications for the conduct of air operations are summarised below.

[5] While the fundamental nature of conflict endures (for example the 4 core air and space power roles: control of the air; air mobility; intelligence and situational awareness; and attack have remained largely unchanged since the 1930's), the character of conflict changes over time. The DCDC's *Future Character of Conflict* (FCOC), together with its *Global Strategic Trends* programme, examines those factors that are likely to shape the future character of conflict.

704. **Congested**. The future battlespace will be crowded and likely centred on, and around, the urban and littoral areas where most of the population will live. These spaces will be too large to dominate by massing of ground and naval forces alone and an alternate approach of increased mobility of discrete force elements enabled by air control and air mobility may be required. Proliferation of technology will lead inevitably to an increase in friendly, hostile and non-aligned airspace users, including unmanned aircraft, which will require high levels of air situational awareness in order to successfully accomplish operations. The ability to operate above densely populated areas while conducting ISA, attack and mobility missions will continue to be a key advantage of air power.[6] A great strength of western manned air assets is that they are inherently interoperable and already capable of operating in a congested environment, using common systems, links, technologies and procedures, to enable multinational platforms to be rapidly integrated into co-operative packages. The challenge will be to incorporate unmanned systems into this environment. Future air operations will increasingly require improvements in co-operation and co-ordination between units that are enabled by advanced information networks and disparate software agents acting as *on scene* intelligence and airspace co-ordinators. Unmanned systems are ideally suited to this task and many of the agents and control functions may be hosted on such platforms. Proliferation of space-based assets in increasingly congested orbits and the increasing dependence on space to support operations, both as an information provider and as an information bearer, will become a key vulnerability and *Stratellite* UAS may be a crucial asset in reducing the operational risk inherent in this domain.

705. **Cluttered**. A cluttered battlespace will provide adversaries with increased opportunities for concealment – providing safe-havens and multiple avenues for attack and escape. The ability of adversaries to blend into the local environment will require the establishment of localised control of the air that will facilitate subsequent ISR sensor deployment for the collection, analysis and understanding of *patterns of life* to develop models of behaviour. These latter tasks are ideal for unmanned platforms. Emerging technology and all-spectrum intelligence fusion will aid this activity which will be uniquely enabled by the air environment with its technological/networked focus and its inherent qualities of height, reach, ubiquity, and persistence.

706. **Contested**. Adversaries are likely to contest any and all environments, often using novel or asymmetric methods facilitated by the diffusion of western technologies. They will seek to deny air freedom of manoeuvre, challenging friendly forces through asymmetric responses which aim to hold air power at

[6] Which may come from any of the environments.

*arm's length* and prevent full use of western air capabilities. Denial techniques will range from the physical (including destruction of air platforms or operating facilities) to cyberspace and influence operations, which will seek to remotely attack command and control and logistics networks. Alternatively they may manipulate public opinion through the media with arguments that air power, in particular unmanned air power, is too much of a cruel overmatch or a blunt instrument. Air power proponents must prepare for, and rigorously counter, such arguments through the proactive and positive interpretation of international law; air power is, and will remain, one of the West's own asymmetric advantages. Thus, philosophies such as the Chinese 'assassin's mace'[7] concept of anti-access/area denial are likely to become common, while the use of computer network operations in warfare or attempts to deny use of space assets is likely to proliferate. We can increasingly expect attempts by adversaries to move conflict beyond the traditional battlespace to include denial of access or use of the *global commons*.[8] The theatre of operations will become truly global and attacks are likely to take place anywhere that UK, dependent territories, or allied interests are present, including the UK homeland. Air power can respond in the timely manner required to counter these threats and prevent situations escalating beyond localised events. We should plan to fight for access to the battlespace and assume that the air environment (and particularly the ground environment and lower-airspace where rocket propelled guns, small-arms, IEDs and suicide attacks will be pervasive) will be contested. Unmanned systems reduce the risk of friendly aircrew being shot down and used as information warfare assets by an enemy.

707. **Connected**. The concurrent blurring and broadening of conflict activities will be a global phenomenon that is most apparent at physical and virtual nodes in cities, the littoral and in space and cyberspace. As the strategic and operational value of the control of these nodes increases, military activities will tend to converge towards them. Examples of nodes include strategic locations, such as centres of governance, urban areas and maritime choke-points; these are often described as the *globalised core*. Networks between, and within nodes, can be physical or electronic and include logistical re-supply routes, sea and air lines of communication and computer and communications links. Broadband data and narrowband control links via satellite or very high altitude persistent air platforms will become pervasive, implying a pressing need to address issues surrounding control and

[7] Krepenevich A F, *7 Deadly Scenarios: A Military Futurist Explores War in the 21st Century*, Bantam: New York, 2009, page 185.

[8] The *global commons* are those regions used jointly by the members of a community. They include, but are not limited to, those parts of the earth's surface beyond national jurisdictions such as the open ocean and the living resources found there, the atmosphere and orbital space. The only landmass that may be regarded as part of the *global commons* is Antarctica. Access to the *global commons* remains vital, as many trade routes and network links pass through them.

management of the electromagnetic spectrum. Localised link capacity problems may, though, be eased within 5 – 10 years as short and medium-range laser-based data-link technology matures. Air operations will be a key pre-cursor activity to the establishment and maintenance of physical and electronic networks; as a minimum, localised control of the air will be required above and around nodes, while concurrent ISA activity, using a range of disparate, but fused sensors, will protect the networks and warn of impending attack or exploitation. There will be significant challenges for air power in terms of connecting with other surface and air platforms and gaining and maintaining situational awareness.

708. **Constrained**. Western legal and societal norms will continue to constrain air operations while the legal and moral requirement to take all feasible precautions in avoiding or minimising collateral damage, will lead to greater use of precision weapons. This is likely to drive the air environment to seek ever more precise kinetic weapon technology as well as non-lethal and directed energy weapons. Conversely, adversaries are unlikely to be constrained by legal issues and may even have a support base which has a different view on moral and ethical norms. Legal challenges may be expected against novel weapons and may even extend to unmanned aircraft systems. Media and public perceptions will continue to exert an effect on operational planning and execution, while in the short term, funding and environmental issues are likely to be increasingly dominant factors. Legal review should continue to form a part of the development cycle of new air systems and concerns relating to legal, moral and ethical issues pertinent to any particular system must be identified and risk-managed as part of a through-life management process.

## SUMMARY

709. The most likely scenario between now and 2030 is of a manned/ unmanned mix that sees a slow but steady increase in the unmanned element. UAS will dominate those ISA tasks which require persistence and provide high altitude *stratellite* capability. Developments in rotary unmanned aircraft, as well as fixed wing, make it likely that UAS will soon be able to contribute significantly to tactical mobility. Complex control of the air, attack and strategic air mobility missions will remain with manned platforms, though over time these will be increasingly aided by accompanying unmanned platforms providing *loyal wing man* or *swarming* services. Sometime after 2030, air effect is likely to be delivered from an *air cloud*[9] from which end users will call down a service. The cloud is likely to be populated by a range of manned

[9] The use of the term *cloud* here is analogous to that of the cyberspace data cloud, extended into the physical domain.

aircraft as well as smart and dumb unmanned platforms carrying a range of sensors, weapons and fuel, optimally controlled by a *cloud management agent*. It will become largely transparent and irrelevant to the end user as to what kind of platform delivers a particular effect. Thus, while the 4 core air and space power roles discussed earlier will remain, they will be delivered simultaneously by single complex platforms, or a range of simpler platforms whose outputs are fused to deliver a capability.

710. Much of the capability or technology described in this paper is already available in experimental systems or will become available within a short timescale (say 5 years), but due to spending constraints is unlikely to be affordable in the same time scale. The equipment programme is now, post SDSR, mostly well understood and there is very little opportunity to veer and haul on existing programmes before around 2020. It is likely, therefore, that other than *Scavenger*, no significant new programmes will be introduced before 2030.

**Epochs 5 to 6 – The Future Battlespace?**[10]

**Scenario**. A coalition force has been struggling to detect and neutralise the constituent elements of a terrorist organisation embedded in a *super city* of 38 million people. The city is on the verge of bankruptcy and risks economic collapse which if allowed to happen, would have global consequences. The city occupies nearly 1800 square miles of coastal plain and has 5 seaports and 4 airports. Due to size and numbers, only key areas can be dominated by ground forces of nearly 80,000 personnel and then only for short periods. Anti-state forces located in the city conduct smuggling, cyber-crime, people trafficking and other activities alongside their ongoing struggle with the state for greater control of the city, its assets and its population. Their ideology, global connections and willingness to use extreme violence and armed force means that establishing a secure environment is beyond the capability of local security forces. It is vital that operations, however mounted, allow normal life and economic activity to continue.

**Concept of Operations**. The concept of operations is to use highly mobile air and ground forces to exploit information gained from a wide array of unmanned ground and air sensors, as well as network analysis, communications interception and cyberspace monitoring. At sea, the coalition task force takes data from a range of organic and land-based unmanned aircraft and unmanned surface and underwater vessels. This data is used to control key points and routes, to intercept vessels suspected of conducting illegal activity and to dominate the waters within 1000nm radius of the city.

[10] This vignette is designed to promote thinking about how UAS may be used in the future and does not represent a real location nor represent any particular MOD view.

Rules of engagement are restrictive as city authorities are wary that over-zealous activity by coalition forces could be used by the terrorists to provoke further riots and mass strikes, similar to those that led to the loss of 28,000 lives in the previous year. All classes of unmanned aircraft operate in and around the city and are fully integrated into the airspace.

**Current Situation**. Ten days previously, 100 x Class I micro ISR *Perch and Stare* unmanned aircraft were deployed to key locations in the city. Their nano-material coatings provide camouflage by adopting the same colour as their surroundings, while embedded solar cells augment the on-board fuel cells by recharging capacitive energy stores during daylight. Working collaboratively in a network, many of the aircraft have self-repositioned to gain further intelligence data and 72 are still operational. This morning at 0400, an unmanned ground vehicle deployed small swarms of nano unmanned aircraft in 3 separate locations. These aircraft, resembling hand-sized insects and weighing less than 50g have penetrated and concealed themselves inside more than 20 buildings believed to be connected with terrorist leadership operations.

At around 0530, data began to be received from the swarms and is currently being analysed by the coalition's data processing centre, a secure underground facility located over 1000 miles away and capable of collating, analysing and exploiting nearly 100 petabytes of data[11] every day. Bio-identification software agents in the swarms will allow them to identify and attack known terrorist personnel when authorised. Following terrorist strikes against ground-based communication system nodes, a high level constellation of hybrid-engine powered *stratellite* unmanned aircraft provide a city-wide data network for both military and civilian use. Unmanned air-to-air refuelling tankers provide fuel to the small number of manned aircraft that provide a city over-watch and unmanned aircraft co-ordinating function: a potent symbol of the high technology resources available to the coalition. These are seamlessly integrated into the air effect cloud – a range of mostly unmanned, intelligent software agent controlled, aircraft that are able to provide the full range of air effects.

Tactical mobility rotary wing aircraft are ready to lift ground forces into position when offensive operations are authorised. They will be accompanied by new medical evacuation unmanned aircraft, which have a full remote medical aid capability built in; a team of rear-based surgeons will oversee and advise the on-board robo-doctors if required.

[11] This is probably a vast under-estimation of the capability that will be available; Google currently processes 24 petabytes of data every day.

## CONCLUSION

1. Unmanned Aircraft Systems (UAS) have already changed, and will continue to change, the way that we conduct warfare. Associated technologies are developing at an unprecedented rate and the relentless nature and speed of these advancements make it hard to assimilate, analyse and fully understand the implications: this makes it difficult to plan clearly and confidently for the future. Our conceptual thinking lags behind the art of the currently possible, never mind what lies in the future – and there are as many threats as there are opportunities. Do military planners and politicians understand the full implications of the systems they are currently tasking and those they hope to procure? In the current economic climate, who will decide the best balance between keeping existing equipment and personnel, or whether to give these up to fund new unmanned systems? Do we understand even the basic implications of such decisions for the associated defence lines of development? Crucially, do we have a strategic level of understanding as to how we will deliver the considerable number of changes that will need to be made to existing policy, concepts, doctrine and force structures?

2. This Joint Doctrine Note (JDN) cannot answer many of these questions directly. Often, the policy that could direct such decisions does not yet exist. For some, it will not be possible to make progress until we enter a post-Afghanistan period of regeneration and consolidation of forces. Instead, this JDN is intended to raise awareness of those areas where informed decisions or discussion is required. It should provoke discussion about how we wish to shape our future air forces and which technological and organisational paths we wish to follow. The research for this JDN, and attendant workshop, identified a number of specific issues that need to be addressed:

a. The successful joint development and governance of UAS would be helped considerably by the formal appointment, with appropriate terms of reference, of a Joint Senior Responsible Owner, to co-ordinate UAS issues across the whole of defence. This could logically come from the joint capability area.

b. UAS governance requires a clear and agreed *roadmap* that describes the future UK programme of UAS development, procurement and operation.

c. A lack of procurement agility is a major issue. Traditional procurement processes do not support the provision of rapidly changing technology in a timely manner.

d. A Joint UAS Centre of Excellence could be the most effective way of co-ordinating UAS test, evaluation and doctrine development for the UK.

e. The UAS R&T Pipeline, designed to provide high level direction for MOD-funded research over the next 5 years, is a step forward. Its remit should be extended to deliver a research programme that would underpin the delivery of the agreed roadmap beyond the next 5 years.

f. There are opportunities for the military to take the lead and co-ordinate UAS issues across other government departments and the emergency services.

g. Management and sustainment of UAS-related manpower and equipment will present challenges, especially in periods of transition between peacetime operations and warfighting and vice versa.

h. Military unmanned aircraft are likely to require access to non-segregated airspace post-2015 and consideration should be given as to how and when the MOD may wish to involve itself in civilian integration projects.

i. While some operational analysis has been conducted in niche unmanned aircraft capabilities, it is not yet broadly based enough to inform all potential areas of unmanned aircraft employment.

j. Further analysis is required on the potential for UAS to contribute to the maritime environment.

3. For convenience, the major issues raised throughout the JDN are summarised in a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis. Strengths and weaknesses are internal factors, opportunities and threats are external factors. Some issues, with further technological development or changes of policy, could easily move from one category to another.

4. The life of this JDN is of the order of 18 months and during that period much of its detail and many of the issues raised will be overtaken by events. By that time, improved understanding should allow those ideas that withstand scrutiny to be taken forward into new policy and doctrine. Whatever happens, unmanned aircraft have arrived and are here to stay. We can choose to either grasp the opportunities they offer and shape our own future, or stand aside while others decide the nature of air power. The choice is ours.

| STRENGTHS | WEAKNESSES |
|---|---|
| • Good for dull, dirty dangerous tasks<br>• Operations can be conducted without risk to aircrew<br>• Can be cheaper (caution – through life costs need to be considered)<br>• Availability - unmanned aircraft can support tactical activity where manned assets would not be available<br>• Small/medium scale can provide immediate, tactical situational awareness (in uncontested airspace)<br>• Reduced manpower footprint in theatre<br>• Very good at intelligence, surveillance and reconnaissance and attack missions (in uncontested airspace)<br>• Removal of human limitations can allow different performance factors to be developed and exploited<br>• Persistence<br>• Can help reduce harmony issues by operation from rear base | • Lack of small, tailored weapons<br>• Lack of long air carriage life weapons<br>• Vulnerable to cyber and communications link attack<br>• Legal, ethical, moral thinking needs further development<br>• Law of Armed Conflict may constrain high levels of automation/autonomy<br>• Current systems are not built to airworthy standards – costs will rise as these are enforced<br>• Integration into non-segregated airspace is problematic, potentially costly and there is uncertainty over when it will happen<br>• No experience of non-urgent operational requirement procurement<br>• Public perception issues (killer drones)<br>• Limited UK experience in the operation of unmanned aircraft across all Classes<br>• Key technologies remain immature<br>• Very good at niche roles but lacks overall flexibility and adaptability compared to manned aircraft<br>• Poor penetration and utilisation within the maritime environment |

| OPPORTUNITIES | THREATS |
|---|---|
| • Focused UAS research and procurement could underpin national industrial sustainment in key areas<br>• Ideal platform to rapidly exploit new and advanced technologies<br>• Directed energy weapon/electromagnetic weapon employment<br>• Novel approach to operations.<br>• Opportunity to develop new acquisition processes<br>• Expand into control of the air and mobility air power roles<br>• Export potential (but International Traffic in Arms Regulations and Missile Technology Control Regime issues)<br>• Civil markets, interoperability<br>• Cross governmental cooperation<br>• Quicker, cheaper into service<br>• UAS pipeline to provide coordinated research and technology programme<br>• Swarming/networks new ways of working | • Threat to operational sovereignty through declining national industrial capability<br>• Seen by some as policy/financial panacea without appropriate understanding of relative strength and weaknesses of current systems<br>• Entrenched views skew arguments both for/against<br>• Requires new thinking<br>• Funding new systems difficult in financial climate<br>• Current defence industrial strategy and procurement system is not agile enough, may not be able to sustain full range of capabilities (particularly the high end)<br>• Research funding under pressure<br>• Technology may promise too much and fail to deliver<br>• Technology may provide effective counter UAS systems<br>• Pressures to increase develop high end systems may starve simpler more affordable systems of funding/development<br>• High accident/loss rates<br>• Bandwidth requirements and spectrum management<br>• Uncertainty over when certain technologies will deliver makes planning of manned/unmanned mix difficult and transition planning problematic |

# ANNEX A – THE UK UNMANNED AIRCRAFT ORDER OF BATTLE

## CLASS I

### Honeywell RQ-16a *T-Hawk*

A1. *T-Hawk* was procured in 2010 under the Urgent Operational Requirement (UOR) process, as part of the TALISMAN route proving and clearance system. Six complete systems[1] were procured at a cost of around £3.3M. *T-Hawk* is a Vertical Take-Off and Landing (VTOL) ducted-fan system that is specifically designed to provide a hover and stare capability. Sensors include one downward and one forward-looking gimballed electro-optical or infrared cameras for day/night operation. The system is used primarily to give Explosive Ordnance Device (EOD) operators a close look at suspicious vehicles, structures or disturbed earth. The system is operated by squadrons of the Royal Engineers, although it is planned to transfer them to the Royal Artillery in the future.


**RQ-16A *T-Hawk***

A2. Key technical and performance details are as follows:

- Weight – 7.7kg, dry weight
- Duration – 50 minutes
- Range – up to 10km
- Operating altitude – typically below 200ft with launch up to a pressure altitude of 11,500ft
- Speed – up to 40kt
- Maximum wind speed for VTOL operation is less than 15kt

[1] Each system comprises 2 aircraft, an operator control unit and a ground data terminal.

**Lockheed Martin Desert Hawk 3**

A3. *Desert Hawk 3* was procured under a £3 million UOR, this latest variant of the Desert Hawk (DH) series commenced operational service with UK forces at the end of August 2010. DH3 is an unarmed, small, electric-powered UAS designed to provide ground forces with a live tactical video feed. The airframe is a carbon-fibre/Kevlar composite over a foam core and is hand launched. The payload is either a 360 degree stabilised colour electro-optical camera, or a thermal imaging camera, giving day and night capability. An improved wing design, new to the 3 series, is designed to improve performance in the environmental conditions of Afghanistan. Key technical and performance details are as follows:

**British Army *Desert Hawk 3***

- Weight 3.2kg
- Wingspan 1.37m
- Duration – 60 minutes
- Range – 15km radius, but must remain within line of sight of the ground control station
- Operating Height – typically 200ft – 1000ft
- Speed – 32kt cruise, 44kt dash
- Weather – clear of rain and thunderstorms (lightning)
- Maximum wind speed for operation – less than 25kt
- Recovery to re-launch in less than 5 minutes
- Maximum operating altitude is 10,000ft pressure altitude for launch, 11,000ft ceiling for operation

A4. The role of DH3 is normally to provide surveillance of small named areas of interest, targeted areas of interest and decision points, operating as part of an integrated ISTAR[2] matrix; it can also assist in tracking mobile targets. Its limited sensor footprint means that it has better utility when given a discrete task or cueing by other ISR[3] sources. DH3 is particularly useful to patrols, where it can provide an over-watch function. Other tasks may include force protection, deterrence and influence, targeting, battle damage assessment and support to EOD.[4] As well as the real-time feed at the ground control station, DH3 can provide:

- Real time full motion video on a remote video terminal in either the brigade or company operations room.
- Still images for target packs.
- Play back video for a route recce.
- Story boards
- Threat warnings

## CLASS II

### Elbit/Thales Hermes 450

A5. The British Army operates the Class II *Hermes 450* (H450), which is leased from Elbit Systems/Thales. H450 is an interim capability, until the arrival of the more capable *Watchkeeper* system (expected to be operational at the end of 2011). Operating solely in support of operations in Afghanistan, the H450 is flown from a bespoke location adjacent to the main runway in Camp BASTION, Helmand Province.

***Hermes 450* operating from Camp BASTION**

[2] ISTAR: Intelligence, Surveillance, Target Acquisition and Reconnaissance
[3] ISR: Intelligence, Surveillance and Reconnaissance
[4] Although as a preference EOD tasks would be given *T-Hawk* which was specifically designed for this role.

The role of H450 is to provide tactical level imagery and imagery intelligence to unit and formation commanders in the land environment. The H450 is a strip-launched unmanned aircraft operating at up to 150km for between 12 and 16 hours. Its payload is a COMPASS 4 electro-optical and infrared system and a laser target marker. It has up to 10 times optical zoom and can be operated in a number of modes, including target tracking. Key technical and performance details are as follows:

- Maximum gross weight – 450kg
- Wingspan 10.5m
- Duration – normally 12hr, but can be up to 16hr
- Range – 150km radius, but must remain within line of sight of the ground control station
- Operating Height – up to 16000' pressure altitude
- Speed – 65kt cruise, 90kt dash
- Maximum cross wind for launch – up to 15kt crosswind and up to 22kt head wind
- Temperature – up to 43C
- IFF Transponder Modes 3 and 3C
- Automated GPS based system for take-off and landing
- Arrestor cable based landing

## CLASS III

### General Atomics MQ-9 *Reaper*

A6. The RAF currently operates 5 Class III General Atomics MQ-9 *Reapers*, which between them are capable of providing more than 24 hours of support per day to operations in Afghanistan.[5,6] The MQ-9 *Reaper*, a medium-to-high altitude, long-endurance unmanned aircraft, is operated by Number 39 Squadron, based at Creech Air Force Base, Nevada. Although operated from Creech, the air platform is forward deployed to Afghanistan and controlled via a satellite datalink. *Reaper* is primarily tasked in the Intelligence and Situational Awareness (ISA) role and can provide real-time data to commanders and intelligence specialists at all levels. The *Reaper*'s imagery is provided by an infrared sensor, a colour/monochrome daylight camera and an image-intensifier. The video from each of the imaging sensors can be viewed as separate video streams or fused with the infrared sensor video. It also has a very capable Lynx II synthetic aperture radar and ground moving target

[5] It was confirmed by the Prime Minister on 15 December 2010 that the number of *Reaper* will be increased to 10 aircraft. This will require approximately 40 crews.
[6] A single *Reaper* system consists of up to 4 *Reaper* unmanned aircraft, one ground control station, a datalink/comms system, spares, support and operating personnel from all 3 services and contractor ground crew.

indicator, providing all weather capability. A laser rangefinder/designator provides the capability to precisely designate targets for laser-guided munitions. A separate colour nose camera is provided to assist the pilot with flight control.

**Royal Air Force MQ-9 Reaper**

A7. Reaper can also provide geographic location information to commanders on the ground or to other systems capable of employing global positioning system guided weapons. The aircraft requires a prepared runway surface for take-off and landing. The aircraft effectively provides an equivalent armed ISR capability to that of many manned aircraft. Key technical and performance details are as follows:

- Maximum gross weight – 4760kg
- Wingspan 20m
- Duration – normally 18hr+ depending on payload
- Range – 5,900km
- Operating Height – normally up to 25,000ft but can operate up to 50,000ft
- Speed – 160kt cruise, 250kt dash, 120kt loiter
- Weapons – Up to 4 *Hellfire* and 2 x 500lb GBU[7] 12 *Paveway II*

[7] Guided Bomb Unit

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# ANNEX B – INTEGRATION OF UNMANNED AIRCRAFT INTO NON-SEGREGATED AIRSPACE

B1. The main focus of many discussions on future Unmanned Aircraft Systems (UAS) is the issue of integrating unmanned aircraft into civilian controlled non-segregated[1] airspace and, in particular, how to achieve *sense and avoid*. It is a fundamental, legally required, tenet of flight safety that a pilot will be able to maintain safe separation from other aircraft by the situational awareness created by his or her physical presence in the cockpit and the ability to *see and avoid* when operating in visual flight rule conditions. Clearly this is not possible in an unmanned aircraft, since the pilot or operator cannot physically see around the aircraft, although they will normally gain situational awareness of other airspace users in the vicinity of the unmanned aircraft through procedural means or by access to the recognised air picture.[2] Operators of small unmanned aircraft are required to maintain direct unaided visual line of sight with the aircraft in order to operate legally, but this is clearly impractical for longer range, or high altitude aircraft. The unmanned aircraft equivalent of see and avoid is termed sense and avoid, whereby sensors on the unmanned aircraft detect adjacent air users and alert either an automated on-board system, or the remote pilot to their presence and a potential need to take avoiding action.[3]

B2. Unfortunately, an acceptable sense and avoid system, (one that has been approved and licensed) does not yet exist, nor has what such a system might consist of been formally agreed.[4] This leaves prospective UAS operators in somewhat of a chicken and egg situation; they are unable to build a system that has yet to be defined and the aviation authorities will not define such a system without seeing what systems have to offer. Currently, therefore, the use of unmanned aircraft within *non-segregated* (mixed manned and unmanned) airspace is normally prohibited, requiring the establishment of segregated airspace such as danger areas or restricted airspace (temporary) for unmanned aircraft operations.[5]

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[1] Segregated airspace is that airspace which is reserved for specific users, which may include unmanned aircraft. Non-segregated is everything else.

[2] With a more benign working environment and without the physical stresses of flying, the unmanned aircraft pilot/operator may even develop better situational awareness than the pilot of a manned equivalent. However what is commonly lacking is peripheral vision, depth perception, and the 'seat of the pants' feeling.

[3] Civil Aviation Authority (CAA), CAP 722 *Unmanned Aircraft System Operations in UK Airspace – Guidance* Section 2, CAA's CAP 722 *Unmanned Aircraft System Operations in UK Airspace – Guidance*, Section 2, Chapter 1, Page 3, paragraph 6.3.1.

[4] Parameters that may need to be defined include such items as field of view, avoidance rules etc

[5] The regulations vary by country and may be modified depending on the weight of the unmanned aircraft. In the UK use of, and access to, airspace by unmanned aircraft is regulated by the CAA and detailed instructions are detailed in *CAP 722 Unmanned Aircraft System Operations in UK Airspace – Guidance.*

B3. Some tasks can, however, avoid the need for integration or access into non-segregated airspace, by climbing in segregated airspace to a sufficient height, normally 50,000ft and then operating above the non-segregated airspace.[6] This is likely to be the method employed by the NATO Alliance Ground Surveillance (AGS) *Global Hawk* when operated out of *Sigonella*, at least initially. In operational theatres, much of the airspace may be under military control. Separation between manned and unmanned as well as military and civilian users can be maintained through the temporary use of military procedural and co-ordination measures. In future contingency operations, this may not be the case and other DCDC[7] work has, in any case, identified that the rapid re-instatement of a sovereign civilian airspace structure can be a significant driver toward a nation's ability to generate much needed revenue. This national source of finance is itself, a powerful pillar in support of stabilisation efforts. The rapid development and deployment of many in-use unmanned aircraft also means that they lack the equivalent of manned aircraft type certification. This means that, even if retro fitted with an approved sense and avoid system, they would not be permitted to operate in most nations' civilian non-segregated airspace when no longer required for operations. This restriction may apply to the RAF's *Reaper* aircraft when withdrawn from Afghanistan. Although *Watchkeeper* is the first UK unmanned aircraft to be type certified, until retro fitted with an appropriate sense and avoid system (if possible), its use will remain constrained to segregated airspace as at present.

B4. There are many other technical challenges to safely integrating unmanned aircraft into manned airspace and considerable work has been conducted into how these may be overcome. Two key principles will drive the cost, complexity and eventually the success or otherwise of this work: unmanned aircraft operations must be at least as safe as manned aircraft operations; and the operation of an unmanned platform must not create any extra workload for air traffic agencies. The 2 major initiatives of primary interest to the UK and Europe are known as Autonomous Systems Technology Related Airborne Evaluation and Assessment (ASTRAEA) Programme and *Air4All*.

B5. **The Autonomous Systems Technology Related Airborne Evaluation and Assessment Programme**. The ASTRAEA programme was first conceived by the UAS Council in 2004. The programme was instigated to facilitate co-operation between the UK's major UAS stakeholders in order to address key technology and regulatory issues and hence enable the operation of unmanned aircraft in non-segregated airspace. The first £32M phase of the

[6] There would still be issues, using this method, of airworthiness considerations when operating above urban areas.
[7] Development, Concepts and Doctrine Centre.

project ran from early 2006 to the end of 2008. It involved a consortium of aerospace companies including British Aerospace Systems, European Aeronautic Defence and Space Company, Cobham, QinetiQ, Rolls-Royce, Thales, autonomous systems specialist Agent Oriented Software, many innovative small companies and leading academics from the universities of Cranfield, Lancaster, Leicester, Loughborough, Sheffield, West of England, Aberystwyth and Glamorgan. ASTRAEA was funded jointly by the companies involved, the Department for Business, Enterprise and Regulatory Reform[8] and regional funding. As the MOD had no need, at the time, to integrate military unmanned aircraft into non-segregated airspace, it provided no funding but maintains a listening watch on the programme; a member of the Air Staff sits on the ASTRAEA board. Phase 1 of the programme finished successfully in 2008 with a demonstration of a simulated unmanned aircraft flight through UK airspace. The work conducted during this phase of the ASTRAEA programme has helped to keep the UK at the forefront of worldwide efforts to achieve integration of unmanned aircraft into non-segregated airspace.

B6. **Phase 2**. Work has recently commenced on a £30.5M second phase which will investigate 2 specific problems: separation assurance and control; and autonomy and decision-making. The main aim of the programme is to enable the routine use of uninhabited air vehicles in all classes of UK airspace without the need for restrictive, specialised or non-routine conditions of operation.

B7. **Air4All**. Air4All is a European programme run by the AeroSpace and Defence Industries Association of Europe. Twelve leading members of the aerospace industrial sector, who have special interest in UAS issues, form the Air4All group, with BAE Systems leading for the UK. The group's vision is 'to open European Air Space and have the required technology demonstrations in order to produce UAS that can routinely fly across national borders'. The group has identified 4 separate groupings of challenges to be overcome; technical, rules and regulations, procedures and training and transversal issues. Topics under investigation range from separation, collision avoidance, weather detection/protection on board and autonomous behaviour/decision-making through to pilot/operator training, public acceptance and impact on the environment.

B8. **Process**. The Air4All roadmap describes a 6 step process (although steps 5 and 6 each have 2 parts) that provide incremental increases in capability from the simplest Step 1: 'fly experimental UAS within national borders in segregated airspace (regular, at short timescale) – unpopulated

[8] DBERR was disbanded on 6 June 2009, following the formation of the Department for Business, Innovation and Skills.

range', through to the most complex Step 6a, 'fly a civil UAS as Instrument Flight Rules (IFR) and visual flight rules traffic across national borders, routinely in non-controlled airspace (airspace classes A, B, C, D, E, F, G). The step that is probably of most use to medium/large military UAS is Step 5: 'fly a civil or state UAS as IFR traffic across national borders, routinely in controlled airspace (airspace classes A, B, C).[9] Informed commentators indicate that Step 5 will be achievable, at least technologically, by around 2015. Whether the regulatory system will be ready to accept such activity by then remains a risk. It is likely that military systems will achieve the capability to operate solely within national borders before then, probably sometime during 2013.

B9. **Standardisation**. In a related issue and key to successful delivery of unmanned aircraft, NATO, US and UK military forces and most civilian aviation authorities are slowly moving toward consensus on standards for most aspects relating to the design, production and operation of UAS. Key documents include, but are not limited to:

a. DEFSTAN 00-970 *Design and Airworthiness Requirements for Service Aircraft Part 9 – UAV Systems*.

b. STANAG 4671 *Unmanned Aerial Vehicle Systems Airworthiness*.

c. CAP 722 *Unmanned Aircraft System Operations in UK Airspace – Guidance*.

d. JAR-23 *Joint Aviation Requirements: Normal, Utility, Aerobatic, and Commuter Category Aeroplanes*.

e. CS-23, European Aviation Safety Agency, *Certification Specifications for Normal, Utility, Aerobatic, and Commuter Category Aeroplanes*.

[9] Step 5a adds in airspace classes D and E.

# ANNEX C – FURTHER LEGAL ISSUES AND THE MISSILE TECHNOLOGY CONTROL REGIME

C1. **The Missile Technology Control Regime**. The Missile Technology Control Regime (MTCR) is an informal and voluntary association of countries that share the goals of preventing proliferation of unmanned delivery systems capable of delivering weapons of mass destruction, by co-ordinating national export licensing efforts.[1] Established in 1987 by Canada, France, Germany, Italy, Japan, United Kingdom and the United States, membership has now grown to 34 countries. Although missile focussed, the MTCR also limits the export of unmanned aircraft and associated technologies as listed in an Annex to the agreement. The list of items considered to be the most sensitive (Category 1) includes 'complete unmanned aerial vehicle systems (together with cruise missile systems, target drones and reconnaissance drones) capable of delivering at least a 500kg payload[2] to a range of at least 300km'.[3] Also listed are all of the key equipment, materials, software and technology that would be needed for unmanned aircraft development, production and operation.

C2. **MTCR Implications**. It is not clear how the MTCR would affect the export of UK built systems or the import of foreign ones but it would affect the scope of a defence industrial strategy aimed to support UK manufacturers and the export of unmanned aircraft systems. From a legal perspective, the MTCR is neither law, nor a treaty and has no enforcement mechanism of its own; it does not create legal obligations in its own right. However, it has already influenced, and is reflected in, European Community (EC) and national law. This creates legal obligations which are enforceable and affects which particular equipment, technologies and related items must be licensed. MTCR membership provides no entitlement to obtain technology from another partner and no obligation to supply it. This applies also to trading between partners and non-partners, and once export of an item listed in the Annex is denied by any partner, a *no-undercut* policy commits other partners to consult before considering export themselves. Regardless, export of Category I listed items, and their associated production capability, is subject to an unconditional strong presumption of denial regardless of the purpose of the export. Application by any company for an export licence for listed items needs to include a strong rebuttal of the provisions of the MTCR.

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[1] More detailed information on the Missile Technology Control Regime (MTCR) can be found at http://www.mtcr.info/english/index.html (last accessed 26 January 2011).

[2] MTCR defines payload as *the total mass that can be carried or delivered by the specified rocket system or unmanned aerial vehicle system that is not used to maintain flight*. The meaning of payload with specific respect to unmanned aircraft is further defined at page 11 of the Annex. It includes munitions, countermeasures, recording equipment and recovery equipment (e.g. parachutes) amongst others.

[3] *MTCR Equipment, Software and Technology* Annex dated 11 June 2010, page 16.

C3. **European Community Law**. Council Regulation (EC) number 428/2009 of 5 May 2009 sets up a community regime for the control of exports, transfer, brokering and transit of dual-use items. Listed items and restrictions on export by member states are very similar to those of the MTCR. The specific provision on unmanned aerial vehicles[4] in the EC Order, including those capable of carrying a payload of greater than 500kg for a range of greater than 300km, is laid out in 9A012 *Unmanned Aerial Vehicles, Associated Systems, Equipment and Components* and largely controls the following unmanned aircraft technology:

- Autonomous flight control and navigation capability.
- Capability of controlled-flight out of the direct visual range of a human operator.
- Equipment and components, specially designed to convert a manned aircraft to an unmanned aircraft.
- Air breathing reciprocating or rotary internal combustion type engines, specially designed or modified to propel unmanned aircraft above 50,000 feet.

C4. **UK Law**. UK export is controlled by the Export Control Order 2008, as amended in 2010. Schedule 2 covers military goods, software and technology, while Schedule 3 covers dual-use items. Definitions in Schedule 2 include: aircraft, lighter-than-air vehicles, unmanned aerial vehicles, aero-engines, aircraft equipment and related goods, as follows, specially designed or modified for military use and specially designed components. Unmanned aircraft are specifically mentioned at section ML10.c to the Export Control Order, which also includes: remotely piloted air vehicles; autonomous programmable vehicles; lighter-than-air vehicles and their launchers; ground support equipment; and related equipment for command and control. Export of unmanned aircraft would, therefore, have to conform to the rules and licensing regime of Export Control Order 2008, as amended.

C5. **Export Licensing Issues**. It is likely that authorisation for export of any unmanned aircraft system from, or import to the UK, would be dealt with on a case-by-case basis. Legal advice and a formal position on export licensing should be sought from the Department of Business, Innovation and Skills to better understand the implications and limitations of entering into bi-lateral or other development arrangements. This is particularly the case if the desire is to drive down costs by enabling production numbers that would allow an effective economy of scale.

[4] Here, unmanned aerial vehicle means *any aircraft capable of initiating flight and sustaining controlled flight and navigation without any human presence on board*.

# LEXICON

## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AGL | Above Ground Level |
| AP | Air Publication |
| AP1 | Additional Protocol 1 |
| ASW | Anti-Submarine Warfare |
| BAES | BAE Systems |
| BAMS | Broad Area Maritime Surveillance |
| BLOS | Beyond the Line of Sight |
| CBRN | Chemical, Biological, Radiological and Nuclear |
| C-RAM | Counter-Rocket, Artillery and Mortar |
| DCDC | Development, Concepts and Doctrine Centre |
| DEW | Directed Energy Weapons |
| DH | Desert Hawk |
| DOTMLPF | Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities |
| EC | European Community |
| EMS | Electromagnetic Spectrum Management |
| EOD | Explosive Ordnance Disposal |
| EO/IR | Electro-optical/Infrared |
| FCOC | Future Character of Conflict |
| GPS | Global Positioning System |
| HALE | High Altitude, Long Endurance |
| HAV | Hybrid Air Vehicle |
| H450 | Hermes 450 |
| IED | Improvised Explosive Devise |
| IFR | Instrument Flight Rules |
| ISA | Intelligence and Situational Awareness |
| ISR | Intelligence, Surveillance and Reconnaissance |
| ISTAR | Intelligence, Surveillance, Target Acquisition and Reconnaissance |
| JDN | Joint Doctrine Note |
| JDP | Joint Doctrine Publication |
| JSP | Joint Service Publication |

| | |
|---|---|
| LOAC | Laws of Armed Conflict |
| LEMV | Long Endurance Multi-intelligence Vehicle |
| LOS | Line of Sight |
| MALE | Medium Altitude Long Endurance |
| MOD | Ministry of Defence |
| MTCR | Missile Technology Control Regime |
| NATO | North Atlantic Treaty Organization |
| NAV | Nano Air Vehicles |
| QEC | Queen Elizabeth Class |
| ROE | Rules of Engagement |
| RPA | Remotely Piloted Aircraft |
| RPAS | Remotely Piloted Air (or Aircraft) System |
| SDSR | Strategic Defence and Security Review |
| SWOT | Strengths, Weaknesses, Opportunities and Threats |
| TRL | Technology Readiness Level |
| UA | Unmanned Aircraft |
| UAS | Unmanned Aircraft Systems |
| UAV | Unmanned Aerial Vehicle |
| UCAS-D | Unmanned Combat Air System Demonstration |
| UOR | Urgent Operational Requirement |
| US | United States |
| USAF | United States Air Force |
| USN | United States Navy |
| VTOL | Vertical Take-Off and Landing |
| WCG | Weight Classification Group |

## TERMS AND DEFINITIONS

**Automated System**
In the unmanned aircraft context, an automated or automatic system is one that, in response to inputs from one or more sensors, is programmed to logically follow a pre-defined set of rules in order to provide an outcome. Knowing the set of rules under which it is operating means that its output is predictable. (JDN 2/11)

**Autonomous System**
An autonomous system is capable of understanding higher level intent and direction. From this understanding and its perception of its environment, such a system is able to take appropriate action to bring about a desired state. It is capable of deciding a course of action, from a number of alternatives, without depending on human oversight and control, although these may still be present. Although the overall activity of an autonomous unmanned aircraft will be predictable, individual actions may not be. (JDN 2/11)

**Remotely Piloted Aircraft**
A remotely piloted aircraft is defined as an aircraft that, whilst it does not carry a human operator, is flown remotely by a pilot, is normally recoverable, and can carry a lethal or non-lethal payload. (JDN 2/11)

**Remotely Piloted Aircraft System**
A remotely piloted aircraft system is the sum of the components required to deliver the overall capability and includes the pilot, sensor operators (if applicable), remotely piloted aircraft, ground control station, associated manpower and support systems, satellite communication links and data links. (JDN 2/11)

**Unmanned Aircraft**
An unmanned aircraft (sometimes abbreviated to UA) is defined as an aircraft that does not carry a human operator, is operated remotely using varying levels of automated functions, is normally recoverable, and can carry a lethal or non-lethal payload. (JDN 2/11)

Note: in the UK, cruise and ballistic missiles are not considered to be unmanned aircraft.

**Unmanned Aircraft System**
An unmanned aircraft system is defined as a system, whose components include the unmanned aircraft and all equipment, network and personnel necessary to control the unmanned aircraft. (JDN 2/11)

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## JOINT DOCTRINE PUBLICATIONS

The successful conduct of military operations requires an intellectually rigorous, clearly articulated and empirically-based framework of understanding that gives advantage to a country's Armed Forces, and its likely partners, in the management of conflict. This common basis of understanding is provided by doctrine.

UK doctrine is, as far as practicable and sensible, consistent with that of the North Atlantic Treaty Organization (NATO). The development of national doctrine addresses those areas not covered adequately by NATO; it also influences the evolution of NATO doctrine in accordance with national thinking and experience.

Endorsed national doctrine is promulgated formally in JDPs.[1] From time to time, Interim JDPs (IJDPs) are published, caveated to indicate the need for their subsequent revision in light of anticipated changes in relevant policy or legislation, or lessons arising out of operations.

Urgent requirements for doctrine are addressed through Joint Doctrine Notes (JDNs). To ensure timeliness, they are not subject to the rigorous staffing processes applied to JDPs, particularly in terms of formal external approval. Raised by the DCDC, they seek to capture and disseminate best practice or articulate doctrinal solutions which can subsequently be developed in due course as more formal doctrine. Alternatively, a JDN may be issued to place some doctrinal markers in the sand, around which subsequent debate can centre.

Details of the joint doctrine development process and the associated hierarchy of JDPs are to be found in JDP 0-00 *Joint Doctrine Development Handbook*.

[1] Formerly named Joint Warfare Publications (JWPs).