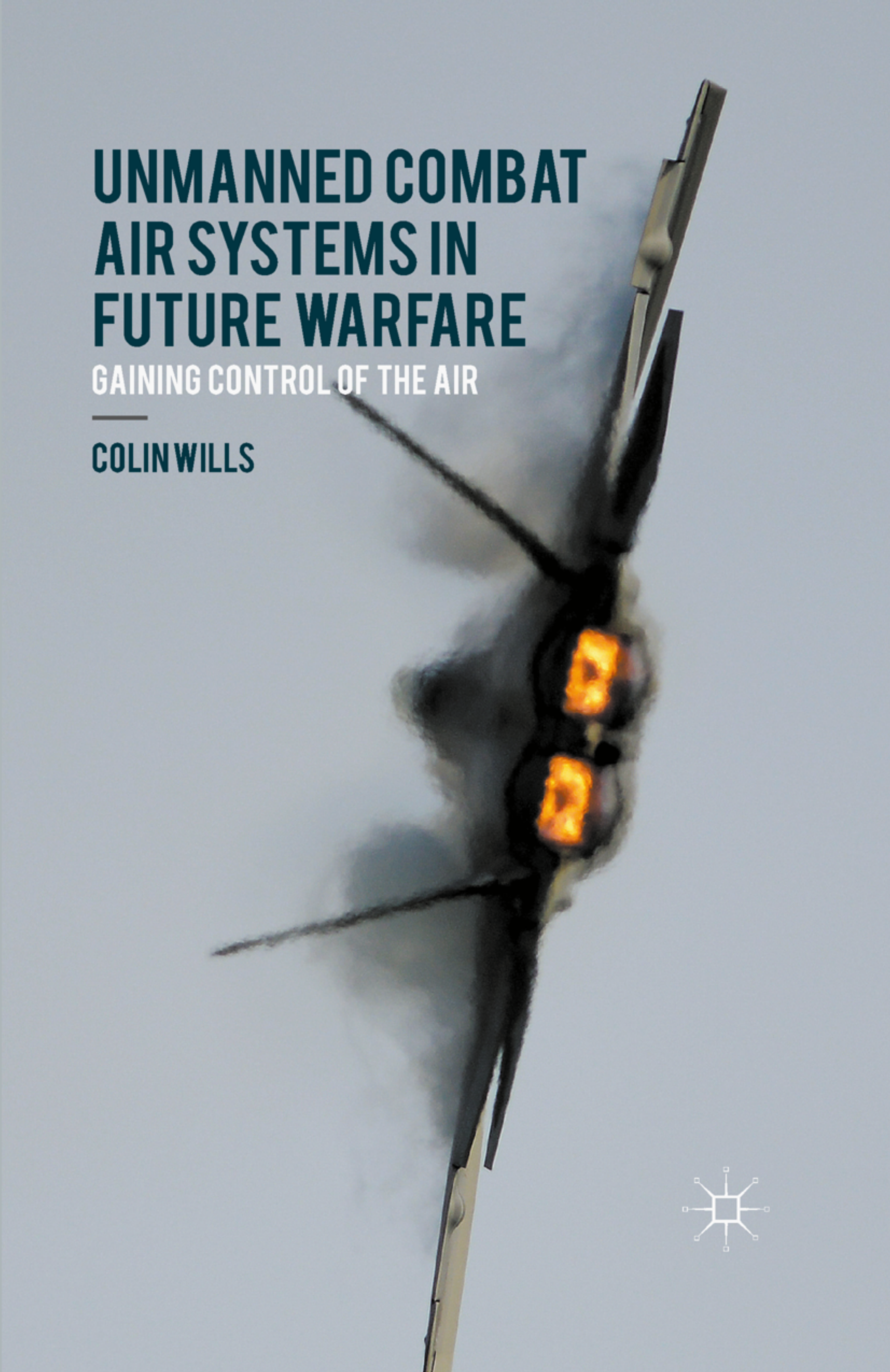
UNMANNED COMBAT AIR SYSTEMS IN FUTURE WARFARE

GAINING CONTROL OF THE AIR

COLIN WILLS



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Gaining Control of the Air

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Contents

List of Acronyms and Abbreviations

A2/AD	Anti-Access/Area-Denial
AAG	Air-to-Air Gun
AAM	Air-to-Air Missile
AAR	Air-to-Air Refuelling
AAS	Air-to-Air System
ABM	Anti-Ballistic Missile
ACEVAL	Air Combat Evaluation
ACM	Air Chief Marshal
ACMI	Air Combat Manoeuvring Instrumentation
AESA	Active Electronically Scanned Array
AEW	Airborne Early Warning
AFRL	Air Force Research Laboratory
AI	Artificial Intelligence
AM	Air Marshal
AMRAAM	Advanced Medium-Range Air-to-Air Missile
AAA	Anti-Aircraft Artillery
ASBM	Anti-Ship Ballistic Missile
ASCM	Anti-Ship Cruise Missile
ASRAAM	Advanced Short-Range Air-to-Air Missile
ASMS	Advanced Surface Missile System
ATD	Automatic Target Detection
ATI	Automatic Target Initiation
ATR	Automatic target Recognition
AWACS	Airborne Warning and Control System
BACN	Battlefield Airborne Communication Node
BM	Ballistic Missile
BVR	Beyond Visual Range
C2	Command and Control
C4ISTAR	Command, Control, Communications, Computers, Intelligence, Surveillance, Targeting Acquisition and Reconnaissance
CAS	Chief of the Air Staff
CCP	Chinese Communist Party
CDE	Collateral Damage Estimation
CID	Combat Identification

CIHL	Customary International Humanitarian Law
CNP	Comprehensive National Power
COIN	Counter Insurgency
COMAO	Composite Air Operations
CNO	Computer Network Operations
CONOPS	Concept of Operations
COP	Common Operating Picture
CSBA	Center for Strategy and Budgetary Assessment
CSG	Carrier Strike Group
DAMM	Dynamic Airborne Mission Management
DCA	Defensive Counter Air
DCDC	Development, Concepts and Doctrine Centre
DEW	Directed Energy Weapons
DIRCM	Directed Infrared Countermeasures
DMT	Distributed Mission Training
DoD	Department of Defense
DPOC	Deep and Persistent Offensive Capability
DRFM	Digital Radio Frequency Memory
DSTL	Defence, Science and Technology Laboratory
EA	Electronic Attack
ECM	Electronic Countermeasures
ELINT	Electronic Intelligence
EMS	Electromagnetic Spectrum
EP	Electronic Protection
ES	Electronic Support
EW	Electronic Warfare
FJ	Fast Jet
F2T2EA	Find, Fix, Target, Track, Engage and Assess
FLOAAT	Function-specific Level of Autonomy and Automation Tool
G	Force of Gravity
GCS	Ground Control Station
GDP	Gross Domestic Product
GPS	Global Positioning System
HEL	High Energy Laser
HITL	Human-in-the-Loop
HMCS	Helmet Mounted Cueing System
HMI	Human Machine Interface
HOBS	High-Angle Off-Boresight
HOTL	Human-on-the-Loop
HPM	High-Powered Microwave
HVAA	High Value Airborne Asset

IADS	Integrated Air Defence System
IISS	International Institute for Strategic Studies
IOT&E	Initial Operational Test and Evaluation
IR	Infrared
IRSTS	Infrared Search and Track System
ISR	Intelligence, Surveillance and Reconnaissance
ISTAR	Intelligence, Surveillance, Target Acquisition, and Reconnaissance
JSF	Joint Strike Fighter
JTIDS	Joint Tactical Information Distribution System
km	Kilometre
LADAR	Laser Detection and Ranging
Lt	Lieutenant
Lt Col	Lieutenant Colonel
LO	Low Observable
LOAC	Law of Armed Conflict
LVC-IA	Live Virtual and Constructive Integrating-Architecture
Maj	Major
MAKS	Mezhdunarodnyj Aviatsionno-Kosmicheskij Salon
MAWS	Missile Approach Warning System
MOD	Ministry of Defence
NASA	National Air and Space Administration
NATO	North Atlantic Treaty Organisation
NCADE	Network-Centric Airborne Defense Element
NCW	Network Centric Warfare
NEC	Network Enabled Capability
NIESR	National Institute of Economic and Social Research
nm	Nautical Mile
OCA	Offensive Counter Air
OED	Oxford English Dictionary
OG	Objective Gateway
OODA	Observe-Orient-Decide-Action
OUE	Operational Utility Evaluation
OTH	Over the Horizon
PACOM	Pacific Command
P_k	Probability of a Kill
P_{ssk}	Probability of a single-shot kill
PLA	People's Liberation Army
PLAAF	People's Liberation Army Air Force
PLAN	People's Liberation Army Navy
PRC	People's Republic of China

QWI	Qualified Weapons Instructor
RAF	Royal Air Force
RAM	Radar Absorbent Materials
RCS	Radar Cross Section
RF	Radio Frequency
RFC	Royal Flying Corps
RMA	Revolution in Military Affairs
RN	Royal Navy
RNAS	Royal Navy Air Service
ROE	Rules of Engagement
RPA	Remotely Piloted Aircraft
RPAS	Remotely Piloted Air System
SAM	Surface-to-Air Missile
SEAD	Suppression of Enemy Air Defence
SIGINT	Signals Intelligence
SLOC	Sea Lines of Communication
Sqn Ldr	Squadron Leader
TDL	Tactical Data-Links
TIBS	Tactical Information Broadcast System
TLC	Through-Life Costs
TPT	Third-Party Targeting
TRA	Taiwan Relations Act
TST	Time-Sensitive Target
TTP	Tactics, Techniques, and Procedures
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UCAS	Unmanned Combat Air System
UCAS-D	Unmanned Combat Air System – Demonstrator
UCAV	Unmanned Combat Aerial Vehicle
UCLAS	Unmanned Carrier Launched Air Surveillance and Strike
USAF	United States Air Force
USMC	United States Marine Corp
USN	United States Navy
VHF	Very High Frequency
Wg Cdr	Wing Commander
WSO	Weapon Systems Operator
WVR	Within Visual Range

1
Introduction

The era of manned flight is not yet over, nor is its demise imminent. Unmanned Aircraft Systems (UAS) are, however, currently assuming roles in air power that were previously undertaken by manned aircraft. In future warfare will it be possible for Unmanned Combat Air Systems (UCAS), the next stage in UAS evolution, to undertake the tasks and accept most of the risks that until now have been the lot of military aviators? The aim of this book is to determine where the major threat to a United States-led alliance in 2040 is likely to come from, and whether UCAS will be effective in undertaking all the counter-air missions that are required of a nation's armed forces in order to gain control of the air.

Control of the air is the foundation for all conventional military operations against an adversary with an air defence capability. While there are a number of academic opinions and government 'roadmaps' on the use of UCAS in gaining control of the air, these do not scrutinise in detail their full potential.[1] The United States acknowledges, through its Department of Defense's (DoD) *Unmanned Aircraft Systems Roadmaps and Flight Plans*, that counter-air UCAS are intended to be in service by 2025–2030; however, it does not detail any development programmes.[2] The United Kingdom's Ministry of Defence (MOD), conversely, views that up to 2035, although UCAS, '. . . are likely to form part of the future control of the air force-mix . . . a wholly unmanned capability for the air-to-air role is unlikely to be achievable or desirable within the concept timeframe'.[3] As far as can be ascertained, this is not based on any incisive analysis.

Within the North Atlantic Treaty Organization (NATO), control of the air is classified into two subdivisions – air superiority and air supremacy. Air superiority is defined as 'that degree of dominance in the air battle of one force over another which permits the conduct of operations by the former and its related land, sea, and air forces at a given time and place without prohibitive interference by the opposing force'.[4] Air supremacy is defined as, 'that degree of air superiority wherein the opposing air force is incapable of effective interference'.[5] Although these terms are not consistently used by commentators, they do illustrate that air power may not allow absolute dominance of the airspace all of the time.

Standard military acronyms are used throughout this book where appropriate; these are based on NATO terminology and standard convention.[6] The term UAS itself is often misunderstood. Many 'experts' refer to the air vehicle component of a UAS as a 'drone'. This is a legacy term, more fitting to the German World War II V-1 Doodlebug or the target drones used for gunnery practice. V-1s were designed to impact a target and not to be recoverable; they were effectively cruise missiles. An Unmanned Aerial Vehicle (UAV) is not a cruise missile; it is an Unmanned Aircraft (UA) designed to be reusable. A cruise missile, on the other hand, has a one-way mission.[7]

UAS consist of a number of physical components and other strands: the UAV, their sensors and weapons, communications links, the Ground Control Station (GCS), the personnel involved in operating the system, and the logistics support required.[8] This may seem obvious, however, few analysts refer to the system as a whole. A similar situation exists with UCAS terminology. At writing, there was no agreed standard definition of UCAS. The *Humanitarian Policy and Conflict Research Manual on International Law Applicable to Air and Missile Warfare* defines an Unmanned Combat Aerial Vehicle (UCAV) as 'an unmanned military aircraft of any size which carries and launches a weapon, or which can use on-board technology to direct such a weapon to a target'.[9] This is a useful description for the purposes of this book. Although the UK and US, for example, do not normally term weaponised UAS as UCAS, there are exceptions.[10] Until there is conformity, and for the purposes of this book, I define UCAS as weaponised UAS, utilising a level of automation/autonomy – which may also be capable of Intelligence, Surveillance, Target Acquisition, and Reconnaissance (ISTAR) tasks – and designed to survive in highly contested airspace. This can be achieved by utilising a combination of stealth features including Network Enabled Capability (NEC), Electronic Attack (EA), countermeasures, and weapon systems capable of self-protection (as a minimum), speed and manoeuvrability.

While there is no internationally agreed upon policy regarding UAS terminology, there are a number of working agreements that attempt to align common lexicon as far as is possible. The UK's MOD *Joint Doctrine Note 2/11 Unmanned Aircraft Systems: Terminology, Definitions and Classification* aims to be consistent with NATO doctrine.[11] This document offers direction on the use of common terminology; however, the terms used in this *Joint Doctrine Note* are for guidance only. In an attempt to confirm that humans are still involved in the operation of UAS, the terms Remotely Piloted Air System (RPAS) and Remotely Piloted Aircraft (RPA) have been adopted by the Royal Air Force (RAF) and the United States Air Force (USAF).[12] The reasons for this are valid; however, there appears to be no consistency at all within the wider military and academic community. Even the term UAV seems to evade a consistent definition, with a recent RAF Chief of the Air Staff (CAS) referring to a UAV as an Uninhabited Air Vehicle, and another senior RAF officer using the term Unmanned Air Vehicle.[13] None of these terms are incorrect; however, I believe accurate definitions and consistency are important. The terms UA, UAV, UAS, UCAV and UCAS are used throughout this book. I do not use the term 'drones'.

A number of countries are developing UCAS, though these programmes do not currently include any that will enable these systems to gain control of the air in its entirety. As of 2014, UCAS development focused on detecting and destroying Time-Sensitive Targets (TST), utilising ISTAR, and Suppression of Enemy Air Defence (SEAD) roles, the air-to-surface portion of the counter-air task.[14] The air-to-air component of counter-air warfare, a true TST issue, is as important. It is envisaged that developmental UCAS, such as the X-47B Unmanned Combat Air Demonstrator (UCAS-D) programme, part of the overarching US Unmanned Carrier Launched Air Surveillance and Strike (UCLASS) programme, will conduct air-to-surface and surveillance missions but not counter-air missions.[15] The UK's *Taranis* UCAS technology demonstrator programme has similar aims, although not currently from a carrier.[16]

The roles of UCAS should not be viewed in isolation, but rather as part of a system of systems that aid, it can be argued, the most critical component of warfare – situational awareness. The importance that situational awareness plays in warfare, particularly in control of the air, is crucial. An NEC is required in order to establish consistent and reliable battlefield situational awareness, and will form the basis upon which UCAS are being developed. The threat environment in which any weapon systems must operate will also reinforce capability requirements. Some countries adhere to principles that are different from those of developed democracies; it is relationships with these countries that are likely to dictate the frequency and severity of future military challenges. An understanding of where threats come from is essential. Ultimately, policy and procurement decisions are underpinned by all-source strategic and intelligence analysis. This scrutiny is fundamental, as any specious assumptions may result in erroneous conclusions leading to the wrong strategy and procurement decisions.

Warfare in the 20th century demonstrated the potential and performance of air power. The 21st century promises to be a period of military revolution, sometimes referred to as a Revolution in Military Affairs (RMA), with NEC and the utilisation of UCAS coming to fruition. The current utilisation of UAS and future potential use of UCAS could be viewed as an RMA, with the potential to bring a transformation to the ways in which future battlespace will be controlled and victory achieved. There have been a number of false dawns preaching the virtues of unmanned aircraft. General Hap Arnold, Chief of the US Army Air Forces, predicted future possibilities when he observed on V-J Day in 1945:

> We have just won a war with a lot of heroes flying around in planes. The next war may be fought by airplanes with no men in them at all . . . Take everything you've learned about aviation in war, throw it out of the window, and let's go to work on tomorrow's aviation. It will be different from anything the world has ever seen.[17]

Although not quite prescient, Arnold's words are gaining relevance. Whether the ascendancy of UAS is an RMA or not, it is worth remembering that the fundamentals of war will likely remain extant.

This book does not examine in detail the current or future use of UAS by either nation states or non-state organisations. The focus is on unmanned air systems that are required to operate in highly contested airspace, capable of achieving control of the air, which require major investment and infrastructure for operation. Currently only UCAS fit this description. If UCAS cannot control the airspace in which they operate, and unless control can be gained by other than manned systems, then manned fighter aircraft will be required to achieve this task. This would be perverse, largely negating the purpose of utilising UCAS. The effect that political and legal issues of using UCAS might have upon decision makers cannot be underestimated, particularly in terms of their willingness to deploy such systems at little, if any, risk to their own military personnel. There is currently a lack of cohesion and clear thought on the future utility of UCAS in the counter-air role, particularly within the UK, which requires cogent and informed input. This book examines these issues, allows value to be added to the procurement decision process and helps inform future policy over the debate on manned versus unmanned aircraft. Ultimately, this book advocates that UCAS, capable of gaining control of the air, have the potential to offer a revolution in the way warfare will be conducted in the 21st century.

2
Research Interviews

When conducting research for this book, it was an absolute requirement to be meticulous in the removal of bias from any conclusion. To help achieve this, a survey was conducted among military aircrew and officers, MOD engineers and aviation specialists, and civilians, to collect their views on, *inter alia*, whether UCAS can gain control of the air in future warfare in 2040. The intention was to determine any emerging trends in thought, in particular identifying divergence in interviewee's views, dependent on their experience and qualifications, both academic and military. The interviews included questions enabling confirmation that the crux of the book warranted investigation. More importantly, the responses to questions, specifically designed to elicit expert views, yielded answers that allowed robust investigation questioning the efficacy of some current fundamental maxims of counter-air warfare.

Analysis of the responses to the interview questions helped validate those areas of research that are central to this book, allowing these to be focused on. Valuable insight has also been gained allowing comment to be made on the ethical and legal issues, and what systems UCAS will require, including the type of air vehicle necessary. The following breakdown of responses allows later analysis to be put in context.

Interviewee background and experience

The number of interviewees totalled 75. The sample size was a trade-off between the time available to conduct and collate the interviews and the number of interviewees considered necessary to allow proper analysis. A large proportion of the interviewees were RAF aircrew. This was necessary because most of the questions were geared towards aircrew experience. That said, where questions were more technical, the views of scientists and aviation specialists were just as pertinent. On the other hand, questions regarding the ethical and political aspects of using UCAS, and future recruitment motivations, were equally pertinent to civilians.

Although the interviewees had a diverse number of academic and professional qualifications, all military aircrew were qualified air pilots, air navigators or Weapon Systems Operators (WSO). The majority of interviewees, 62 per cent, were either serving or ex-serving military aircrew. The remaining interviewees were military ground personnel, MOD aviation analysts and civilians. When considering whom to interview, it was decided that the majority should be Fast Jet (FJ) aircrew, experienced in the air defence role. This is important, as their views on the technical and tactical aspects of conducting counter-air missions are crucial, particularly concerning the type of air vehicle UCAS requires, and also which systems/weapons would be effective. A total of 50 military aviators have been interviewed: most were either current or ex-FJ pilots or navigators and a few have experience on other aircraft, such as the maritime Nimrod and the Nimrod R1 Signals Intelligence (SIGINT) and Electronic Intelligence (ELINT) aircraft. The majority of FJ crews have a background in counter-air, with some dual qualified, having either flown multi-/swing-role aircraft or been experienced in both counter-air and ground attack roles on different aircraft. Eighteen of the aircrew were Qualified Weapons Instructors (QWI). A qualification of a QWI (Air Defence) indicates that these aircrew are trained to teach air defence tactics, including air combat manoeuvring, and weaponry to an advanced level. The overall experience on different aircraft types is diverse, covering Tornado F-3, F-4 Phantom, F-14 Tomcat, F-15A/C/E Eagle, F-16 Falcon, F-22 Raptor, Harrier FA-2, GR-7/9, Tornado GR-1/1A/4/4A, Jaguar, Predator/Reaper UAS, Global Hawk UAS, U-2, BAE Systems HERTI UAS, MiG-17 Fresco, MiG-21 Fishbed, Nimrod R-1 and R-2, C-130 Hercules, C-17 and the Puma helicopter. Nine MOD aviation analysts were interviewed – all with a background in UAS/NEC. One ex-military interviewee is an academic instructor at the USAF Weapons School, at Nellis Air Force Base, with a background as an Aggressor pilot instructor at 'Exercise Red Flag', having flown various US and Russian fighters, including the MiG-17 and MiG-21; he also flew air-to-air combat missions in Vietnam and Laos.[1] Exercise Red Flag is a multi-faceted military training exercise, centred on flying operations. It is conducted in airspace situated in training ranges in the Nevada desert, north of Las Vegas, and considered the premier training programme for US military aviators and their allies and Integrated Air Defence System (IADS) operators. It includes cyberspace and covers all aspects of modern air power. Its aim is to simulate, as closely as possible, the conditions that 'warfighters' are likely to meet in operations. Red Flag was instigated as a direct result of the losses suffered by the US during the Vietnam War.[2] Eleven non-aviation specialist civilians were interviewed; their views on the future ethical and motivational issues are valid. The remaining civilian interviewees are from diverse professional backgrounds, including engineering and management. A number of senior RAF and USAF commanders were interviewed, and although small in number, their views give weight to future MOD/DoD policy towards the use of UCAS. Five interviewees chose to express their views under 'The Chatham House Rule'.

Analysis

Questions asked of interviewees were designed to elicit opinions on a number of issues concerning the utility of UCAS. Some questions concentrated on the aerodynamic and stealth capabilities of the UCAV itself. Others sought to establish any trend in views regarding the perceived capability of UCAS being able to effectively undertake counter-air missions, either semi-autonomously or fully autonomously.[3] Three questions, in particular, sought to establish whether a future UCAV would require the capability to conduct highly agile air combat manoeuvring, in order to either achieve a kill or defend itself against a highly agile adversary. In attempting to define the weapon systems which a future UCAS will require, it is necessary to decide whether the UCAV will need the same attributes of current counter-air fighters in airframe performance, sensors and weapons. In order to achieve this, it is essential to establish which attributes are important, desirable or unnecessary. For example, is the ability to conduct highly agile air combat essential? Also, will it still be vital for a fighter to have a gun? This may well be true currently, but will it remain so by 2040? Another question that needs to be asked: how much emphasis should be placed on stealth, NEC, EA, aerodynamics, endurance and payload?

Third-Party Targeting (TPT) capabilities will be central to the effectiveness of UCAS.[4] NEC will play a pivotal role in achieving this. Opinion was sought as to the viability of TPT in all three phases of an air-to-air engagement: Beyond Visual Range (BVR), Within Visual Range (WVR) and close combat. The purpose of this question is to seek judgement on when these methods will become possible. An important consideration is whether there are any legal or political concerns which need to be considered when pursuing the procurement of autonomous systems. Three questions have been designed to elicit approximate statistics regarding the frequency required by aircrew during training sorties: (1) to enter the visual merge in order to kill an adversary; (2) to conduct air combat manoeuvring to either achieve a kill or defend against being killed and (3) to use the gun to achieve a kill.[5] The purpose of these questions is to establish what emphasis is likely to be needed in these three phases of an engagement, when considering any preference towards weapon systems development. Where percentages are given as responses to questions, they are not intended to be totally accurate. Many aircrew have flown in numerous training exercises of these types, some covering decades of flying. No aircrew keeps an exact tally of their kills achieved, or by what method. Their answers, therefore, are the best estimate of what they consider to be kills achieved from relevant sorties. The answers do, however, indicate a trend. This trend has helped examination of the types of weapons that future UCAS will require. The results of the interviews are largely qualitative, rather than statistical. They have, however, allowed with a high level of confidence further research and analysis to be conducted, in the knowledge that the process has been peer reviewed and found to be fundamentally sound. The following are the results of the questionnaire.[6]

NEC and requirement to enter the close-combat fight

Ninety-five per cent of interviewees believe NEC is vital in effecting control of the air in 2040, while 5 per cent believe it is highly desirable. Essentially, all believe NEC will provide a very important function in future warfare. These figures add integrity to the hypothesis that NEC is crucial to situational awareness and success in future warfare.

There have been a limited number of air-to-air engagements in the modern era, which for the purpose of this study is defined as post-1990. Pre-1990, BVR air-to-air engagements were conducted using semi-active Radio Frequency (RF) and Infrared (IR) Air-to-Air Missiles (AAM), whereas post-1990 saw the 1991 Gulf War that, while still a semi-active AAM air-to-air war, can be used as a benchmark for future BVR air-to-air engagements. The 1999 air campaign in Kosovo saw the AIM-120 Advanced Medium-Range Air-to-Air Missile (AMRAAM) used for the first time against an adversary. The Vietnam War and the Israel/Arab conflicts of the 1960s and 1970s were the last known occasions when the gun was used in air-to-air engagements, to any great extent.[7] In response to the three questions asked of interviewees, the majority, 78 per cent of FJ air defence aircrew, have been required to enter the visual merge, in order to kill an adversary, on less than 10 per cent of their Composite Air Operations (COMAO) sorties; 13 per cent have been required to do so between 10 and 15 per cent of occasions, and 9 per cent between 16 and 20 per cent of sorties. Thirty per cent of aircrew have conducted visual air combat manoeuvring, post-merge, in order to achieve a kill on less than 3 per cent of their COMAO sorties, with 39 per cent required to do so on less than 5 per cent of sorties, 17 per cent on less than 10 per cent of missions and 14 per cent on greater than 10 per cent. Nineteen per cent of aircrew have never used the Air-to-Air Gun (AAG) in a COMAO training sortie, while 28 per cent have used the gun on less than 1 per cent of sorties, 20 per cent have used it on less than 2 per cent of sorties, 31 per cent on less than 5 per cent of sorties, and 2 per cent have used the AAG on 5 per cent or greater. The majority of aircrew that have never used the AAG have 2000–3000 hours front-line flying experience.

All those who stated that they were required to enter the visual merge between 16 and 20 per cent of occasions have had no experience of the AMRAAM or the Advanced Short-Range Air-to-Air Missile (ASRAAM). Although those experienced with the most modern AAM were required to enter the visual merge less often, the analysis indicates that BVR AAM and tactics do not always allow fighters to remain outside of the visual combat environment. Significantly, AAM probability of a kill (P_k) was not considered with this question. The BVR and WVR analysis leads to the conclusion that it is likely there will be a need for a UCAV to enter the classic visual merge on occasion, in order to achieve a kill – if weapon systems, combined with NEC, do not obviate this requirement by 2040. The usefulness of an AAG is more debatable, in particular when employed in high-intensity air warfare. The question is – does a gun need to be procured, and if so, at what cost? Also, even if a gun should be included as part of a UCAV's weaponry, could the vehicle use it successfully? However, while difficult to quantify, the gun does not play a significant factor in air-to-air engagements during training sorties.

Third-Party Targeting

Having the capability to conduct TPT when utilising UCAS will be fundamental to the system's effectiveness. It will also dictate the type of air vehicle and range of weapon systems UCAS will require in order to optimise such effectiveness. Three phases of an engagement were considered – BVR, WVR and close visual combat.[8] For each phase it was asked whether TPT was possible now; if not, when it might be, or if it would never be thought possible. Military personnel and MOD/aviation analysts answered these questions. Eighty-two per cent of interviewees believe

BVR TPT is possible now, while 15 per cent believe it will be possible by 2020 and 3 per cent by 2040. Thus, 100 per cent of those interviewed believe it is possible now or will be possible by 2040. Sixty-one per cent of the interviewees believe WVR TPT is viable now, while 21 per cent believe it will be possible by 2020 and a further 11 per cent believe it will be possible by 2040. Four per cent have stated it may be possible but do not know when, with 3 per cent stating they do not know. Overall, 97 per cent believe WVR TPT is possible now or within the next 25 years. Unsurprisingly, only 5 per cent of the interviewees think close-combat TPT is viable now. More surprisingly, 54 per cent believe it will be viable by 2040. Eighteen per cent think it will be possible but cannot say when, with 12 per cent stating they do not know. Eleven per cent believe that it will never be possible. The majority of MOD aviation analysts believe it will be possible.

Open sources confirm that BVR TPT is currently conducted.[9] However, WVR TPT is more difficult to quantify; if an adversary is manoeuvring aggressively, it is likely to become more difficult to achieve success the closer the fighter or the weapon gets to an adversary. Although TPT is currently used on some systems, its classification makes it somewhat difficult to quantify. That said, as a basic principle of operation, its viability is unclassified. Current TPT is achieved via Tactical Data-Links (TDL), such as those used in Airborne Warning and Control System (AWACS) E-3, Typhoon, F-15, F-16, F-18 and ground- and sea-based units. This capability has been available for over 15 years, and its utility is continually being expanded. It is not known if close-combat TPT is currently achievable; however, it is the most dynamic of any air-to-air engagement, requiring a high level of skill by aircrew to manoeuvre their aircraft and coordinate weapon systems and other aircraft.

Questions remain, however. Will TPT continue to develop to the extent that it allows UCAS, and other systems, to conduct all phases of the counter-air mission? If only certain phases of this mission are possible, what constraints does that put on UCAS? Ultimately, if reach-back to Command and Control (C2) is lost, will NEC allow the 'system' to operate autonomously? If TPT is effective for all phases of an air-to-air engagement, the requirement for highly agile dynamic manoeuvring will be negated, for what is currently termed 'the visual fight'. Close-combat TPT will be the most difficult technological hurdle. It may be possible in the future, but to what degree is difficult to predict. All of these processes will be underpinned by NEC.

UCAS airframe characteristics and manoeuvrability requirements

Will it be necessary to conduct highly agile manoeuvring, either for general survival or for manoeuvre in the 'visual' phase of a combat engagement? What aerodynamic capabilities would counter-air UCAS require? Will stealth be of crucial importance? The capability of current modern air-to-air fighters is based on a number of fundamental principles, excluding fifth-generation stealth technology: the ability to fly at high altitude – 45,000+ feet, to fly at high speed – Mach 1.5+, and to be highly manoeuvrable. The attributes of height and speed allow for an increase in the ability to launch an AAM at further range from an adversary than that of a slower and lower fighter. The ability for a fighter aircraft to fly high and fast gives an AAM, once launched, increased energy above its own launch speed. This extra energy can achieve a greater advantage by increasing the R_{maximum} and $R_{\text{no-escape}}$ of an AAM.[10] In addition to the R_{maximum} and $R_{\text{no-escape}}$ of an AAM, the distance between opposing fighters at AAM impact, referred to as $R_{\text{separation}}$ or F-pole, is of great significance. This distance can mean the difference between winning and losing an engagement where both fighters are exchanging AAM. F-pole can be greatly increased, depending on the higher and faster an aircraft can fly.

How much emphasis needs to be placed on agility in the design of either manned or unmanned systems? Manoeuvrability may allow for survivability when conducting close visual combat or a last-ditch missile defence manoeuvre against an adversary's AAM or Surface-to-Air Missile (SAM). That said, in the coming epochs, will it be the agility of the airborne vehicle or the agility of its weapon systems that is the mitigating factor in this phase of an engagement? If agility is vital, then a UCAV has the potential to fulfil this requirement to a very high degree, whereas a manned fighter is constrained by human physiology. A human can sustain a maximum of approximately 9 G, and then only with the aid of anti-G systems such as anti-G suits, and even then only for limited periods.[11] UCAV airframe strength would still need to be considered. It may be possible that the weapon systems are robust enough to conduct all the manoeuvring necessary in the close-in visual arena. Helmet Mounted Cueing Systems (HMCS) aligned with High-Angle Off-Boresight (HOBS) AAM – such as ASRAAM and AIM-9X, which are currently in use – could militate against the need for this type of combat.[12]

Fifty per cent of interviewees believe a UCAV will not need to be highly agile in 2040, while 25 per cent have stated that it will be, with no caveats. Fifteen per cent believe it will be desirable, while 20 per cent want it for survivability reasons, having the ability to conduct defensive manoeuvres against SAM or AAM systems. Thirty per cent of interviewees believe a manned fighter will not need to be highly agile in 2040, while 24 per cent have stated that it will be, with no caveats. Thirty-two per cent believe it will be desirable, and 14 per cent want it for survivability reasons, having the ability to conduct defensive manoeuvres against situational SAM or AAM. Forty-seven per cent of interviewees believe it will not be necessary for a UCAV to be able to conduct highly agile close combat in 2040, while 27 per cent have stated that it will be, with no caveats. Twenty-four per cent believe it will be desirable, and 2 per cent want it for survivability reasons, having the ability to conduct defensive manoeuvres against SAM or AAM.

Twenty-five per cent believe that both a UCAV and a manned fighter will need to be highly agile. While this view is consistent, the differential for not requiring high agility, 50 per cent and 30 per cent, respectively, is interesting. The difference being that most interviewees believe that weapon systems should be able to prevent the UCAV from needing to engage in this type of fight. The views on the requirement for a UCAV not to be highly agile are more consistent, although only one interviewee believes it is important for self-defence. The overall result is that approximately 70 per cent believe a manned fighter will need to be highly agile, while only 50 per cent believe a UCAV will need to be so. This begs the question: why is this not the case for a manned fighter? Would the same weapon systems not be available?

The overarching attributes that the interviewees believe a UCAV would require vary. The most prominent of these is reach/endurance/persistence, followed by speed, the ability to use the full height envelope, stealth and agility. Endurance and reach will be the fundamental strengths of UCAS; the ability to fly at high altitude and speed is also an important consideration. Although stealth was not the top requirement, it is interesting to note that, in the responses to a different question, 63 per cent of interviewees view stealth in 2040 as crucial, 30 per cent as desirable and 7 per cent state that it will not be crucial. Most believe that stealth will play an important part, but it will need to be in all domains, not just the RF but also in the IR and visual spectrums. In an interview in 2010 with the RAF's Chief of the Air Staff (CAS), Air Chief Marshal (ACM) Sir Stephen Dalton stated that he believed that stealth will continue to be crucial.[13] His predecessor, ACM Sir Glenn Torpy, is of the same opinion although he caveats that stealth needs to be balanced against the requirements for agility and speed.[14] Air Marshal (AM) Christopher Nickols, the 2011 Chief of Defence Intelligence and a former Commandant of the RAF's Air Warfare Centre, views future stealth as important but not in its present form.[15] A former RAF Commander-in-Chief Air Command, ACM Sir Simon Bryant, believes stealth, persistence, height and weapon systems to be the critical capabilities for future UCAS.[16]

A common belief is that an adversary's situational awareness will need to be destroyed by whatever means necessary, whether by stealth, cyber, EA or a combination. Overall, 63 per cent of interviewees believe it will be a crucial requirement for a UCAV to have stealth attributes, with 30 per cent viewing it as highly desirable. Seven per cent believe that it will not be crucial. The F-22 has been designed with stealth in mind.[17] The forthcoming F-35 Joint Strike Fighter (JSF) also has stealth as a significant part of its design. However, is stealth the panacea? Will future adversaries develop counter-stealth technology that render the present advantage void? Is there a cost–benefit trade-off with other systems or airframe characteristics? Fundamentally, it appears that some interviewees may be viewing stealth as the solution to all the problems with which an advanced IADS can confront combat aircraft. Stealth technology will remain important, but how much is debatable.

Ethical and political implications

Issues concerning the ethics of using autonomous systems to enforce government policy, including interstate warfare and the political implications surrounding any decisions to do so will need to be addressed, particularly before any decisions on procurement are made. These issues are currently causing debate within academia and governments worldwide. It is worth remembering, however, that these types of systems have been used for centuries. Bombs, artillery, cruise missiles, ballistic missiles and AAM are all unmanned, of course, but should these be regarded as being in the same family of systems as UAS/UCAS? Nonetheless, there is certainly some deliberation on whether it is ethical to use UAS in warfare. One common view is that it gives an unfair advantage. Another is that it shows that a country is not prepared to risk its own people in warfare, thus taking the moral 'low-ground'. These are questions worth debating. A just and moral cause has been part of societies' principles for many hundreds of years. But would any nation consider not using technology because of moral concerns when an adversary did not have these concerns, thereby offering them an operational and strategic advantage – particularly if national survival was at stake?

It is emphasised that this book is, in the main, researching the role of UCAS gaining control of the air in its purist sense – specifically in air-to-air engagements. The counter-air roles of SEAD and strike will, by their nature, incur more debate concerning collateral damage and civilian casualties. If the perceived thinking is that there is a huge ethical ambiguity in using these systems, will this skew development and procurement of UCAS? In the first instance, it needs to be established whether there are really any major issues or if this is just the perception of a few. The views of senior RAF and USAF commanders are particularly pertinent. ACM Dalton stated he 'has no moral concerns, however, society has a way to go before accepting an autonomous war-fighting/killing system'. AM Nickols is neutral, opining that '[we] are already using UAS and [are] tackling moral and political issues'. ACM Torpy believes that it is 'a moral component that hasn't been fully investigated, and needs to be thought through by policy makers . . . [it] depends on willingness to accept political risks'. ACM Bryant believes, 'Checks on C2 will need to be rigid. [It will be] driven by levels of confidence in the system. [I am] concerned if it doesn't work, [which] would inhibit utility. If all of this is satisfied, then it is morally OK . . . if politicians can be satisfied, then it is OK.' At the other end of the spectrum, perhaps, are the views of younger officers and aircrew. Flight Lieutenant Jonathan Skinner, a 26-year-old RAF pilot, with approximately 350 hours on the Tornado F-3 and 200 hours on the Typhoon, believes, 'It [UCAS] would just need extensive testing . . . A decision matrix can be inputted into UCAS as easily as trained into a pilot. The necessary human input is just at the programming stage.'[18] Colonel Gaillard Peck USAF (Retd), a vastly experienced US fighter pilot, having flown in the Vietnam War, and one of the founding members of Exercise Red Flag, simply states, 'Go for it! There is no substitute for victory.'[19] Major General Lawrence Wells, Commander 9th Air Force in 2013, has 'no issues, as long as the ROE considers collateral damage [sic]'.[20]

The emphatic response to this question is that there seems to be little concern on ethical or political issues, overall, in the future utility of UCAS. Eighty-six per cent of interviewees have no issues, with 14 per cent having some reservations. It could be argued that those interviewees that have no issues have not thought through the implications of this technology. However, most have direct experience with combat operations and some have been air component commanders during conflicts, responsible for the conduct of all air operations. Others have operated UAS in Iraq and Afghanistan, while most aircrew are immersed with the doctrinal and collateral damage issues of large wartime missions.

That is to say, their views, including those of senior officers, need to be considered. Most civilian interviewees have no concerns, with 17 per cent having some issues – broadly in line with military interviewees. A British army lawyer familiar with the Law of Armed Conflict (LOAC) stated that the ethical and legal implications for the use of UCAS are no different from those applicable to any weapon system. The LOAC will still need to be applied, and it is there to protect the person authorising the mission, as well as the civilian population and infrastructure.[21] It is apparent that military aviators and RAF commanders have a practical view of the future utility of UCAS. If operated within the LOAC, then the overwhelming majority do not have concerns.

Is the manned fighter necessary and could UCAS gain control of the air in 2040?

The main purpose of the interviews was to garner views on whether a manned fighter was necessary, or if UCAS could perform the full gamut of combat air tasks by 2040. Two questions were asked – both similar. 'Will it be crucial to have a pilot in the cockpit, or will a semi-autonomous UCAS, or a fully autonomous UCAS, be able to gain control of the air, in 2040?' Also, 'Would a UCAS be able to effectively conduct counter-air missions in 2040?' These two slightly different questions were asked to establish whether there was consistency in opinion if the term pilot was introduced into a question.

Overall, 98 per cent believe UCAS could conduct counter-air missions, with 1 per cent stating that it cannot, and 1 per cent not being sure. Senior commanders' views are worth highlighting: ACM Torpy believes UCAS could, as do ACM Bryant and AM Nickols. ACM Dalton sees no reason, in principle, why UCAS could not effectively conduct counter-air missions – it will rely on sensors, both off- and on-board, and NEC. Major General Wells states, 'Yes, but with caveat. We need a man-in-the-loop. This is the future.' Flight Lieutenant Skinner, our archetype junior fighter pilot, simply states: 'UCAS will be effective counter-air systems and that pilots will not be required by 2040.'

Summary

This is a relatively short summary of interviewee responses, as in general, the answers were either yes or no. A large proportion of the interviewees are knowledgeable about air power, both in theory and practice; others are experts in the technological aspects of counter-air warfare. While not providing proof that UCAS could conduct all counter-air roles by 2040, the responses support the hypothesis that it is at least worth investigating the potential for UCAS that are capable of gaining control of the air. Ethical and legal issues also require some thought; it is evident from the responses to the questionnaire that there is little compunction against their use if the LOAC is adhered to. Likewise, recruitment concerns do not appear to be thought a major issue, for the moment at least. Ultimately, examination of expert opinion and technological capabilities, aligned with a review of international relations, and analysis of the questionnaire have informed the findings of this book. The following chapters examine these issues in depth.

3
Overview

UCAS background

UCAS may eventually be capable of the full gamut of air missions, including ISTAR, Air-to-Air Refuelling (AAR), perhaps even autonomous AAR from one UCAV to another, Strike Control and Reconnaissance, Close Air Support, SEAD, interdiction, EA and conceivably control of the air in its entirety, including Defensive Counter Air (DCA) and Offensive Counter Air (OCA) missions.[1] One of the greatest advantages UCAS can have is a small Radar Cross Section (RCS), if Low Observable (LO) technology is used.[2] UCAS could have long endurance, enabling persistence and availability, and with no aircrew allowing operations in a toxic environment. Mitigating the effects on aircrew may be a partial driver, but it is the potential reduction in procurement and life cycle costs, and the capability to persist on task for periods currently not capable by manned fighter aircraft, that will be the main reasons for their usage. Human endurance has historically limited fighter sortie duration to approximately 10 hours.[3] A report from the US DoD's Defense Advanced Research Projects Agency states: 'a UCAV weapon system has the potential to fully exploit the emerging information revolution and provide advanced airpower with increased tactical deterrence at a fraction of the total life cycle costs of current manned systems'.[4]

The relatively recent advent of UAS, such as the Predator, is now considered an essential part of the utility of air power. Recent UAS Counter Insurgency (COIN) operations in Iraq and Afghanistan have concentrated on ISTAR and Close Air Support capabilities, with Intelligence, Surveillance and Reconnaissance (ISR) missions in the Arabian Gulf. More strategic missions will require attributes that current UAS do not possess. Although UAS are capable of conducting ISTAR and strike missions, they are not currently survivable in highly contested airspace. For example, in November 2012, Iranian Su-25 Frogfoot aircraft unsuccessfully attempted to shoot down a US Predator UAV. Subsequent Predator missions have been escorted by US fighters. An Iranian F-4 attempted to engage a Predator in March 2013, but was warned off by a US escorting fighter.[5] This is a classic example of how vulnerable UAS, that are unable to protect themselves, will be in contested airspace. The current perceived view is that strategic UCAS will need to have LO characteristics – this capability is an obvious advantage and will perhaps be their greatest asset, but it significantly increases the cost of a UCAS and, while enabling greater penetration of an adversary IADS, also imposes design limitations. Importantly, this very asset will drive counter-LO techniques, potentially mitigating any benefit gained. For example, the development of multi-static and bi-static radars may offer a potential counter to LO technology.[6]

UCAS capable of conducting these combat air tasks, while operating with a high degree of survivability, are being developed by the US, UK, France, Russia, China and other nations. The US Navy's (USN) UCAS – Northrop Grumman's X-47B UCAS-D programme, which has replaced the USAF's Joint-UCAS effort, aims to demonstrate the technical feasibility, military utility and operational value for a networked UCAS.[7] As part of the overarching UCLASS programme, the X-47B first flew in 2011, with trials from carriers beginning in 2013, for an anticipated in-service date of 2020.[8] This programme was instigated by the Deputy Chief of Naval Operations for Information Dominance. The USN has identified a requirement 'for an aircraft carrier based aircraft system providing persistent ISR and strike capabilities that will enhance the versatility provided by an aircraft carrier'.[9]

Already mentioned, the UK is developing the *Taranis*, a UCAS risk-reduction demonstrator, while a European consortium is developing the *Neuron* system.[10] Russia unveiled the *Skat* UCAV at the 2007 Mezhdunarodnyj Aviatsionno-Kosmicheskij Salon (MAKS) Air Show, and although not much was heard of it again until 2011, Russian aircraft manufacturers MiG and Sukhoi announced in the same year that they will be working jointly on the *Skat*.[11] China is also known to have its own UCAS programme, the *An Jian (Dark Sword)*, which has been shown as a mock-up at the 2006 Zukhai Air Show.[12] These systems will likely begin to enter the service of these nations in the 2020–2025 epoch.[13]

The fundamental understanding of the components that comprise a UCAS, and the types of roles that these systems may be able to undertake, is essential when attempting to analyse any utility that these weapon systems may have in future warfare. Strategic UCAS that have stealth characteristics are being developed in both the IR and RF spectrums, and while enabling greater penetration of enemy defences it also imposes design limitations. Significantly, UCAS will not be stealthy in all RF spectrums. Older Very High Frequency (VHF) search radars, updated with the latest computing hardware and software, are able to detect current platforms, such as the US F-22 Raptor. Although the range at which these are detected is still somewhat less than that of third or fourth generation non-stealth aircraft, it may be enough to direct counter-air assets to intercept and destroy any hostile aircraft.[14] Open source material is available which highlights the significant advances that the Russians and Chinese have made, particularly in the areas of IADS and counter-stealth technology.[15] The requirement to analyse these capabilities is central to understanding the requirements that UCAS will need in order to dominate the airspace in future warfare.

Future threat environment

Historically, for every new military capability established by nation-states, their potential enemies will inevitably attempt to counter any such advantage. Predicting future wars is extremely difficult, and as Clausewitz observed, 'No other human activity is so continuously or universally bound up with chance.'[16] It is self-evident, however, that there will always be potential threats; identification of such threats and their resources is continually analysed by government agencies and policy institutions. At some point, it becomes necessary to make certain assumptions; these will then drive governments' defence procurement and scientific development policies. Some developing nations are on the brink of economically entering the developed world, all seeking access to the raw resources that stimulate development. The West's current focus is on irregular warfare; while this type of conflict is likely to be ongoing for some time, possibly indefinitely, circumstances may drive nations to believe that the only way to survive, let alone prosper, is to instigate conflict in order to establish dominance over natural resources. A lack of natural resources, whether for manufacture or sustenance, may prove crucial. A resurgent Russia, or an economically powerful and resource-hungry China, aiming to establish hegemony within their spheres of influence, may dictate future governments' defence policies. Not least, containing Iran's nuclear ambitions will continue to test international relations. How will these threats be countered? Will the character and nature of warfare, forcing operations over long distances be such that UCAS are the only viable solution to gaining control of the air?

Technologies

Threat systems continue to evolve and potentially hostile regimes are able to obtain sophisticated military hardware, relatively easily. It should be possible to estimate the extent of their capabilities. How they are deterred and, if required, defeated is not so easily achieved. The types of systems required to carry out nations' aspirations will depend on a range of scenarios. If range and endurance are required, systems will need to be procured accordingly. In the years before World War II, the US faced choices between procuring more short-range assets and opting for sea and air systems with greater range – the latter helped win the war. The US' current and likely future security responsibilities in the Western Pacific offer a similar scenario. An editorial in *Defense News* emphasised that: 'The U.S. is shifting its strategic focus to Asia, where allies worry about rapid military rise and increasing assertiveness. Boosting U.S. regional presence is key, but the Pacific is a vast theater and distance is a tyrant.'[17] The types of weapon systems required to meet this challenge will test current doctrine.

The paradigm has shifted. A fundamental rethink is taking place in the way C2 is conducted, and the ways in which military objectives are achieved. Significant advances in capabilities, together with flexibility in force employment and improved efficiency, will result in a vastly increased ability to achieve the desired outcome. It can be argued that technology offers military forces a solution to solving the difficult tactical and operational conundrums posed by future wars. Whether this is correct or not, the dramatic results of recent military operations indicate a major expansion in military capabilities. Advances in a broad range of technologies have begun to enable the integration of joint forces not previously possible.

Future US air doctrine will be NEC-centric, probably utilising stealth technology as a key enabler.[18] TDL are a fundamental part of NEC; these are utilised by air, sea and land forces, enabling Joint Fires (the delivery of an effect using a combination of platforms and systems, whether ground, sea, air or spaceborne), particularly by US and UK armed forces. The US F-22 Raptor air supremacy fighter is, currently, the only fifth-generation stealth aircraft of its type, but how long will this last?[19] The F-22 may be very manoeuvrable, certainly superior to any other comparable aircraft; however, the question remains, is this of any significance? If it is not, then what are the prerequisites of a future counter-air aircraft? Is it speed, manoeuvrability and endurance or is it stealth and NEC, or a combination of these? The importance that EA capabilities and defensive countermeasures have in future air power scenarios will also be of enormous significance. Advances in technology will continue to allow weapon systems to develop, and a 'system of systems' may be capable of achieving the desired effect. An understanding of what might be achievable, and an ability to appreciate the 'art of the possible', is required of a state's military and political commanders. There continues to be a dramatic expansion in computing technology. 'Moore's Law' states that computing processing power doubles approximately every 24 months. This principle has been proven correct, thus far; indeed, the video gaming industry is taking the lead in developing processing capabilities. Understanding the significance of this is vital, with future improvements in processing power potentially increasing in excess of the rate stated by 'Moore's Law'.[20] This expansion in processing power will be crucial for almost all future technological advances.

Aerial warfare

Most major conflicts since World War II have involved some form of aerial warfare. The Korean War, the Israeli/Arab conflicts of 1967 and 1973, the Vietnam War, the 1982 Israeli/Syrian Bekaa Valley conflict and the 1982 Falklands War involved air-to-air engagements, some of which required aggressive visual manoeuvring in order to engage and kill an adversary, employing either short-range IR AAM or AAG. However, since the 1980s, in conflicts such as the 1991 Gulf War, Bosnian and Kosovo Wars, most successful airborne engagements have been conducted BVR with RF AAM, or WVR with RF and IR AAM (see Chapter 6).

The US F-35 JSF is being procured as a replacement for the F-16 Fighting Falcon and other aircraft. While it is relatively manoeuvrable, it is not in the same league as the US F-22 Raptor, UK Typhoon, French Rafale or the Russian Su-27 Flanker and MiG-29 OVT Fulcrum fighters. A project such as the JSF is highly classified, with much of the information on its capability not available in the public domain. For the moment, let us assume that the JSF is capable of at least defending itself in a high-threat environment against an air-superiority platform. How much research, development and expense should there be towards an air vehicle, whether manned or unmanned, which is capable of pure 'dog fighting' – that is, highly manoeuvrable visual air combat? It is arguable whether this ability to out-manoeuvre fighters is relevant in an era when long-range BVR AAM capability is of such importance. It is perhaps surprising, therefore, that current Western, Chinese and Russian fighters strive for an ability to obtain a maximum sustained and instantaneous turn performance, which are the most important attributes for fighters in the visual air-combat environment.[21] This area is one of the core questions of whether UCAS could successfully conduct counter-air operations in future warfare.

The more advanced an adversary's counter-air capability, the more important gaining and maintaining control of the air, and the more sophisticated a force's own counter-air capabilities requires to be. Having freedom from attack and freedom to attack are the fundamental principles of control of the air. The ability to conduct the full range of air operations, unhindered, against enemy forces is vital; it enables the safe deployment, resupply and protection of those forces once deployed. This concept of aerial warfare has been validated since World War I. In future warfare, will it be possible for UCAS to conduct these combat roles and accept most of the risks that thus far have been the lot of military aviators, in particular the counter-air role? Control of the air was quickly gained in Iraq, and in Afghanistan it was essentially a given from the beginning of operations. However, there is a risk of forgetting the lessons of previous conflicts: if control of the air is not gained, a campaign is likely to fail. The Libya campaign of 2011 reinforced the importance of air power, and was an exemplar of how air power, on its own, virtually attained the required outcome. Control of the air was quickly gained by a coalition led by the UK and France, and with a great deal of aid from the US in terms of initial strikes from combat aircraft, cruise missiles and support assets, including intelligence, planning and material support, enabling coalition air forces to conduct operations essentially unhindered.[22] It was the destruction of the Libyan IADS and attacks on the Libyan regime's centres of gravity that eventually enabled the Free Libyan Forces to defeat Gaddafi's forces. Libya's IADS was not an example of a highly integrated system, however. It was basically eliminated within 72 hours.[23] Other potential adversarial states – for example, Syria, Iran and China – with access to more modern and lethal sensors and weapons, will offer stiffer resistance with China, particularly, presenting a formidable counter-air threat.[24]

US UAS roadmaps

As already mentioned, the US has published a number of UAS developmental paths, setting out its vision for the employment of unmanned systems, including ground, sea and air. Two of these official publications are particularly pertinent to UCAS development: the *Unmanned Aircraft Systems Roadmap: 2005–2030*, published by the Office of the Secretary of

Defense, and the *USAF Unmanned Aircraft System Flight Plan 2009–2047*. The *Unmanned Aircraft Systems Roadmap* states: 'The overarching goal of this Roadmap is to guide the Department towards a logical, systematic migration of UAS mission capabilities focused on the most urgent warfighter needs.'[25] In 2009, the then Secretary of the USAF, Michael B. Donley, and the USAF Chief of Staff, General Norton Schwartz, signed the *USAF Unmanned Aircraft System Flight Plan 2009–2047*. This *Flight Plan* is the USAF's own vision for the development of UAS. It details an 'actionable plan' for UAS/UCAS and sets out the USAF vision for the implementation of UAS/UCAS into its service in 2047.[26] The USAF's vision emphasises the attributes of persistence, speed of reaction, potential reduced costs and automation.[27]

The *Flight Plan*'s emphasis of the man-on-the-loop, and the range, reach and lethality of combat operations requirements, captures a number of fundamental premises of this book. Comments by General Mike Hostage, commander of the USAF Air Combat Command, in December 2012, offers an insight into the current US thinking on the utility of UAS/UCAS; he gave his view on the applicability of current UAS developments, and what would be required for future high-intensity operations. Speaking to reporters, Hostage stated:

> We are now shifting to a theatre [the Western Pacific] where there is an adversary out there who is going to have a vote on whether I have that staring eye over the battlefield . . . and [I am] pretty certain they are not going to allow that to happen . . . The fleet I've built up, and I'm still being prodded to build up too, is not relevant in that new theatre.[28]

Hostage believes that the USAF will have to adjust its force structure to meet the demands of the Pacific theatre. He also said that 'the USAF has no intention of backing away from the capability unmanned aircraft bring and the "new style of warfare" that they enable'.[29] A prescient point of view, perhaps, or is Hostage merely stating the obvious, that is, the present crop of UAS designs will not survive in the type of scenarios envisaged in the Western Pacific and further afield.

Bringing all of the UAS 'roadmaps and plans' together, is the US DoD's 2011 *Unmanned Systems Integrated Roadmap FY 2011–2036*. Now in its 3rd edition, it was first published in 2007, and has evolved into a document that focuses on the issues faced by all US Armed Services, setting out a vision that acts as a single, unified source.[30]

The UK MOD seems to be somewhat behind the US in its UAS/UCAS developmental philosophy.[31] While there are no equivalent UK UAS roadmaps in the public domain, one strand of the RAF's recent Deep and Persistent Offensive Capability (DPOC) study examined the feasibility of UCAS as a replacement for the GR-4 Tornado bomber.[32] When interviewed in 2011, ACM Sir Glenn Torpy, the RAF's Chief of Air Staff, stated he believed that, due to their potential capabilities and cost benefits, UCAS will become a prominent part of the RAF's inventory.[33] The UK's MOD is also looking at a range of options for its future combat air power; a part of the Future Combat Air System programme is a France/UK study, which is considering the potential use of UCAS as a replacement for some currently manned platforms.[34]

Autonomy or automation?

The term autonomous is often used when referring to the operation of UAS/UCAS; this has caused some concern among certain sectors of the military and media, with the belief that the use of autonomous UAS would not be acceptable in some scenarios. The debate over the meaning of autonomy is ongoing. The UK MOD Development, Concepts and Doctrine Centre (DCDC) defines an automated system as a system 'in response to inputs from one or more sensors, is programmed to logically follow a predefined 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.'[35] The Oxford English Dictionary (OED) defines automation as: 'Like the action of an automaton; unintelligent, merely mechanical; done without thought, unconscious; occurring as a matter of course without debate. Working by itself, without direct human involvement.'[36] An autonomous system is described by DCDC as: '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.'[37] OED defines autonomy as: 'Freedom of the will. Independence, freedom from external control or influence. Personal liberty. Self-governing. Free to act independently.'[38]

A report for the US Office of Naval Research defines autonomy as: 'The capacity to operate in the real-world environment without any form of external control, once the machine is activated and at least in some areas of operation, for extended periods of time.'[39] The *Commentary on the HPCR Manual on International Law Applicable to Air and Missile Warfare* defines autonomous UCAV as: 'Autonomous action means that the unmanned aircraft has sensors and an onboard data processing capability to make decisions to attack according to a computer program.'[40]

The Office of Naval Research report's view of autonomy comes closest to my vision of UCAS employment, but this is still only a high level of automation. DCDC describes automation as: 'its output is predictable'.[41] It should be expected that any weapon system's output is predictable, when working correctly. Similarly, a pilot's output should be predictable, as would be UCAS'. Even an adversary's actions should be predictable, within defined boundaries. This is not in the sense that adversaries' actions can be predicted; but it does mean that 'systems' will follow a set of rules, defined within pre-programmed matrices, while manned systems will use tactics and procedures that are constrained by the laws of physics and convention. Unpredictable actions should not be confused with a pilot, for example, who carries out a manoeuvre that allows him to defeat an adversary in air-to-air combat, one that his adversary was not expecting. This manoeuvre would not be invented on the spot: it would be one that was within the pilot's skill set, one that had been practised or one that would be the best manoeuvre for that situation. It may seem unpredictable to the adversary but, in reality, it is in the bounds of what the pilot and the aircraft could actually do – within the bounds of tactical doctrine and the laws of physics. Strict convention would have been followed to achieve the best result. Manoeuvres made up on the spur of the moment, invariably lead to a suboptimal situation. Major Robert Trsek USAF, himself a fighter pilot on F-15Cs, believes automation is the way forward: 'automated [basic flight manoeuvres] can provide far superior maneuvering against the majority of pilots the world over'.[42] It seems that even some UAS autonomy industry experts now acknowledge that what they really mean by an autonomous UAS is not a truly autonomous system. It was acknowledged at the 2012 Autonomous Systems Technology Related Airborne Evaluation & Assessment Conference that the UAS industry 'had not done itself any favours with its choice of [autonomy] terminology'.[43]

In summary, I define 'Automatic Systems' as systems which use pre-programmed instructions, however complex these may be, aided by Artificial Intelligence (AI) software. 'Autonomous Systems' are defined as systems that make decisions which are not based on specific directions from pre-programmed instructions, but more random decisions based on their own interpretation of influences. I use the term 'autonomous', acknowledging that 'a high level of automation' is more accurate and also argue that it is actually how UCAS would be utilised. It is probable that UCAS will only act 'autonomously' when communications links are lost, and then only in the sense that there is no human input into its decision-making, but as the decision-making is based on pre-programmed instructions, the UCAS will still be in automation mode. This is an important distinction, as it should help both military and political decision-makers understand the legal boundaries within which new weapon systems are required to operate, according to the LOAC.[44] Whatever interpretation is used, automatic/autonomous systems are already in the inventory of most militaries. Cruise missiles, anti-radiation missiles and AAM are just some examples of weapons systems that once launched use on- or off-board systems to continue to seek their target, independent of the launching platform. The US AEGIS SAM sea-based system and the Patriot SAM land-based system have been in service since the 1970s/1980s.[45] Both of these systems are intended to be operated automatically in an environment that requires engagement decisions to be made more quickly than those by a human.

The one-seat versus two-seat debate

A USAF Advanced Staff College paper states, 'Airmen provide the flexibility and adaptability that is synonymous with airpower. UAVs will play a large role in our future but airmen will be required to ensure that UAVs are employed correctly and manned aircraft will be vital for dealing with the uncertainties of war.'[46] Previous arguments have questioned the requirement for one-seat versus two-seat. This question has divided air forces on both sides of the Atlantic. Are we now on the cusp of any aircrew being required at all?

Since the beginning of manned flight, pilots have been regarded as pivotal in the flying and operating of powered aircraft. Since the Wright brothers, other innovators have added to the surge in aviation progress, with subsequent developments leading to aircraft capable of the full gamut of civil and military tasks: including transport, AAR, reconnaissance, bombing and air-to-air combat. Over time, other aircrew skills were required to help facilitate the ever-increasing complex requirements that flying *per se* required, particularly in military scenarios. These have included navigators, bomb aimers, observers, air engineers, air signallers, air electronic operators, radio operators, air gunners and, latterly, WSO. Some of these airborne professions are now redundant, at least in those air forces equipped with modern aircraft and systems.

As technology has developed, the role of the navigator and other associated airborne professions has become less crucial. The change of professional status from navigator to WSO was an attempt to capture the many functions for which a navigator was responsible, with navigation being just one part. Now defunct, the role of an air defence navigator, for example, was always more of a battle manager, manipulating the air-to-air radar, the Link-16 based Joint Tactical Information Distribution System (JTIDS) – a TDL system – and other avionic systems, while directing the pilot of his aircraft, and other aircraft and crews in his formation, to a position where engagement of adversary aircraft could take place, hopefully with some advantage. This was, more often than not, much harder to achieve than one would suppose. First, the adversary had to be detected, which could be challenging, especially when airborne sensors, such as radar, were not capable of detecting aircraft in a heavy clutter environment, created by ground returns and Electronic Warfare (EW) techniques.[47] If an adversary was attempting to achieve the same aim, while utilising EA techniques, such as Digital Radio Frequency Memory (DRFM) jammers, against detection systems to confuse the air picture, engagements could be prolonged affairs, not always resulting in mission success.[48] In training scenarios, this produced battered egos at best; in real-world operations, it could have catastrophic consequences at worst.

Some advocates of the single-seat fighter use cockpit confusion as a reason against two-seat operations; it is also advocated that it does not take two men to handle the workload. The cockpit confusion objection to a two-seat fighter rests on concern that the need to take votes between cockpits delays the decision-making process.[49] Another pro-single-seat argument is that, although there are many tasks, they do not all come at once; therefore, a fighter pilot should be able to do them. However, while it is possible for one man to perform most tasks in a benign counter-air environment, it is an entirely different matter in poor weather, at night, when one's own systems are being jammed by EA.

Improvements in radar and other sensor technology, aligned with increases in computer processing power, have meant more automation can be incorporated into weapon systems, particularly radars. This has allowed the better-designed fighters to dispense with the navigator/WSO. There have been concerns and problems along this developmental path, however. Nonetheless, fighters such as the F-22 Raptor, F-15 Eagle, F-16 Falcon, F-18 Hornet, Typhoon and Rafale, and the Russian Su-27 Flanker and MiG-29 Fulcrum, are all predominantly single-seat. Where there are two-seat versions of these aircraft, they are designed for use mainly in the air-to-surface role, concentrating on the EA and SEAD tasks, against sophisticated IADS.[50] These missions have traditionally necessitated a heavier workload on aircrew, which, until quite recently, meant two-seat FJs have been required to achieve the task. On the other hand, the single-seat F-15C has proven to be an immensely capable air-superiority fighter. Flown by, amongst others, the US and Israel, it has achieved a kill ratio of 105.5:0 in conflicts in the Middle East.[51] The F-22 Raptor is acknowledged as the pre-eminent fighter flying today and the only fifth-generation fighter that is operational.[52] The F-35 JSF is publicised as being capable of achieving all combat air power tasks. Both of these aircraft are flown and operated by a single pilot.[53] Whether operated by a single pilot, or more aircrew, recent conflicts have seen strategic decision-making to be made by the aircrew during sorties, due to lack of communication with their C2.[54] This is an important consideration; if unmanned air systems are to be utilised, mission-critical decisions will need to be made autonomously at times. If unable to do so, whether for technical reasons, or a lack of willingness by commanders, the roles of UCAS will be severely curtailed.

Along with the trend towards single-seat aircraft operations, doctrine and tactics have evolved to take advantage of the transformation evolution that technological advances have allowed manned flight to utilise. What advances in flight does the future hold? With the demise of non-pilot aircrew, will advances in aviation systems mean there will be fewer requirements for pilots? The evolution of flying continues. Other than the actual act of flying an aircraft, historically, navigation has been deemed critical to mission success. For much of the history of flight, accurate navigation has proven somewhat problematic, especially until the advent of inertial navigation systems, and, significantly, satellite-based navigation systems. Is technology just following a natural trend which means that computers and associated avionic systems will do the required task more efficiently? Are we now coming full circle, where navigation accuracy and the precision of weapon delivery is by far the predominant requirement for combat air power?

The Gulf Wars of 1991 and 2003, and COIN operations in Afghanistan and post-war Iraq, have demonstrated the vital role that precision weapon delivery plays in modern warfare. Russia and China have taken note of these advances in weaponry, and have been making steady advances in their development of comparable systems.[55] The primacy of navigation, and all that the mastery of it brings, is now, arguably, firmly established as the priority of any nation that wishes to have, and use effectively, a military force. The fact that pilots have historically been required to fly aircraft that facilitate achieving the requisite military task should not be a driver for future doctrine, tactics or procurement. Technology now allows greater time, effort and resources to be focused on systems that will not require a human interface in an aircraft. With the demise of the two-seat fighter and the development of UCAS, capable of undertaking ISTAR and SEAD roles, considering their use in counter-air tasks seems a reasonable step.

Potential cost benefits

Aircrew in high-performance aircraft, capable of sustained high 'Gravity' (G) manoeuvring, can suffer marked physical effects. A UK study concluded that: 'Good evidence is available to show that aircrew of high performance aircraft will experience degeneration of the cervical spine during their career which is greater than that observed in the normal population.'[56] Although the preservation of aircrew is undoubtedly important, it is questionable whether this will be paramount in any decision on UCAS development. The capability to operate longer than manned aircraft and maintain persistence are attributes that make UCAS very attractive. It is these attributes, and the economics and effectiveness of a system, including the cost of training aircrew and associated Through Life Costs (TLC), which are likely to affect decisions on procurement and capability. UCAS may well offer a significant TLC advantage over a manned system. Notwithstanding that manpower will still be required to operate an autonomous system, taking aircrew out of the equation could mean substantial savings. The cost of training an RAF Typhoon pilot to a point where he/she can start training on an operational squadron, for example, is £4 million as of 2008.[57] Further training to actually become, and remain, capable of conducting operational tasks would be considerably more, perhaps as much as £9 million overall. This is based on the capitation cost (the calculation used for overall cost) of the RAF Typhoon being £92,000 per hour, with it taking approximately 60 hours of further training on a squadron before a Typhoon pilot becomes fully operational.[58] Once operational, a Typhoon pilot currently requires 180 flying hours a year in order to undergo training to remain operational.[59] The operating costs of a UCAS would be significantly less, essentially because the UCAV remains on the ground, containerised, unless or until it is actually required for operations, or maintenance procedures.[60]

The cost of personnel normally forms the largest part of a country's military budget. For example, the actual cost of employing a relatively junior RAF officer, a flight lieutenant, is calculated using their annual salary, plus other associated costs. In 2011, an RAF flight lieutenant pilot was paid on average £50,000, including flying pay.[61] The actual capitation cost includes annual salary plus pension contributions (Superannuation Contribution Adjusted for Past Experience) – for officers this is 42.8 per cent for FY 2011/12, plus Earnings Related National Insurance Contributions at 7.7 per cent, plus housing, uniforms, training and other associated costs at 25 per cent.[62] This brings the average annual capitation cost for a junior officer pilot to £87,800. The range of personnel costs varies according to rank; however, it can be broadly seen that by reducing manpower, costs can be significantly reduced.

A substantial cost saving in training and personnel can be gained by the use of simulation. Advances in this area are creating opportunities for improvement in training that were previously not thought possible. Most of the training and currency requirements could be achieved through Distributed Mission Training (DMT) systems. Although the UK uses a number of these types of training systems, it is the USAF that has been at the forefront of its development, with its Live, Virtual and Constructive (LVC) Integrating-Architecture (IA) (LVC-IA) Plan. USAF training specialists believe that the increased use of simulators and the ability to connect simulators and/or aircraft at dispersed locations, and new applications of LVC, are essential, allowing fifth-generation pilots to acquire the required skills, enabling training risks to be minimised.[63] LVC simulations allow aircrew and other personnel to conduct training to an extremely high level of fidelity, and at significant cost savings. These systems may actually allow for better training – by offering the scenario that everything always works – aircraft, weapon systems and C2 all work, and the weather is suitable – but, if required, effectiveness of individual systems and weapons could be degraded, to simulate austere operating conditions. This is preferable to the haphazard way in which most live-flying training is currently conducted, where the vagaries of system serviceability and the whims of the weather have a significant impact on the value of training – at great wasted cost, and, ultimately, operational effectiveness. There is a balance to be maintained, of course; however, technology advances should allow for the utilisation of these systems to greatly enhance the effectiveness of all air operations, including the use of UCAS, with associated cost savings.

Leadership challenges

Will future leaders of the military flying cadre have the necessary qualities to lead if they have never flown a military aircraft, let alone flown in combat? Indeed, would it be necessary for any of the operators of a UCAS to be combat-experienced aircrew? The once pilot-centric command hierarchy in the RAF is changing. The 2011 RAF Commander-in-Chief of Air Command, the second most senior officer in the RAF, was a navigator. The commander of the new UK Joint Forces Command, announced in 2011, was also a navigator. The 2nd edition of UK MOD's *AP3000: Air Power Doctrine* emphasises the importance of leadership, stating, 'Leadership can take many forms and styles both in the air and on the ground, but invariably includes professional mastery and moral courage.'[64] Although it is not emphasised in current publications, this is still pertinent. ACM Sir Stephen Dalton believes that air power's significance is being diluted by a lack of understanding. Addressing a conference at the International Institute for Strategic Studies (IISS) in 2010, ACM Dalton stated:

> I would contend that air power is, and must be, our comparative advantage over potential opponents in future conflict. So success depends on our ability to exploit this critical advantage, through mastery of its capabilities by people who have the knowledge, professional expertise and competence to apply that advantage. Such mastery requires years of training, and our advantage must not be squandered by non-experts who do not really understand the third dimension – or relative and space advantage – that mastery of the air can deliver.[65]

ACM Dalton's views are relevant and hard-hitting; they get to the crux of the general malaise in the understanding of the attributes of air power, and should be a reminder to military leaders in all disciplines and academics alike, that it is imperative to understand the dynamics of air power. The relevant skills are not easily gained, or maintained. This is axiomatic for sea and land power. Notwithstanding the prescience of Dalton's comments, would it be possible to have a Chief of the General Staff who has not led soldiers in the field, or a Chief of the Naval Staff who has not captained a ship or a Chief of the Air Staff who has no military flying experience? Not least, a lack of emotional connectivity with the battlespace will require particular attention by military leaders. These are valid issues. However, they should not detract from frank analysis regarding the utility of UCAS in future warfare. The US, at least, has acknowledged there is a lack of 'UAS-expert leaders', and aims to identify future UAS expert senior leaders, integrating them into their Air and Joint Staffs.[66]

The UCAS debate

The debate over the future utility of UCAS is particularly fierce within the US military hierarchy. General Norton Schwartz, the USAF Chief of Staff in 2011, apparently rejected the development of a completely unmanned long-range bomber. Schwartz, speaking to reporters, outlined the current state of US technology stating in his view, 'at least for the next 25 years, maybe 50 years, there's going to be a mix of manned and unmanned [aircraft]. Beyond 50 years, anything's possible.'[67] He also stated, '. . . that he isn't ready to contemplate a nuclear sortie on a remotely piloted aircraft'.[68] His reasoning for this is not clear, after all Intercontinental Ballistic Missiles, armed with nuclear warheads, have been part of the US arsenal for decades; these cannot be recalled.

In contrast, also speaking to reporters, US Marine General James Cartwright, the vice chairman of the Joint Chiefs of Staff in 2011, stated he believes that unmanned bomber technology is ready for deployment. General Cartwright who had the authority to determine all of the military's major hardware requirements, said the US should buy an affordable bomber to replace its ageing fleet of conventional B-1s and nuclear-capable B-52s and B-2s.[69] Cartwright stated that he would 'throw down the gauntlet by asking whether the bomber truly requires a human pilot, or if instead all of them could be remotely controlled . . . . Nobody's shown me anything that requires a person in that airplane. Nobody.'[70] Whoever is correct, some military aviation analysts believe it is probable that the US has had UCAS projects in development for a number of years, including a probable project run by Northrop Grumman; this programme is likely to be a demonstrator for the US requirement for the original Next Generation Long-Range Strike System programme, now referred to as the Long-Range Strike Platform.[71]

Concept of operations

While a Concept of Operations (CONOPS) is required for a UCAS, regardless of whether the platforms are manned or not, the doctrine with which forces are employed should remain constant. Future military actions, and specifically air power, will still be based on the extant principles of war and, specifically, manoeuvrability. Describing the Manoeuvrist Approach, UK MOD Doctrine states: 'Emphasis is placed on the defeat, disruption or neutralisation of an opponent through ingenuity, even guile, rather than necessarily, or exclusively, through the destruction of his capability or gaining territory for its own sake.'[72] This is essentially the employment of forces on the battlefield through movement combined with firepower to gain advantage over an opponent. The air power characteristics of reach, speed and flexibility are particularly relevant to manoeuvre warfare. Frans Osinga believes that the manoeuvrist approach is 'pure Boyd', referring to Boyd's OODA Loop.[73]

The US has a formidable and deserved reputation for carrier operations. Beginning in earnest in the build-up to war in the Pacific in World War II, the USN was pivotal in the joint campaign against Japan. So important was the carrier, that the US Army acknowledged that the decisive combat element in the Central Pacific was the large aircraft carrier.[74] The US Army Air Force, although acknowledging the crucial role of aircraft carriers during World War II, sought to emphasise the role of land-based air power, viewing the Leyte Gulf operation as an exemplar of air, land and sea cooperation.[75]

Permanence is one of the weaknesses of air power. Nonetheless, US carrier operations were so effective in projecting power that they rendered battleships obsolete.[76] This ability to conduct long-range strike and counter-air missions since World War II, including from carriers, has given the US a decisive military capability. Is this now the case? Dr Thomas Ehrhard and Robert Work, in *Range, Persistence, Stealth and Networking: The Case for a Carrier-Based Unmanned Combat Air System*, views current US capabilities to operate at long range as deficient. They believe that both land- and sea-based US fighter assets lack the necessary range and persistence for air campaigns in non-permissive scenarios.[77] These aircraft are best suited for striking targets at a maximum of 450 nm from their operating bases/carriers. Anti-Ship Ballistic Missile (ASBM) and cruise missile threats are likely to force US Carrier Strike Groups (CSG) to operate at least 1000 nm from adversary borders.[78] Why is this relevant? Mark Gunzinger from the US Center for Strategic and Budgetary Assessments (CSBA) believes that a number of states, including those of China and Iran, are investing in Anti-Access/Area Denial (A2/AD) doctrine that 'poses a direct and formidable challenge to the traditional forms of US conventional power-projection in all operating domains'.[79] The US DoD defines A2 as: 'Action intended to slow deployment of friendly forces into a theater or cause forces to operate from distances farther from the locus of conflict than they would otherwise prefer. A2 affects movement to a theater.'[80] AD is defined as: 'Action intended to impede friendly operations within areas where an adversary cannot or will not prevent access. AD affects maneuver within a theater.'[81]

While the US military currently enjoys a huge advantage over the People's Republic of China (PRC), the geography of the Western Pacific nullifies some of this superiority. According to Gunzinger, scenarios involving such A2/AD systems would require US short-range land- and sea-based combat aircraft to operate from much longer ranges, curtailing their ability to attack land targets deep in adversary territory and greatly reducing sortie generation rates. The development of advanced IADS would probably make most areas impassable to non-stealth aircraft and cruise missiles.[82]

Although Rules of Engagement (ROE) constraints and moral and political necessities may initially militate against full autonomy, the development of AI and Human Machine Interface (HMI) technology may offer a level of integration which enables a greater degree of certainty when conducting Combat Identification (CID) and Collateral Damage Estimation (CDE), than that of a Human-in-the-Loop (HITL) system. This would allow missions to be planned and then executed using on-board decision-making – with a Human-on-the-Loop (HOTL) monitoring the system and taking action only when necessary, and perhaps, totally autonomously.

Concentration of force is a fundamental principle of war that is particularly well suited to air power. Experience has shown that air power concentrated in both time and space is more effective in achieving an objective than if it were dispersed over a wider area and longer time.[83] Moreover, a concentrated force will use support forces more efficiently increasing overall capability and survivability. Whether operating from carriers or land, UCAS would conduct missions as part of a COMAO concept. A COMAO formation normally consists of counter-air, strike, AAR, ISTAR and other supporting assets. Benefits of operating in large formations include minimising attrition by optimising mutual support and saturating adversary IADS, generally by concentrating force. However, due to UCAS' extended range and persistence, other assets may be stretched to support. Fundamental to the future employment of UCAS will be their utility within COMAO packages. Ultimately, it may be possible for a large COMAO formation of combat and support aircraft, combining manned aircraft and UCAS or made up entirely of UCAS, to operate together or autonomously. This autonomy may permit a quicker and more accurate response, allowing not only a high probability of survival but ultimately achieving the desired strategic effect.

Although persistence is a key force multiplier of UCAS for missions requiring engagement of an adversary, weapons expenditure may become a limiting factor. Development of Directed Energy Weapons (DEW) may alleviate this problem by permitting a range of targets to be engaged, either lethally or non-lethally, allowing an engagement capability to persist for as long as a UCAV can remain airborne.[84] The question of whether UCAS will ever be allowed to operate totally autonomously is an emotive one. The LOAC, which is based on Customary International Humanitarian Law, as defined by the International Committee of the

Red Cross, may mean that the authorities are not willing to take the risk of allowing decisions to be made by a 'machine' without reach-back to a command centre.[85]

Summary

Current US-led operations in Afghanistan utilise the advantages that UAS bring over manned aircraft, such as persistence and operating costs. Other nations, including China and Iran, have seen the force multiplier attributes of these systems. The momentum of UAS development is increasing worldwide. The next stage is the development and use of UCAS for operation in highly contested airspace; this will require a fundamental change in approach in a number of disciplines, including procurement, planning, doctrine and the tactics used. This will not be easy – a thorough and robust understanding of the international environment over the coming decades is necessary to inform the debate. The types of situations in which any military system needs to operate dictate that system's requirement. The relationships between nations will dictate the resources allocated to nations' military infrastructures. Predicting future conflicts poses problems; however, tensions and conflicts will continue to be a part of international relations. According to a report from the US National Intelligence Council, there is an economic shift in emphasis away from the Organisation for Economic Cooperation and Development countries to Asia. When observing China's economic advancements, the report states, '. . . . This high economic growth has resulted in an unprecedented demand for natural resources . . . change is inevitable and that many stress points are likely to emerge in the future global environment.'[86] Economic constraints and competition over natural resources will likely create focal points that result in nations making claims and counter-claims, flexing their economic and military apparatus in attempts to achieve objectives.

A2/AD networks being developed by China, Iran and other states will pose unacceptably high risks to land- and sea-based forces, compelling them to be based initially as far as 1000 nm or more from an adversary's closest threat systems. Aircraft with a range that is at least two to three times that of the F/A-18E/F Super Hornet or F-35 JSF are required, if combat air is to contribute to future operations.[87] If NEC assets are compromised, combat air will be required to operate effectively independent of these networks. Ultimately, the combination of range, persistence, stealth, EA and autonomy will likely be the prerequisite for effective strike operations over the coming decades. These strike missions will necessitate operating in highly contested airspace, where control of the air will be required. UCAS capable of conducting all parts of this task may offer a solution to the range and persistence challenge. However, the cost of advanced military system development and implementation, and the returns to any civilian manufacturer, may have a significant impact on the ability of the military/industrial complex to pursue the development of UCAS. A balance between the requirements of the state and industry will always be difficult, but must be taken into account.

UCAS, or any other system, manned or unmanned, that cannot operate autonomously when required, will only be of use in certain scenarios. Large state conflicts, that could mean the survivability of one state over another, may require a response that is currently not part of most nations' doctrine. A radical approach to this issue is required, particularly if potential adversaries are prepared to use similar systems fully autonomously.

Precision has been the driving characteristic of air power in recent conflicts. Although this will remain extant, with the advent of improved IADS and modern SAM, low probability of detection may become crucial with EA, persistence, payload and discrimination also being vital to the utilisation of air power. Persistence is enabled by a number of technologies, such as significant advances in propulsion and aerodynamics. Autonomous in-flight refuelling, potentially with unmanned tankers, and advanced power sources would allow for increased endurance. UCAS would stay on task for as long as fuel permits, and then leave the hostile airspace to refuel and return. Separating aircrews from their platforms is also a factor in increasing range and endurance. However, although UCAV can deploy over great distances and with reduced logistic chains, their operating tempo may stretch any manned airborne supporting system. If the TLC of a UCAS means that these systems are High Value Airborne Assets (HVAA), it may denote that manned HVAA are required to protect them, thereby mitigating any advantage that these systems offer. In order to operate effectively, UCAS will need to be able to control the air space they fly in. It is important, therefore, that UCAS are capable of operating independently of other HVAA, with a high chance of survival. This premise is at the crux of this book.

4
Unmanned Combat Air Systems: Technical and Legal Challenges

UCAS developments

The development of UCAS worldwide is consistent with the evolution of UAS as a whole. Countries such as Iran see UAS as offering a significant problem to US maritime forces in the Gulf, for example. Stuart Yeh, in *Comparative Strategy*, argues: 'A small force of UAVs could decimate entire divisions of soldiers . . . destroy all aircraft in a given theater, and put Nimitz-class carriers out of action.'[1] As discussed in Chapter 1, the US DoD's *Unmanned Aircraft Systems Roadmap: 2005–2030* outlines a programme for the development of UAS/UCAS. This roadmap is not policy but it does give guidance on what is possible if procurement leans towards unmanned systems. The USN has now taken over the development of the US UCAS with its UCLASS programme, detailed earlier. A number of other US companies are mirroring Northrop Grumman's UCAS programmes, although not necessarily aligned with seaborne operations in mind. Boeing has been developing the X-45 Phantom Ray UCAS. General Atomics Aeronautical Systems is developing the Predator-C Avenger. This system is a jet-powered semi-stealthy UAS, which has the potential to be more survivable than current UAS.[2] Whether Avenger-type UAS has a place in warfare is debatable, as it appears that it is not UCAS as defined by me. Other systems have been trialled, such as the Lockheed Polecat that crashed during trials in 2006 and has since been cancelled.[3]

Pictures published by bloggers on the web in 2009 of a strange-looking UAS led the USAF to acknowledge that it was fielding a stealthy UAS, the RQ-170.[4] It is believed that the RQ-170 is being utilised in and from Afghanistan in the ISR role.[5] Whatever its role, it seems to be a precursor to the shape of future UCAS. In December 2011, an RQ-170 flying over Iranian territory was captured by Iran with open sources indicating that it was virtually unscathed.[6] The US has acknowledged the loss of an RQ-170 while on a mission over Iranian territory. Speculative reports suggest that the RQ-170 may have suffered a cyberattack against its command-and-control system, allowing Iranian forces to take control of it.[7] Iranian officials claimed that they jammed the Global Positioning System (GPS) and guided it to a landing area. Although Western experts indicate this is plausible, US officials blamed the loss on a malfunction.[8] How damaging the loss may be to any technological advantage that the US has in UAS/UCAS development is difficult to comment on. Significantly, however, in May 2013, photos of what appears like an RQ-170 taxiing at an airfield in China appeared on a Chinese website.[9]

The US *Unmanned Aircraft Systems Roadmap 2005–2030* and *United States Air Force: Unmanned Aircraft Systems Flight Plan 2009–2047* give details of the possible timelines for the different systems and missions for which UAS/UCAS could be utilised. The USAF is analysing the requirement for a follow-up to the MQ-9 Reaper UAS. Its vision is for a medium-sized UAS, referred to as the MQ-M, to be operational by 2020.[10] From approximately 2030 onwards, the *USAF UAS Fight Plan* foresees the MQ-Mc version as capable of performing a number of roles, including autonomous swarm, aero-medical evacuation, personnel recovery, EW, SEAD, ISTAR, Close Air Support, air interdiction, AAR as a tanker, missile defence, strategic attack and counter-air missions.[11] These counter-air missions are defined within the *United States Air Force: Unmanned Aircraft Systems Flight Plan* as DCA missions. In addition to all these roles, larger UAS, nominated as MQ-L, will be capable of Battle Management Command and Control, Joint Surveillance Target Attack Radar System, AWACS, and air mobility and humanitarian assistance operations, but excluding counter-air.[12] In the special system category, the roles of LO persistent and penetrating ISR and SEAD, hypersonic ISR, C2, lift and strike are emphasised as specialised roles. These missions will demand high levels of autonomy and the capability for ultra-long endurance or hypersonic flight. Significantly, due to the sensitive nature of these types of UAS/UCAS programmes, they will be developed in the classified domain.[13]

Looking forward to 2025, for a replacement for the F/A-18E/F and F-22, Boeing is working on design concepts for a sixth-generation fighter; conceptually, its design will be stealthy and tailless, with the ability to super-cruise, and, significantly, it will be optionally manned.[14] This has traction with some aviation experts, as it is far easier to make a stealthy air vehicle if it is unmanned, since there is no requirement to have a cockpit with very reflective surfaces – which make them attractive radar targets.[15]

The UK collaborated with the US on a UCAS programme, referred to as 'Project Churchill', forming a partnership in establishing a CONOPS. This project ceased in 2009, but has, nonetheless, proved extremely valuable in allowing fundamental research to be undertaken.[16] Already mentioned, as part of the overarching DPOC study, BAE Systems has been awarded a contract by the UK MOD to build UCAS as a technology risk-reduction demonstrator – the *Taranis*. A European consortium of six counties, led by Dassault Aviation, aims to have its own UCAS Project, *Neuron*.[17] All of these programmes are demonstrators; they are not necessarily intended to become operational systems. Their successes, or otherwise, will help inform future procurement decisions. Unlike the US, there are no detailed UK or European equivalents of the US *Unmanned Aircraft Systems Roadmap 2005–2030* and *United States Air Force: Unmanned Aircraft Systems Flight Plan 2009–2047*. Making an informed comment on these countries' UCAS ambitions is, therefore, difficult.

It is likely that the People's Liberation Army Air Force (PLAAF) is developing concepts for UCAS along the same lines as Western doctrine, with UCAV that can conduct AAR and long-range missions, including ISTAR, strike and SEAD.[18] Since first appearing at the 2006 Zhuhai air show as an advanced UCAS concept, *Anjian (Dark Sword*) has posed questions for Western analysts about its proposed role. Initially portrayed as being intended for air-to-air superiority roles, the design reflects the potential for a combination of concepts. Due to its size, and corresponding fuel capacity, a UCAV of this type could theoretically support air-to-air operations after reaching its target. According to Peter La-Franchi, a defence analyst from *Flightglobal*: 'Dark Sword hints at an operational concept that is part of developing ideas for the conduct of extremely long-range deployments, followed by highly dynamic operations.'[19] Although this objective is technologically challenging, it is consistent with the PLA's desired approach to be able in future to engage an adversary at great distances. At the Zhuhai Air Show, a representative called the aircraft the 'future of Chinese unmanned combat aviation', emphasising its projected ability to evade enemy radar and to engage in air-to-air combat.[20]

The Dark Sword concept may well represent an attempt to field a counter-air UCAS; however, it appears very conceptual. A counter-air UCAS would require far more than just a very fast, high-altitude capable, and manoeuvrable airframe. It is the avionics, sensors and networking capabilities that are fundamental to this type of system. That said, China's showing of its J-20 and J-31 fifth-generation stealth fighters in 2011 and 2012, respectively, demonstrates how quickly it can develop concepts.[21] It is likely that future UCAS developments are aligned with China's A2/AD doctrine; it is also likely that these systems will form part of the matrix of sensors and weapon systems that China aspires to in building a viable deterrent force, one that is also capable of enforcing its aims, if required.[22]

The unveiling of a full-scale mock-up of a Russian UCAV at the 2007 MAKS Air Show highlighted Russia's desire to venture into UCAS development. The Skat UCAV was seen again at the 2009 MAKS Air Show. As recently as June 2013, Russian Aircraft Corporation MiG had announced that a research and development contract has been signed with the Russian Defence Ministry to build a prototype.[23] Major General Oleg Barmin, chief of procurement for the Russian Air Force in 2011, has suggested that the UCAV could carry the same weapons as the PAK-FA fifth-generation fighter.[24] MiG and Sukhoi are also working together on UCAS developments. Sukhoi General Designer, Mikhail Pogosyan, has commented that the development of a UCAV could be the first common effort between the two fighter manufacturers.[25] How these would fit in with manned systems is difficult to judge; it is likely though that UCAS would need to be used in the same way as Western systems. Perhaps Russia does not intend to enter into strategic UAS/UCAS development to any great extent. It is possible that Russia's desire to enhance its own UAS industrial base is as much an attempt to enter the world UAS/UCAS market than gaining military capabilities.[26]

UCAS technological challenges

The necessary components of a counter-air campaign are examined in Chapter 5. Most, if not all, of these components will be necessary for the successful utility of future UCAS. The future challenges that these systems will face require reviewing. The weapon systems, sensors, overall airframe and engine design that UCAS require are fundamental to their successful development, and ultimately the doctrine by which they will be employed. Whether the air vehicle itself requires being as manoeuvrable as the F-22 Raptor, for example, in the close-combat arena, is an important consideration. To this end, part of my research asks the question: how often, since the Vietnam War, has it been necessary to use a fighter's AAG as a means to achieve a kill? As previously discussed, the evidence available from interviews conducted with a number of counter-air aircrew suggests that an AAG is not required, although it may be applicable for low-intensity operations in an air-to-surface role. This does not mean that a visual manoeuvring capability for visual combat will not be necessary. To what extent it is necessary will depend on how well NEC is integrated and aligned with the employment of HOBS AAM, or other weapon systems.

Advances in a broad range of technologies have begun to enable the integration of joint forces, which was not previously possible. Perhaps the most significant is the expansion in computing technology. The principle of 'Moore's Law' has been proven correct, thus far. The *Unmanned Aircraft Systems Roadmap: 2005–2030* emphasises this: '[that if the ultimate goal is to replace aircrew with a system of] superior capacity, and responses gained from training and experience, then processors of human-like speed, memory, and situational adaptability are necessary'.[27] According to the roadmap, human capabilities are generally agreed to equate to 100 million instructions per second in speed and 100 million megabytes in memory; the cost of developing a system that could conduct most human thought processes is currently uncompetitive with that of a trained human. It is likely, though, that by 2030 the cost of a 100 million Microprocessor without Interlocked Pipeline Stages should approach US$10,000.[28] Raymond Kurzweil, a prominent computer technologist, believes that the inevitable rate of continuing growth in processing power means there will be a point in the future where the rules of ordinary physics do not apply, sometimes referred to as *singularity*. Kurzweil's analysis of the exponential growth of processing power agrees with Moore's Law. He believes that the human brain will be successfully reverse-engineered by the mid-2020s, and by 2030 computers will be capable of human-level intelligence. Kurzweil estimates that by 2045, due to the vast increases in computing power and the reductions in cost, 'the quantity of artificial intelligence created will be about a billion times the sum of all human intelligence that exists today'.[29] The limit of computer processing power has been predicted many times; however, Justin Rattner, Chief Technology Officer of Intel Corporation, believes this is not the case, stating that 'there are a lot of smart people at Intel and they are able to reinvent the cruise [complementary metal-oxide semiconductor] transistor using new materials. Intel is now looking beyond 2020 at photonics and quantum effects spin . . . The arc of Moore's Law brings singularity ever closer.'[30] These views are not universally accepted, but they are worth considering.

What does this mean for future UCAS development? It is assumed that UCAS will use AI technology, such as 'Agent' software. Agent programs have evolved from other legacy AI software, such as Fuzzy Logic and Neural Networks; these are now maturing into a feasible technology, aligned with a viable HMI. Agents are normally defined as self-governing (autonomous), problem-solving computational units capable of effective operation in dynamic and open environments. They are often deployed in environments in which they interact, and sometimes cooperate, with other agents (including both people and software) that have possibly conflicting aims. These situations are known as multi-agent systems. Essentially, Agent programs are autonomous entities capable of exercising choice over their actions and interactions, acting in order to achieve individual objectives.[31]

Current UCAS programmes indicate that their UCAV are not high-performing airframes in the classic fighter sense. That is to say, they do not have a supersonic, very high level, capability. The X-47C UCAS-D, for example, is capable of heights and speeds of 40,000 ft and M0.85.[32] These are well below current counter-air aircraft traits, such as the F-22.[33] These aspects of air-to-air combat are normally fundamental to the success of BVR engagements, unless other aspects of the vehicle's design mitigate this advantage, for example, stealth technology, which may allow a platform to get close enough to an adversary, unseen, allowing first use of AAM, before the adversary's detection systems have allowed them to launch their own AAM. Already established, in its simplest form, the higher and faster a fighter aircraft can fly, the further and faster its AAM will travel, and the larger will be the distance between fighters at AAM impact. This may enable the fighter to stay outside an adversary's AAM Engagement Zone, while allowing the aircrew time to plan and coordinate the appropriate tactics and escape, if necessary.[34]

Future weapon systems and autonomy capabilities

Barry Watts, in *Six Decades of Guided Munitions and Battle Networks*, argues that a question facing the US is, how long can it have superiority in guided munitions and Network Centric Warfare (NCW) capabilities? China is currently focused on developing guided munitions and battle networks, predominantly as part of the A2/AD doctrine. In the long term, China may be the most likely state to field combat systems capable of opposing those of the US. This does not mean that weapon delivery technology development will stagnate. As potential adversaries develop counters, other more effective means of delivering objectives are likely to have their own revolution.[35]

Until AAM and SAM systems are developed to achieve an acceptable level of kill probability, alternative means will be required. DEW could radically transform the conduct of future warfare. From the perspective of the current guided-munitions systems, DEW are more than likely to be a technology that could eventually produce radical and far-reaching changes in the conduct of war. DEW not only offers the possibility of achieving an extremely fast kill through vastly improving weapon systems but, in an application such as the intercept of ballistic missiles, cruise missiles, AAM and SAM, extends the maximum feasible range for negating these weapon systems to several hundred nautical miles.[36]

The leadership of the RAF understands the implications of the revolution that weapons technology can bring to the effectiveness of future combat air structures. In 2011, the RAF's CAS, ACM Sir Stephen Dalton, remarked to reporters: 'There's a lot more capability out there in terms of using microwaves, heat waves and lasers, and we need to further our understanding of them . . . we might be able to use a [DEW] of some form or other from a non-combat platform.'[37]

Autonomy

Communication bandwidth constraints may not allow for full-time two-way communications with C2, the UCAS GCS and the UCAV. Operating deep into adversary territory may militate against robust communications. Not least, decisions made by a HITL, or indeed a HOTL, may not be quick enough to attain the desired aim. It is, therefore, crucial to at least investigate the effectiveness that autonomous UCAS operations may have in achieving the commander's intent. The USAF, in *United States Air Force: Unmanned Aircraft Systems Flight Plan 2009–2047*, believes that advances in computing speeds and capacity will change how technology affects the Observe-Orient-Decide-Action (OODA) Loop, ostensibly supporting the concept of a HOTL:

> Today the role of technology is changing from supporting to fully participating with humans in each step of the process. In 2047 [the USAF predicts] technology will be able to reduce the time to complete the OODA loop to micro or nanoseconds . . . . Increasingly humans will no longer be 'in the loop' but rather 'on the loop' – monitoring the execution of certain decisions. Simultaneously, advances in AI will enable systems to make combat decisions and act within legal and policy constraints without necessarily requiring human input.[38]

Is this statement valid, or is it so far-fetched as to be absurd? I believe it is highly unlikely that the USAF would publish an 'actionable plan' that it does not support. If some degree of autonomy is authorised, the ability to retain and refine the level of autonomy UCAS uses will be fundamental to their effectiveness. This should be established by mission role and in some cases within the phase of the mission, just as is the current doctrine for manned systems. The USAF requires that '[t]o achieve a "perceive and act" decision vector capability, UAS [UCAS] must achieve a level of trust approaching that of humans charged with executing missions'.[39] Although it is acknowledged that UCAS AI autonomy should be based on human intent, the USAF envisages that humans will still be required to monitor the execution of operations and retain the ability to override the system or change the level of autonomy during the mission, with a HOTL at all times. Whether this is possible in a communications-link denied environment is crucial to whether UCAS could, or would be authorised to, operate totally autonomously if this was the only mechanism by which the 'system' could achieve the commander's intent.

A metric by which autonomy levels are measured is required in order to understand what is necessary for a successful operation. However, before any metric can be designed, an appreciation of the complexities which an unmanned system may encounter, and the tasks required of that system, is necessary. As technology advances, the autonomy on board these systems also advances. Since autonomy cannot be evaluated quantitatively without a sound and thorough technical basis, the development of autonomy levels for unmanned systems must take into account many factors such as task complexity, human interaction and environmental challenges.[40]

A paper from the UK's Defence, Science and Technology Laboratory in 2003 describes a real-time adaptive automation and real-time task, interface and timeline management tool, designed to support pilot operations by using computerised assistance. Referred to as Pilot Authorisation and Control of Tasks (PACT) levels, the system 'uses military terminology to distinguish realistic operational relationships for five aiding levels, with progressive pilot authority and computer autonomy supporting situation assessment, decision making and action'.[41] Six levels of control are offered: Level 0, has no computer autonomy, with the pilot having full authority and control; Level 1 introduces computer assistance to the pilot when requested; Level 2 uses the computer to offer advice, but the pilot needs to accept it; Level 3 uses computing to conduct tasks, with the pilot accepting or rejecting the recommendations; in Level 4 the computer conducts all tasks, unless revoked, and Level 5 is fully automatic, with monitoring only.[42]

Another example of giving metrics to different levels of autonomy is used by the US National Air and Space Administration (NASA). NASA uses the Function-specific Level of Autonomy and Automation Tool (FLOAAT). It has constructed this tool to aid its future Crew Exploration Vehicle, as this will be designed at higher levels of autonomy and automation than previous NASA vehicles. This is due to a number of reasons, including, significantly, communication delays, as well as computer enhancements and the emergence of highly reliable decision-making algorithms.[43] At the centre of this evolution in design are the questions, '"What is the *right* balance of ground versus on-board authority (autonomy)?" [and] "What is the *right* balance of human vs. computer authority (automation)?"'[44]

Using both the Defence, Science and Technology Laboratory and NASA autonomy levels as a guide, I consider the minimum autonomy level at which UCAS should operate is Level 3. Levels 1 and 2 are for information only; these levels would best describe current UAS operations, such as Reaper UAS in Afghanistan.

Concern over the ability of autonomous systems to conduct the Find, Fix, Target, Track, Engage and Assess (F2T2EA) cycle will be assuaged by systems that use Automatic Target Detection (ATD), Automatic Target Initiation (ATI) and Automatic Target Recognition (ATR) technologies.[45] Faster and more-capable computers, communications and weapon systems contribute to a faster pace in the battlespace and to the requirements for more rapid decision-making. The proliferation of integrated, accurate sensors provides the opportunity to create a detailed, cohesive picture of the battlespace that could enhance and accelerate combat decisions. Throughout the history of warfare, human senses and reasoning have been the predominant tools used to discriminate friendly forces from targets and to prioritise and direct strikes against the targets. With the volume of data threatening to overwhelm, some assistance is now necessary to reduce the requirement for humans to analyse data and make decisions. ATR can exploit sensor-data gathering by using algorithms to analyse data. Ideally, ATR algorithms integrated with high-resolution data and communications fusion would provide a list of recognised targets along with sufficient data to assess the associated fratricide and CDE issues.[46] This technology is particularly pertinent to UCAS conducting SEAD and air-to-surface operations, but also has efficacy in air-to-air roles. In the long term, it seems inevitable that autonomous robotic combat systems will be fielded. The USAF certainly plans to do so, with the aim of 'leverage[ing] a fully autonomous capability, swarming, and Hypersonic technology to put the enemy off balance by being able to almost instantaneously create effects throughout the battlespace'.[47]

As Watts observes, the main obstacle to the fielding of truly autonomous strike systems does not seem to be technological maturity. It may not even be unit cost. It appears to lie in a traditional reluctance to turn attack decisions over to software algorithms. Whether potential adversaries such as China will have similar inhibitions is doubtful.[48] The gap between the US and Russian/Chinese technological capabilities is rapidly closing. Much of the computing processing technology required for advanced weapons and upgrades can be obtained through commercial sources. China has access to these sources and, significantly, is very adept at reverse engineering, copying these systems and subsequently improving on their design.[49]

TDL

Integrated TDL, which are a fundamental part of NEC, are being utilised by air, sea and land forces – particularly by US forces. UCAS GCS personnel would utilise all aspects of integrated TDL displays and systems if UCAS were not operating totally autonomously. Most modern Western combat aircraft and support assets, such as AWACS, ELINT and AAR aircraft, are fitted with TDL. Ground- and sea-based units, such as ships and radar sites, are also fitted. The aim is to allow an integrated Common Operating Picture (COP) to be used by all friendly forces.[50] In warfare, situational awareness is king; TDL harness information from all sources, increasing situational awareness, if integrated correctly, to a level that gives an advantage over an adversary without the same capability. This is, in part, why on day one of any campaign C2 nodes are targeted as a priority. A level of integration with mapping displays and vastly superior HMI has been achieved because of the evolution of computer processing power. When UCAS are used autonomously, the information produced would be fused through 'objective gateways', such as Battlefield Airborne Communication Node (BACN), allowing decisions to be made much more quickly than if humans were involved.[51] If a HITL was not possible because of loss of communications, then a fused COP could still allow UCAS, and other systems, to operate effectively until, and if required, communications were re-established. TDL, as part of an NEC, will aid TPT. The Japanese, for example, military refer to this as 'Cloud Shooting' – fighters would fire their AAM using off-board targeting data.[52]

AAR

AAR has enabled air forces to project air power over great distances, sustaining these forces for extended periods, offering huge savings in both manpower and hardware. AAR capability is seen as a force multiplier. Unless a platform has the ability to stay airborne long enough to achieve its task unrefuelled, AAR assets will normally be required to extend their time airborne. If AAR is unavailable, or limited, aircraft need to have the range and endurance for the required mission; this will require not only significantly more aircraft, but also radically altered designed characteristics. AAR assets, by virtue of their importance, are normally considered HVAA.

It is anticipated that UCAS will be able to conduct AAR from the normal array of manned AAR assets. Automated tanking from receiving UCAV will be critical to the persistent surveillance and deep-strike capabilities envisioned for UCAS. It is intended that the Northrop Grumman X-47B UCAS-D will conduct trials proving that autonomous aircraft can refuel in flight from the same AAR assets, using the same methods as manned aircraft.[53] The UCAS and manned tanker aircraft exchange position information from on-board global-positioning/inertial-navigation systems via a high-integrity data link. The UCAS calculates its location relative to the tanker and flies into formation, from where it is directed, by its GCS or the tanker itself, to the standard refuelling positions used by manned aircraft.[54]

A surrogate F/A-18D Hornet has been used to conduct trials using the X-47B precision navigation software and hardware. The F/A-18 pilot was hands off, monitoring the procedure. The surrogate F/A-18 performed 36 approaches to a carrier, 16 touch-and-go landings and 6 arrested landings. The challenges associated with landing UCAS aboard a carrier are similar to those in autonomous AAR, such as being able to determine a precise position relative to another moving object, to hold that position and to maintain proper levels of command and control. This was demonstrated in April 2015 when a X-47B refuelled autonomously from a K-707 tanker.[55]

While the USAF and the USN are developing a common approach to automated refuelling, the Navy version requires an additional step. In the USAF system, the unmanned aircraft navigates itself to the centre of the boom envelope, where the refuelling operator on the tanker takes over and steers the boom into contact with the receiver. In the USN probe-and-drogue system version, the UCAS will navigate itself to where the drogue is expected to be, where an on-board sensor will guide the probe into contact with the refuelling basket.[56] If these systems work, there is no reason why unmanned AAR assets could not be used, allowing UCAS to refuel its kind. This capability would further extend the range and persistence of UCAS, particularly if these AAR assets are also survivable in high-threat environments. Extending endurance of aircraft, whether manned or unmanned, presents problems not only with fuel requirements and human endurance, but also with the oil required for engine systems. Engine oil capacity will be a critical node for UCAS operations required to operate over extended periods.

Weapon systems and sensors

The types of weapon systems and sensors UCAS will require in the coming decades will be the key to the successful utility of these systems. This may be by kinetic effects, or ultimately by cyber means. Mostly on-board at present, the trend towards off-board networked systems aiding the establishment of a COP is becoming increasingly important, if not vital.[57] In addition to the array of normal airborne targets, current UCAS programmes have a range of sensors being considered for deployment; these range from Active Electronically Scanned Array (AESA) radars, Synthetic Aperture Radar and Ground Moving Target Indicator radar to IR/optical systems.[58] AESA radar technology has revolutionised the capabilities of aircraft and other platforms with which it is fitted.

The ability of AESA radars to use rapid electronic inertia-less scanning allows for the extremely fast processing of information. The rapid scanning within the search ambit of the system results in a much quicker target-track detection than that of mechanically scanned radar. This permits high-accuracy tracking of multiple targets, enabling multiple target engagement while maintaining other functionality. It is not only the superior capability of AESA radars to find and track airborne targets that is revolutionary, but also their capacity to be used in the full EW spectrum. The emergence of AESA radars and the ability to provide high average power for significant periods make them extremely effective.[59] AESA systems offer the opportunity to employ non-kinetic effects. Current AESA radars are focused on detecting and negating cruise missiles, anti-radiation missiles and AAM. They are particularly effective against AAM because the energy focused on the approaching AAM increases as an inverse square as distance decreases.[60] Fighter aircraft AESA radars use thousands of small transmitters/receivers, each a couple of inches square, which allow the antenna to conduct multiple tasks simultaneously. These include detection of small, even stealthy targets, tracking and communications.[61] Along with the AESA radar's high average power, there are also bandwidth benefits and the ability to utilise flexible waveforms. This means AESA can also be used for EA. Possible AESA techniques for attacking radar systems include burning through the target radar's antenna side lobes, filter side lobes or other known features of the system. AESA transmitters can also be focused on other targets to deliver bursts of RF energy into the electronics of adversary aircraft or computer systems.[62]

AESA radars can also utilise High-Powered Microwave (HPM), which is beginning to emerge as a missile defence system. A handful of F-15C modified with the APG-63(V)2 radars for cruise missile defence and the latest production F/A-18E/F are HPM capable. It is planned to be included in the F/A-22 and B-2 as part of a radar upgrade programme. It is also likely that HPM is eventually to be part of a USN UCAS payload.[63]

The US defence company Raytheon plans to build conformal AESA radar that will weigh 2 to 5 pounds per square foot and is less than an inch thick. This will allow installation in places inaccessible by current radars. Additionally, Raytheon believes it can expand the capabilities of AESA radar so they can be used by 2015 to feed ISR and other data to other sources at high speed.[64] UCAS may become flying antennas, with data imaging and weapons arrays making up the aircraft's skin. Conformal multi-aperture sensors, referred to as smart skins, will be central to UCAS development.[65] AESA radars, or any active radar for that matter, can act as large reflectors, which could compromise RCS. However, frequency-selective radomes could be designed to allow only signals to pass through that are in the frequency band of the radar itself; adversary EA would require to be in the same frequency band, which would be hard to achieve. Tunable radomes that can change their filtering characteristics as the AESA changes frequency will further enhance capability.[66] Raytheon's single-curve AESA is the first step in creating antennas that wrap around aircraft, missiles, ships and ground vehicles. These are eventually expected to serve as combination sensors, TDL and EA weapons.[67]

High Energy Lasers (HEL) as part of the UCAS weapon system would offer an ideal effector, which would not necessarily be reliant on reloads when depleted. Currently in development, these types of lasers are too large to be incorporated into fighter-sized airframes. However, if these were able to be part of a future UCAV, lasers would offer a potential solution to the kill-probability conundrum of AAM. Richard Dunn, in *Operational Implications of Laser Weapons*, gives the view that 'laser weapons offer warfighters opportunities for quick and precise target engagement, flexibility and a light logistics burden'.[68] The push for laser weapon systems on fighter aircraft reached a significant milestone in 2013, when the US Air Force Research Laboratory (AFRL) requested information describing concepts for airborne laser systems for future air dominance platforms. Significantly, the requirement is to identify potential laser systems that could be integrated into a platform that will provide air dominance in the highly contested A2/AD environment likely to exist after 2030.[69] If utilised, HEL could potentially achieve soft kills, without the need to achieve hard kills, for the majority of scenarios. The mere fact that an adversary can and will use HEL may well cause the recipient to spend great efforts to counter these systems.

AAM are being considered for use on UCAS. The USAF and the US Missile Defense Agency, allied with Raytheon, are developing AESA radar systems in conjunction with an extended range AAM, as part of their Network-Centric Airborne Defense Element (NCADE), aiming to engage ballistic missiles. Initially to be carried by F-22, Philip Pagliara, Raytheon Missile Systems' programme manager for NCADE, believes UCAS could be used as effectively. According to Pagliara, 'a longer-term solution would be to put radars and missiles on larger unmanned aircraft . . . The operational concept for both manned and unmanned is similar.'[70] If counter-air UCAS were fielded today, their killing payload would consist of AAM. If AAM kill probability was not to an acceptable level, and not enough could be carried, then other negating mechanisms would be required, that do not suffer a limit on expenditure.

Countermeasures

Countermeasures to defeat or confuse the components comprising a sophisticated IADS will be a critical element of any future UCAS. These will range between EA systems, either utilised through AESA radars, and/or other systems. The full panoply of countermeasures includes DRFM jammers, towed radar decoys, expendable radar decoys, stand-in jammers to defeat RF missile systems, Directed Infrared Countermeasures (DIRCM) and flares to defeat IR missile systems. DRFM technology has transformed the ability to counter adversary radar defence systems. A DRFM-countermeasures system can duplicate an incoming signal from enemy radars by converting it from analogue to digital and back again. DRFM jammers then modify the digital duplicate so that the manipulated signal will be coherent with the threat radar. This signal manipulation can deceive threat radars by altering the target's apparent RCS, range, velocity and angle.[71] In addition, there would be a requirement to counter laser and HPM systems. Active and passive countermeasures are inherently costly and difficult to implement into manned aircraft and stealthy aircraft in particular. The process of defeating any missile system involves two necessary tasks, detecting missile launch and deploying countermeasures to defeat the missile guidance system. Currently, classic detection techniques rely either on visual acquisition or aircraft sensors mounted on the aircraft. Reliable missile launch detection, via a Missile Approach Warning System (MAWS), is a technological challenge but offers a viable solution. MAWS forms part of a DIRCM system.

If UCAS is to be stealthy, and is required to operate in highly sophisticated IADS, the essential requirement of the surface of the UCAV airframe to be smooth, with very few, if any, protrusions, will take priority. A UCAV would also likely carry the same EA system fitted to manned fighters. For example, the USN is developing the Next Generation Jammer, which could be utilised by UCAS.[72] A balance may be required between the necessity for absolute stealth and countermeasure capability. The need to have systems such as Closed-Loop DIRCM jammers, HEL, AAM, HPM and the like fitted internally, or as a conformal part of the UCAV airframe, will be difficult to align with other requirements. It can never be assumed that an aircraft is invulnerable to missile, laser or HPM attack; therefore, negating systems and countermeasures are essential, as is defence against cyberattack.

The LOAC and employment of UCAS

The development of UCAS in future warfare requires scrutiny to ensure compliance with international laws, both practically and ethically. The current employment of UAS has raised issues over the legality of their use. The future utility of UCAS will require scrutiny to ensure that the LOAC is adhered to, not least, if these systems are employed autonomously. Authorising an unmanned system to make combat decisions autonomously will be dependent upon the political and military cadre resolving legal and ethical issues. These include the appropriateness of unmanned systems having this capability, under what circumstances these should be utilised, where responsibility lies for mishaps and what limitations should be placed upon the autonomy of such systems. International laws and treaties in modern warfare govern the use of weapons. Individual nations interpret their political, legal and operational constraints, which dictate the ROE for their forces, specific to each operation. Different ROE may be set for different phases and locations during a campaign. The ROE set clear criteria for the decisions made by humans in the command chain. Could these decisions be made autonomously by 'systems' used by UCAS? For armed autonomous systems, the critical issue is the ability for the weapon to discriminate a legal target.

There is considerable discussion within the military, media and academic institutions on the ethical and legal implications of the current use of UAS, and the future utility of UCAS.[73] The two issues are essentially separate disciplines, but ethical, sometimes referred to as moral, issues do enter into the realm of the laws of war, at times. Reviewing existing opinions on the legal issues will allow an understanding of the current concerns, and whether these will impact the development of UCAS.

In a report published in 2011, the UK MOD offers the view that policymakers need to be aware of the potential legal issues involved in UAS procurement and use.[74] This is a legal requirement.[75] Whether UCAS will operate with a HITL, HOTL or autonomously seems to be causing the most concern. Currently, UAS operate with a HITL. Future UAS/UCAS may not follow this *modus operandi*. P. W. Singer, in *Wired for War: The Robotics Revolution and Conflict in the 21st Century*, discusses the issue of autonomy and keeping a HITL. Singer gives a number of examples of both military and civilian professionals who opine that keeping a HITL will always be required.[76] My own survey, however, indicates that this is not necessarily the majority view among military professionals and civilians. As detailed earlier, analysis of the responses to the questionnaire sought views on whether ethical or political constraints should affect future UCAS doctrine; these views confirmed that there is little ethical compunction against using UCAS, autonomously, if required, with 86 per cent of interviewees having no concerns. Nonetheless, these issues are relevant and it does not take much sagacity to see the actual benefits from conducting in-depth analysis.

The LOAC

The LOAC, also known as Customary International Humanitarian Law (CIHL), is part of that body of international law that governs the relations between states; it is derived from two main sources of international law – treaty law and customary law (rules developed from the practice of states which are binding on them).[77] The LOAC regulates the rights and duties of the belligerents in time of armed conflict. It seeks to protect combatants and non-combatants from unnecessary suffering, and to provide safeguards for civilians and persons who fall into the hands of an adversary.[78]

Proportionality and distinction are fundamentals of the LOAC, and will likely remain so. The current law on targeting (distinction) is contained within the 1977 Additional Protocol 1 (AP1) to the Geneva Convention of 1949. The basic rule, encapsulating the principle of distinction, is contained in Article 48 of AP1.[79] AP1 to the Geneva Convention represented an unprecedented change to the protection of civilians in the LOAC.[80] Unlike other binding documents of the LOAC in the past, AP1 explicitly stipulates the protection of civilians.[81] It is argued by some theorists that in contemporary armed conflicts, especially in internal wars, the principle of civilian protection in its most elementary form continues to be violated.[82]

The International Committee of the Red Cross (ICRC) has published 161 rules that apply to the LOAC.[83] When a weapon system is being procured for use, countries must ensure that these principles are taken into account. Within the LOAC, the term combatant applies to those persons who have the right under international law to participate in armed conflict. These persons include members of the regular armed forces (except medical personnel, chaplains, civil defence personnel and members of the armed forces who have acquired civil defence status) and irregular forces, which carry their arms openly and distinguish themselves from the civilian population.[84] In general, civilians are considered non-combatants. Since only combatants may lawfully participate directly in armed conflict, non-combatants who do so are acting unlawfully and are considered illegal combatants. Rule 106 – *Combatants and Prisoner-of-War Status* – covers civilian personnel who are illegal combatants; these constitute a legitimate military target, which can be legally prosecuted for their wartime actions and do not have the same prisoner-of-war protections as lawful combatants.[85] This may apply, for example, to the software engineers of UCAS.

Opinions differ; there is an argument that the use of UAS, and the associated weapons and sensors technology, will allow for greater discrimination and the prevention of collateral damage.[86] There is also a view that to rule out the legality of the targeting of terrorists on foreign territories is at odds with the obligations of nation-states to protect their citizens from terrorist attacks.[87] Andrew Orr, in *Unmanned, Unprecedented, and Unresolved: The Status of American Drone Strikes in Pakistan under International Law*, argues persuasively that the use of UAS by the US in Pakistan adheres to the LOAC, although he acknowledges that the facts of the engagements remain classified.[88]

William Boothby, in *Weapons and the Law of Armed Conflict*, details the LOAC issues that are pertinent to the use of Unmanned Combat Vehicles. Air Commodore Boothby RAF (Retd) was Deputy Director of Legal Services for the RAF until 2011. Boothby describes an Unmanned Combat Vehicle ‘as unmanned air, land, or maritime vehicles of any size which either carry and deliver force, which may have been deployed from another platform, to a target'.[89] He emphasises that the important question is the ability of the vehicle to direct a weapon to a target, whether it took the weapon there or not.[90] If the system has an autonomous attack capability, Boothby states that the legal reviewer, that is, the person responsible for advising the authoriser on the legal aspects of the mission, 'is to assess whether the system is capable, in the circumstances of intended use, of being used in a discriminating way'.[91]

Article 57 of AP1 details the considerations required for sparing civilians and civilian objects. Article 57(2)(a) details the precautions that must be taken in respect of attacks, addressing the requirements for 'those who plan or decide upon an attack'.[92] A problem arises for the reviewer when autonomous technology is employed. The reviewer is required to determine whether Article 57(2)(a) can be adhered to. A HITL, Boothby believes, able to monitor systems and countermand an attack decision, if required, would satisfy the LOAC.[93] JDN 2/11 states that '[l]egal responsibility for any military activity remains with the last person to issue the command authorising a specific activity'.[94] However, Boothby gives the legal opinion that if a human was not in the loop, the use of autonomous weapons would still be within the principle of distinction if appropriate technology was used. Boothby argues that by using software algorithms and AI, attacks may be restricted to legitimate objects.[95]

UAS are now accepted as part of the military inventory, with their current C2 structures ensuring that ROE are met with HITL at the critical points in the decision cycle. Research programmes around the world are developing ways of introducing autonomy into the decision processes of UAS; the next step is UCAS. UCAS may include several UCAV operating together making cooperative decisions.[96] Authorisation of weapon release is a clear example of where the current position of human intervention may be expected to continue for some time.[97] However, technology will become available, for example, to task UCAS to survey a given area, looking for particular target types, and destroying them when found, without reference to a human commander – a system with the capability of delivering effects autonomously.[98]

Articles 13 and 16 of The Hague Rules of Air Warfare detail that only military aircraft can exercise belligerent rights.[99] UCAV are defined as military aircraft.[100] International law already allows UCAS to be used autonomously, with the *Commentary on the HPCR Manual on International Law Applicable to Air and Missile Warfare* stating:

> UCAVs . . . whether remotely piloted or acting autonomously, may engage in attacks as long as they qualify as military aircraft.

> Autonomous action means that the unmanned aircraft has sensors and an onboard data processing capability to make decisions to attack according to a computer program. The sensors and computer programs must be able to distinguish between military objectives and civilian objects, as well as between civilians and combatants.[101]

Boothby believes that an autonomous UCAV is capable of being used within the principle of distinction, although there may remain a legal requirement for a person to remain in the decision loop unless 'it is possible at the sortie planning stage to take precautions in attack, which will remain valid throughout the period of [Unmanned Combat Vehicle] search to an acceptable level of confidence . . . for example, in areas remote from civilians . . .'.[102] This is particularly pertinent to counter-air operations.[103] Opinion will continue to remain divided. However, in the area of gaining control of the air, certainly in air-to-air engagements, the issue of collateral damage is treated differently from some other types of attacks. In law, current counter-air air-to-air practice is not required to take into account collateral damage from shot-down armed military aircraft.[104] Certain counter-air operations will be conducted entirely over the sea, minimising the chances of any collateral damage virtually to nil. Nonetheless, even for counter-air operations conducted over, or near, populated areas, collateral damage is not a legal issue. This removes any legal arguments against using UCAS in an air-to-air role, as far as collateral damage is concerned. That said, the normal laws of war will still apply, whether manned, unmanned or autonomous unmanned systems are used.[105]

The LOAC already allows for the use of autonomous UCAS within the constraints adumbrated. Ultimately, individual states are responsible for ensuring that weapon developments adhere to Article 36 of the 1977 AP1 to the Geneva Convention of 1949. Article 36 requires each State Party to ensure that the use of any new weapons, means or methods of warfare that it studies, develops, acquires or adopts comply with the LOAC.[106] In general, once a system has been released into service, legal responsibility will always remain with the person who issued the command to the UAS.

Summary

Kenneth Anderson and Matthew Waxman, from the Hoover Institution Task Force on National Security and Law, believe that HITL will initially be included as a fail-safe mechanism, but as improvements in technology and the pace of operations increases, the requirement will diminish.[107]

They are of the view that autonomous military systems developments will not pose a crisis for the LOAC, provided ethical and legal norms are incorporated into the design at the initial stages.[108] Armin Krishnan's extensive research concludes that there are less concerns with regard to accountability 'than some critics of military robots believe'.[109] Anderson and Waxman sum up the future of autonomous weapon systems, such as UCAS: 'Some view these automated technology developments as a crisis for the laws of war. To the contrary, provided we start now to incorporate ethical and legal norms into weapon design, the incremental movement from automation to genuine machine autonomy can be made to serve the ends of the law on the battlefield.'[110] 'International law has never approved the defensive plea of superior order as a mandatory bar to the prosecution of war criminals.'[111] The Nuremberg Principle requires that individuals be responsible for their actions with the LOAC requiring participants to limit collateral damage through accurate target recognition and identification prior to engagement.[112] The question is, who is responsible for an autonomous system? Arkin and others, in *Responsibility and Lethality for Unmanned Systems: Ethical Pre-mission Responsibility Advisement*, argue 'that by making the assignment of responsibility transparent and explicit, through the use of a responsibility adviser at all steps in the deployment of these systems, this problem is solvable'.[113]

The current employment of UAS is generally consistent with the LOAC. Whether these systems are weaponised or not does not alter their legal use; it is whether the weapons are used legally.[114] The principles of the LOAC will apply equally to the use of UCAS. If these principles are adhered to, then there are no legal reasons why these autonomous systems cannot be utilised in warfare. Some nations may be less inclined to adhere to the LOAC when faced with stark decisions on survival, or an action is initiated to achieve an aim at all costs. As Noel Sharkey observes, although the future use of autonomous UAS 'could be at the cost of sacrificing or stretching International Humanitarian Law . . . with other countries closing the military gap and able to use similar systems, why be disadvantaged by having a [HITL]?'[115] If autonomous systems could not be employed for long endurance and complex scenarios, without a HITL or HOTL, many of the advantages of UCAS would be lost. Ultimately, if the normal path that Western weapon systems development has taken, certainly since the end of the Cold War, is continued, with all the rigorous debate concerning ethics and the LOAC that this has entailed, the future utility of UCAS will be ensured.

5
The Role of Air and Space Power and Control of the Air

In order to understand the possible future roles of UCAS it is necessary to recognise the role that both air and space power plays in modern warfare. Air power was seen as NATO's most valuable asset by many during the Cold War. The British definition of air and space power, which is reflected in UK military Joint Doctrine publications, is, 'The ability to project power from the air and space to influence the behaviour of people or the course of events.'[1] Rightly, space is regarded as a crucial domain, in addition to land, sea and air. The latest definition of air power in *Joint Doctrine Publication 0-30, UK Air and Space Doctrine* is 'using air capabilities to influence the behavior of actors and the course of events'.[2]

Space power should not be viewed as a stand-alone tenet of military doctrine; rather, it is an intricate part of air, land and sea power. When viewed in this light, the components of space power that enable control of the air can be summed up as the assets that help facilitate those parts of warfare that allow for the critical enablers of Command, Control, Communications, Computers, Intelligence, Surveillance, Targeting Acquisition and Reconnaissance (C4ISTAR) and space-based navigation systems, which are fundamental to the accurate delivery of information, many weapon systems, as well as cyber warfare.[3]

Three types of air campaigns have traditionally been utilised within air power doctrine: counter-air, anti-surface force and strategic air offensive.[4] Although all three of these campaigns may have to be prosecuted simultaneously, experience has shown that, when facing an adversary with potent air power, priority has to be given to achieving the required level of control of the air, that is, the counter-air campaign. The RAF now advocates that there are four fundamental air power roles: control of the air, air mobility, attack, and intelligence and situational awareness.[5]

Within air power roles, control of the air has primacy. The RAF's *British Air and Space Power Doctrine* emphasised the importance of counter-air stating: 'Control of the air is the *primus inter pares* of the four air power roles. It has doctrinal primacy because it enables freedom of manoeuvre in all of the military domains: air, land and sea.'[6] JDP 0-30 now simply states: 'Control of the Air is the most important air power role because it secures our freedom of manoeuvre.'[7] Significantly, the importance of situational awareness has been acknowledged and is now acknowledged to be a major factor in air warfare.

For the purposes of this book, when the term air power is used it encompasses the domain of space, but will not examine its strengths and weaknesses in depth. It will, however, scrutinise those aspects of space power pertinent to the employment of future UCAS. The RAF's air power doctrine identifies the core attributes of air power as height, speed and reach. Additional attributes are ubiquity, agility, ability to concentrate, flexibility, cost-effectiveness and precision.[8] However, there are inherent limitations as well as strengths – constraints are given as impermanence, limited payload, fragility, cost, dependency on bases and sensitivity to weather.[9] Although AAR is of primary importance as a force multiplier *par excellence*, and is used to enhance the capabilities of many aircraft types in almost all air power roles, no means have yet been found to re-arm, re-crew or service an aircraft in flight. As discussed previously, these limitations may be overcome, to some extent, in future systems, such as UCAS equipped with DEW.

The enduring lesson of the last 90 years is that air power does not win large-scale high-intensity conflicts on its own, although the two recent Gulf Wars have given the impression that air power achieved this. While this is not true, air power has a vital role in any campaign. Although these wars were indeed on a large-scale and of high-intensity, they were of relatively short duration. Following the 1991 Gulf War, air power was used to enforce a no-fly zone over two separate areas of Iraq, north and south. The experience of living under the threat of any Iraqi combat fixed-wing aircraft or helicopter being shot down during the period 1991–2003, aligned with periodic targeting of selective C2 facilities, led the Iraqi Air Force to essentially give up when faced with overwhelming force during the 2003 Gulf War. No Iraqi combat aircraft got airborne during this conflict; the Iraqi military started to bury most of its combat aircraft – a classic example of deterrence at work.[10] Although the Iraqi IADS presented a threat, at least initially, control of the air was achieved relatively quickly. This reinforced the utility of air power, allowing coalition air forces to operate with confidence; it forcefully demonstrated the utility of contemporary air power. Most recently, the 2011 Libya campaign conducted by a UK/France/US-led coalition demonstrated that air and space power alone can, in certain scenarios, achieve all the required objectives.[11] Air power has other attributes, of course; it can be utilised not only to effect the destruction of an adversary's centre of gravity, for example, but also to help prevent conflict in the first place. Perhaps air power's capability to concentrate force in time and space is its greatest asset, although this is only for limited periods unless massive assets are available.

Historical examples help give a perception of the relative strengths and weaknesses of air power. Alexander Seversky argued that the rescue of the British Army from Dunkirk was only possible because the RAF had control of the air. This control permitted the Royal Navy (RN) to evacuate over 300,000 troops.[12] Had the Luftwaffe owned the skies, the British evacuation operation would not have been anywhere near as successful as it was.[13] During the 1982 Falklands War the Argentinians started from a position of considerable strength relative to the British Task Force, yet their apparent lack of any coherent air strategy meant that they quickly lost air superiority over the Falkland Islands. This was despite the British Forces having no dedicated all-weather air defence aircraft. The RN's Sea Harrier and the RAF's Harrier were very definitely limited to short range, visual and clear weather intercepts owing to a limited capability of the airborne radar in the Sea Harrier, and in the case of the RAF's Harrier, no radar at all.[14] If the British Task Force had possessed dedicated Airborne Early Warning (AEW) and if any of the RN's aircraft carriers had been capable of operating the F-4 Phantom – at that time the RAF's primary air defence fighter – equipped with a radar and weapons with the ability to find, track and engage aircraft at all heights and in all weather, at significant ranges from the Task Fleet, British naval losses would probably have been far fewer. Major James Thigpen, United States Marine Corp (USMC), emphasises the lack of AEW assets, which the F-4 Phantom was capable of providing, viewing that 'the British were lucky that their static defence in-depth worked given their inability to see, shape, and manoeuvre in the skies over the Falklands'.[15]

Although air power does have limitations, thanks to its speed and reach, it can counter threats across a far wider geographical area than is generally possible with surface systems. These two tenets make air power unique and are perhaps its greatest strengths; it can be deployed rapidly to provide visible and timely support or to act as a deterrent, particularly over great distances. Growing effectiveness has tended to progressively widen air power applications. For example, for closer threats it can also be used rapidly, direct from its peacetime bases. The Kosovo conflict in 1999 is an example of this when RAF Tornado GR-1 strike aircraft flew night sorties from their bases in Germany.[16] Nonetheless, the full utility of air power can, at times, be limited by political constraints. Both Gulf Wars were examples of how politicians and commanders were intensely aware that a large loss of life of Iraqi civilians and coalition troops would be publicly unacceptable; great effort was also made to avoid collateral damage to structures, wherever possible. Where poor targeting has resulted in civilian deaths, as in Kosovo during Operation Allied Force in 1999, public perception is that air power was used indiscriminately. In fact, the targeting error rate was 1 per cent and although it led to approximately 500 civilian deaths, it was considerably better than any previous operation.[17] There is a trend amongst the democratic international community to not countenance casualties amongst civilians in conflicts that are not directly affecting their own country, or national interests. Large inter-state conflicts, risking global escalation, may alter this antipathy to accepting casualties and collateral damage.

While air power has been employed for strategic effect since its inception, the differences now, as opposed to operations as recently as the Falklands War, are the accuracy of delivery systems aligned with the capabilities of ISTAR assets, enabling these systems to be used to maximum effectiveness while using fewer assets. All forms of modern military power depend on base support if they are to operate at their maximum sortie rate. Armies in the field need depots to support them and navies need harbour facilities. However, air power is often more dependent on its bases than either land power or sea power. If this base support is vulnerable to attack, then base dependency can be a source of potential weakness. This axiom can also apply to a carrier task force, if it cannot adequately protect itself or if it does not have the option to remain outside the range of adversary threat systems.

An air force's mission is to deliver air power in the most effective manner possible to meet a nation's security and defence requirements. In order to achieve this a balanced force must be maintained, one capable of all air power roles and able to meet the requirements for high- and low-intensity conflict, if mandated to do so. Although there has been an increasing requirement to deploy and sustain forces for expeditionary warfare, it is necessary for the UK and other members of NATO to retain the capability to meet the requirements of NATO Article 5, which means that an attack on any NATO country is considered an attack against all members and will be met by joint responsive action.[18] The UK has provided a level of air power support in the Iraq and Afghanistan theatres of operations, second only to the US. Although Man-Portable Air Defence Systems pose a threat, importantly, no air threat existed in either country; the RAF's role has currently been biased towards the COIN threat, concentrating on Close Air Support and gathering intelligence through its ISTAR assets. This is very much 'today's' threat. The threat faced by the UN alliance during the Libyan conflict in 2011 was not from a capable IADS. The lack of competent C2 and the actual poor density of SAM meant that, although still a threat, the Libyan IADS was made redundant relatively quickly, for no coalition losses, from bases that were largely land-centric within 200–500 nm of the threat targets.[19] In certain future conflict scenarios it is extremely likely that a UK/US NATO or other alliance will have to contend with significantly more capable IADS, with states intent on denying access to safe bases and sea-operating areas. The USAF acknowledges that since the fall of the Soviet Union, while it has had overwhelming dominance in air power capabilities, it faces new challenges, not least from China, which will test its current force structures.[20]

The US's approach to its air power capabilities is closely aligned to the UK's, but does emphasise other areas. A recent strategy study by the Air Force Research Institute, *Air Force Strategy Study 2020–2030*, sought to analyse US interests including economic, demographic and technological trends, defence scenarios and the USAF's capabilities to meet future strategic challenges. Its findings recommend that the USAF focus on five critical capabilities out to 2030: power protection; freedom of action in air, space and cyberspace; global situational awareness; air diplomacy and military support to civil authorities. The study emphasises the importance of integrating the three domains of air, space and cyber.[21] In recognising that the two mediums of cyberspace and the Electromagnetic Spectrum (EMS) are converging, the US is attempting to combine cyber, EW and Computer Network Operations (CNO) into what is termed 'the third dimension'.[22]

Air power, although crucial, is just one role making up the matrix required to target an adversary's 'centre of gravity' – that point where the enemy is most vulnerable and the point where an attack will have the best chance of being decisive.[23] Colonel John Warden USAF (Retd), in *The Air Campaign*, articulates very effectively on the centre of gravity: 'Every level of warfare has a center, or centers, of gravity. If several centers of gravity are involved, force must be applied to all if the object is to be moved.'[24] Clausewitz was perhaps one of the originators of the

'Centre of Gravity' doctrine; however, Colonel John Boyd, in *Patterns of Conflict*, argues that:

> Clausewitz incorrectly stated: 'a center of gravity is always found where the mass is concentrated most densely' . . . He failed to develop [the] idea of generating many non-cooperative centers of gravity by striking at those vulnerable, yet critical, tendons, connection, and activities that permit a larger system . . . to exist.[25]

Although air power may be capable of achieving the strategic aim, the capability to undertake such missions is not easily gained or maintained. Ultimately, I believe that the capabilities demanded of high-intensity conflict remain paramount; the preservation of such capabilities will underpin the ability to field forces structured adequately for low-intensity conflict and Peace Support Operations. Air power can provide coercive or retaliatory actions to discourage regimes from unacceptable actions, adding to nations' deterrence capabilities. Once gone, this ability could take considerable efforts to regain. In the meantime, a valuable strategic influencing tool is also lost. In particular, the demands of control of the air require special consideration.

Control of the air

'The struggle for air superiority is part and parcel of all air operations against a first-class enemy',[26] Slessor's dictum remains extant. Within combat air structures there are a number of key enablers crucial to achieving airspace dominance. Before any attempt to hypothesise on future counter-air requirements, it is important that these enablers be understood. These are BVR air-to-air combat, gaining situational awareness of the battlespace, stealth technology, NEC, AAR and EW. Other components consist of the sensors required, sea-, land- and space-based assets and, if defending one's own homeland or sea-based forces, an IADS. A system that gives the first detect, first engagement, first kill capability is vital. Gaining this capability requires an understanding of AAM and Air-to-Air System (AAS) P_k principles, and how these affect the air battle.

During the initial stages of World War I, military aviation was mainly concerned with the role of reconnaissance; however, the potential for bombing and air-to-air combat soon became apparent. The development of fighter aviation in 1915, including mechanical interrupter gears, enabled guns to fire through the arc of spinning propellers. By 1916, control of the air emerged as the crucial issue in the Germans' Verdun offensive and the British Somme counteroffensive. A revolution was beginning; control of the air was increasingly viewed by air and ground commanders as a means of allowing the observation and the attack of enemy ground forces. The development of fighter aviation to counter these missions was a direct result of their increasing importance.[27] By 1917 it was becoming evident that poor reconnaissance of an enemy's disposition could nullify all the gains of a successful previous attack.[28] The disparate requirements of the British Army and the RN, both with independent air services, led to the Smuts Report that recommended the formation of a single air service combining the Royal Flying Corps (RFC) and the Royal Naval Air Service (RNAS), and that an air ministry be instigated as soon as possible.[29] The RFC was formed at the start of World War I, with Lieutenant General Sir David Henderson as its first commander.[30] The 1st of April, 1918, saw the establishment of the RAF by amalgamating the RFC and the RNAS.[31] Hugh Trenchard was appointed General Officer commanding the RAF on 13 May 1918.[32] Air power had come of age and was now seen as an integral part of military operations, with control of the air acknowledged as being an essential element of any campaign.

Some air power strategists have stated that gaining control of the air is so important it might bring victory in itself. General Giulio Douhet, the Italian air power theorist, in his seminal work *The Command of the Air*, stated that 'to have command of the air is to have victory'.[33] General Erwin Rommel, speaking after the failed North African campaign, stated: 'Anyone who has to fight, even with the most modern weapons, against an enemy in complete control of the air, fights like a savage against a modern European army.'[34] Whatever the desired degree of control of the air required against an adversary with a capable IADS, or the ability to project air power, air superiority, let alone air supremacy, may be very difficult to achieve. However, unless control of the air is achieved, the full utility of a nation's own military force may not be achievable.

Richard Hallion, in *Control of the Air: The Enduring Requirement*, articulates the importance of control of the air. Going further than most academics and military theorists, he delineates control of the air into three spectrums within the field of warfare as a whole: the freedom of initiative, the freedom to operate and the freedom to manoeuvre, which he describes as:

> Freedom of initiative refers to the ability of the air-dominant adversary to control the . . . nature of the conflict: to hold an adversary . . . behind-the-decision-making-curve. Freedom to operate is

> characterized by the ability of military forces to conduct all of their functions . . . without fear of that foe attacking them in any meaningful or significant way . . . Freedom to maneuver embraces the ability for joint military forces to operate unhindered on land, [air] and sea within an area of operations.[35]

Hallion emphasises that when fighting a near-peer or peer adversary, the battle for control of the air takes on even more critical importance and at the same time will become increasingly difficult to achieve. Fighting under these circumstances, a force's own survival is crucial before any other mission objectives are achieved. Counter-air assets are required to defend as well as attack, limiting their ability to gain advantage over an adversary.[36] Warden also emphasises this aspect and the importance of maintaining reserve forces.[37] Indeed, an air-to-air battle can arise which consumes all air assets so as to not lose the battle before anything else is achieved. Having the capability to achieve air supremacy, and even localised air superiority, is crucial in this scenario; else all other forces are severely constrained, if not made impotent. Having mere parity, or even superiority, may not be enough when confronted with an adversary that utilises its military forces across all fronts. Air supremacy would seem to be the only option – is this possible to achieve against a peer or near-peer adversary? The US DoD defines a peer competitor as 'in the national sense, is any nation whose capabilities are such that in a supreme test of wills with the [US], the outcome is uncertain'.[38] Near-peer adversaries are less able but would have the capabilities to attack satellites with DEW and also conduct CNO, for example.[39] If the threat from China were such that it was a peer adversary, the required systems to counter or deter it would need to be revolutionary.

The counter-air campaign

Knowledge of the components of a counter-air campaign is fundamental to an understanding of the requirements for future UCAS. Although definitions of counter-air have varied, the principles that encompass the full range of counter-air tasks have remained constant. The combat air component of the counter-air campaign consists of OCA and DCA operations. OCA is a combination of SEAD, EW, air-to-surface and, not least, air-to-air missions. Equally important, but at times completely independent of OCA operations, are DCA operations, which comprise all measures designed to neutralise or reduce the effectiveness of hostile air action normally over own territory or when a particularly high-value asset requires protection, such as a navy task group or military command structures.[40] These counter-air operations can be reduced in a number of ways; firstly, by defensive actions to minimise the risk of air attack and the damage which may be sustained by friendly forces and facilities; secondly, by seeking out the critical nodes of an IADS, and enemy aircraft, before or after they have attacked their targets to inflict maximum attrition – although it is always preferable to destroy these aircraft before they reach their target; finally, as part of an OCA campaign, by mounting air operations in depth and, if necessary, over potentially hostile territory to seize and retain control of airspace. Ultimately, OCA operations are mounted to destroy, disrupt or limit enemy air power as close to its source as possible. Deciding where the priority lies between the various types of counter-air operations will depend partly on friendly vulnerabilities and partly on the nature of the threat.

Most air campaigns will invariably contain some offensive operations. The success of OCA operations against an enemy with a credible air threat requires dedicated SEAD, fighter sweeps and air-to-surface capabilities. SEAD operations are an integral part of achieving control of the air – they neutralise, destroy or temporarily degrade enemy air defence systems in a specific area by physical attack and/or EW. The US DoD describes SEAD missions as '[involving] the electromagnetic spectrum to neutralize, degrade, disrupt, delay, or destroy elements of an enemy's IADS . . . SEAD targets include radars for early warning/ground-controlled intercept, acquisition radars, SAM, and anti-aircraft artillery'.[41] SEAD capabilities have become increasingly important, as countries with a capable IADS pose a significant threat to all combat and support aircraft.

Within an OCA formation of aircraft, fighter sweeps, also referred to as fighter screens by US forces, are used to seek out and destroy enemy aircraft in an allocated area of operations. A fighter sweep is generally broken down into two groups, area and route sweep. An area sweep is used to establish control of the air in a given area. It may be used in isolation from other air assets, or it may be used indirectly to support an attack force by decoying or destroying enemy aircraft that pose a direct threat to the attack force. This form of sweep may be some hours ahead of the main attacking package.[42] A route sweep is used in direct support of an attack force, clearing the planned route of enemy aircraft that may pose a threat to the attack force. It is usually used in conjunction with escort, which involves the mission of aircraft to protect other aircraft. Escort fighters present a direct last line of defence to an adversary's fighter aircraft.[43]

The counter-air response is likely to be shaped by the nature of the overall military campaign. Fundamentally, the counter-air campaign has three elements: first, the means to detect, identify and track potential targets and to direct weapons systems; second, a command, control, communications and information infrastructure to link the weapons and detection systems; finally, weapons systems to destroy adversary air systems, and more frequently the requirement to counter cyber and space assets.[44] The axiom of 'know your enemy' still holds. Without knowledge of an adversary's capabilities and disposition, it is likely that a nation's combat assets will not be used to best effect. This knowledge is not easily gained. A comprehensive mechanism of information gathering is required. This will include national intelligence agencies and academic institutions that are able to give a holistic view of nations' capabilities and intent. An adversary's intent is just as important as its capabilities. Although the two may go hand-in-hand, it is important to have an understanding of what is behind an arms build-up; for example, is it as part of an overall deterrence strategy, or is it part of a plan to launch an offensive to gain control of shipping access points, or to force another country to capitulate to demands? Information, which is part of the situational awareness chain, is critical to the counter-air campaign. Many of the necessary assets described are part of this chain; without this information, all the impressive military hardware available could be made almost useless.

The ability to conduct the full gamut of counter-air operations requires a wide range of skill-sets from all personnel involved. Fighter aircrews need to be able to digest information quickly, react accordingly, assess and then start the process again. Much of this is done BVR; however, the classic air-to-air combat arena is usually perceived as being a Battle of Britain-type scenario, or from the 1986 film *Top Gun*, where kills were achieved by getting in close to the enemy – that is, seeing him and manoeuvring hard to achieve a kill or prevent being killed.[45] Whether there will be a call for this type of combat in 2040 demands examination. Leaving this argument aside for the moment, air-to-air combat is one of the most cognitively and physically demanding tasks fighter crews engage in, particularly in the visual, close-in, arena.[46] It demands that a pilot skilfully manipulates the control column and throttles – referred to in modern fighter aircraft as Hands on Throttle and Stick – to control radar and weapon systems, while keeping track of, and responding to, opponents and friendly aircraft manoeuvres in a rapidly changing three-dimensional environment. The pilot must do this while often flying the aircraft at the very limits of its turning performance and straining to prevent loss of consciousness resulting from extreme G-forces. It is difficult to quantify all the skill sets required. John Stillion's PhD thesis discusses the issues facing the training of fighter crews, viewing that 'air-to-air combat skills are among the most perishable fighter crew combat skills'.[47] The US experience during the Vietnam War, for example, viewed counter-air missions as the most demanding, requiring 'an intimate knowledge of the weapon system, a thorough knowledge of high performance characteristics and capabilities of the aircraft, and extremely close coordination between cockpits and flight members'.[48]

Summary

In 1918 it was appreciated by the British military that 'air supremacy' would become as important as 'sea supremacy'.[49] Since then, control of the air has become a fundamental prerequisite for any planned military endeavour in the 21st century. Unless control of the air is achieved, all other types of air, surface and sub-surface operations become increasingly difficult, and often impossible, to sustain. Ground and naval surface forces can and have made major contributions to the counter-air campaign. Their contribution can be even greater if they are thoroughly integrated into the mission.[50] Once control of the air is obtained, the potential of air power can be fully exploited allowing effective combined attacks to be conducted. The more formidable the opposing air power, the more important this task becomes. Achieving the desired degree of control of the air will continue to be an essential element of any military campaign.

Implementing UAS to conduct ISTAR and air-to-surface strike missions has been achieved, at least in non-contested airspace, while the utility of air-to-air UCAS has barely entered into the academic sphere of interest, let alone military procurement requirements. Whatever systems are used, there are some maxims that will drive the key enablers required to gain control of the air. What happens if some of the key enablers fail? Will there be access to secure air bases or aircraft carriers close enough to the threat? Will stealth technology work as publicised? Will BVR AAM work? Perhaps most importantly, can the required advantage be gained if outnumbered?[51] Analysis from the Center for Strategic and Budgetary Assessment questions 'whether the USAF can depend on any of these key enablers of air power in the future, primarily due to growing challenges associated with anti-access and area-denial (A2/AD) strategies and enabling capabilities'.[52]

Minimal vulnerability to attack, sometimes aided by stealth and superior BVR systems, are the current requirements to engage and destroy adversary fighters and maintain an advantage. Putting all of this into context enables a clear understanding of the foundation that underpins the future counter-air systems that will be essential in successfully dominating the battlespace. The PRC is an example of a nation approaching peer adversary status. Although it is highly unlikely that Iran will even be a near-peer adversary in 2040, it will certainly seek to develop a highly sophisticated IADS.[53] Both China and Iran will likely utilise A2/AD doctrine, presenting a significant challenge for the US and its allies.

Components of the counter-air campaign

An air campaign will begin with intricate planning, normally as part of joint operations. The many components required to mount an air campaign will depend on the complexity of the task, but will normally consist of a number of essential branches. Gaining control of the air comprises many of these branches. Operating bases, stealth technology, weapon systems, C2, NEC, the sensors on counter-air aircraft, AAR, EW and ground-based assets, such as IADS, are some of the component parts.[54] All of these capabilities aid, both directly and indirectly, situational awareness. When planning any OCA mission, a thorough understanding of the assets available, and their capabilities, is essential. It is inconceivable that any offensive force will not have all the assets required. All major Western powers place great emphasis on OCA training; it is in this sort of scenario in which counter-air assets are tested to their limits. While this type of training is essential for high-intensity conflicts, it builds on capabilities that are suitable in low-intensity conflicts as well. While OCA training has largely been a Western preserve since the end of the Cold War, significantly, China has begun to conduct Large Force Employment training exercises, venturing as far as Turkey to conduct joint exercises. China wishes to be able to project power at distances that it is not currently capable of achieving, and is keen to learn Western doctrine and tactics.[55]

When planning for and conducting a counter-air campaign, planners are required to consider a number of aspects, not least the capabilities of any potential adversary. There are, however, some axioms that do not change or at least have not to date. Control of the air itself is rarely achievable by air assets alone. The forces required for adequate control of the air will vary, depending on the threat. The level of control required will depend on the level of risk/attrition the planners are willing to accept. Component elements of a counter-air package will include the full range of combat air and support assets, and infrastructure; included are all the ground- and space-based effects that make up a campaign. These assets will consist of the following:

- Air-to-air, SEAD and strike-attack aircraft – unless capable of achieving air dominance, SEAD and strike assets will be behind the fighters;
- C4ISTAR, ELINT assets – used in friendly airspace, until control of the air is gained, unless capable of self-protection;
- AWACS – Used to provide battlespace management; sometimes combined with an AEW role – positioned well behind the combat air, although, sometimes pushed forward, if protection is offered by combat air;
- AAR – positioned well behind the combat air, although, sometimes pushed forward, if protection is offered by combat air;
- ground- and sea-based radar units;
- own IADS, for land- and sea-based defence; and
- EW, communications, space assets, and all support personnel.[56]

All air assets can 'retrograde' (fly in the opposite direction to enemy fighters) if required – however, this would normally render them incapable of providing a viable service.[57]

Basing

Close and secure land bases and sometimes carriers, close enough to an adversary's centre of gravity, are necessary to generate sufficient sorties. If these do not exist, against an adversary capable of projecting force at great distances, fighters must attempt to dominate the air battle from bases situated at suboptimal distances. This presents significant difficulties, particularly if an opponent has a quantitative advantage. Due to a normal fighter aircraft's size, fuel constraints limit most fighter operations to within 500 nm of the battle area, from AAR orbits to operating bases on land and sea.[58] Although AAR can greatly extend a fighter's on-task time, these assets may themselves be forced to operate in contested airspace. According to John Stillion and Scott Perdue, in *Air Combat, Past, Present and Future*, a RAND Corporation brief of a potential conflict between the US and China, an example of the distances combat aircraft travel was demonstrated in the 2003 Gulf War, where the fighter distance to Baghdad was approximately 550 nm, while during the 1999 Kosovo conflict, the fighter distance to Belgrade was approximately 350 nm.[59] All of these operations were backed with the full gamut of support required, including large numbers of AAR, ELINT and C2 assets. Importantly, neither conflict offered a significant counter-air threat to coalition forces.

This RAND brief uses a possible China versus Taiwan conflict as an example. The analysis describes the PLAAF as having 27 bases within 500 nm of the Taiwan Strait, while the USAF has just one – Kadena, in Japan.[60] This analysis states that current and planned US combat aircraft fleet range/payloads are optimised for a Cold War scenario, centred on a Soviet invasion into Central Europe. The scale of the Western Pacific theatre is significantly larger.[61] If US CSG are forced to remain at distance from a Taiwan conflict, then it is axiomatic that operating the current and planned US combat aircraft in the Western Pacific will result in low sortie rates, thus reducing effective combat power while still demanding a huge AAR task. China would also have the capability to target bases like Kadena and others further afield, potentially rendering them ineffective.[62]

Stealth

Stealth has its roots in long-standing efforts to reduce the detection of military aircraft through camouflage paint schemes. Since electronic sensors have replaced the eyes of pilots as the primary means of tracking other aircraft, more intricate means of defence are needed. Stealth has evolved as a complex design philosophy to reduce the ability of an opponent's sensors to detect, track and attack an aircraft.[63] The design of stealth systems does, however, require careful trade-offs, some of which can impact on other areas of aircraft performance. A range of technologies are combined in order to make an aircraft difficult to detect by radar. These include a smooth surface design, Radar Absorbent Materials (RAM), and electronic support and protection.[64] The aircraft's RCS reduces the range at which ground- and air-based radars can detect the aircraft. RAM absorbs some of the adversary radar's energy, with the aircraft's suitably designed shape redirecting much of the remaining power away from the radar source – in theory. Where possible, engines are incorporated into the fuselage with air intake and exhaust ducts placed on top of the aircraft in order to reduce the heat signature, and hide the jet engine's compressor blades from radar detection, impeding Non-Cooperative Target Recognition techniques.[65]

The experience of both the Vietnam and 1973 Arab-Israeli Wars was the single strongest factor in encouraging the development of stealth aircraft. Soviet supplied SAM systems accounted for a large number of US and Israeli aircraft losses.[66] A Central Intelligence Agency (CIA) report from 1968, declassified in 2007, details the lengths the Soviet Union went to in order to supply SAM systems to the North Vietnamese regime.[67] The Egyptians, for example, possessed a range of Soviet-supplied

SAM, including 40 SA-2, 85 SA-3 and 40 SA-6 batteries, with over 400 early warning, acquisition and fire control radars.[68]

Knowledge of the capabilities of Soviet SAM systems led directly to the development of the first truly stealth aircraft, the US F-117 Nighthawk.[69] A product of the Lockheed Corporation's Skunk Works, the F-117 was also the first combat aircraft to use an automatic flight control system capable of controlling every aspect of a mission, from take-off, execution and delivery of weapons.[70] Most current 21st-century fighters lack real stealth; only the F-22 Raptor can be classified as truly stealthy. However, China and Russia are making great strides in development of their own fifth-generation fighters, with the J-20, J-31 and PAK-FA.[71]

Although RCS reduction is important, there are limits to the utility of stealth techniques. Since the RCS of an aircraft depends on the angle from which it is viewed, it will typically have a much smaller RCS when viewed from the front or rear than when viewed from the side or above. In general, stealth aircraft are designed to minimise their frontal RCS. Current technology struggles to allow the contouring of the surface of an aircraft to reduce the RCS equally in all directions, and reductions in the frontal RCS may lead to a larger RCS from above.[72] While a stealth aircraft may be difficult to track when it is flying towards ground-based radar or another aircraft at the same altitude, high-altitude airborne radar or space-based radar may be more successful.[73] These and other detection systems, when their data is fused as part of a NEC system, may offer the counter to stealth technology.

Counters to stealth

While stealth techniques are considered very important to achieving control of the air, whether they are crucial is open to debate. Many publications describe the fundamentals of sensor and platform physics.[74] There is a general perception that stealthy aircraft are undetectable. This is not the case, as they are just difficult to detect at certain radar frequencies.[75] Their stealth qualities are optimised against X-Band (fighter radars generally work in this frequency band, 8–12 GHz) engagement radars.[76] According to the designers of the F-117, for example, it could be detected by the Iraqi IADS but it could not be tracked accurately enough to allow weapon engagement.[77]

Although knowledge of the principles of stealth may be relatively easy gained, implementation of stealth technology is another matter entirely. Some of the materials used require special and costly maintenance. The manoeuvrability of an aircraft can be compromised by the introduction of stealth design features, which may also impact on operational efficacy. Sensors pose a problem for stealth aircraft, in particular large radars used by conventional aircraft.[78] As a result, future air-to-air missions may largely rely on passive detection of transmissions by hostile aircraft as well as IR tracking. The use of on-board EA and radar systems emits RF energy that can be detected by adversary systems. Other means of establishing situational awareness are therefore preferred. Aircraft face a similar problem for attacking targets on the ground. Any aircraft, including stealth, will be vulnerable to detection by Infrared Search and Track System (IRSTS). The natural heating of an aircraft's surface makes it visible to this type of system. The faster an aircraft flies, the hotter it gets, making it easier to detect through IR. Although Forward Looking Infrared can be used for detecting targets of known locations, they are ill-suited for searching targets over a wide area. In order to locate targets, stealth aircraft may rely on airborne Laser Detection and Ranging (LADAR) although such a sensor may prove to be of limited utility in poor weather.[79]

A number of countries produce radar systems that have been specifically developed to detect LO/stealth aircraft. The Belorussian Nebo SVU VHF Digital AESA radar is an example, which is in service and available for export. The Nebo SVU is being integrated into mobile VHF acquisition radar.[80] Its digital AESA design allows accurate bearing measurement of altitude and range; this accuracy may be enough to allow mid-course updates for long-range SAM or AAM, acting as part of a TPT system. Another novel approach to counter-LO has been the development of passive systems such as the Czech VERA-E, which uses radar, television, cellular phone and other available signals of opportunity reflected from stealthy aircraft, to find and track them.[81]

Although stealth may not be the panacea, its importance is generally acknowledged. Barry Watts, in *The Maturing Revolution in Military Affairs*, suggests that the shift to digital AESA radars and continuing growth in computer processing capabilities, which aid the attacker, can also be exploited by stealthy adversaries.[82] The F-35 JSF's planned fusion of sensors aligned with NEC, for example, gives the F-35 an ability to react automatically to threats. The F-35's AESA radar can be used for EA of adversary IADS, as well as DRFM jamming capabilities that offer the potential to increase survivability.[83] Although the use of active AESA radars and DRFM jammers could alert adversary systems, there will be occasions when their use is warranted. For example, DRFM techniques can be utilised against both aircraft and AAM radars.[84]

Watts writes that the F-35, like the F-22, has been developed for survivability in daytime operations and will probably operate in networked groups of four or eight aircraft, greatly multiplying their capacity to overcome adversary IADS such as Russian S-300/400/500 class SAM.[85] Chinese SAM systems such as the HQ-9, based on the S-300, have similar capabilities.[86] It is this class of SAM that presents a counter-air planner with the greatest test. Although stealth will undoubtedly aid the counter-air mission, it is but one part of the matrix to the mission's success. Essentially, Watts believes that the US decision makers are committed to the JSF programme and are able to evaluate the capabilities of all-aspect LO technologies into the 2040s.[87]

Stealth's primacy may well be tested with the result that other techniques, systems and tactical doctrine are required. As with any game-changing technology, such as the tank during World War I, and the development of radar in the 1930s, other industrial-based societies will eventually develop the same types of systems and counter-systems. Science is not the preserve of certain countries; however, having the economic and industrial base required to develop this advanced technology may limit the number of countries capable of doing so. Whether stealth is the panacea for obtaining control of the air is debatable, nonetheless. Against a peer or near-peer adversary, however, there is no doubt that stealth will cause the adversary to seek ways to counter any advantage that it brings. It is perhaps telling that the US will now only have a maximum of 187 F-22 in its inventory.[88] Systems will be developed, with the aim of allowing the US to maintain its counter-air supremacy in the coming decades. In 2009, writing in *The Washington Post*, the Secretary of the USAF, Michael Donley, and the USAF Chief of Staff, General Norton Schwartz, in a joint statement said, 'Within the next few years, we will begin work on the sixth generation [fighter] capabilities necessary for future air dominance.'[89] Since this statement, Donley, speaking to a USAF journalist, has indicated that although there is no sixth-generation programme, 'the early pieces of what would constitute a program are already out there'.[90] Although there is no universal definition of what 'sixth generation' entails, a definition used by some aviation journals, for example, the US *Air Force Magazine* is 'extreme stealth; efficient in all flight regimes . . . possible "morphing" capability; smart skins; highly networked; extremely sensitive sensors, optionally manned, [and utilising] directed energy weapons'.[91] Optionally manned and DEW are particularly interesting aspects.

Weapon systems, sensors and enablers

It may seem a fairly basic principle but in order to engage and destroy adversary aircraft, these first need to be detected, tracked and identified.

Detection and tracking information on hostile aircraft may be obtained from a variety of sources: for example, visual sightings, IR or acoustic monitoring, conventional radar (including airborne radar), over-the-horizon radar, ELINT and Electronic Support (ES) systems and space-based detection systems.[92] Fighter aircraft have relied on airborne radars, positioned at the front of the aircraft, since World War II. Referred to as air-intercept radars, these have evolved from very basic pulse systems into the sophisticated AESA systems used today. AESA is set to become critical in target detection, with other systems being incorporated, as part of an NEC. The information from these systems needs to be merged into a recognised air picture, which can then be disseminated to all agencies and forces involved in counter-air operations.

A counter-air system is not entirely air-to-air centric. It will normally consist of two complementary components: surface-to-air defences, if protecting land- or sea-based assets, and AAS.[93] Surface-to-Air defences consist of SAM systems and Anti-Aircraft Artillery (AAA), and the associated detection systems; they allow high-readiness states to be maintained over long periods, giving quick response and, in certain cases, they can be used to counter ballistic missiles, for example, the American Patriot SAM system that was used to some effect during the 1991 Gulf War against Iraqi Scud missiles, although its efficacy has been questioned.[94] However, in comparison to fighter aircraft, SAM have limited range and low mobility and therefore relatively large numbers of surface-to-air defence systems may be required. These air defences can be fully effective only if they are integrated into the wider air defence organisation. They not only help to protect air installations from air attack, but also form an integral part of the counter-air campaign by inflicting attrition on the enemy air forces.[95] Fighter aircraft are the 'front-line' of counter-air. They are flexible and reusable, and can be switched to tasks other than counter-air should the operational situation demand it. If required, fighter aircraft can be used to protect very large areas or be concentrated rapidly to counter enemy saturation raids. They may also be used to identify targets positively before engaging them, if no other means is available.[96]

The primary current means of destroying adversary aircraft in air-to-air engagements is by the use of AAM, both RF and IR; their importance in achieving the endgame – that is destroying attacking aircraft – has been crucial since the Vietnam War. Most fighters are also equipped with an air-to-ground gun, normally the same gun used for air-to-air. Having the ability to engage an adversary at long-range, classically known as BVR, can enable an attacker to stay outside an enemy's weapon systems engagement zone. This advantage is negated, however, if an adversary also has a BVR capability; in this case, one's own kinematic advantage and AAM stand-off supremacy is paramount. If a fighter's BVR AAM are negated, or a fighter is outnumbered, it is probable that an air-to-air engagement will be forced to enter into the visual arena. The first part of WVR combat will include the exchange of AAM, when fighter crews have a visual of each other. If this happens, although RF AAM can be used, more manoeuvrable IR AAM become the primary means of engaging adversary aircraft with the last resort being the AAG.[97] The AAG is generally seen as a tertiary weapon, used if both RF and IR AAM fail.

Electronic warfare

Since the advent of radar in World War II, EW has played a prominent role in air power, particularly, in counter-air tasks. The Vietnam War saw the use of EW increase dramatically when it became clear that normal 'kinetic' methods would not achieve the desired result, that is, the nullification of the North Vietnamese IADS.[98] Although this was never achieved, once EW techniques were harnessed, US airborne losses decreased dramatically.[99] The aim of EW is to disrupt an adversary's use of the EMS at critical points, while ensuring continued friendly use of the EMS.[100] EW is defined as any military action involving the use of the EMS, including DEW, to control the spectrum or to attack an enemy. This is not limited to radio or radar frequencies, but includes IR, visible, ultraviolet and other less used portions of the EMS.[101] The three major components of EW are EA, Electronic Protection (EP) and ES.[102] EA is the component of EW involving the use of the EMS, DEW or anti-radiation weapons with the intent of degrading, neutralising or destroying an adversary's combat capability. EA also prevents or reduces an enemy's use of the EMS. It includes direct attack with high-speed anti-radiation missiles; active applications such as decoys, noise jamming, deceptive jamming, expendable miniature jamming decoys, HPM and DEW are also employed. Electronic emission control and LO technologies are passive applications of EA.[103] EP includes the actions taken to protect personnel, facilities and equipment from EW. Examples of EP include radar frequency agility and changing pulse-repetition frequency.[104] ES is that part of EW that intercepts, identifies and locates sources of radiated electromagnetic energy for the purpose of threat recognition. ES information can be correlated with other ISR information to provide a more accurate picture of the battlespace, which may then be developed into an electronic order of battle for gaining situational awareness; it may also be used to develop new countermeasures.[105]

The importance of EW is generally understood by military planners; however, the significance that modern, easily obtained EA systems have in denying the F2T2EA cycle is perhaps not so readily understood. The effectiveness of relatively simple DRFM jammers, for example, can have devastating consequences on the ability of a force to gain control of the air. The Russian 'Sorbtsya' and the Chinese 'KG300G' systems are examples of widely proliferated jammers.[106] The effects of various EW techniques can significantly disrupt an IADS, sensors, communication links, weapon systems and C2. Jamming, chaff and decoys degrade an adversary's ability to conduct the F2T2EA cycle. Even if targets are detected through this wall of confusion caused by EA techniques, and AAM weapon systems get through to their intended targets, they lose some effectiveness; their likelihood of actually destroying the target can be greatly reduced. EA can also affect the AAM fuse, for example, resulting in an early or late detonation, causing a failure.[107]

EA techniques have changed the approach to warfare. Every sensor, RF and IR weapon can be affected by EA; mitigating the effect of EA on these systems requires significant effort. The future use and countering of EA systems forms a crucial part of military doctrine. Aligned with weapon systems and sensors, stealth and NEC, EW has become a key element in gaining supremacy in the battlespace.

Cyber warfare

Cyber warfare is another area of critical importance. The air power environment is extremely dependent upon good data links and communications, in general. With the recent formation of US Cyber Command, the US has emphasised that cyber issues are now part of the spectrum of warfare. The US military was the first to merge its EW areas of interest with those of cyber – described as the 'cyber-electromagnetic contest'.[108] For the purposes of this book, however, EW and cyber will be referred to as two different strands. Both disciplines use the EMS, and computer hardware and software. An example of how cyber-attacks can have an effect is an alleged 2011 attack on Iran's nuclear programme. In 2011, Iran accused the German engineering firm Siemens of helping Israel and the US launch a computer virus to sabotage its nuclear facilities. Both the US and Israel have not denied the computer experts' claims that they were behind the development of the Stuxnet Worm.[109]

China is considered by many Western governments to be one of the most frequent practitioners of cyber warfare. A report from the *U.S.-China Economic and Security Review Commission to the US Congress* states, 'Chinese capabilities in computer network operations have advanced sufficiently to pose genuine risk to U.S. military operations in the event of a conflict. . . . A few weeks before a potential conflict over Taiwan, the [PLA] may mount a computer network attack on systems operated by the U.S.'[110] It is likely that many countries, such as China, will seek to utilise computer network attack as a military tool from ground-, air- and space-based assets.[111]

Command and control

Any fighting force must have a cohesive and effective C2 system. Its purpose is to integrate all of the various elements of weapon and detection systems into a coordinated entity, ensuring the optimum use of available resources against threats.[112] When working with surface forces within a theatre, in particular, a good C2 system is essential to ensure that joint counter-air assets are employed in a fully coordinated approach. If not, assets can be under-utilised, increasing the possibility of fratricide, which is always of major concern to any air defence unit. C2 can be land-, sea- or air-based, or a combination of these. For identification of friend or foe, C2 is critical, unless forces can operate to some level of autonomy. Taking out an adversary's C2 is an important task, starting in the first stages of a campaign. Conversely, however, having forces with the capability to operate autonomously can mitigate the criticality of C2.[113] It may be prudent, in certain scenarios, to allow for the C2 to remain functioning.

Network enabled capability

Much is made today of the possibilities of NEC. The aim of NEC is to have superior understanding of the battlefield by virtue of the ability to gather and assess information from many sources – especially in relation to that of an opponent – and act on it. General Rupert Smith believes that NEC has effectively been used since World War II – 'To my mind, from their reconnaissance and analysis to their ability to engage the enemy, RAF Fighter Command fought the first "network enabled" battle.'[114] An example of the force multiplier attributes of NEC is the introduction of the JTIDS. In the mid-1990s, the USAF conducted the JTIDS Operational Special Project. This trial tested the capabilities of the F-15C equipped with voice-only communications, compared with F-15C equipped with voice and JTIDS Link-16 TDL communications in tactical air-to-air combat; more than 12,000 sorties were undertaken. Blue OCA formations varied in size from two to eight F-15Cs. In all cases, the packages were controlled by AWACS aircraft. Engagements ranged from 2 Blue fighters on 2 Red fighters to 8 Blue fighters on

16 Red fighters. On average, Blue OCA formations equipped with JTIDS achieved two-and-a-half time's the improvement in kill ratio, over those that used traditional voice communications only.[115] This is a significant dichotomy. Essentially, aircrew's situational awareness is significantly enhanced by the use of JTIDS, enabling all participants to share the information they possess and allowing a fuller air picture to be established. Once JTIDS was installed in all the Tornado F-3s, it became one of the best counter-air aircraft in the West's inventory despite its inherent deficiencies, such as lack of agility in the visual environment.[116] NEC is more than one system; it encompasses all information nodes enabling situational awareness to be gained, actions to be taken and reassessment to be made – a classic example of Boyd's OODA Loop.

Integrated air defence system

An IADS fuses all anti-aircraft sensors including radar, visual observers, anti-aircraft weapons such as AAA and SAM, air superiority fighters and interceptors under a common system of C2. Today's battlefield, in many respects, starts as a duel between the IADS and the SEAD campaign against it. During World War II, the RAF's Fighter Command benefited from an early version of an IADS. This was developed into a genuine NEC as radar and radio became available in the interwar period. Data from radar stations and Observer Corps posts was collected, filtered, fused, analysed and disseminated using a network of landlines and ground-to-air radio. This early example of NEC resulted in the RAF being able to make decisions quickly, getting inside the Luftwaffe's OODA Loop.[117] Churchill understood the importance of control of the air, describing the necessity for Germany to gain both air and sea superiority, but as it was unable to do so Operation Sea Lion became untenable.[118] Warden is of the view that the Battle of Britain was a classic example of the Germans choosing the wrong 'Centre of Gravity'.[119] The term IADS had not yet been invented, but more importantly the Germans did not see the British system as a system. They saw airfields and radars, but did not grasp that the most critical and vulnerable parts were the control centres.[120]

A modern IADS has multiple layers of sensors and defensive systems. An example is in the protection of US naval CSG, in which the outermost ring consists of fighters and well-escorted airborne radar aircraft with the next ring made up of long-range SAM.[121] A further example is the protection of key C2 centres or nuclear facilities. The critical nodes that comprise an IADS, such as its C2 links, can be considered the centre of gravity. Attacking these nodes may well render an IADS toothless, without having to negate the radar and missile sites or, indeed, the fighters themselves. As already established, a functioning IADS is only as good as its C2/NEC.

Situational awareness

Understanding the implications of what is happening in any given scenario is crucial in warfare – that is, having situational awareness. It is the importance of NEC in driving future doctrine that will be integral in gaining situational awareness and to the effectiveness of any UCAS. NEC aims to compress the OODA Loop, enabling cross cueing and the sharing of information, allowing sustained high tempo F2T2EA operations. With data-fusion, from sources such as TDL, ISR assets and Blue Force Tracker, it offers an RMA, providing greater situational awareness, helping to mitigate ROE and CID constraints.[122] There are a number of interpretations of the meaning of situational awareness. In warfare, situational awareness generally means the view of the whole air, and ground picture, including not only location but also likely future activity of both friendly and enemy forces. Mica Endsley, in *Theoretical Underpinnings of Situation Awareness: A Critical Review*, defines situational awareness as 'knowing what is going on around you'.[123] This explanation is succinct and applies to both military and civilian situations; it has huge significance when applied to counter-air operations. Endsley's three-level model of situational awareness: perception (what is happening), comprehension (what does it mean), projection (what should I do about it) – are all applicable to air warfare.[124] Stillion from RAND believes situational awareness 'is a most important aspect of air combat. The pilot, or group of pilots, who maintains the best understanding of where friends and foes are relative to their own position during the confusing, time compressed, air combat engagement will most likely emerge the victor.'[125] A NATO report is of the view that pilots are required to answer many questions during air-to-air combat, including 'Where am I? Where am I going? Where are the enemies? Where are the enemies going? . . . Where are friendly aircraft going? What is the aircraft's energy status? What is the status of on-board systems? What is my weapon delivery envelope?'[126]

Gaining situational awareness is vital, perhaps the key enabler in air combat. Its importance is understood today; however, it was not until the Vietnam War that the dominant role of situational awareness in war was fully comprehended. Situational awareness in air warfare is enabled by a number of technologies and skills, NEC and sensors, and, not least, by the acquired skills of those aircrew and battlespace managers involved in forming an accurate picture of the battlespace. If UCAS were to be extensively used, NEC would form a crucial part of the enabling capability. NEC, with all its facets included, allows commanders and operators to gain situational awareness, which, I contend, is the most important part of the kill-chain, enabling all other parts of the F2T2EA cycle to be conducted. While aircraft and sensor performance are crucial to the effectiveness of any counter-air system, situational awareness facilitates their use; its importance cannot be overstated.

An example of the stresses of air combat, and the factor that this can have on situational awareness, is the number of times US fighters were lost due to running out of fuel during the Vietnam War. For example, on one engagement between four F-4Cs and four MiGs, one F-4C crew was forced to eject when they ran out of fuel due, it seems, to a total lack of awareness of the type of AAR available. During the same mission, the F-4Cs failed to shoot down any MiGs, despite being in a position of advantage. The F-4Cs had a total of 24 AAM between them; none were used – instead 1200 bullets were expended, with no hits.[127] Ultimately, situational awareness is fundamentally a function of the aircrew flying and operating their aircraft and systems, with the ability to combine strands of information into a coherent air picture of what is taking place around them, often in a highly dynamic situation. It is a skill that is hard to gain and maintain.

What about the aircrew? Aircrew and other personnel are, currently, part of the situational awareness chain in air warfare. This may presently be necessary, particularly in situations that require speedy decision making that is not always based on linear events, that is, the 'fog of war', which may be best used to describe resistance, or friction, to plans. Ultimately, can gaining total situational awareness reduce this resistance to such a level that it does not affect campaigns? Watts, in *Doctrine, Technology and War,* believes that the greater the stress, more data will be ignored, and the greater will be the confusion.[128] This rationale has merit – there is only so much that any human being can absorb, digest and act upon in a given period of time; however, technology should allow friction to be less of a factor by not relying on human capabilities, which are generally not consistent and are certainly vulnerable to the stresses that high-intensity air combat scenarios generate.

Historical analysis of situational awareness

Prior to the 1991 Gulf War, for all the apparent progress in RF AAM technology, only IR AAM had much success in combat. Why was this? Was technology not the panacea that technologists and military tacticians envisaged? What role does modern technology play in gaining situational awareness, and therefore an advantage in gaining control of the air? Reviewing evidence from historical and test data on air-to-air engagements can aid analysis of what the vital elements of gaining control of the air are. It can be argued that the absence of situational awareness has been the cause of the majority of losses in actual air-to-air combat. Neither the introduction of advanced fighters, equipped with air intercept radars, nor the development of AAM have changed the fact that many air-to-air kills have been achieved without the targeted aircrew knowing that the enemy was targeting them. Watts' analysis of historical combat data and anecdotal evidence from World War II to the Vietnam War suggests that lack of situational awareness has been fundamental in approximately 80 per cent of kills.[129] Watts' analysis is extraordinary; his main findings are that situational awareness has played a far more important role in air combat than a technological advantage.[130] Is this correct?

Watts' analysis starts with the experience of a number of World War II pilots. For example, Lieutenant Colonel Mark Hubbard USAAF, a P-38 Lightning pilot, stated that in his experience during World War II, 'A wing man should always stay with his leader. Under no circumstances should there be less than two airplanes working together . . . and 90% of all fighters shot down never saw the guy who hit them.'[131] This was emphasised by another USAAF pilot, Colonel Hubert Zemke, who stated: 'Remember few pilots are shot down by enemies they see.'[132] Similarly, the German Me-109 pilot Erich Hartmann, one of Germany's most successful fighter pilots during World War II, said that 'Today I am sure that eighty per cent of my kills never knew I was there before I opened fire . . . one factor always worked for me more than any other. I found I could spot enemy planes long before my comrades – sometimes minutes before them.'[133] 'The pilot who sees the other first already has half the victory.'[134]

Were the successes of Hubbard, Zemke and Hartmann down to superior flying skills or was it having superior situational awareness? During World War II, training and experience played a significant part in the success of US and Allied air forces. The superior performance of US fighters against German adversaries with similar equipment is believed to be due to the great advantage in basic and operational training which US fighter pilots enjoyed. Less-skilled German pilots led to higher combat losses, which further increased the pressure to produce large numbers of progressively less-skilled pilots, resulting in a devastating downward spiral in pilot quality.[135] By early 1944, US fighter pilots had, on average, twice as much flight training as their German counterparts and over three times as much training in air-to-air combat and other operational skills.[136] Training was certainly a factor during World War II. Warden emphasises this in *The Air Campaign*, when referring to the huge losses the Luftwaffe suffered on the Eastern Front.[137] He also believes that '[i]f it has not been practiced in peace, losses are likely to be high and the plan is unlikely to go as expected'.[138]

Watts' examples of air-to-air engagements between the US and opposing Vietnamese forces using Russian-built fighters, in Southeast Asia from 1971 through 1973, offers further evidence that situational awareness plays a major part in air combat. His views are based on a 1974 report from the USAF Tactical Fighter Weapons Center, *Project Red Baron III: Air-to-Air Encounter in Southeast Asia, Volume III: Analysis – Part 1: Tactics, Command & Control and Training*.[139] This report was a follow-on from the initial USAF evaluation of air-to-air encounters during the period from 1965 through to 1968 of the Vietnam War.[140] These reports collated and analysed data from all air-to-air engagements in Southeast Asia from January 1965 to March 1967. Volume I identified and reconstructed 78 air-to-air encounters.[141] Volume II covered 151 engagements.[142] Volume III completed the study with 346 engagements.[143] Volume IV analysed these engagements, offering recommendations, with the aim of enhancing US air-to-air combat effectiveness.[144]

Project Red Baron III: Air-to-Air Encounter in Southeast Asia, Volume III: Analysis emphasises the vulnerability of fighters lacking situational awareness, concluding that '[t]he most important factor affecting the loss of both MiGs and US aircraft was the element of surprise. The absence of attack warning was a serious handicap to both sides.'[145] The report states that: 'Of the [US] 37 total losses, 30 (81 percent) were judged to have received inadequate real-time warning. The remaining 19 percent (7 losses) were induced by fuel starvation when US aircraft continued to engage below safe separation fuel levels.'[146] Significantly, the report states that 35 per cent of all US losses received no attack warning at all, and while the remaining 65 per cent received some warning, 'the absence of real-time threat positioning did not enable US aircrews to acquire the threat in time to perform effective defensive actions'.[147] From this analysis, it is apparent that the lack of situational awareness played a part in 100 per cent of US losses, to some extent. North Vietnamese MiG losses were also analysed, with 42 per cent (31 of 75) not manoeuvring before being shot down; in addition, 14 other MiGs were shot down in undetected attacks as they positioned to engage other US aircraft giving a total of 60 per cent (45) which were destroyed in surprise attacks.[148]

Colonel James Burton USAF, in his brief *Letting Combat Results Shape the Next Air-to-Air Missile*, observes that from 1965 to 1968, of the 117 air-to-air kills achieved by US forces, 44–80 percent of the enemy were unaware of being targeted, while between 1971 and 1973, of the 73 kills claimed, around 60–80 per cent were unaware.[149] Burton's brief comes with no references; however, my reading of *Air-to-Air Encounters in Southeast Asia: Volume IV: Analyses* offers more granularity for engagements from 1965 to 1968. The absence of situational awareness was a factor on virtually all occasions when US aircraft were shot down. One of the main conclusions of the analysis observes:

> The analysis of the attack phase demonstrated that enemy success in achieving a position to fire was almost entirely dependent upon the ability to maneuver into a rear quadrant attacking position before detection. Conversely, whenever U.S. aircrews acquired the enemy aircraft before the attack maneuver was completed, U.S. aircraft negated the maneuver 95 percent of the time. The requirement for real time information on the position of enemy aircraft is apparent from these two results.[150]

The fact that crews were able to negate the MiGs 95 per cent of the time (when seen by US crews first) means that if they had not had situational awareness of their presence, they would have suffered far more losses. In approximately 50 per cent of cases, crews were not aware of enemy MiGs until less than 2 nm away.[151] The report emphasises the significance of firing first: 'The importance of firing first can be seen in that for 209 encounters studied, in only four cases did an aircraft attacked first by another aircraft manage to destroy the attacking aircraft.'[152] This meant that most MiG attacks from the stern were successful: 'When the enemy attained a rear quadrant position before detection, the enemy fired first approximately 90 percent of the time.'[153] Although US crews had a kill ratio of 9:1 in scenarios where they possessed situational awareness, ultimately, if they had possessed better situational awareness they would have suffered far fewer losses, and shot down more MiGs. Conversely, it was noted that if North Vietnam had been able to use their Ground Control Intercept radar more effectively, and had weapons parity, far more US losses would have occurred.[154] At the time of the report, the US had a 9:1 attack effectiveness against MiG-21 fighters (if situational awareness of the enemy was obtained first), but it was estimated that this would fall to 1:1 if MiGs achieved the rear quadrant 100 per cent of the time, with the MiGs enjoying an advantage of 2:1, if weapon parity was achieved as well.[155] In addition to the lack of situational awareness leading to US losses, from April 1965 to August 1967, US crews were forced to terminate engagements on 160 occasions. About 51 of these (32 per cent) were due to losing contact with the MiGs, either radar or visual.[156] This is an extraordinary number, clearly illustrating that the lack of situational awareness can not only lead to being shot down but also affect a mission's success by allowing an adversary freedom of manoeuvre.

While not quite correlating with *Project Red Baron's* deductions, Burton's figures do support the conclusion that situational awareness, or the lack of it, played a significant part in losses. This lack of situational awareness resulted in the relatively poor, and unexpected, kill ratio during the Vietnam War of approximately 2.5:1.[157] This was indicative of a number of causes, including poor training, restrictive ROE and an expected technological advantage that did not in fact exist.[158] Even before the end of the Vietnam War, US analyses had identified enemy position and direction information, and long-range positive identification, as two of the main causal factors in poor US performance in air-to-air combat operations; the others were: 'Weapon versatility and reliability. Target discrimination against ground return. Aircraft rearward visibility. Man/machine compatibility.'[159] The overarching lesson from this period was that situational awareness is not easily gained; training, technology and experience is essential to the development of this vital skill. Marshall Michel describes the evolution of training exercises, such as the USN's Top Gun and the USAF's Red Flag as a direct result of the poor performance of US aircrews in Vietnam.[160] Watts concludes that this relationship with World War II and Southeast Asia regarding situational awareness is significant.[161]

Post-Vietnam statistics also offer evidence of the criticality of situational awareness. Some analysis comes from US simulations of air combat conducted on instrumented ranges and in-flight simulators. Although not actual combat flying, these tests, such as the Air Combat Evaluation (ACEVAL) and the AMRAAM AIM-120 Operational Utility Evaluation (OUE), were designed to gather statistics on engagement results.[162] ACEVAL was conducted using an Air Combat Manoeuvring Instrumentation (ACMI) range, which relayed information from all the aircraft involved to a ground monitoring system.[163] The friendly force consisted of F-15 or F-14 fighters armed with AAG, AIM-9L IR AAM and AIM-7F Sparrow semi-active AAM; the opposing force flew F-5Es, simulating, to a degree, the Soviet MiG-21 in performance with AIM-9L Sidewinder and an AAG.[164] Watts observes that from the results of this trial, it was demonstrated that 'human factors dominated results 83–84 percent of the time'.[165]

My survey of counter-air aircrew asked the question, 'How often were you required to enter the visual merge to kill an adversary, during Large Force Employment/COMAO training sorties?' Seventy-eight per cent were required to on less than 10 per cent of the time, with the remaining required to on 20 per cent or less occasions. Why is this relevant? The responders to the question have on average 3000 hours counter-air experience; many have flown hundreds of these types of training sorties. Almost 80 per cent were able to kill their adversaries in greater than 90 per cent of occasions, without having to conduct visual air combat, with 100 per cent having to in 20 per cent of occasions or less.[166] These statistics are similar to World War II, Vietnam and the ACEVAL trials. The lack of adequate situational awareness appears to be a fairly constant metric in having to enter the visual merge in counter-air warfare, approximately in 80 per cent of engagements.

In 2005, the F-22 Raptor completed its Initial Operational Test and Evaluation (IOT&E). Similar to the AMRAAM OUE and ACEVAL, this trial included scenarios conducted in simulators and on an ACMI range. Open-source official reporting indicates that the Raptor was able to dominate opposing fighters for the vast majority of the time, even when outnumbered. Major General Mark Welsh, the USAF's director of global power programmes, speaking to reporters in 2005 stated that the, 'Pilots in [the] IOT&E – most drawn from the F-15C community – raved about it being a huge leap over the time-tested Eagle.'[167] The report seems to indicate that the F-22 (and these types of aircraft) will achieve control of the air without entering the visual arena. However, these results need to be examined in context – should everything said by the US military be believed? On the basis that we cannot know for sure, a judgement needs to be made on the likelihood that the Raptor is as good as it is 'officially' stated to be. I contend that the Raptor is likely to be an extremely capable air superiority fighter, not least because the US has proven to be adept at producing world-beating air combat systems.

The Raptor's stealth and speed, when aligned with appropriate tactics, and advanced avionics, sensors and sensor fusion apparently allowed the Raptor pilots to kill adversaries without being detected. The required situational awareness would have been garnered through NEC, combining data fusion – using gateways such as BACN and the US Tactical Information Broadcast System (TIBS), an Ultra High Frequency line-of-sight or satellite-interactive network. The TIBS network provides secure near-real-time, multi-sensor, multi-source situational awareness and threat warnings. BACN is an airborne communications relay and gateway that is part of the US DoD's Objective Gateway programme, which is developing advanced gateway capabilities allowing real-time information interactions between different TDL systems.[168] The F-22's apparent dominance in the IOT&E reiterates that situational awareness most often determines the outcome of the counter-air battle, especially when technology is harnessed to augment situational awareness.[169] These results were achieved by the F-22s operating as a single fighting force, unable to transmit their own situational awareness via NEC means. Currently, stealth aircraft are not equipped with conventional TDL, such as Link-16, and cannot communicate with other aircraft types as this can be detected by electronic sensors – instead they use an Intra-Flight Data Link, designed to relay data and synchronised air picture only amongst the Raptors. A new programme to provide secure TDL for the F-22 and other stealth aircraft is being developed. Objective Gateways, such as BACN, should help solve this problem.[170]

Can the human factor input to situational awareness be considered crucial, or can technology allow the required level of situational awareness to be used by an autonomous/highly-automated system? Computer programs exist which are capable of interpreting the information available, that is, the situational awareness, making decisions for the operator and the mission commander; there are few apparent reasons why aircraft systems could not react as required using these programs. An example is Soar software, which is a cognitive architecture program, giving both a view of what cognition is and an implementation of that view through a program for AI. Since its beginnings in 1983, it has been widely used by AI researchers to model different aspects of human behaviour.[171] Glenn Taylor and others describe the benefits of Soar in a paper, *Enabling Battlefield Visualization: An Agent-based Information Management Approach*. This paper identifies the requirements of a system for enabling battlefield visualisation through automating the information management process.[172] Soar-based simulations have been trialled; for example, all aircraft flown in a USAF synthetic operational training exercise, conducted over 48 hours, were controlled by Soar-based AI software.[173]

Trials with UCAS have been conducted under simulation by the US, UK and others to determine the levels of autonomy to which these systems can operate.[174] These systems require a high level of situational awareness. The more autonomous a system is required to be, the higher the level of situational awareness necessary. It is planned that software programs will allow for automatic responses by UCAS to real-world (simulated at the moment) conditions, for example, reacting to being targeted by SAM or AAM.

Lack of situational awareness in the battlespace has historically been a major factor in which side wins. Watts, in *Doctrine, Technology, and War*, argues that future advances in technology will 'lift "the fog of war" to enable future commanders to "see and understand everything on a battlefield" . . . while turning the opponent's [situational awareness] into a "wall of ignorance"'.[175]

The removal of this 'fog of war' has been an ambition of military strategists for centuries. In 1995, US Admiral William Owens advocated the doctrine 'Dominant Battlefield Awareness'. This doctrine proposes connecting existing sensors and personnel together via information and C2 systems making it possible to detect, track and classify most, if not all, of the relevant entities on land, sea and air or in space.[176] Current programmes, particularly in the US, are pushing the boundaries of this principle. BACN, a data-fusion engine as already mentioned, is an exemplar of the vision that the US military has with regard to merging all entities and sensors into one fused system.[177] Simply put, Watts and Owens are stating that situational awareness is, and will be, the critical factor in warfare. Unless targets can be found and tracked, all the precision weapon technology available will be of little use.

AAM development

The weapons effectors required for future counter-air systems are open to discussion. Current means of destroying adversary aircraft invariably use AAM and AAG. Evaluating the effectiveness of current AAM systems requires an understanding of AAM development and current doctrine; this allows the potential incorporation of air-to-air weapons onto UCAS to be evaluated and to establish what killing or negating systems will be required in the 2040 battlespace. Prior to the advent of AAM, fighters were generally armed with guns or cannons that fired forward along the aircraft's longitudinal axis. From 1914 to the early 1950s, air-to-air combat was led by the use of the AAG. Military forces continually sought to improve aircraft manoeuvrability and engine performance to give pilots manoeuvre advantages which they could exploit to achieve effective firing positions. Without AAM that could reliably target aircraft from significantly greater ranges than those at which AAG were effective, there was little alternative, whenever the target could not be taken unawares, but to fall back on air combat manoeuvring skills and aircraft performance to reach the close-in firing positions required. This also applied to early versions of IR AAM, which were only effective in the stern sector of enemy aircraft.[178]

Since the Soviets had also gained access to German technology and scientists in 1945, with the onset of the Cold War there was an obvious incentive for the US to develop effective AAM before the Russians did.[179] The UK, Israel and France were also involved in developing AAM during this period, and developed a number of effective AAM types. However, it is the US and Russia that are the world leaders in AAM development and doctrine, with Israel, France and the UK close behind. China is playing catch-up with a combination of Russian AAM in its inventory, a number of its own programmes, the capacity to reverse engineer almost anything and a seemingly easy route to gaining technology from the US and others; it is possible that there will come a point in the future when China reaches parity with the West.[180]

Western AAM development

The first US AAM appeared in the mid-1950s, when the USAF declared its Air-Intercept Missile (AIM), the AIM-4 Falcon, operational in 1955.[181] That same year, the first production model of the IR AIM-9 Sidewinder AAM became operational and the RF AIM-7 Sparrow I, which was a beam-riding RF AAM, slaved to an optical sight, entered service.[182] Despite the AIM-9 Sidewinder's simplicity and maintainability, the missile has limited range. While it was a substantial advance over the AAG for air-to-air combat, early versions of the Sidewinder were still a close-in weapon, its effectiveness limited to WVR engagements and in clear air outside of clouds. Although the Sidewinder has some utility at night, if target acquisition can be achieved by the fighter's radar, for most night or all-weather engagements, particularly at distances BVR, early variants of it offered little capability. Early AIM-9 IR AAM, which relied on detecting the exhaust heat plume from a jet engine, was designed for use against non-manoeuvring targets, attacking from the rear aspect of the defending aircraft. During the Vietnam War, North Vietnamese MiG fighters countered the AIM-9 by turning in towards the attacking fighter, negating the heat source at the rear of the aircraft.[183] Post-Vietnam, the US developed the all-aspect highly manoeuvrable AIM-9L IR AAM. The AIM-9L entered service in the US in 1978 and in Europe in 1982, when UK Harriers were equipped with AIM-9L AAM for the Falklands conflict. Twenty-six AIM-9L were fired, achieving 19 kills, giving a P_k of 0.73.[184] This appears a vast improvement over the Vietnam experience, but needs to be kept in context; Argentinean aircraft were not equipped with flares to counter these IR AAM. Also, many AIM-9L shots were taken from the stern, unseen by the Argentinean aircrews, again emphasising the importance of situational awareness.[185]

By the mid-1980s many nations had developed and deployed IR decoy flares in response to emerging IR AAM lethality. To mitigate this, the USAF developed an improved AIM-9, the AIM-9M. This was an AIM-9L with improved flare rejection technology designed to counter decoy flares.[186] The USAF, USN and USMC fired 48 AIM-9M during the Gulf War of 1991, achieving only 11 kills. The AIM-9 P_k was reduced to just 0.23 – much closer to Vietnam era performance than the 1982 Falklands War.[187] The US AIM-9X, UK ASRAAM, French MICA and Israeli Python 4 and 5 AAM are all examples of IR AAM developed with the main emphasis being counter-measures and manoeuvrability, including a HOBS function.[188] The lethality of late generation IR WVR AAM is in a large part due to their ability to sustain very high load factors during the endgame manoeuvre (the phase at which an AAM may have to manoeuvre to hit an aircraft which is manoeuvring itself, in self-defence), precisely the scenario in which most AAM fail to kill their targets. Although mainly employed in the visual arena, modern IR AAM can be employed BVR, particularly in the head-sector, at ranges outside the visual acuity of most aircrew, and at night, when even with the use of Night Vision Systems, aircrew cannot acquire targets easily.[189] When utilised with TDL, IR AAM can be launched without an acquisition, flying through cloud, achieving target positioning from on- and off-board systems (TPT).[190] However, the true BVR realm belongs to the RF AAM, which are usually much larger, with a corresponding greater range, and possessing their own radar seeker-head.

Conventional radar-guided AAM for air-to-air combat with sufficient range to be launched BVR, entered the inventory in the early 1960s when the initial USN variants of the F-4 Phantom II, equipped with the AIM-7 Sparrow II AAM and the AN/APQ-72 radar, became operational. By the Yom Kippur War in October 1973, the Israeli Air Force also had F-4s equipped with AIM-7 AAM.[191]

The requirement to engage targets at ranges from a CSG, which mitigated any weapon delivery systems that an adversary might have, emphasised the need for the USN to acquire an AAM with the ability to engage aircraft at very long range. The AIM-54 Phoenix was the first operational radar-guided AAM that could be launched in multiple numbers against different targets from an aircraft, making the Phoenix the USN's main air defence long-range weapon.[192]

The late 1980s and early 1990s saw the development of a new generation of RF AAM. The AIM-120A AMRAAM was introduced at the end of the Cold War to provide a 'fire and forget' active radar-guided weapon with data link support provided by the radar on the launch aircraft, allowing multiple simultaneous shots. Until the advent of the AIM-120, the use of semi-active AAM still required the launching fighter to continue towards the target using its on-board radar to guide the missile until impact. This would mean both aircraft getting within a few miles of each other at missile impact.[193] If the adversary aircraft is also equipped with AAM, a race against each other will ensue with each fighter crew vying to increase any advantage they may have; each crew would be attempting to achieve the best stand-off range – $R_{separation}$. Although an important part of counter-air engagements, $R_{separation}$ is matched by the importance of AAS to counter EA techniques.[194]

The introduction of the AIM-120 AMRAAM sought to give the advantage back to US fighter crews. AMRAAM employs active radar target tracking and active RF target detection to provide an autonomous launch, rendering a capability against single and multiple targets in all environments. However, early AMRAAM variants suffered from a lack of robust capability in an EW environment. The AIM-120A was followed by the improved B-model, and then by the AIM-120C. Versions of the AIM-120C are currently the backbone of the US and its allies. Open sources indicate improvements in AIM-120 capabilities.[195] The latest version, the AIM-120D, introduces a redesigned seeker – which is a conformal antenna – probably of AESA design, a two way data link, GPS to supplement inertial guidance, improved kinematics and better seeker performance against HOBS targets.[196] Combat statistics for the AIM-120 variants to date amount to ten kills (including a friendly fire incident against a UH-60 Black Hawk helicopter) of which six were genuine BVR shots, for the expenditure of 17 AIM-120 AAM – giving a P_k of 0.59.[197] Significantly, no target was equipped with a modern defensive EW capability, and therefore was not representative of the type of AAS likely to be used against US and other Western forces in a modern peer-on-peer BVR engagement. In addition, AMRAAM class missiles lack the extended range that may be required when pitted against Su-35 Flanker type aircraft, equipped with ramjet propelled AAM, now being developed in Russia and Europe.[198] A European consortium is developing the Meteor AAM which will use advanced air-breathing motor technology. Conventional rocket motor-powered AAM rely upon an initial boost phase to achieve the high speed required, followed by a 'coast' phase to intercept the target. Latest generation highly manoeuvrable aircraft are able to outrun and out-manoeuvre conventional missiles at the extremes of their range. The air breathing ramjet motor used by Meteor provides sustained power, following the initial boost that offers extended maximum ranges, and no-escape zones, over AIM-120.[199]

The advantage of ramjet BVR AAM lays in their ability to sustain thrust and turning performance in the endgame phase of an engagement, where conventional solid rocket AAM fly on inertia alone for much of their flight and rapidly lose speed when turning.[200]

Russian and Chinese AAM development

Until the 1980s, Soviet AAM technology lagged the West in rocket propellants, airframe and guidance designs. That changed with the deployment of the RF Vympel R-27 (NATO reporting name AA-10 Alamo) and IR Vympel R-73 (NATO reporting name AA-11 Archer) AAM during the 1980s.[201] In kinematic terms, the IR R-73 series, and the BVR R-27 and R-77 (RVV-AE) (NATO reporting name AA-12 Adder), are highly competitive against their Western equivalents, and the long-burn variants of the R-27 outperform all Western solid propellant competitors.[202] The next step for the Vympel series is the production of the air-breathing ramjet RVV-AE-PD design displayed since the 1990s at numerous trade shows.[203]

Russian seeker technology has made great advances since the early 1990s, largely as a result of the availability of digital signal processing chips in the world market. The Russian weapons company Agat, which manufactures semi-active and active radar seekers for the AA-10 and AA-12 AAM, has openly acknowledged its use of Western digital signal processing chips in a variant of its seeker head.[204] The move away from analogue and early digital seekers to software programmable digital seekers is significant, since it opens up many choices in signal processing and counter-countermeasure techniques hitherto only used by US, EU and Israeli manufacturers. In practical terms, there is no reason why a later model digital variant of the AA-10 and AA-12 would be no less difficult to defeat by jamming than Western equivalent active seekers. With modern seeker technology, AAM can be updated with new software fixes relatively quickly. Replacement modes can be kept secure until combat operations commence.[205]

The Russian philosophy has been to make fighters that can carry an exceptional payload of AAM. Up to 14 AA-12s can be carried on the Su-35 Flanker, at the expense of other weapon stores. It is envisaged that the Su-35 will also be able to carry up to five long-range missiles as part of its inventory. Labelled 'very-long-range' AAM, the K-100-1 (*Izdeliye* 172S and 172S-1) has been developed from the earlier K-172 AAM. The *Izdeliye* has a range of 160–215 nm, and is capable of reaching speeds up to 2160 knots (approximately Mach 3.0–4.0) to engage targets flying at altitudes ranging from 10 ft. to 100,000 ft.[206] This type of AAM is a significant threat to HVAA such as AWACS and AAR aircraft. The AA-11 IR AAM continues to evolve. Russian industry is working on a Focal Plane Array seeker for their future WVR missiles, to compete against the ASRAAM, AIM-9X and Python-5 seekers, adding further IR counter-countermeasure capabilities. Details of a Russian passive X-band RF anti-radiation seeker are classified, but it is a unique capability in the AA-10 and AA-12 AAM, if brought to fruition.[207] It seems Russia may be reaching parity with the West in AAM technology, and may even be exceeding this capability.

China is making significant progress in the development of AAM technology. The PLAAF operates a diverse mix of indigenously manufactured and imported Russian AAM. Imported Russian AA-10, AA-11 and AA-12 AAM are primarily used with the imported Russian-built Su-27SK and Su-30MKK Flankers and the home-grown copy of the Flanker, the J-11. Indigenous Chinese-built AAM are dominant across the Chinese built fleets of J-10A/B Sinocanard, J-11B Sino-Flanker, J-8 Finback, J-7 Fishbed, J-6 Farmer, A-5/Q-5 Fantan and JH-7 Flying Leopard.[208] Currently, China manufactures only two BVR-guided AAM, the active radar-guided PL-12/SD-10 'Sino-AMRAAM' and the reverse-engineered semi-active radar-guided Selenia Aspide Mk.1, designated the PL-11.[209] It is highly likely that advanced versions of these AAM are being developed. Publications are available that detail Chinese research into millimetre wave radar seekers onboard AAM, for example.[210] China has a diverse inventory of IR AAM. These include the PL-5 to 9 series, which are derivatives of a range of Western AAM such as the AIM-9 and Rafael Python AAM.[211]

What is the significance of Western, Russian and Chinese AAM development? The sheer diversity of AAM types in service or being introduced into the US, Russian, EU, Israeli and Chinese inventories, and the prospect of evolving regional clone variants and derivatives, presents a genuine long-term problem in intelligence gathering, analysis and countermeasures. If all major nations have similarly effective AAM in the coming decades, unless there is a radical change in advantage for one nation against another, the employment of AAM may be deemed the least effective means of destroying or deterring an adversary. Should this be the case, then a radical reappraisal of Western BVR doctrine and tactics is required.

The P_k of AAM and AAS is, and will continue to be, a major issue requiring research and understanding. Whether future systems carry a payload of AAM will largely depend on whether other means of disabling adversary counter-air air-breathing systems will be necessary.

6
The Evolution of Air-to-Air Warfare

Will future air-to-air combat follow the norms that previous major conflicts have witnessed? It is possible that future peer-on-peer combat will result in more intense air battles, compared with those seen since the Vietnam War, Middle East and Falklands conflicts, with all sides potentially experiencing high attrition rates. The requirement for an appropriate air dominance system compels assessment. Before this can be done, it is important to understand how AAS have performed in the past. Evaluating statistical trends in historic air-to-air combat allows for a methodical approach in analysing the effectiveness of the types of weapon systems which were used, and those which may be required in the future. Addressing the question of how often more lethal or effective weaponry determines tactical outcomes requires the examination of statistical data. The best evidence comes from the domain of air-to-air combat. There is a large amount of data available from both actual and simulated air combat.

AAM are the primary weapons in air-to-air combat and have been so since the beginning of the Vietnam War. The employment of AAM has not been without difficulties and controversies, however. An understanding of the history and P_k of AAM is crucial before any evaluation of future systems can be conducted. The P_k achievable of any AAM depends on a number of factors, including its kinematic performance (the ability to react to and guide to a target during the last seconds of an AAM flight) against the intended target, especially during the endgame phase of flight and the performance of its seeker head and fusing subsystems, predominantly in an EW countermeasures environment.[1] Understanding the capabilities and constraints of AAM is absolutely central to the whole process of the development of air platforms, sensors, weapons and the tactical doctrine employed.

AAS kill probability

Frequently misunderstood, or, indeed, little understood by some air power proponents, is the likelihood of an AAM actually achieving a kill.[2] To recap, AAM P_k affects the choice of how many AAM need to be fired in order to kill an adversary aircraft. In addition, this, in turn, affects almost every other consideration, such as the number of AAM carried on a fighter aircraft, affecting the required size of that fighter, and/or the number of fighters required to counter potential adversaries. The formula for AAM P_k is based on the ratio of AAM to P_k – this is referred to as the probability of a single-shot kill (P_{ssk}).[3] How this is calculated depends on numerous factors, but will essentially be constructed on a series of AAM live-firing trials against the full range of target profiles, and simulated firings, which are ground-based tests conducted in a Hardware-in-the-Loop facility, simulating actual aircraft and missile sensors and the EA techniques which would be used against them.[4] These are normally centred on the ability of the AAS to operate in the full range of conditions likely to be encountered during an air battle.

While it is important to have a thorough understanding of the principles of AAM P_k, missiles are but one part of a system required in achieving a kill – the AAS. A number of factors affect AAS P_k: adversary EA capabilities, target manoeuvre, the serviceability of the AAS, the performance/capability of the AAS – including own aircraft air sensor and third-party sensor effectiveness, the skill of the aircrew and situational awareness. The USAF, for example, when assessing AAM effectiveness during the Vietnam War, defined a fighter weapon system as containing the major subsystems of 'the airframe, propulsion, and controls; avionics; weapons and fire control; the human being (pilot and crew)'.[5]

AAS form the basis from which all current counter-air doctrine and tactics are formed. The overall capability of the AAS is consequently used when assessing P_k. An acceptable AAS P_k in the most difficult scenario is an extremely important part of a counter-air system. If aircraft are limited in the number of BVR AAM carried, then AAM P_k needs to increase. There comes a point with AAM P_k when firing more than one AAM in a salvo does not increase the P_k significantly. As the P_k of a single AAM increases, the corresponding increase in AAM P_k with the number of AAM fired decreases relatively. The numbers of AAM fired in a salvo will therefore depend on the known P_{ssk} of the AAM in a particular scenario.[6] There is no panacea for this; it will depend on several factors, including the type of conflict – COIN, policing or interstate war. These will alter with the risks which politicians and military leaders are prepared to take – loss of aircrew and/or aircraft, loss of the assets that the fighters are protecting, and, not least, the repercussions if the battle is lost. The point at which the P_{ssk} of an AAM makes it worthwhile to have a one-shot doctrine is, therefore, subjective. With a P_{ssk} of 0.5, two AAM are required to be fired in salvo in order to achieve a P_k of 0.75 – if that is the desired P_k.[7] If three AAM were launched, the P_k only increases to 0.88. If the AAM P_{ssk} were as low as 0.15, then even launching eight AAM in a salvo would only achieve a P_k of 0.73. It is my view that in high-intensity state-on-state warfare against a peer adversary, the outcome of which is deemed critical, an AAS P_k of greater than 0.9 is required – when applied to a salvo of AAM. Even this may not be enough if an adversary has similar AAS P_k and greater numbers of AAM and aircraft.

When considering firing a number of AAM in salvo in order to increase P_k, it is difficult to predict if each AAM will encounter the same conditions. Therefore, the actual P_k may be somewhat different from that calculated on paper. It is, nonetheless, a crucial factor when deciding AAM load-out, salvo numbers and tactics.[8] Russian and Chinese air power tacticians understand the issue of AAM P_k and have adopted procurement strategies and doctrinal tactics to counter this challenge. The Russian exemplar of BVR combat has its origins in the Cold War, when Soviet operational analysis identified that the low P_k of AAM seekers and airframes, especially if degraded by countermeasures, would have a significant impact on effectiveness. By the 1970s the standard Soviet technique in BVR tactics was to launch a salvo of two AAM.[9] It is not unreasonable to expect future Russian-trained aircrews to launch a salvo of two or more BVR AAM. The aircraft being targeted must jam, decoy and/or out-manoeuvre three or four tightly spaced inbound missiles. Even with P_{ssk} of 40 per cent, a three-round salvo has a P_k of approximately 0.8. If neither side has a decisive advantage in EW capability, the Flanker does have a decisive advantage in aircraft and AAM kinematics, in addition to having up to 6–7 times the payload of BVR AAM to expend, when compared to the current proposed load-out of two internally carried AMRAAM AAM for the F-35 JSF.[10] The introduction into service of the Russian PAK-FA and Chinese J-20 stealth fighters in the coming decades will only add to these countries' capabilities.

Significantly, the Chinese appear to be mirroring Russian doctrine and BVR AAM capability. This has implications for any future counter-air system. An important trend in the PLAAF's modernisation is the development and deployment of support aircraft serving as force multipliers to enhance the effectiveness of its combat aircraft. These support aircraft include AAR, AEW, AWACS, and EW and ISR.[11] An example of the determination of the PLAAF to adopt Western doctrine is the 2011 deployment of J-10 fighters to Kazakhstan, where they participated in a Shanghai Co-operation Organisation COMAO exercise.[12]

Historical analysis of air-to-air kills

That a given capability is technically feasible does not necessarily mean that it is operationally useful in an actual combat scenario. For example, during the early years of the Vietnam War, air combat training on instrumented ranges revealed that approximately 50 per cent of simulated AAM shots were being taken out of parameters. Furthermore, from 17 June 1965 to 17 September 1968, around 600 AAM were fired during 360 air-to-air engagements against Vietnamese fighter aircraft, achieving a probability of a kill of approximately 10 per cent.[13] Since the advent of BVR AAM, approximately 660 air-to-air kills have been recorded by Western-equipped BVR AAM forces. Using RF AAM, 107 of 663 (16.1 per cent) kills have been achieved, of which only 26 of 663 (3.9 per cent) have been BVR.[14] RF AAM were very seldom used successfully in air combat either by US aircrews in Southeast Asia during 1965–1973 or by Israeli aircrews in the conflicts of 1973 (Yom Kippur) and 1982 (Bekaa Valley).[15]

An example of AAM P_k (in this case, a probability of a hit) is figures used for pre-combat AAM P_k by the US during the Vietnam War. The calculations took into account four causal factors: the probability of successful launch; whether the missile was fired within a successful envelope; whether the missile tracked the target and whether the missile actually hit the target. The probability of the 'system' working is the sum of these factors.[16] The RF AIM-7E had a pre-combat P_k of 0.71, while the IR AIM-9B was 0.65.[17] From April 1965 to 1 August 1967, however, the actual combat results were somewhat different, with the AIM-7E being 0.15 and the AIM-9B 0.25.[18] As discussed earlier, when P_k is so low, if it cannot be improved, launching AAM in salvos can offer a solution.

US RF AAM actual demonstrated P_k during the Vietnam War, from March 1965 to January 1973, was 0.06 (55 of 918).[19] The Yom Kippur War of October 1973 was a much shorter conflict, but the air-to-air combat was intense. Burton, in *Letting Combat Results Shape the Next Air-to-Air Missile*, states that despite the large number of engagements, with 261 kills claimed, Israeli F-4 Phantoms only fired 12 AIM-7 AAM, claiming 5 kills (2.0 per cent), with one being a single BVR kill (0.4 per cent).[20] Israel's June 1982 invasion of Lebanon offers a similar example. By 1982, the Israelis had F-16s and AIM-7-equipped F-15s in their inventory. During the major air battles between Israeli and Syrian fighters that occurred over the Bekaa Valley in Syria in June 1982, the Israeli Air Force split counter-air responsibilities between their F-15s and F-16s, the latter being armed only with an internal gun and short-range IR AIM-9L AAM. The Israelis are thought to have shot down approximately 80 Syrian fighters.[21] Twenty-three AIM-7 AAM were launched, achieving 12 kills, giving a P_k of 0.52, with only a single BVR kill.[22]

From March 1965 to the end of US air operations against North Vietnam in January 1973, only 2 BVR kills were officially recorded out of a total of 918 reported attempts at launching RF AAM.[23] From 1965 to 1982, approximately 95 of 953 (10 per cent) of US and Israeli RF AAM firings occurred at distances beyond 5 nautical miles.[24] Prior to the 1991 Gulf War, only 4 of 614 (0.65 per cent) kills achieved were BVR. Since 1991, 22 of 49 (45 per cent) kills achieved have been BVR.[25] Statistically, this appears to be an exceptional increase, with the proportion of BVR kills increasing 69-fold. However, how applicable is this? Attempts to achieve BVR firings by US and Israeli aircrews from 1967 to 1982 were few, and are indicative of the problems inherent in the early evolution of BVR combat. As discussed, since the 1991 Gulf War, with US and allied forces enforcing a No-Fly-Zone over Iraq and during the 1999 Kosovo campaign, AIM-120 AAM has demonstrated an overall 0.59 P_k in combat to date.[26] Thirteen AMRAAM have been fired to achieve six BVR kills, giving a BVR P_k of 0.46.[27] Significantly, the Iraqi MiGs shot down were fleeing and non-manoeuvring; also notable is that the Serbian J-21 Jastreb aircraft shot down during the Kosovo conflict had no radar or Electronic Countermeasures (ECM) and the MiG-29 Fulcrums that were shot down had inoperative radars. In addition, there are no reports of ECM used by any fighter, and no fighter had comparable BVR weapons. All engagements involved numerical parity or superiority.[28] Although a significant achievement for forces operating at great distances from their own bases, and proving the efficacy of AWACS and other assets, the fact that the opposition was relatively inept and incapable of posing any real threat needs to be acknowledged. This is absolutely essential when analysing the actual effectiveness of counter-air systems involved. Will these conditions apply to a peer adversary, such as China?

Why was the exploitation of the technical capability to launch BVR RF AAM prior to the 1991 Gulf War, and the advent of the AIM-120, so rare? Why were there not considerably more BVR launches and kills? The reluctance of US and Israeli fighter crews to risk BVR shots in actual combat during the Vietnam War and Middle East conflicts was not only due to ROE issues, but also an initial mistrust of the effectiveness of RF AAM. Fighter aircrew were reluctant to shoot BVR unless they could be highly confident that the target was the enemy. This reluctance to risk air-to-air fratricide, known as 'Blue-on-Blue' within the counter-air community, was often reinforced by rigorous ROE.[29] Burton observed, 'The most dominant aspect of missile air combat to date [1985] has been the requirement to positively identify the target. Results in dogfights [were] almost all shots within visual range and from the rear hemisphere.'[30] As a result, BVR AAM kills were only practicable when the ROE criteria were fulfilled by the use of special equipment, such as identification, friend or foe interrogators.[31]

As already highlighted, Burton's analysis of US engagements during the Vietnam War established that of approximately 90 RF AAM launched BVR by US pilots, only 2 kills were achieved, an abysmal success rate.[32] These results would naturally lead to crews wishing to delay AAM launch; however, both the RF and IR AAM used up to the end of 1967 were not particularly effective in the closer, more manoeuvrable engagements either. Analysis from *Project CHECO* emphasised the extremely poor effectiveness of the AAM used at the time, particularly the AIM-7:

> 35 percent of the AIM-7s and 26 percent of the AIM-9s were considered launched outside permissible parameters . . . There were only 11.1 percent recorded hits, with 2.8 percent designated probables, of the AIM-7 . . . For the slightly more effective AIM-9, there were 18.6 percent hits recorded, of which 1.7 percent were probable.[33]

Ultimately, US fighters were required to use the gun on North Vietnamese Russian MiG fighters, almost 100 times more than originally expected.[34] North Vietnamese statistics were no better. Although they possessed the Alkali RF AAM, only five firings were witnessed by US aircrews, with no hits.[35] The Atoll IR AAM, which was similar to the AIM-9B Sidewinder, was the preferred weapon, achieving 24 kills of 209 launched, giving a P_k of 0.11.[36] The dominant limitations, however, were perhaps not technical, but a matter of aircrew preference. Although the CHECO analysis highlights the poor AAM performance of both Soviet-built and US AAM, it is worth noting that US aircrew would launch missiles early, outside of valid parameters, in order to distract MiG pilots:

> The most effective escort-counter to a close-in attack was found to be a hard turn to point at or slightly in front of the MiG, followed by early launch of an AIM-7/9. Under these conditions the escort aircraft normally did not have time to achieve a radar lock-on or to satisfy valid launch parameters; the AIM-7/9 was launched primarily

> to disrupt the MiG's attack. Despite the absence of effective missile guidance, these early firings were frequently the escort's only chance of diverting the MiG's attention and causing it to abort its attack on the strike elements.[37]

Examples of fratricide in modern air warfare are fortunately few; however, the 2003 Gulf War saw an RAF Tornado GR-4 and a USMC F-18C shot down by US Patriot SAM.[38] During the 1982 Falklands War, an Argentinian Mirage II suffered damage by an AIM-9L AAM fired from a RN Sea Harrier; subsequently, Lt Garcia Cuerva's Mirage was shot down by his own side while attempting to make an emergency landing at Port Stanley Airfield.[39] Missiles of all types, air-to-air, surface-to-air and air-to-surface, have grown ever more reliable and lethal, yet military operators must still make quick shoot/no-shoot decisions in order to be effective and, under the extraordinary pressures of combat environments, those decisions remain open to fatal error. The tragic downing of two US Blackhawk helicopters by two US F-15Cs in the no-fly zone over northern Iraq in 1994, which resulted in the deaths of all 26 people on board, graphically demonstrates the difficulties of reliably identifying adversaries in air-to-air engagements, and this was not in contested airspace.[40] It is essential for military forces to be able to identify friends from adversaries; technological advances should enable significant improvements in gaining this situational awareness.[41] The potential for fratricide remains a characteristic of modern air warfare. Advances in sensors and information systems ought to deliver improved methods of identifying adversaries; already examined, JTIDS is an example.

Analysis of air-to-air kills in the modern era show a definite trend towards the use of AAM, in particular BVR RF AAM. It was not until the Gulf War of 1991 that the synergy of equipment, including by this time E-3A AWACS aircraft, and operational circumstances permitted a significant portion of the engagements resulting in BVR AAM kills. US forces expended 88 RF AAM.[42] Of the 23 RF AAM kills achieved by USAF F-15s, 29 were launched BVR, achieving 16 kills (BVR P_k of 0.55).[43] Prior to the Vietnam War, all air-to-air kills were achieved by the use of the AAG. I have examined the majority of air-to-air kills achieved by the US, UK and Israeli forces from the Vietnam War to the present, but have not included minor engagements, such as those that have occurred between Israel and Middle Eastern countries outside of major conflict, between the US and Libya during the 1980s or between India and Pakistan in 1971. These and other engagements, including those during the Iran/Iraq conflict during the 1980s, have not been examined due to the difficulty in verifying the results. It is considered that these engagements do not unduly affect the overall statistical analysis. While not intended to be definitive, my analysis is, nonetheless, consistent enough to allow statistical trends to be used and understood.

From the Vietnam War, beginning in 1965, to the 1982 Falklands War and Bekaa Valley conflict, 614 air-to-air kills were achieved, most by IR AAM (338) – 55.0 per cent, with 32.7 per cent (201) by AAG. Only 12.2 per cent (75) of kills were from RF AAM, with a derisory 0.6 per cent (4) BVR. From 1991 to date, 66.7 per cent (34 of 51) air-to-air kills have been from RF AAM, with 47.05 per cent (24 of 51) of these BVR; 29.4 per cent (15 of 51) per cent have been from IR AAM.[44] No kills have been by AAG, although two kills – 3.9 per cent – were achieved by US A-10 Thunderbolt anti-tank aircraft with an air-to-ground gun; both of these kills were against slow-moving helicopters.[45] The significance of the analysis is the establishment that air-to-air kills from AAG since 1991 have been zero. Further, none of the kills achieved since the Vietnam War have involved classic visual air combat manoeuvring.[46]

There have been far fewer air-to-air engagements since 1991, than the period from 1965 through to 1982. Are Western states mentally prepared for conflicts that require control of the air to be achieved against peer or near-peer adversaries? The advent of AIM-120 AMRAAM has dramatically changed the way in which BVR air-to-air combat is conducted. Since 1992, all Western RF AAM kills have been achieved by the use of the AIM-120 AMRAAM. An overall P_k of 0.59 may seem impressive; however, this increase in P_k needs to be kept in perspective. The analysis illustrates the increase in the percentage of BVR kills, from 0.6 per cent prior to the 1991 Gulf War to 45 per cent in all major air-to-air engagements since. IR AAM kills have fallen from 55 per cent to 29.4 per cent. What is the significance of this improvement? The analysis needs to take into account the causal influences that have achieved this paradigm shift. There are a number of factors that have come together to enable this apparently dramatic increase in effectiveness of BVR AAM. Notwithstanding the AAS P_k, as discussed, the evolution of air-to-air tactics has changed a great deal since the Vietnam War. The continuing development of AMRAAM class systems and, most importantly, the integration of NEC, allowing a significant improvement in situational awareness and BVR tactics, have helped achieve this transformation. Statistically, however, the number of air-to-air engagements and AAM used does not offer compelling proof that AAM are the panacea for future air combat.

The biggest difference in weapon kills is the use of the AAG in air-to-air engagements, falling from 33 per cent in the period up to the 1991 Gulf War to 0 per cent since. This is significant when making any judgement on the procurement/integration of AAG into future counter-air platforms. It is my view that the efficacy of future AAG employment requires examination, if indeed the fitment of an AAG will be relevant at all. Though acknowledging that what has happened in the past will not necessarily be the case in the future, trends do need to be analysed. While the statistical analysis of air-to-air kills cannot offer definitive guidance on procurement strategy, or tactical doctrine, the results should aid decisions on future platforms, sensors, doctrine and tactics. The analysis conducted has established that although BVR RF AAM use and P_k, and AAS P_k, have greatly improved, it is insufficient to guarantee gaining control of the air in future conflicts. Unless AAM/AAS P_k is significantly improved, particularly in the EA environment, other methods of negating adversaries will be required, particularly when a peer adversary has dominance in numbers, in both aircraft and weapons.

Too few AMRAAM have been used in air-to-air scenarios to offer any meaningful statistical analysis. Without a near-peer or peer adversary, with all the capabilities these will have, AMRAAM performance in the 'real world' can only be analysed by using open sources. It is axiomatic that unless AMRAAM, or any AAM, can operate in a complex EA/denial environment, any NEC and all other sensors, weapons and qualities of aircraft and aircrew will be severely tested.

Modern air-to-air combat philosophy

It is not normally possible to destroy a competent adversary's force in one engagement – this applies in all domains, including the air. Even if this were possible, reserves would (or should) be in place, to fight another day. Depending on the exchange ratio, and the number of reserves, the destruction of even a small percentage of an attacking force can have serious repercussions, especially if the war goes on for an extended period. Terms such as decimation and annihilation are sometimes used to describe an engagement outcome. 'Decimate' means to 'kill one in ten'. 'Annihilate' means to kill more than 90 per cent of a deployed force.[47] Even if a force is 'only' decimated, it would not take many similar outcomes before that force has been effectively annihilated, rendering it completely ineffective. The 1982 Falklands War took a massive toll of the Argentine Air Force. Of the 129 air combat aircraft available, approximately 47 were destroyed. This was not quite annihilation, but much more than decimation.[48] On the other hand, the Israeli Air Force essentially annihilated the Syrian Air Force in the Bekaa Valley in June 1982, for no losses in air-to-air engagements.[49]

The drive in BVR AAM development is to achieve a kill on an adversary aircraft as far from your own aircraft and forces as possible, before a kill on you is achieved. This doctrine offers a number of advantages, including less danger to the shooter, allowing a greater separation range (F-Pole) between the shooter and the target at AAM impact. There are problems with engaging adversaries at great ranges, however. As discussed earlier, without robust means of identifying a target at range, incidents of fratricide may increase. The cost of developing fighters and sensors that are capable in the BVR environment is significant. In terms of kinematic performance, the impact of the aircraft's kinematics at the point of AAM launch is vital.[50] Ramjet AAM, such as Meteor, may offer a viable alternative, as these are not significantly affected by an increase in the launch fighter's speed and height.[51]

According to Stillion and Perdue, in *Air Combat, Past, Present and Future*, if a conflict develops between China and the US over Taiwan, it would be very difficult to predict who would have the advantage in the technological/countermeasure game. China could enjoy a 3:1 advantage in fighters if the US could fly from Kadena Air Force Base in Japan, or approximately 10:1 if forced to operate from Andersen Air Force Base in Guam.[52] Historically, overcoming these odds requires huge qualitative superiority. Such qualitative superiority is extremely difficult to achieve against a comparable power. An example of this was World War II, which saw Germany pit its air force against a number of opponents; in all cases, until the summer of 1940, the Luftwaffe proved a formidable force, annihilating all adversaries, until it came up against the RAF in what became known as 'The Battle of Britain'.[53] This was a classic example of an air campaign waged at such distances from their own operating and support bases that the Luftwaffe lost the battle.[54] The military/industrial complex played a significant part, allowing greater RAF fighter aircraft production and more fighter pilots being trained when measured against Germany; this, aligned with the fact that pilots lost by the Luftwaffe were almost always lost for the duration of the war, made it unnecessary for much of the RAF's central and northern commands to be used.[55] Klaus Maier, in *Germany and the Second World War*, states: 'The German failure to achieve air supremacy and the unfavourable time of year reduced British fears of a landing. [The] war-economy considerations forced a disbanding of the deployment of Operation Sea-Lion.'[56] Operation Sea Lion, the planned invasion of Britain, was effectively cancelled when Hitler issued his Directive No. 21 'Barbarossa', which turned the German military's attention towards Russia. Alexander Dallin, in *German Rule in Russia 1941–1945*, writes, 'Gone were the last illusions of downing Britain "by one stroke", gone was the pretence of German-Soviet "friendship cemented by blood".'[57]

Lack of control of the air by Germany over the airspace of northern France and southeast England was one of the deciding factors in Britain avoiding an invasion. Any success of invasion depended on gaining air superiority over the area of operation.[58] Alexander Seversky certainly believed that Germany had no hope whatsoever of gaining air superiority over the south of England. Seversky argued (in August 1940) that the Luftwaffe had inferior fighters, and their doctrine, which was based largely on supporting the army, with aircraft such as the Stuka, meant that they were not geared to conduct successful counter-air operations against the RAF.[59] The fact that an actual invasion of Britain may not have been the main German objective does not alter the point that Germany underestimated the importance of gaining control of the air. The importance of 'winning', however, is made clear by Richard Overy: 'It is evident that not a lot was needed to deter Hitler from the idea of invading Britain. Fighter Command tipped the scales. The failure to destroy the Royal Air Force ruled out the possibility of a cheap, quick end to the war in the west and kept alive an armed anti-Axis presence in Europe.'[60]

Russian and Chinese fighter doctrine relies on a number of basic tenets, including superior numbers and firepower; sensor diversity on aircraft and weapons; advanced EW, for example, DRFM cross-polarisation jammers conducting EA, and towed radar decoys; and, significantly, a greater ability to absorb attrition.[61] The West's lead-in sensors and electronics is not nearly as substantial as in the past. Significantly, technologies developed for the computer, gaming, television, medical imaging, telescope and wireless network industries can be directly applied to fighter sensors and weapon systems. The impressive Russian Su-27 Flanker (and its later variants) is unquestionably the aircraft which has caused Western experts most concern to date.[62] Of the West's fighters – the Swedish JAS-39 Gripen, the French Rafale, the Eurofighter Typhoon and the US F-22 Raptor – only the fifth-generation F-22 has thrust vector control.[63] Russian developers believe that the key to dogfight supremacy will rest in their pilots' ability to engage enemy fighters in any position relative to their own aircraft. It is arguable, however, whether this ability to out-manoeuvre fighters is relevant in an era when long-range BVR AAM capability is of such importance and the potency of HOBS AAM and HMCS are gaining prominence.

Nonetheless, it is not by accident that all Western fighters strive for an ability to obtain an advantage in maximum sustained and instantaneous turn performance. These two attributes allow fighter aircraft to turn quicker, while maintaining energy, allowing weapons, such as IR AAM, to be used quickly. It is also crucial when attempting to get into the rear hemisphere of an adversary's aircraft in order to employ the AAG. Currently, it is considered essential that any modern fighter must have the ability to manoeuvre to defend itself in the visual arena. Furthermore, in a high-intensity conflict, when faced with an adversary with capable aircraft, weapons and highly trained aircrew, it is not always guaranteed that the BVR shoot-out will succeed. The introduction of extremely agile AAM, capable of being employed at very high off-boresight angles, and HMCS, which enable a pilot to look at a target and shoot, have altered the way in which air-to-air combat is fought. If required to enter a visual merge, the requirement for an aircraft to 'turn and burn', as fighter aircrew say, is greatly diminished. Future requirements may differ, but do need considerable thought.

The Flanker has a large internal fuel capacity and load-carrying capability.[64] All Flankers carry an IRSTS. The Su-35BM Flanker is set to have the full panoply of sensors and electronic defences, including an IRSTS to detect the launch flare of an AAM, a Radar Warning System to sense radar and AAM active seekers, a MAWS to detect AAM, DRFM jammers to jam the AAM seeker heads and the launch fighters' radars, a towed decoy and the inherent ability to generate extremely high turn rates to out-manoeuvre incoming AAM.[65] The PAK FA is likely to have even greater capabilities.[66]

Future air-to-air scenario

The importance that AAS P_k plays in air-to-air combat has been highlighted in the RAND study, *Air Combat, Past, Present and Future*, hypothesising on a possible conflict scenario between the US and China over Taiwan.[67] This study offers a realistic scenario in which opposing US and PRC fighters are pitted against each other. It effectively illustrates the implications of fighter numbers and AAS P_k. Using this as an example, I have established a scenario of US F-22 Raptor versus PRC F-35 Flanker aircraft. Operating in formations of 24 aircraft, a Flanker regiment can employ 16 very long-range anti-HVAA AAM, 240 AA-12/PL-12 BVR AAM and 48 AA-11 WVR AAM, giving a total of 304 AAM. Conversely, 24 F-22s can employ a total of 192 AAM: 144 AIM-120 AMRAAM and

48 AIM-9 IR AAM.[68] In the following scenario, Chinese forces are RED, while US forces are BLUE. In a possible air-to-air scenario, it is worth examining an air engagement where 72 RED fighters encounter 24 BLUE fighters.[69] For the purpose of this analysis, the AAS P_k required is 0.93. Both sides launch their BVR AAM at the same time. Blue has 144 BVR AMRAAM. Red has 720 BVR PL-12 AAM and 48 HVAA AAM. Neither side enters WVR of each other, and therefore their IR AAM are discounted. Both RED and BLUE field the same aircraft, sensor and air-crew capabilities.

With an AAS P_k of 0.93 for both sides, BLUE would kill all RED fighters but all BLUE fighters would also be destroyed in the process. If AAS P_k of both RED and BLUE is less than 0.87, all BLUE fighters are killed, with some RED fighters surviving. This questions the basis for using any AAS that does not have an appropriate P_k. If we take the known P_k of the AMRAAM in operations, thus far, as 0.59 then 232 AMRAAM are required to kill 72 opposing fighters, if the overall P_k required is greater than 0.90. If AAS P_k falls to 0.10, all BLUE fighters are destroyed; however, 66 RED fighters survive. If BLUE AAS have a P_k of 0.5, and RED AAS have a P_k of 0.10, all BLUE fighters are destroyed while 38 RED fighters survive. Do the odds alter significantly if the size of the BLUE force is doubled? In a scenario with 48 BLUE fighters against 72 RED fighters, with the same parameters used previously, with both RED and BLUE having an AAS P_k of 0.25, all 48 BLUE fighters would be destroyed, with 43 RED fighters surviving. Even with a P_k of 0.1 for both, 29 BLUE fighters would be destroyed, leaving 61 RED fighters. BLUE and RED fighters have very few RF BVR AAM remaining, forcing both to enter WVR. BLUE fighters are now outnumbered by 2 to 1. The actual number of RED versus BLUE fighters is not unrealistic, when considering the number of tangible fighter assets capable of being deployed, from the total numbers available – for both sides.[70]

These examples are designed to illustrate the importance that AAS P_k can have on the outcome of an air-to-air battle and the significance of mass in numbers. As already highlighted, the importance of AAS P_k and mass needs to be understood. When faced with a peer adversary, the US, or any other state, will need to consider whether it has the necessary weapon systems and balance of forces to gain control of the air.

There comes a point where quality cannot compensate for sheer force of numbers. History advocates that this limit is a ratio of approximately 3:1.[71] Joseph Stalin is reputed to have said, ‘Quantity has a quality all of its own.’[72] Perhaps this maxim holds true. The PLAAF training and operational doctrine is not, yet, as sophisticated as the USAF. However, they will not lack numbers when it comes to counter-air assets. In 1992 the PLA had approximately 5000 fighter and ground attack aircraft, with less than 50 considered modern fourth-generation fighters. By 2012, China had reduced its total to 1900 fighter and ground attack aircraft, but with many considered fourth-generation, including 268 J-10 and 405 Su-27/30.[73] By comparison the US had more than twice as many such combat aircraft, with 3020 fourth-generation fighter and ground attack aircraft and 212 fifth-generation aircraft.[74] This imbalance will not last. It is projected that the PLA will increase its combat aircraft inventory significantly in the coming decades. Analysis varies; however, by 2020 the PLAAF could be able to field 450+ Flanker-type fighters.[75] Air Commodore Ramesh Phadke, a retired Indian Air Force officer, believes that by 2030 'the PLAAF and PLAN would have 800+ J-10, another 800 Su-30/J-11Bs, and many JF-17 . . . advanced trainers and [a number of] fifth generation stealth fighters'.[76] Although the PLAAF have a way to go in attaining anything like the capabilities of their Western counterparts, significant progress is being made. In testimony presented before the US-China Economic and Security Review Commission in 2010, Roger Cliff, an analyst with the RAND Corporation stated, 'China's air forces are no longer those of a third-world country. Improvements in China's air force capabilities . . . mean that prevailing in an air war with China will be increasingly challenging.'[77] The use of large numbers of converted unmanned fighter aircraft, and purpose-built UAS, would also add to targeting difficulties – these would still require engagement, attriting own AAM stocks; the problem would be even greater if these were able to conduct EA and launch their own AAM. What, therefore, is the solution? Quality will not necessarily be the answer to an adversary that has effective counter-air systems, with a mass advantage. Perhaps it is the utilisation of UCAS that is able to operate independently from centralised control, when required. UCAS could operate at great range and for long periods from bases, both land- and sea-centred. These could field current AAM, with an appropriate AAS P_k (calculated, taking into account AAM load-out), in all contested scenarios. The questions are – how much degradation of BVR AAM performance can the Western concept of gaining control of the air accept? If AAM are not the panacea to gaining control of the air, then what is?[78] Other weapon systems would be required, such as on-board DEW, aligned with other game-changing technologies which may confuse an adversary's situational awareness enough to gain the advantage – that is, gaining air control of the air for the defined period required.

UCAS CONOPS

Already in development, probably becoming operational towards 2020, UCAS capable of ISTAR and SEAD missions will form part of the matrix of future air forces' combat air power. The US is at the forefront of developing CONOPS for UCAS conducting these roles.[79] If an air-to-air role is to be developed, an appropriate CONOPS needs to be devised for the operation of these systems. A doctrine of swarming airborne assets may be an option, certainly for UCAS tasked with conducting TST ISTAR and SEAD missions.[80] A swarming concept for UCAS would consist of a group of UCAV operating in support of both manned and unmanned units. Swarm technology would allow the mission commander to use NEC to monitor UCAS, both individually and as a group. NEC would connect UCAS to each UCAV and the swarm mission commander. The UCAV within the swarm would fly automatically to an operating area. It is intended that these UCAS would conduct area searches, as directed within pre-programmed systems, automatically processing imagery and detecting threats and targets, through the use of AI and NEC, fusing sensor information and image processing. The *modus operandi* of swarming allows UCAS networks to de-conflict and assign the best UCAV to each task.[81] Before this could happen, however, control of the air is required. This same swarming technology could be used to conduct counter-air missions.[82]

Autonomy will be incorporated where it increases overall effectiveness of UCAS. Currently, automation is implemented in UAS to decrease operator workload and increase efficiency. This can include both auto take-off and landing and transit operations. The terms autonomy and automation have been discussed previously. Autonomy can be viewed as more dynamic than simple pre-programmed flight in that the aircraft will manoeuvre automatically, based on sensors inputs from internal and external sources that include manoeuvring to avoid threats, such as IADS. The US concept certainly envisages that some autonomy will also apply to ground operations, maintenance and repair. Aircraft will integrate with other vehicles and personnel on the ground during launch and recovery, including auto taxi.[83] If it is deemed necessary to have a HITL at all times, UCAV could operate as part of a COMAO package, acting as wingman to a manned fighter, or even a C2 asset, such as AWACS. This concept differs from swarming in that UCAV will accompany and work with a manned aircraft in the battlespace, acting as ISTAR assets, also capable of delivering kinetic effects, greatly increasing the situational awareness and airborne weapons available. Wingman UCAV could also act as a refuelling asset.[84]

Two of the main strengths of UCAS, range and endurance, would mitigate the requirement for a large number of AAR assets. UCAV with capabilities of remaining airborne for 30+ hours (refuelled), with time on task periods of 5–10 hours, would allow for fewer air vehicles, and consequently fewer AAR assets. If still necessary, these AAR assets would not be required to operate at distances close to adversary counter-air assets, rendering them inherently vulnerable. A report from the US Center for Strategy and Budgetary Assessment, *The Unmanned Combat Air System Carrier Demonstration Program*, believes UCAS design features may give a potential endurance of up to 100 hours. The report gives examples of the number of UCAS required versus manned fighters/bombers operating at ranges from 1500 to 3000 nm from land bases or carriers: 'UCAS would be two to six [times] as effective as manned alternatives in generating persistent "Combat CAPs".'[85] Although the report is thorough and meticulous in examining the advantages that UCAS would bring, it only mentions air- and cruise-missile defence once.[86] It would seem that the report believes that control of the air is assumed to be achievable by UCAS, although it does not detail any specific requirements regarding weapon systems. Manned ISTAR facilitating nodes such as AWACS and ELINT aircraft may still be required; it is envisaged though that the 'systems' available as part of the 'system of systems' utilised by UCAS would enable these very HVAA to remain outside of adversary threat systems. The aerodynamic characteristics of UCAV would depend on the robustness of NEC and the types of weapons employed.

Unless dramatically improved, the AAM part of the AAS will need to be replaced with other means of defeating an adversary's counter-air aircraft. Assuming that NEC continues to feature as a critical node in warfare, and that whatever weapons are used are integrated into an overarching 'system of systems', a counter-air UCAS would require the capability to achieve altitudes of 50,000+ ft and a supersonic dash speed of at least Mach 2; that is, it must be at least as capable as Su-35, J-20 or PAK-FA fighters. This speed and height capability allows a greater ability to avoid threats and to use energy advantage when employing AAM. The UCAV would need the ability to manoeuvre aggressively for defensive purposes but not to achieve a position in order to employ weapons, as HOBS systems would be used. The UCAV would need to be of such a size that it could contain enough fuel to achieve an operating radius of 1500 nm, the probable range of China's ASBM while maintaining on-station for at least 1 hour, with 30 minutes of combat fuel, unrefuelled.[87] This should enable a safe separation to be established between highly capable A2/AD weapon systems and operating platforms. Some effectiveness will be lost if denial systems are developed that have greater range. If this occurs, the basis on which such UCAS were developed would still have efficacy, although greater emphasis would be required on AAR assets. Current UCAS programmes, such as the X-47B, propose a UCAV that will not be capable of supersonic speed, a high-altitude capability, even with up-rated engines, or high G manoeuvrability.[88] The question is, could this system survive against the air-to-air component of a highly sophisticated IADS, unless supported by appropriate counter-air systems?

Concentration of force is a fundamental principle of war that is well suited to air power. As previously described, when this is used, particularly with combat air power, experience has shown that air power concentrated in both time and space is more effective in achieving an objective than if it were dispersed over a wider area and longer time. Moreover, a concentrated force will use support forces more efficiently, increasing overall capability and survivability. The COMAO concept involves packaging a large number of aircraft, with a variety of roles, complementing each other, in order to achieve a task. A COMAO formation normally consists of counter-air, strike, AAR, ISTAR and other supporting assets. As with manned aircraft, it will be vital that UCAS operating deep within adversary territory, if denied reach-back because NEC is compromised or inadequate, are able to continue to conduct the tasked mission. If unable to continue the mission, autonomously if necessary, UCAS, or any other platform for that matter, would be valueless. In this instance, 'autonomous' means operating independently of C2, as would manned systems. One of the benefits of operating in large formations includes minimising attrition by optimising mutual support and saturating adversary IADS. Fundamental to the future employment of UCAS must be their ability to operate within a COMAO package. The following is an example of a COMAO formation flown during the 1991 Gulf War by US forces, against Baghdad C2 facilities: Target: Baghdad C2 Facilities; Over the Target Time: 1200–1220Z; Assets and Mission: 24 × F-16 – destroy specified targets (ATTACK); 08 × F-15 – OCA; 04 × F-4G – suppression of enemy air defenses (SEAD); 04 × F-16 – SEAD; 02 × EF-111 – close-in-jamming (CIJ); 02 × EF-11 – stand-off-jamming (SOJ); 01 × EC-130 – communications jamming; 04 × RF-4C – tactical reconnaissance; 08 × KC-135 – AAR; 01 × E-3A – AWACS; 04 × F-15 – DCA.[89]

Future military actions, and specifically air power, should still be based on the same principles that apply today, that is, DCA, OCA, attack and ISTAR capabilities. Although the emphasis of air power may change, its characteristics of reach, speed and flexibility are likely to remain relevant. With the advent of improved IADS, stealth technology may become less effective, with persistence, EA capability, payload, discrimination and countermeasures being the vital components of an air battle. Weapon and detection systems that are able to operate from bases outside of threats, may offer an alternative form of counter-air and counter-IADS capability. UCAS could offer this option. If it is accepted that control of the air is vital in any campaign against a capable adversary, and that UCAS could undertake this task, how would it be employed? Current counter-air Tactics, Techniques and Procedures (TTP) have aircraft such as the F-22 Raptor, F-15C Eagle and Typhoon conducting operations in accordance and within a defined CONOPS, developed over many decades of experience. While a CONOPS is required for UCAS, regardless of whether aircraft are manned or not, the doctrine with which air, sea and land forces are employed will likely remain constant. It is proposed that UCAS would use the same TTP.

It may be possible for a large COMAO formation of combat and support aircraft, combining manned aircraft and UCAS, or made up entirely of UCAS, to operate together or autonomously. This autonomy may permit a quicker and more accurate response, with UCAS utilising automated flight and mission management systems, such as the Dynamic Airborne Mission Management (DAMM) system, which could also be used by manned aircraft.[90] If these management systems reach a level of capability allowing them to be trusted to an acceptable level, then HITL would not be required for other than legal considerations. Using the autonomy levels previously illustrated, Level 4 would be the normal envisaged operating mode, with a HOTL only intervening if required. Level 5, giving full autonomy, would be implemented if communications links were lost and the importance of the mission was deemed crucial enough to warrant the potential risks that this may involve.

7
International Relations and Future Threats

Introduction

The issues that form military doctrine and political policies towards international relations are complex. The types of military systems required to enforce these doctrines and policies are predicated on the likely scenarios that states may encounter. It is important, therefore, to have an understanding of where future threats are likely to emerge; only then can coherent strategic doctrine be formulated and the correct military equipment procurement and training policies be implemented. No country or region should be viewed in isolation; rather how they relate to each other should be considered. This is a fundamental premise of international relations. Whether there will be major state-on-state conflicts in the coming epochs is debatable, but is, nonetheless, a major consideration for any government's military strategy.

Rupert Smith, in *The Utility of Force*, argues that major state-on-state wars involving the whole population and industrial complex are highly unlikely, and that our armed forces need to be reorganised to fight different types of conflicts.[1] While Smith's views are worth considering, there are other opinions. Colin Gray believes that although future wars between states cannot be predicted, they are likely to occur.[2] Amongst other possible conflicts, Gray hypothesises that a China versus US clash, either over Taiwan or over the hegemony in East Asia, is possible, with both countries arguing that the other is becoming the defining threat for national security.[3] Gray does not wish to opine that this type of conflict is a certainty, but he emphasises that it would be prudent to be prepared for 'strategic surprises'. Perhaps Gray's most important observation is his belief that the future of warfare will contain interstate conflicts that no one today who carries weight as a supposed expert on the future is imagining.[4]

Michael Howard, in *The Invention of Peace & the Reinvention of War*, states that while the probability of major state-on-state wars is becoming less likely, nations such as China, Russia and the US will offer the potential for confrontation.[5] The historian Hew Strachan suggests that a lack of understanding of the true nature of war has led to a failure to understand its 'changing characteristics'.[6] Strachan believes that '[w]ars have become fuzzy at the edges: they have no clear end and army forces increasingly have to reject the appropriateness of classical definitions of military victory'.[7] Another view comes from Azar Gant from Tel Aviv University, who wonders whether, although the probability of major wars remains low, the 'near disappearance of armed conflict within the developed world is likely to remain as stark as it has been since the collapse of communism'.[8] Gant is of the view that the re-emergence of capitalist non-democratic states, such as China and Russia, is a paradigm shift in international relations. Strachan further argues that we are likely to see a change back to the ideas of deterrence and limited war.[9] He believes that '[t]he wars of the later twenty-first century may well be waged for assets, to which we feel in theory all humanity should have equal access but for which in practice we compete'.[10] I believe we cannot ignore the possibility that there will be a major state-on-state conflict in the coming epochs.

Following World War II, and the devastating attacks on Nagasaki and Hiroshima, Bernard Brodie, one of the most imminent theorists of strategic deterrence, wrote: 'Thus far the chief purpose of our military establishment has been to win wars. From now on its chief purpose must be to avert them. It can have almost no other purpose.'[11] Brodie's remarks capture the essential reason for a nation possessing armed forces. He succinctly stated: 'The threat of war, open or implied, has always been an instrument of diplomacy by which one state deterred another from doing something of a military or political nature which the former did not wish the later to do.'[12] Perhaps Brodie's most prescient observation was the likelihood that one's own behaviour in extremis is unpredictable, let alone that of an adversary: 'The wrong kind of prediction in the future could precip[it]ate the total war which too many persons have lightly concluded is now impossible.'[13]

It is not possible to accurately predict future events; it is, however, possible to learn from previous events, and to apply sound analytical judgement to the state of current international affairs, enabling the formulation of coherent policies. Most major nations utilise think tanks and other institutions to help devise strategic policy.[14] What makes a state a superpower? Analysis from DCDC defines power status as 'the amalgam of military strength, access to resources, size of economies, educational opportunity, demographics, geo-political position and political stability amongst others'.[15] China uses its own method of calculating a nation's power – Comprehensive National Power (CNP). While there is no unified definition or method of calculation with regard to CNP, it is generally defined in China as 'the comprehensive capabilities of a country to pursue its strategic objectives by taking actions internationally and the core factors to the concept are strategic resources, strategic capabilities and strategic outcomes, with the strategic resources as the material base'.[16] Since the demise of the Soviet Union, and while the US is the only current true superpower, there is a view among economists that China is likely to overtake the US economically as early as 2020. According to the UK's National Institute of Economic and Social Research (NIESR), China is likely to overtake the US as the world's largest economy by 2019, as Western nations struggle to recover from the global banking crisis.[17] Others, such as Goldman Sachs, estimate that the size of the Chinese economy will overtake America's by 2027, and by 2050 will be almost twice as big.[18] These predictions underline the contrasting fortunes of Asia, which is enjoying rampant growth, and the more subdued economies of the West. China's Gross Domestic Product (GDP) grew by 10.4 per cent in 2010, compared with 3 per cent growth in the US and 1.8 per cent in the Eurozone. NIESR forecasts that Chinese growth will average 8 per cent a year out to 2018, compared to 2.5 per cent in the US.[19] China's GDP growth for 2013 was 7.7 per cent.[20]

The future world view is impossible to predict. DCDC does, however, attempt to give some judgement as to the likely structure of the future international landscape. While DCDC believes that the US will still be the pre-eminent military power in 2040, it assesses that China *may* reach great power status.[21] The struggle for control over resources and the Global Commons may indeed increase the incidents of conflict. The Global Commons is described thus: 'The domains of the high seas, international airspace, outer space, and cyber space are interlinked and critical to the prosperity and security of the Alliance nations. Access to these domains is both a military and economic necessity in today's world.'[22]

As part of a coalition, the UK may be required to confront a near-peer or even a peer adversary, and there will remain the necessity for nation-states to maintain military capabilities that deter potential aggression. China will be the benchmark by which the US and its allies judge their capability requirements.[23] Are we possibly seeing a transfer of power, from the US to China, similar to that which took place in the early part of the 20th century, when Great Britain began to cede its prominence to the US?[24] Other states such as Russia, North Korea, India, Australia, Brazil, Taiwan and Japan will all play a major part in future international relations. Russia, in particular, is pushing the boundaries of what will be accepted of a major state. Its annexation of Crimea in 2014, and support of the independence movement in Eastern Ukraine, has incurred the anger of many nations. Russia denies involvement in Eastern Ukraine, despite significant evidence to the contrary.[25] Whatever Russia admits to, at the very least, it has highlighted to many countries the potential doctrine that it intends to follow, and the resulting repercussions. Australia and Japan, also, are important economic powers in their own right; it is in relation to the security of the near abroad that these two countries will seek to maintain and build alliances, attempting to balance China's influence. North Korea will likely continue to be a failed and unstable state, generally undermining the stability of that area of the Pacific.[26] Russia, India and Brazil are states whose economies are growing faster than those in the West, and are predicted to continue to do so, although recent economic sanctions on Russia have stalled its progress. DCDC believes that in 2029 the major powers will be the US, China, Russia, UK, France, India, Japan, Iran and possibly Brazil.[27] Another view comes from Joseph Nye, who believes that although the US is likely to remain the most powerful state in the 21st century, it does not mean it will have domination.[28]

Middle Eastern countries such as Iran and Saudi Arabia will likewise have a significant impact on the nature of international affairs. International attention regarding Iran's intent to gain nuclear weapons capability drives much of the international communities' current efforts to reign in these ambitions. It is probably too late in North Korea's case, but Iranian containment may be possible, but at what cost? What if Iran does gain nuclear weapons? The effect this will have in the Middle East, and further afield, will test international relations and military doctrine. South America is similarly becoming increasingly important, economically. It is quite possible that an alliance of South American powers may align to challenge the UK's resolve over the Falkland Islands, creating tensions between the UK and those who have been traditional allies. Argentina certainly shows no sign of giving up its claims to sovereignty over the Falkland Islands.[29] Although not confirmed, a potential acquisition of Su-24 Fencer bombers from Russia has caused some angst within the UK government.[30] This does, however, need to be kept in perspective. Just how much of a threat these aircraft represent would depend not just on their potential capabilities but also on Argentina's capacity to fund the support infrastructure required to operate them and, not least, the intent to use them.

Most governments base their military policy and procurement decisions on a range of scenarios in which they have deemed the state is likely to become involved in. Those departments of government that are responsible for foreign affairs and military doctrine usually decide upon these scenarios, which are normally set in future epochs, 2015–2020, 2020–2025 and so on. The UK, for example, uses a set of Studies Assumption Group scenarios developed by the Force Development department of DCDC; these are derived from British Defence Doctrine to represent realistic examples of the types of operations involving UK forces envisaged by UK government policy.[31]

Within this procedure there is a process which turns these scenarios into credible joint campaign plans from which the force package necessary to execute the plans is estimated. Each is then evolved into a campaign plan, which is the subject of extensive analysis. The output from these results, referred to as Joint Campaign Development Force Estimation, is used to inform the central planning process within the UK MOD.[32] This procedure is a valid tool; however, if the initial assumptions are flawed, then all subsequent findings will be based on unreliable foundations. Other states use similar procedures to calculate their own force requirements, each placing a different emphasis on their own scenarios. This is one of the causes of such a variation in countries' spending on their defence force structures. Rupert Smith stresses the importance of proper analysis.[33] Colonel John Warden suggests that errors of judgement in assessing potential threats are unforgivable.[34] Ultimately, the desired political outcome is the primary driver for a state's foreign and military policy, or at least it should be.

James Kurth, in *The New Maritime Strategy: Confronting Peer Competitors, Rogue States, and Transnational Insurgents*, believes that 'the most obvious counterpart to the old Soviet Union and the only likely near-peer or peer competitor is China'.[35] Most US strategists currently refer to China as a near-peer competitor; however, this is likely to change in the coming decades to a peer adversary. Iran is not currently a near-peer competitor; its asymmetric approach to military doctrine may mitigate this requirement. The consequences of the future political and military policies of both China and Iran will have an effect globally, altering strategic, political and military relationships.

A major realignment in US strategic military thinking is taking place. Commitment to wars on two fronts, in Iraq and Afghanistan over the last ten years, has coincided with a global economic downturn, which has seriously tested the US economy. Large cuts in the Pentagon's budget were announced in January 2012.[36] In a brief to the US House Armed Services

Committee in 2011, the four chiefs of the US Army, Air Force, Navy and Marines cautioned that planned budget cuts and possible sequestration would lead to '[a] hollow force unable to provide a proper national defense . . . [and] of the increasing power of China'.[37] Nonetheless, after delays by President Obama, in March 2013 the US Congress enacted sequestration, and cuts amounting to $46 billion for 2013/2014, to begin with.[38] The challenges faced by the US and others are no less fundamental, simply because the Cold War is long over. Indeed, it is not a straightforward comparison to say that the proposed military budget cuts are far less than previously experienced. Whatever the analysis, the US relationship with Europe, in particular, is likely to be tested. The US focus is shifting towards the Western Pacific while still seeking to maintain influence in the Middle East. Its new strategic guidance, *Sustaining U.S. Global Leadership: Priorities for 21st Century Defense*, states that 'U.S. policy will emphasize Gulf security . . . to prevent Iran's development of a nuclear weapon capability and counter its destabilizing policies'.[39]

Aaron Friedberg believes that by 2030 the US will probably have withdrawn most of its forces from Europe, the Middle East and Southwest Asia, while '[a] far greater fraction of the total American military and intelligence effort will be devoted to the Western Pacific, and to the area that extends from the Strait of Hormuz, in the Persian Gulf, through the Indian Ocean to the Strait of Malacca'.[40] The challenges that an aggressive China will bring to stability, not only in that region but globally, will test alliances and military doctrine. Friedberg argues that because of their vulnerability to China's emerging A2/AD doctrine, the US will need to reconsider its use of aircraft carriers; also, as China's counter-air capabilities improve, and its land bases become more vulnerable to attack, 'the air force may find itself pressed to spend less on relatively short-range air superiority fighters . . . and more on stealthy long-range bombers and unmanned aerial vehicles'.[41] This view is at the centre of the UCAS counter-air discussion.

Whether the EU as a collective, or European countries as individual states, have the ability, or indeed intent, to become embroiled in a Pacific/Asia-centric strategic scene in the coming decades cannot be evaluated with any confidence. However, inadequate analysis may lead to a situation where the lack of willingness to become involved in any stabilising or deterrent measures could lead to the wrong interpretation by belligerent states. Economic constraints necessarily drive a country's foreign policy and military aspirations. These same constraints may well mean that a compulsory contribution is required, if domestic stability and reliable trade mechanisms are to remain a primary objective of the state.

What is the most likely scenario in which a major state-on-state conflict will occur in the 2030–2040 period? Recent conflicts such as Bosnia, Kosovo, the 1991 Gulf War, Afghanistan and the 2011 Libyan uprising were not factored into any defence planning assumptions by the US or the UK, to any great extent.[42] In order to enable the correct policy decisions to be formed, it is essential to consider all viable scenarios, which can only be relevant if a thorough understanding of the intent of potential adversaries is gleaned. Countries' foreign policies, such as those of the US, Taiwan, Japan, Russia and India, will have a significant effect on China's foreign and military doctrine, thus affecting the future security of the Western Pacific and further afield. Iran's position in the Middle East also poses a significant conundrum for international politics; both of these areas will be the likely centres of gravity over the coming decades, at least for the US and its allies. China and Iran pose similar problems, with the likelihood that both will use A2/AD doctrine, forcing adversaries to operate outside their current optimum basing constraints.[43] The analysis in this book concentrates on China.

China

An appreciation of China's history and current path towards becoming a world power is fundamental to understanding its perceived status in the world. There are a number of excellent works of reference that detail China's progress; these help understand some of the reasons behind China's internal and foreign policies.[44] China's position in international relations is increasingly significant, not only in regard to its position in the world economy but also in relation to its military build-up and intent. China is no longer the insular state it once was; over the past 30 years, great progress has been made in its pursuit of economic growth and development, enabling higher living standards for its people and increasing its international profile.[45] These economic achievements, combined with progress in science and technology, have also enabled China to embark on a comprehensive transformation of its military. With this economic success has come a revival of the view within China that it should be appreciated for what it is – a great power and the pre-eminent one in Asia. Martin Jacques, in *When China Rules the World*, believes: 'We are now witnessing an historic change which, though still in its relative infancy, is destined to transform the world.'[46] China, as a civilisation, has existed for longer than any other comparable society. Henry Kissinger, in *On China*, states that the history of China as a civilisation seems to have no beginning: 'It appears in history less as a conventional nation-state than a permanent natural phenomenon.'[47] Jacques also believes that China should not be seen primarily as a nation-state, but be viewed as a civilisation.[48] Since its unification in 221 BC, until the early 19th century, China's rulers, through all its dynasties, took the view that it was the most important civilisation, by far.[49] Indeed, until the late 19th century, China produced a greater share of the world's GDP than any other society.[50]

The fundamental social change China has undergone since the 1970s has shifted its aspirations and changed its worldview. It is an economic dynamo and, as previously highlighted, is likely to usurp the US as the world's No. 1 economy in the coming decades. Although difficult to pinpoint, China's economic rise essentially began in 1971, when the US dropped its economic embargo and China took Taiwan's place as a permanent member of the UN Security Council.[51] Aligned with its growing economic power, its armed forces remain the world's largest and are being reorganised and re-equipped to be able to meet any perceived threat.

According to the *Annual Report to Congress: Military and Security Developments Involving the Peoples' Republic of China 2010*, the overriding drivers for China are, currently, 'ensuring internal stability; reunification of Taiwan; gaining respect for its perceived global position; a balanced continuation of its economic development; and the securing of its energy supplies, including the routes through which they pass'.[52] Friedberg sees China's view of the future strategic situation as 'characterized by tenuous near-term stability, serious medium-term dangers, and expansive long-term possibilities'.[53] China may historically have no inclination to control its neighbours' territory; however, it will likely reinforce its vision that it is the key regional power, which will defend itself, will not be threatened and will protect what it identifies as its legitimate interests. Although China's leadership emphasises its peaceful intentions, some international relations theorists believe that this is not the case, with the use of 'Soft Power' and 'String of Pearls' strategies to mislead the international community.[54] Professor Joseph Nye developed the concept of 'Soft Power' in 1990, which he describes as 'the ability to get what you want through attraction rather than coercion or payments'.[55] China is not the only major state to use 'Soft Power' – the US has been a proponent for decades, not least, following World War II, with the introduction of the Marshall Plan.[56] Others, such as Avery Goldstein, do not consider this China's intent.[57]

Whichever views are correct, China's growing economic stature helps its drive for a more active external posture in which it is prepared to demonstrate a willingness to assert its interests. In a significant move from its normal rhetoric, China's 2008 Defence White Paper states:

> China has become an important member of the international system and the future and destiny of China have been increasingly closely connected with the international community. China cannot develop in isolation from the rest of the world, nor can the world enjoy prosperity and stability without China.[58]

Mitsuru Kitano, a Japanese diplomat, believes that China is tending towards a China-centric order, as opposed to a responsible Great Power path.[59] Jacques, writing in *The Times*, views China's rise from a historical perspective, believing that 'the Chinese do not think of themselves in terms of nation but civilization; it is the latter that gives them their sense of identity'.[60] He firmly believes that China's rapid growth will lead to a reconfiguration of the region.

PLA military strategists perceive the US as posing both an immediate and long-term challenge to Chinese national security interests. This perception is based on a set of concerns about US policies on Taiwan–US alliance relationships and defence ties in Asia, and overall US national security strategy.[61] Japan's re-emergence as a regional military power, India's growing military power and regional influence, its own border and coastal defence, and defending its territorial waters and airspace are also viewed as critical areas.[62] The writings of Chinese military officers, and official government assessments, suggest a range of specific threats and potential challenges to Chinese security. These perceptions drive current and future directions in doctrine and force structure planning. While most Chinese commentators do not see a rapid decline in the comprehensive power of the US, they do believe Iraq and Afghanistan have weakened its position in the world and it is inevitable that the US hegemony in Asia will erode.[63] Niall Ferguson certainly believes that the 'West' is in steady decline, while the 'East', in particular China, is on the ascendency.[64]

Although China now perceives itself as a world power, there are underlying uncertainties, not least whether the Chinese Communist Party (CCP) structure can adapt to new social and political pressures. In addition, how will it choose to deal with Taiwan? In line with China's view of its place in the world, the PLA has been engaged in a concerted modernisation effort for some time, with the immediate focus being the ability to threaten Taiwan with military defeat if it attempts to break permanently from the Chinese mainland. Although economic and cultural ties between Taiwan and China have made progress, China's military build-up continues undiminished. According to the *2010 Annual Report to Congress*: '[T]he PLA is developing the capability to deter Taiwan's independence or influence Taiwan to settle the dispute on Beijing's terms while simultaneously attempting to deter, delay, or deny any possible U.S. support for the island in case of conflict.'[65]

China's strategic priorities

It may be that the emerging China–US rivalry is due to misperceptions and policy issues that are relatively easy to rectify, although Friedberg does not believe this is the case. Friedberg believes that both the US and China have strategic objectives that threaten the other.[66] China is sure that the US wants to move it away from a one-party system towards liberal democracy. It is largely because of this that the US is seen 'as the most serious external threat to their continued rule'.[67] Aligned with this paradigm, China's likely strategic focus, beyond its priority of reuniting with Taiwan, will be in strengthening its presence in the South China Sea and the Indian Ocean. Andrew Erickson, in *China, the United States and 21st-Century Sea Power*, notes that Chinese analysts are concerned that the US has the power to threaten Chinese interests.[68] Kissinger views China's stance over Taiwan as 'not so much a test of Communist ideology as a demand to respect Chinese history'.[69] According to Robert Kaplan, in *The Geography of Chinese Power*, China is developing as a formidable land and sea power.[70] As Geoffrey Till points out, because of its growing dependence on access to energy supplies and trade, China will naturally become more maritime centric.[71]

Friedberg predicts that although China may displace the US as the world's No. 1 economy, it is unlikely to usurp it as the dominant military power.[72] China does not publish equivalents to the US *National Security Strategy*, *National Defense Strategy* or *National Military Strategy*. Rather, China uses 'white papers', speeches and articles as the principal mechanisms with which to communicate policy and strategy. Although the transparency of China's military and security affairs has improved in recent years, including its biennial publication of the *Defense White Paper* and the 2009 launch of an official Ministry of National Defense (MND) website, it is viewed by the US as not having gone far enough.[73] Previous *Defense White Papers* have outlined a set of national interests that serve as the fundamental basis for formulating China's national defence policy. These include 'safeguarding state sovereignty, territorial integrity and security; upholding economic development and enhancing the overall national strength; adhering to and improving the socialist system; maintaining and promoting social stability and harmony'.[74] The latest *Defense White Paper*, published in April 2013, is shorter in content than previous versions. It does, however, emphasise concerns with US strategy over Asia. It reiterates Japan as a security concern, while also expanding on the importance of the maritime domain as a core interest.[75]

Chinese military strategists emphasise the need to maintain the existence of three conditions for China to survive and prosper. In order of importance, these are national unity, stability and sovereignty. Chinese threat perceptions and strategic planning are largely informed by the need to maintain these three conditions.[76] Although China has a long history of social disobedience, incidents are ruthlessly put down. This has evolved into an indoctrination of civil obedience – the first principle is 'know your place'. The first priority is to stabilise the social order, not overturn it; social harmony is preferred over individual rights. The CCP's priority will continue to be maintaining the *status quo*. There is a growing awareness within China that social reforms are necessary. In 2008, for example, Hu Jintao proclaimed a doctrine of 'harmonious society' with the aim of mitigating the inequalities of growth. It is increasingly recognised that China risks significant domestic instability if democratic reforms are not embraced.[77]

The *2010 Report to Congress* states that 'China's leaders describe the initial decades of the 21st century as a "strategic window of opportunity," meaning that regional and international conditions will generally be conducive to China's rise to regional preeminence and global influence'.[78] The report also assesses that, although China's leaders continue to support the process of reform, there is a growing recognition that the process of change has forced a number of dilemmas. Although these reforms have enabled China to experience rapid growth, they have also led to substantial challenges, particularly to internal stability. Significantly, the report assesses that these conclusions have led China's leaders to determine that they should focus on managing or exploiting external tensions, especially with the US and other major powers, to maintain an environment conducive to China's growth, at least until 2020.[79] The CCP is aware that once begun, unrest could be difficult to control and could easily turn against the state. Additionally, unexpected increases in resource demand, and access to these resources, could affect China's strategic viewpoint and might force it to re-examine its resource priorities.[80] While the report does seem to offer a relatively gloomy picture, there are more moderate views. China's current position could be viewed as an attempt to sustain regional stability and to reassure its neighbours, as opposed to weakening the US position in Asia.[81] That said, there is certainly acknowledgement within China's leadership that the biggest external obstacle to achieving a true great power status is the US.[82]

The possibility of a military conflict with Taiwan and US military intervention remain China's most pressing long-term military concern. A potential conflict will drive China's military modernisation as long as China's leaders judge that the permanent loss of Taiwan could seriously undermine the regime's political legitimacy and hold on power.[83] Coping with these forces will be fundamental to the development of China as a world superpower. Within China itself, there are some strident views. For example, the *Sunday Times* has highlighted a more bellicose trend among the Chinese military, in particular. Michael Sheridan writes: 'army and navy officers [predict] a military showdown, [with] political leaders calling for China to sell arms to America's foes. The trigger for their fury was Obama's decision to sell $6.4 billion worth of weapons to Taiwan.'[84]

Despite an increase in rhetoric from within China, some analysts believe the chance of a war between China and the US is remote, as the Chinese military threat to the US is only indirect. Jacqueline Newmyer, writing in *Orbis*, believes that China's grand strategy today seeks 'to prevent the encirclement of China while encircling prospective enemies, with the aim of creating a disposition of power so favorable to the PRC that it will not actually have to use force to secure its interests'.[85] Rather than fight the US outright, the Chinese may be seeking to influence US behaviour to avoid a confrontation. Nonetheless, the US is required by its own laws to defend Taiwan.[86]

Even if the US stood by its obligations, could it actually defend Taiwan? Stillion and Perdue believe that by the year 2020, the US will no longer be able to defend Taiwan from a Chinese attack. They emphasise the air battle – China is just 100 miles away from Taiwan, whereas the US must project military power from vast distances, with more limited access to foreign bases than it had during the Cold War. This strategy is designed not only to deny USN entry into Chinese areas of interest, but also to keep US forces away generally.[87] If the US were to abandon Taiwan to China, then Japan, South Korea, the Philippines, Australia and other US allies in the Pacific, as well as India, will begin to doubt the strength of the US obligations. According to Kaplan, this could ultimately encourage these states to move nearer to China, allowing the emergence of a China with true supremacy in the Pacific Rim, and further afield.[88] The subsequent fallout would change the balance of power in the region, with the associated ramifications for the rest of the world.

Economic development

It is generally acknowledged that China is now the No. 2 economic power, after the US, having overtaken Japan in 2010.[89] A nation's power is more than its economic clout, however. China's use of its own method for calculating a nation's power, CNP, has varied somewhat in its consistency. There are two contending scientific teams calculating CNP: military and civilian. The Academy of Military Science analysis contradicts the Chinese Academy of Social Sciences, with it assessing that China's CNP score will equal that of the US by 2020, while the Chinese Academy of Social Sciences consider that China's CNP score will be half that of the US by 2020, with Japan's CNP being 20 per cent higher than the US.[90] In the mid-1980s, Deng Xiaoping, China's leader at the time, stressed that it was important to calculate future trends in CNP in order to guide China's reforms; these CNP calculations include economics, science, defence and other factors. Although calculating CNP was developed in 1984, Chinese authors rationalise the use of CNP theory stating that it originally stems from ancient Chinese strategists. Chinese analysts place great store on CNP scores, considering them an important tool in helping to identify five trends: 'The status hierarchy in world politics . . . The power of potential rivals and potential partners . . . Who will best exploit the Revolution in Military Affairs? . . . Which side will win a war? . . . The trend toward world multi-polarity and US decline.'[91] Some Chinese commentators assess that although the US CNP decline will be relative, it will be actual and it will be transformed from a superpower to a common power.[92]

Western forums make their own analysis – with most agreeing that it is only a matter of time before China overtakes the US as the number one economic power, as discussed earlier. There are, of course, contrary views. Joseph Nye believes that the image of the absolute decline of the US is false, but its relative decline is the same as closing the gap. Nye does not believe that China will overtake the US, and believes that the US has time to adapt strategy to mitigate China's rise.[93] James Mackintosh, writing in the *Financial Times*, opines that although the economic consensus believes that China will keep expanding to surpass the US in dollar terms sometime in the next 40 years, research predicts that growth will fall, with many potential triggers for a slowdown, such as a shortage of housing, leading to a housing bubble, and runaway food inflation.[94]

Even the Chinese Prime Minister in 2010, Wen Jiabao, admitted that the economy was 'unstable, unbalanced, uncoordinated, and ultimately unsustainable'.[95] There are, however, those that argue that China's economy is resilient and as long as it continues to manage its power and water supplies this will, aligned with its international reserves and internal financial wealth, allow it to continue to further expand its Gross Domestic Product (GDP) and GDP per capita.[96] This does not mean it will not slow down. Paradoxically, slowdown in economic growth in China will affect the economic recovery of other countries, including Western states. This symbiotic relationship is illustrated with an ironic view that China will need to rely on the US for the protection of its Sea Lines of Communication (SLOC) for energy supplies.[97] Ultimately, China's economic growth should allow it to fulfil its international ambitions, if internal pressures do not force it to deviate from its objectives.

Alex Callinicos, in *The Grand Strategy of the American Empire*, believes China has the capacity to be significantly more powerful than the US.[98] This view may seem somewhat radical, yet Callinicos is by no means the only international relations analyst to raise concerns over China's rapidly expanding economy, aligned with its strategic intentions. A number of US analysts and policymakers have also raised apprehensions about the potential for China to mount a serious strategic challenge to the US in Asia, especially in the Western Pacific, during the course of the next two decades.[99] These concerns are based on China's expanding economy and growing military capabilities. The rapid economic growth of the past three decades has dramatically increased the resources that the Chinese government has available to devote to military spending. Recent double-digit percentage increases in officially reported defence budgets indicate the degree to which China's growing economic base has permitted the Chinese government to increase the resources it expends on the military.[100] The real growth in defence spending is likely considerably more.[101] The economy has not only enjoyed rapid growth rates over the past few decades, it has also benefited from large inflows of direct foreign investment, and massive imports of modern equipment and machinery. All have contributed to the creation of a number of modern industrial sectors, especially in information technology. This economic and technological growth is largely down to the reengagement by the US with China from 1989, and the desire to open up trade connections and invest capital.[102] The continuing of this technological and intellectual evolution and capacity will be fundamental to China's continued economic expansion and military transformation.

String of pearls, SLOC and the South China Sea

With China's economy growing, it is likely that China will continue to use its economic and diplomatic muscle to expand its influence in the

Asia-Pacific region, particularly, in the South China Sea and the Indian Ocean. These represent key SLOC for China's energy supply – the majority of China's crude oil imports transit the Strait of Malacca from the Indian Ocean. This strategic focus is likely to create friction between China and India, at the very least. Kaplan believes: 'China seeks domination of the South China Sea to be the dominant power in much of the Eastern Hemisphere.'[103] If not over Taiwan, then it is the importance that China places on its perceived right of hegemony over the South China Seas that will feature in the coming years. This sea connects Southeast Asian states with the Western Pacific, acting as the conduit for global sea trade. More than half the world's annual merchant fleet tonnage passes through the Straits of Malacca, Sunda, Lombok and Makassar. As much as 80 per cent of China's imported oil and gas has to pass through the Strait of Malacca.[104] One assessment predicts that China will continue to import 60 per cent of its oil, rising to at least 70 per cent by 2035, keeping its import routes crucial.[105] There is little doubt that proven oil reserves of 7 billion barrels and an estimated 900 trillion cubic feet of natural gas in the South China Sea are factors swaying China's position.[106]

Despite China's desire to return Taiwan to the fold, its foreign policy is also currently turned more to engagement and involvement with its regional neighbours. With an Indian naval base on the Andaman and Nicobar Islands, and a large USN presence in the region, China has long feared that its trade and energy routes are vulnerable to blockade. In response, China has created its 'String of Pearls' strategy. This is China's desire to increase its geopolitical influence through efforts to increase access to ports and airfields, develop special diplomatic relationships and modernise military forces extending from the South China Sea through the Strait of Malacca, across the Indian Ocean and on to the Arabian Gulf. Each 'pearl' in the 'String of Pearls' is an interconnection of Chinese geopolitical impact and military presence.[107] China will continue to build strategic relationships and develop a capability to establish a forward presence along the SLOC connecting China to the Middle East.[108]

Projects at strategic points across the Indian Ocean will allow China to extend its growing naval strength well beyond its traditional coastal waters.[109] In addition, China plans to build thousands of miles of new railways to connect the southern Chinese city of Kunming with ports across Myanmar and South East Asia. Not only will China's partnership with Myanmar help safeguard its own energy supply, but it will also give China a key strategic advantage over Japan and South Korea, who also rely on the Strait of Malacca for part of their energy supplies.[110]

China is not limiting itself to the Asia-Pacific region, with many African countries having received large inputs of Chinese funding. China's policy of not linking trade, aid and investment to political reform or human rights issues has paid huge dividends thus far. It is not the only state to use economic power to entice access to natural resources, but it does so, largely without good governance or human rights conditions attached.[111] In less than a decade, it has created a presence across the entire African continent, ensuring a steady supply of much needed raw materials. In Angola, the Chinese have built roads, upgraded ports and transformed railways. They are also deeply involved in new construction projects in Ethiopia and Kenya.[112] China has similarly used its surplus of foreign currency reserves to cement new alliances and finance cut-rate loans and commercial lines of credit. There is only one condition: any money provided must be used to pay Chinese companies and buy Chinese goods that flood the continent's street markets.[113] Will African and other countries presently appreciating this apparent Chinese largesse always be as accommodating? Does this doctrine of a 'String of Pearls' work to China's advantage? Time will tell, but China can afford to play the long game.

China's military build-up

The smaller states in the Western Pacific region accept that there is little they can do to counter Chinese regional aspirations and military capabilities. However, in some cases, particularly Russia, Japan and India, there is likely to be a more robust response, including a potential military build-up to counter China's burgeoning claims. China's 2012 test flight of a 'stealth fighter', the J-20, came as somewhat of a shock to Western intelligence agencies.[114] The speed at which China has reached this stage of development is impressive. China is not in the same league as the US in this type of capability, but is very likely to edge closer to Western concepts and capabilities in the coming epochs.[115] New technologies do not necessarily make a nation's armed services more efficient or capable; however, when aligned with robust doctrine and training, improvements will naturally emerge. The mere fact that China is attempting to field an aircraft such as the J-20 is, perhaps, good news for the US administration, as it focuses on the potential threat. US intelligence apparently failed to spot its rapid development.[116] This is hard to believe but is convenient, nonetheless. Ultimately, this type of development will drive other countries to develop counters. Russia and India are spending billions of dollars in upgrading their armed forces, India being a major importer of Russian military equipment, particularly fighter aircraft. As previously highlighted, both countries are jointly developing a fifth-generation fighter, the PAK-FA, sometimes referred to as the T-50, which is seen as a counter to the F-22; it is planned to be in operational service by 2020.[117] The US is refusing to export the F-22 to any foreign state, no matter how friendly. Japan, while restricted by post-World War II treaty obligations to remain a 'defence force', is considering developing its own sixth-generation fighter as a counter to the J-20.[118] It seems that Japan views its lack of a fifth-generation fighter as a significant disadvantage. Towards the end of 2011 Japan announced its intention to buy 42 F-35 JSF.[119] It is likely that Japan has had to settle for what it views as the second best option.

China's stance on Taiwan and the South China Seas, and its military build-up, is causing other Western Pacific Rim states to reconsider their military requirements. Andrew Erickson from the US Naval War College has argued that China's ASBM programme may produce pressure in Washington and Moscow to revise or abandon the International Nuclear Federation treaty, and that other nations, such as Japan, may feel compelled to develop similar capabilities as well.[120]

Increased investment in hardware and training by Beijing is designed to dissuade the US from interfering in problems such as the long-running dispute over Taiwan. According to Jonathan Holslag, the author of *Trapped Giant: China's Military Rise*, although the US has been the dominating power in the Western Pacific since World War II, '[a]fter the demise of the Soviet Union, China is emerging as the second power that might alter the military balance in a way that fundamentally reshapes the regional security order'.[121]

The US Office of the Secretary of Defense believes that 'The PLA seeks the capability to deter Taiwan independence and influence Taiwan to settle the dispute on Beijing's terms. In pursuit of this objective, Beijing is developing capabilities intended to deter, delay, or deny possible U.S. support for the island in the event of a conflict.'[122] This view may be correct; however, the scale and strategic reach of capabilities being developed by China appears well in excess of what would be required to defeat Taiwan and deter US intervention. Its long-term aim to achieve a dominant position in Asia would allow China to add a coercive element to its extant policy of using 'soft power' to exert influence over regional nations.

The PLA has made modest improvements in the transparency of China's military and security affairs, although it is nowhere near the level required to allow other states to adequately analyse its strategic intentions, in apparent denial of what that means for other states' strategy; it is in effect doubling expenditure on military capabilities. Many doubts remain regarding how China will use its expanding capabilities.[123] This limited transparency in its military and security affairs has only enhanced uncertainty and increased the potential for misunderstanding and miscalculation.[124] The US, Japan and others have repeatedly called on China to be more overt with its defence plans.

Richard Weitz, in *Strategic Posture Review*, notes that foreign analysts believe that official Chinese budget figures exclude spending on nuclear weapons, purchases of foreign weapons, and military research and development. For this reason, analysts generally double or triple the official Chinese defence spending figures.[125] The *2010 Report to Congress* states 'that much more could be said by China about its military investments, the strategy and intentions shaping those investment choices, and the military capabilities it is developing'.[126]

China's annual defence budget supposedly increased in 2010 by 6 per cent to $78.7 billion.[127] This is still only 9 per cent of the American defence budget, which was $693.6 billion in 2010.[128] China's official defence budget for 2011 increased by 9.1 per cent to $90.2 billion.[129] Some defence analysts view these increases, and recent confrontation between the region's militaries over territorial claims in the South China Sea, as indicative of a China prepared to use force, if necessary.[130]

Although increasing national wealth has allowed China to pursue the single largest sustained arms buying spree observed since the Soviet build-up in the last decade of the Cold War, its military faces a number of constraints, not least its ability to acquire the equipment and facilities it desires.[131] Limitations faced also include the deficiencies of China's own defence industry and external restrictions on imports of more capable equipment from foreign suppliers.[132] All that said, unlike the Soviet build-up, which effectively bankrupted its economy, China's build-up should be sustainable if its economy continues to grow at a pace allowing it to spend revenues that would not otherwise be required for domestic purposes. Nonetheless, as already discussed, a number of effects will need to align. First, the economy will have to continue to grow. Second, the government will have to be able to extract revenues for military expenditures. Third, balancing competing pressures for social welfare and education, and more public investment in infrastructure, against increased military spending, will be difficult. Last, not least, China's defence industries will have to be able to produce the weapon systems that it would need to seriously challenge US forces.[133]

Progress is being made in China's ability to manufacture its own weapon systems, nonetheless. A RAND Corporation report cites the possibility 'that China may be more advanced [than the US] technology and militarily in 2020'.[134] This may be a somewhat pessimistic view, with more current analysis giving different timescales. For example, Tai Ming Cheung, from the US Institute on Global Conflict and Cooperation, cites a report from China's International Institute of Management Development giving the view that China will reach science and technology parity with the US between 2040 and 2050.[135] At the very least, it is probable that China may develop the technological wherewithal, at least in some industrial branches, to produce comparable (to the West) modern weaponry.

Whatever the case, the military's ability to acquire the equipment and services it needs will require great effort. A major factor is that the Chinese military has to contend with competitive markets for management and leadership talent, and restricted sources of supply for advanced weaponry; it also suffers from severe weaknesses in integrating weapons systems.[136] Recent concerns by Russia over Chinese production of aircraft engines, reverse engineered from Russian-supplied engines, for its indigenously produced J-11 fighter, highlight the reluctance of some countries, particularly Russia, to allow China unfettered access to their technology.[137] Ultimately, if China's economy continues to modernise over the coming decades, its military equipment and weapons producers are likely to have access to domestically produced components to construct the military equipment and systems needed to narrow the capabilities gap with the US.[138] Notwithstanding domestic and other internal pressures, viewed holistically, this will have consequences for international relations in the coming decades.

Perhaps one of the most important intangibles, when assessing a state's capability to field a potent military force, is the quality of its personnel. It is not a given that the possession of state-of-the-art weapons translates into the ability to achieve superiority over an adversary. History has illustrated that those forces that have achieved a high level of efficiency through training will beat or hold off an opponent, even when evenly matched with equipment and numbers of personnel.[139] The morale and *esprit de corps* of a force should also not be underestimated, both of which can be difficult to establish and maintain. Whether this will be a decisive factor in future warfare is an important point. Will mass outweigh quality and training? This is not to say that the PLA cannot motivate its personnel, but the Chinese people, as a whole, will also need to be encouraged towards a similar mindset.

The First and Second Island Chains

China's horizons have broadened; it acknowledges that to continue its prosperity, maintain its SLOC and supplies of energy, it can no longer continue to be 'land-centric' and wait for an adversary to come to it. It must be able to fend off a possible challenger as far as Japan to the east and the Spratly Islands to the south – the 'First Island Chain'. PRC military theorists conceive of two island chains as forming a geographical basis for China's maritime defensive boundary. The precise frontiers of these chains have never been officially defined by the Chinese government, and are subject to some conjecture. For example, Kaplan states that the 'First Island Chain' consists of the Korean Peninsula, the Kuril Islands, Japan, Taiwan, the Philippines, Indonesia and Australia.[140] Another account states China's 'green water' extends eastward in the Pacific Ocean out to the 'First Island Chain', which is formed by the Aleutians, the Kuriles, Japan's archipelago, the Ryukyus, Taiwan, the Philippines and Borneo. Further eastward is referred to as 'blue water' extending to the 'Second Island Chain' running from the north at the Bonin Islands and moving southward through the Marianas, Guam and the Caroline Islands.[141] Whatever is the real Chinese interpretation, it remains an extant part of China's policy to push US influence beyond the 'First Island Chain', at the very least. Initially, if it was deemed necessary, China would seek to be able to take control over the Yellow Sea, the East China Sea and the South China Sea, all of which are located within the 'First Island Chain' of the Pacific Ocean, including the Ryukyu Islands.[142]

Taiwan and the South China Sea

The China/Taiwan dynamic is perhaps the most important potential flashpoint in the Western Pacific. Taiwan's paramount goal is to preserve its *de facto* independence and reinforce its separate identity, which allows it to govern itself autonomously; an acceptable condition in which neither side risks cross-strait relations by pressing for independence or reunification. China's fears about Taiwanese independence and possible US intervention are the most relevant to the PLA's current planning and procurement.[143] Since the end of the 1990s, PLA reform, modernisation, procurement and training have been predominantly focused on preparing for a conflict over Taiwan. It is at the top of the PLA's list of possible conflicts. In this context, US policies on the Taiwan question are of immediate concern to Chinese defence planners.[144]

PLA strategists perceive US arms sales to Taiwan and bilateral military agreements as part of an effort to keep China permanently divided. Most Chinese and Western analysts presume that the US would intervene in a conflict, unless Taiwan declared independence. As a result, much of the PLA's modernisation has been focused not only on fighting Taiwanese forces, but also on fighting US forces if a conflict was to erupt.[145] US military build-up in the Pacific cannot but affect China's response. An example is the new prominence and expansion of US Pacific Command (PACOM). PACOM is the largest of six regional commands; its emphasis is on improved technologies and infrastructure in its bases in Hawaii, Guam and Japan, which require a huge investment, all of which concerns China.[146]

There is a perception within Taiwan that the US is indeed contemplating a radical reappraisal of its position over Taiwan. With cuts in its military budget, as well as the rise of China's maritime strike capabilities, the US has gradually started to withdraw its first line of defence from Asia in order to avoid a possible confrontation. Domestic protests in Japan have led to the US transferring half of its personnel to Guam in 2011, while a complete withdrawal from Japan is possible in the future. At the same time, the US plans to station troops in northern Australia.[147] What effect will this have on the balance of power in the region? If the US does indeed intend to change its strategy and move its strategic line to the Second Island Chain, thereby extending the distance at which the PLA is required to operate, will this mean it is abdicating its responsibilities under the TRA?

China has a long history of employing ambiguous tactics and nefarious means to conceal the true reasons behind its military revolution and to advance its aspirations in the Asia-Pacific region. In the 1990s, as China accumulated and intermittently fired ballistic missiles across the Taiwan Strait to intimidate Taiwan, it assured the world that its military build-up served only benign ends and that it sought peaceful reunification with Taiwan.[148] This stance was not universally accepted, and in response to China's 1996 firings and military exercises near Taiwan, the US deployed the USS Nimitz CSG, which the Chinese were unable to counter at the time. This US deployment produced a strong sense of resentment, and is considered the principal reason for Chinese efforts to develop ASBM, with the aim of preventing similar US carrier operations in the future.[149] China desires the ability to prevent effective US intervention in the event of a future Taiwan Strait confrontation and to constrain its influence in China's disputed zones of core strategic importance. In order to achieve these ambitions, China has been transforming its military, with emphasis on A2/AD capabilities.[150]

A fundamental requirement for China's policy towards Taiwan is the need to deter moves in Taiwan towards independence by demonstrating the ability to deter foreign intervention in response to its use of force.[151] ASBM and other systems are increasingly viewed as a key aspect of an integrated defence system, with other drivers being a strong desire to enforce sovereignty claims in the South China Sea and ensure access to vital resources. China's view that the South China Sea is of vital strategic and economic importance, in terms of establishing itself as a regional military power and countering the US, is consistent with wider fears that the US is trying to contain China through naval dominance, regional bases and alliances with other regional powers.[152] China's increasingly assertive approach has fuelled fears that it will impede common use of the sea lanes and disrupt commerce in the South China Sea.[153] China claims a segment of the South China Sea extending all the way down to Malaysia and Brunei. As already discussed, the strategically important South China Sea contains some of the world's busiest shipping lanes; it also has valuable fish resources, and some proven oil and gas reserves. The sea also contains hundreds of mostly tiny and uninhabited islands, reefs and rocks. China claims almost the entire body of water as its own, and it claims overlap with that of Indonesia, Vietnam, Malaysia, the Philippines, Brunei and Taiwan.[154]

These territorial claims are regarded as a potential source of conflict in Asia, and there has been a history of military clashes over sovereign rights in the region; if continued, these clashes present a threat to regional security and the uninterrupted flow of shipping.[155] In addition to China, Southeast Asian countries are also dramatically building their militaries.[156] It would seem an arms race has begun in an attempt to contain China's ambitions in the South China Sea.

Summary

A perspective of the significance of an emerging powerful China, which will increasingly seek to influence its own sphere of interest and be a player on the international stage, is highly relevant. The impact this strategic shift will have upon the rest of the Asia-Pacific region will be seismic, and the defensive strategies of Japan, Taiwan and Australia, in particular, must be seriously considered in view of this potential shift of US influence. The relationships that these countries, *inter alia*, develop with each other, and their attitude towards security and defence doctrine, will shape future international relations. The challenges faced by China and the international community are not insurmountable, but will require concessions from all parties.[157]

Some observers believe that the US customary means of projecting power abroad is becoming increasingly obsolete. Andrew Krepinevich argues that 'the Pentagon is ill-equipped to counter rising powers such as China . . . . Aircraft carriers, navy destroyers, short-range fighter aircraft and forward bases such as Guam and Okinawa are becoming increasingly vulnerable to technology and tactics being developed by America's rivals.'[158] This observation emphasises the need to develop a system that is capable of delivering unsupported combat air power at long range and for long periods. The role for conventional deterrence, including that based upon cruise missiles launched from submarines and surface ships, targeting Chinese military and political installations, will continue to be important. However, the main feature of this conventional deterrence would be rather different from that applied to the Soviet Union. In particular, it will focus upon achieving deterrence with the threat of denial, which is denying China access to its crucial SLOC, especially for its imports of oil through the South China Sea and its exports of manufactured goods through both the South and the East China Seas. Friedberg believes it is important for the US and its allies 'to maintain a margin of military advantage sufficient to deter attempts at coercion or aggression'.[159] It will be important for US forces to be able to deny China the capability to exclude the US from these seas, essentially, a counter version of China's A2/AD doctrine.[160]

While this analysis of China's current foreign policy and military doctrine has not been exhaustive, it is considered adequate to allow analysis of the use of UCAS. Bearing in mind that the purpose of this book seeks to analyse the utility of counter-air UCAS in future warfare, it is important to examine the context in which these systems may be used. The following section analyses the significance of China's A2/AD doctrine, and how this is affecting international relations, and the ability of the US to counter China's rise.

China's A2/AD doctrine

The concept of air and sea forces conducting the majority of battles in any potential conflict in the Western Pacific is beginning to gain credence. The term 'AirSea' offers a concept designed to maintain a stable military balance in the Western Pacific, which offsets the PLA's rapidly improving A2/AD capabilities. This concept recognises that this theatre of operations is dominated by naval and air forces and the domains of space and cyberspace – the question is, where do ground forces feature?[161] In a speech to the National Defense University in 2010, General Schwartz, the USAF Chief of Staff, addressed the issue of A2/AD doctrine. He was clear that the current 'AirSea' debate should not be focused on any particular threat from China, but rather it should be viewed in the context of any threat attempting to deny access or hinder US forces from operating in any area of interest.[162] While this is a rational point of view, the greatest A2/AD threat will come from China, although other states, such as Iran, North Korea and India, may also use this doctrine, basing their philosophy on Chinese writings and military practices.[163] It is, therefore, prudent to examine China's A2/AD doctrine when analysing the threat to current and future US and other national strategic forces. By doing this, the debate on the utility of UCAS can be better informed.

The US is aligning its strategy and military capabilities, with the aim of mitigating the A2/AD threat. In a speech in 2009, Robert Gates, the then US Secretary of Defense, gave an important perspective on the direction that US investment is heading in military technology, emphasising the vulnerability of CSG and land bases to China's ability to disrupt the US access to the Western Pacific. In particular, Gates viewed that being able to strike from long-range would be vital, highlighting the limited potential of short-range fighters.[164]

Researchers have postulated a potential Chinese strategy for seeking to drive US forces out of the Asia-Pacific region, one similar to the Imperial Japanese strategy of 1941–1942.[165] The Japanese mounted a surprise attack on Pearl Harbour on 7 December 1941, intending to destroy the US Pacific Fleet. Concurrently, the Japanese Army invaded the Philippines and what is now Malaysia, before moving on to Singapore. Strategically critical islands in the South Pacific were also occupied, with India and Australia threatened. Japan's intent was to present the Western powers with a *fait accompli* from an unassailable position and sue for peace. Their strategy was flawed, not least, because Japan was unable to maintain control of the air in its sphere of operations. According to Richard Overy, in *The Air War: 1939–1945*, because of the importance of the strategic use of aircraft by all sides in the Pacific/China theatre of operations, gaining and maintaining air supremacy was essential to the success of the Pacific campaign.[166]

Although Japan's strategy was seriously flawed, it taught that no scenario can be totally disregarded. The future possibility of conflict in the Western Pacific does feature in some analysts' assessments. Kissinger, for example, believes there are comparisons between British-German rivalry in the 20th century, and between China and the US in the 21st century.[167] In relation to China and the US, Kissinger observes:

> An international system is relatively stable if the level of reassurance required by its members is achieved by diplomacy. When diplomacy no longer functions, relationships become increasingly concentrated on military strategy – first in the forms of arms races, then as a manoeuvring for strategic advantage . . . , and, finally, in war itself.[168]

The doctrine developed by the US DoD following the Cold War was based on the convention that it would be able to deploy and operate its forces from bases comparatively unimpeded by adversarial threats.[169] These assumptions extended to the operations of tactical fighter aircraft, CSG, AAR and ISTAR assets and networks, and all support personnel and logistics. The 1991 Gulf War reinforced these assumptions and contributed to the US DoD's development of a new doctrine based on structuring US forces primarily for conducting two nearly simultaneous regional conflicts, for example, in Iraq/Iran and Korea.[170] In 2012, the US announced it would be adopting a new strategy, which commits the Pentagon to being able to fight a single large-scale war while retaining enough forces to deter or impose unacceptable costs on an opportunistic aggressor in a second region.[171] Notwithstanding this new doctrine, long-range strike was, and still is, viewed as an initial requirement needed to rapidly halt adversary forces; subsequently, short-range tactical aircraft flying from nearby bases in relatively permissive operating environments could carry out the majority of strike missions. Mark Gunzinger, from CSBA, believes this investment in short-range combat aircraft has led to a paucity of investment in long-range strike programmes.[172] Range and persistence are now becoming the dominating requirement against adversaries with an A2/AD strategy.

China is developing a capability that could alter the strategic balance in the Asia-Pacific region and beyond. Research is on-going into development of a range of systems which will allow China's A2/AD strategy to be realised.[173] China's 'Assassin's Mace' doctrine, aligned with its very real desire to bring back Taiwan within its sphere of influence, is having a dramatic effect on the ability of the US to influence policy in the Asia-Pacific region, specifically in the region that China regards as the 'First Island Chain'. The phrase 'Assassin's Mace' is the English translation of '*Shasho Jiang*', a term for ancient Chinese strategy. There are, however, a number of different meanings. The term is used to designate a wide array of technologies that might afford an inferior military an advantage in a conflict with a superior military power.[174] *Shasho Jiang* is not seen as a panacea, but if the correct strategy is used, aligned with the correct timing and conditions, then a superior adversary can be defeated.[175]

China's A2/AD doctrine has been evolving over a number of decades, and increasingly, technical and operationally focused discussions are found in a range of Chinese sources, suggesting that China may be close to employing an ASBM – a weapon that no other country currently possesses.[176] An example of China's determination to achieve this is the recent development of the *Dong-Feng* DF-21D ASBM (NATO designation: CSS-5), modified to sink aircraft carriers.[177] This ASBM is intended to provide the PLA the capability to attack ships, including aircraft carriers, in the Western Pacific Ocean.[178] It can be argued that this ASBM is a game changer and is fundamental to the strategic shift in current US thinking. Its imminent deployment could restrict US fleet operations to outside of the 'First Island Chain', drastically limiting US capabilities and influence. This shift in the balance of power in the Western Pacific is fundamental to the type of systems that will be required to counter China's forces.[179]

China wants to achieve the ability, or at least the appearance of such an ability, to prevent a US CSG from intervening in the event of a future Taiwan Strait crisis. China has designed the DF-21D to be an A2/AD weapon with the specific intent of sinking a US aircraft carrier; it appears that the DF-21D has already been tested.[180] Chinese writings indicate a near-term requirement to keep US CSG at a distance of at least 1100 nm from China's eastern coastline.[181] The deployment of an effective ASBM, such as the DF-21D, as part of a matrix of systems could achieve this objective, profoundly affecting US deterrence, military operations and the balance of power in the Western Pacific.

The ASBM would be just one of the many new platforms and weapons systems that China has been developing since the 1996 Taiwan Strait Crisis. However, an ASBM such as the DF-21D has the potential, well beyond the submarines and Anti-Ship Cruise Missiles (ASCM), which China has been adding to its cache of weapons, to create a strategic shock amongst regional allies of the US. Although in development since 1996, it was not until 2007 when Chinese rocket artillery and engineering papers were published suggesting that the capability was advancing, and that the threat was taken seriously. It was at this point that the US started to take notice, and action.[182]

As well as advances in ASBM technology, China is on the verge of achieving a number of game-changing developments, including the ability to launch multiple cruise missile attacks, robust indigenous satellite navigation, high quality real-time satellite imagery, target-locating data and anti-satellite and other space-related weapons.[183] Should China wish to prevent access to a contested maritime area in the event of conflict, such accomplishments would significantly advance China's A2/AD capabilities by allowing it to threaten the whole gamut of surface- and air-based assets.

The US government is acutely aware of the threat from the DF-21D. The *2010 Annual Report to Congress* does not mince its words:

> China is developing an anti-ship ballistic missile . . . The missile has a range in excess of 1,500 [km], is armed with a maneuverable warhead, and when integrated with appropriate command and control systems, is intended to provide the PLA with the capability to attack ships, including aircraft carriers, in the western Pacific Ocean.[184]

The report also points out that the People's Liberation Army Navy (PLAN) is improving its over-the-horizon targeting capabilities with new radar systems to support long-range precision strikes, including those by ASBM.[185]

An effective ASBM and persistent maritime surveillance capability would form part of the matrix of capabilities that could prevent the US challenging China's use of force against Taiwan, ultimately undermining the principles of the Taiwan TRA. Aligned with the *2010 Report to Congress*, other US governmental departments believe China's extensive campaign to modernise its military forces is moving forward at an alarming rate. The National Air and Space Intelligence Center's report on China's military-technological development highlights concern: 'China has the most active and diverse ballistic missile development program in the world. It is developing and testing offensive missiles, forming additional missile units, qualitatively upgrading certain missile systems, and developing methods to counter ballistic missile defenses.'[186]

In recent years, this build-up has generated some significant new capabilities, all of which serve China's broader strategic and political strategies in the Asia-Pacific region. The *2010 Annual Report to Congress* warns, 'China is aggressively pursuing the military capabilities necessary to wage and win a short-duration, high-intensity conflict with Taiwan – and with the US, should it ever intervene.'[187] A proposed follow-on variant to the DF-21D would extend an ASBM's range to 1500 nm. Subsequent technological advances could extend a conventional precision strike capability out to 4500 nm.[188]

China's military strategists have also been evaluating the feasibility of a global conventional strike capability as an incremental follow-on to the successful deployment of an initial ASBM. China plans to field a fully functional Precision Global Strike capability by 2025.[189] In a future

Taiwan scenario involving US military intervention, China could reserve the option to conduct conventional precision strikes against unhardened facilities that support US operations, including facilities in Hawaii, the US, Australia and elsewhere.[190] These conventional systems would also be utilised with the intention of enforcing China's regional sovereignty claims and ensuring the SLOC remain secure. Ultimately, successful deployment of conventional ballistic missiles and other precision strike systems would offer China a flexible deterrent.[191] A study by the RAND Corporation explores the outcomes of a range of scenarios of a US and Taiwan alliance, against a determined effort by China to take Taiwan by force. The conclusions are emphatic – China will likely have the capabilities to achieve its aims, if the appropriate counters are not instigated.[192] China's doctrinal strategy, aligned with the new panoply of weapons, could achieve the desired strategic and operational effect, giving it the edge in a contest of wills, or indeed, in an actual kinetic confrontation. The balance of power in the Western Pacific would radically change.

Counters to China's A2/AD doctrine

In January 2009, Gates stated: '[T]he Department of Defense is making good progress toward developing a number of programs to counter Chinese technological advances that could put our carriers at risk.'[193] US military officials have stressed that the development of new electronic jammers, a long-range nuclear-capable bomber, modernised radars for the F-15, and significantly, new seaborne UCAS will help mitigate this threat.[194] It is not certain, however, if these programmes will be successful. According to Stokes, the US may need to reassess its capabilities, including different types of ships and submarines. The hardening of US military facilities throughout the Pacific region, including Kadena Airbase and facilities in Guam and Hawaii, will also need to be seriously considered.[195] Most significantly, long-range UCAS may offer a solution in providing the capability to conduct the full gamut of OCA and strike missions, if access is denied to CSG and close land-based assets. Mark Gunzinger recommends that the US develop a UCAS with at least a 1500 nm combat radius, with the capability to operate in an advanced IADS.[196] Krepinevich also argues: 'To avoid operational irrelevance, carriers should reduce their reliance on short-range manned aircraft in favor of much longer-range unmanned aircraft.'[197]

China's ASBM development

An ASBM system, if developed and deployed successfully, would be the world's first weapons system capable of targeting a moving CSG at sufficient range to severely curtail any current aircraft carrier's effectiveness. This could pose a new type of threat to the USN and other navies; the US has not had decades to tackle this new challenge. Even if capable of doing so, if the US was to target these ASBM and support C4ISTAR infrastructure, with strikes in mainland China, the reaction would be incalculable.[198]

China has prioritised ballistic missile development for decades, enjoying an impressive science and technology base, and will likely continue to dedicate considerable resources to ASBM development. The DF-21D challenges the technological superiority that the US has maintained in carrier-borne capabilities for decades; this technological superiority is the foundation of the US military dominance in the Western Pacific.[199] The DF-21D can be launched in the general direction of a USN CSG and while in flight adjust course to directly target an aircraft carrier or other selected seaborne targets. This ability to alter course during flight is a significant technological evolution. No current Anti-Ballistic Missile (ABM) defence system has an acceptable probability of intercepting a Ballistic Missile (BM) that can significantly alter its course during flight. This capability gives the DF-21D its advantage against existing US ABM defence systems.[200] ABM are launched near the intended flight path of a BM; when the ABM is within a predetermined distance from the BM, the terminal guidance and detection system of the ABM should be able to detect and intercept it. However, because the DF-21D alters course at high altitude and detects its target after launch, the calculations sent to an ABM defence system would be incorrect. It will be extremely difficult for any current ABM defence system to detect and defeat the DF-21D ASBM.[201]

Indicators of successful development of the DF-21D include the recent launch of five *Yaogan* satellites – these would offer significantly better coverage of critical areas along China's maritime area of interest. Another indication is a news release from the China Aerospace Science & Industry Corporation citing Wang Genbin, Deputy Director of the 4th Department, stating that 'the DF-21D can hit slow-moving targets with a circular error probable of dozens of meters'.[202] Tests have almost certainly been conducted against static targets. In an interview to a Japanese newspaper, Admiral Robert Willard, commander of US Pacific Command stated, 'To our knowledge, [the DF-21D] has undergone repeated tests, and it is probably very close to being operational.'[203] The *Washington Times* also reports that China conducted a long-range missile test on 25 September 2010.[204]

As with many military doctrinal and capability developments, the deterrent effect of merely possessing the means of denying access could achieve the desired strategic aims. Some Chinese writers believe that even the significant likelihood of a capability may have a substantial deterrent effect. The ASBM is envisaged primarily as a deterrent weapon by Chinese analysts; to many this makes it inherently defensive in nature.[205]

The sequence of events required for any BM to successfully engage and destroy or disable a target is known as the 'Kill Chain'. All parts of this are required to work; if any one part should fail, the objective will not be achieved. For a moving target, such as a ship, the task is significantly more difficult. The essential core of this capability is a missile-borne sensing and data processing system, supported by an initial cueing from a surveillance network, which would include, *inter alia*, UAS, Over the Horizon (OTH) radar and satellites.[206] OTH radars can be used in conjunction with imagery satellites to assist in detecting targets at great distances from China's shores to support long-range precision strikes, including by ASBM.[207] Alongside OTH radars, China has also been working on a sophisticated network of ground- and space-based sensors, including electronic signals detection equipment, which can assist ASBM detection and targeting. Chinese UCAS survivable in highly contested airspace could also be used to assist TPT systems. It is also likely that UAS would be used as decoys; the aim would be to exhaust AAM and SAM stocks. These decoys could also use EA systems.[208] Active radar is the most likely ASBM sensor, for the 'track' part of the kill chain. The largest reflection would normally be the largest ship, usually an aircraft carrier. However, as with any radar-based sensor, deception techniques could be used to fool the ASBM into believing it was targeting a carrier.[209] EA techniques are extensively used to counter AAM, SAM and all forms of radar. However, counters to EA techniques are always being developed.[210]

Chinese PLA writings emphasise coordination and precision as being vital for deterring and blocking enemy CSG. Locating sea targets is also stressed, with real-time target intelligence being critical, with the use of military reconnaissance satellites, domestic and foreign remote sensing satellites, and established satellite reconnaissance target image information processing systems being considered paramount.[211] Developments in access to foreign satellite navigation positioning systems, such as the Russian Global Orbiting Navigation System and US GPS, increase the accuracy of Chinese BM and other weapon systems. The development of a viable independent system, *Beidou*, could allow access to a reliable source of navigation accuracy during a conflict scenario. China's current four-satellite *Beidou*-1 constellation, deployed in 2007, is limited to supporting operations on China's near-maritime border and is accurate to within approximately 20 m – which is not enough for precision strike targeting.[212] To reliably support wider operations, China is deploying a 35-satellite (5 geostationary, 30 medium earth orbit) constellation – *Beidou*-2/Compass – which would provide much improved accuracy, with global navigation coverage by 2015–2020.[213]

US military commanders and politicians are increasingly giving their candid views on the subject of ASBM. During a speech to North Carolina Reserve Officer Training Corp students on 29 September 2010, Gates emphasised the need to factor ASBM development into future carrier operations.[214] How seriously the US takes the development of the DF-21D is evident in the USN's fundamental revolution in its development of ABM defences. The USN's defence against this type of threat has continued to rely on the strategy of defence in depth. Guns were replaced in the late fifties by the first generation of guided missiles in ships and aircraft. By the late sixties, it was recognised that reaction time, firepower and operational availability in all environments did not match the threat. As a result, an operational requirement for an Advanced Surface Missile System (ASMS) was promulgated and a comprehensive engineering development programme was initiated to meet that requirement. ASMS was renamed AEGIS (after the mythological shield of Zeus) in December 1969.[215] The concern defence analysts have regarding the future of the aircraft carrier in the 21st century is due, in large part, to the game-changing nature of the development of the DF-21D. The acceleration of plans regarding the capabilities of the AEGIS weapon system is largely owing to recognition that current systems are not capable of addressing this threat. The DF-21D and US AEGIS ABM defence system represents the first major offensive/defensive military capability arms race of the 21st century.[216] Gates authorised increased investment in weapon systems to counter the growing potential threat posed by China's advanced aircraft and missiles.[217]

Although deterrence would seem to be a clear purpose of any ASBM development, there is a well-founded fear that China's military transformation, aligned with a perceived lack of coherent doctrine, may lead to mismanagement of any crisis scenario. Ultimately, how robust is China's ability to risk-manage, without threatening an escalation in tension, with unpredictable results?[218]

Summary

China is intent on fielding a capability that could weaken the capacity of the US to assist Taiwan in a conflict scenario, and hinder access to the

Western Pacific. While open source reporting indicates that ASBM production has begun and has indeed been tested, it cannot be confirmed when an ASBM will be operationally available. Western intelligence agencies should, however, be able to monitor Chinese developments, including any ASBM testing, pending any formal declaration by China. China's deployment of an ASBM capability could change the strategic balance in the Asia-Pacific region. The PRC's goal is to create the conditions for Taiwan's unification on satisfactory terms, in which regard the US is viewed as the principal remaining hurdle to unification. As well as a real Chinese capability to prevent the capacity of the US to intervene in a future crisis, the perception would be created within Taiwan of US weakness.[219] It is unlikely that China would use ASBM in isolation. ASBM would be backed by a maritime surveillance network, theatre ballistic missiles and extended range cruise missiles, designed to be launched from both conventional and nuclear-powered attack submarines. These could operate in conjunction with submarines, conventional naval aviation and EA assets. Follow-on ASBM variants are likely to strain the ability of US ABM defences, unless fundamental initiatives are taken to develop an anti-ASBM system, capable of negating this type of threat. Forced to operate out of range of these ASBM, the effectiveness of carrier-based assets, such as the F/A-18E/F, would be even more limited than they already are when forced to fight at greater ranges than in the past.[220]

China's A2/AD doctrine gives it a strategic advantage, and it appears increasingly confident of its ability to deny US CSG the ability to intervene in a Taiwan scenario. Overall US qualitative and numerical superiority is of limited relevance. First, the platforms most likely to be employed by the US are those that are based within immediate striking distance from Chinese weapon systems at the outbreak of conflict; here China inherently enjoys the advantage. Second, aircraft sent to the Asia-Pacific region require bases from which to operate; US regional options are limited geographically and politically and are vulnerable to Chinese attack.[221] If China's intent on fielding a system that directly threatens US carriers is not neutralised, the US military alliances and reassurances which have helped maintain peace in the Western Pacific since World War II would be severely weakened; an arms race would inevitably ensue, if it has not already. It is probable that China does not plan to attack US forces, but to deter them. China states that it wants to protect its fundamental territorial interests and to ensure a stable environment for economic development. If ASBM are ultimately developed, China would hope to prevent US projection of military power in circumstances that are hostile to China's security interests. Yet ASBM development for this purpose is complex. China has demonstrated an ASBM intent, if not capability, with substantial tensions certainly now developing. Unless China is willing to open a dialogue regarding its intentions, it will be essential for governments in Taiwan, Japan, the US and other affected states to force multi-lateral debate, failing which to respond with appropriate measures.

As Eric Gons points out in his PhD thesis, 'If forced to operate outside 1,500 km, naval aviation will not be able to contribute heavily to the counter-air effort. And if using USAF tankers, USN aircraft will be displacing USAF aircraft tailored more specifically to the air superiority mission.'[222] The strategic balance is changing; there is a requirement for systems that counter this emerging threat. There is also a requirement for extended range and endurance air platforms; UCAS could form part of the required matrix for gaining and maintaining control of the air in the Asia-Pacific region, thereby fulfilling the air domain's part of the 'AirSea' contract and acting as a deterrent. The US aircraft procurement strategy acknowledges the significance of anti-access threats, which 'could impede the deployment of U.S. forces to a conflict and blunt the operations of those forces that do deploy forward'.[223] The USN, in particular, with its Next Generation Air Dominance aircraft study, is cognisant of the issues; it is looking at replacing the F/A-18E/F and F-35 with 'a new manned or unmanned platform or a combination of both'.[224]

Aircraft carriers are widely seen as exemplars of technological prowess and military dominance. The US, in particular, has supremacy in the number of carriers and support ships its navy possesses, with 11 CSG available in 2011.[225] These CSG form the foundation for US rapid response and power projection and, *inter alia*, deterrence. What happens if these CSG are forced to stay outside of range of adversary attack systems? What if countries such as China establish doctrine that aims to make it so costly to an adversary to commit forces within its sphere of influence that their mighty military systems become so ineffective? When viewed in a conflict scenario in which an adversary has an A2/AD strategy, some of the counter-air maxims generally assumed, such as the capability to operate from close bases and aircraft carriers, may be invalidated. In the case of China, it is building up its forces and establishing doctrine and procedures to enforce such a policy. Chinese threats to CSG include ASBM, submarines equipped with torpedoes and extremely capable ASCM, and aircraft carrying ASCM. China can also threaten air bases with short-range ballistic missiles, intermediate-range ballistic missiles and land- and air-launched cruise missiles. Ultimately, it may be feasible that large, sophisticated Chinese air, naval and missile forces can mass against a relatively small number of US CSG and air bases in the Western Pacific. In this context, the efficacy of UCAS gaining control of the air demands thorough scrutiny.

8
Conclusion

Currently, UAS are assuming roles in air power that have traditionally been undertaken by manned aircraft, at least in permissive environments. Future warfare could see UCAS, the next evolution of UAS, undertaking the tasks and accepting most of the risks in high threat scenarios that have previously been the responsibility of military aviators. UCAS have the potential to offer a revolutionary new set of options, with enormous long-term payoffs to air power in terms of persistence, endurance, tactical deterrence and affordability. The context in which these systems would be used is fundamental to their developmental path. Although the military capabilities of future threats to international security should be adequately assessable, the intent of these nations remains less easy to predict. An understanding of where these threats are likely to come from is essential; any specious assumptions will lead to erroneous conclusions, in turn, potentially leading to wrong procurement decisions. Some countries struggle to balance their aspirations with the threat of political and economic disintegration; it is relationships with these countries that are likely to dictate the frequency and severity of future military challenges. Future conflicts will probably range from peacekeeping and policing roles to minor interstate warfare, with the potential for large interstate warfare. Identification of these possible adversaries is realistically achievable; how they are deterred and, if required, defeated is not so easily accomplished.

China is currently the world's No. 2 economic power, and is likely to overtake the US power by 2030.[1] There is also a view that China will reach technological parity with the US, sometime between 2040 and 2050.[2] Both of these paradigm shifts are aligned with China's desire to become a major military power, being able to influence the *status quo* in the Western Pacific and forcing its hegemony in the region. This will make China the centre of gravity for the foreign and military policies of the US and others in the coming decades. While the US does not view China as an existential threat to the US mainland, it believes that it poses a threat to stability in the region. China's developing A2/AD doctrine will force states, especially the US, to mould foreign and military policies to militate against China gaining dominance in the Western Pacific and the South China Sea. Not only does China wish to bring Taiwan into its sphere of influence, it also desires to hold sway over the natural resources lying beneath the South China Sea and is also hedging against access being denied through the Strait of Malacca, through which most of its oil supplies transit. For many of the same reasons, the US, its allies and others do not wish China to gain strategic dominance in this part of the world. The Middle East, with Iran at its centre, will also test international relations. Iran is also developing a strategy of A2/AD. China and Iran's A2/AD doctrine will likely force the US and its allies to operate from land bases and aircraft carriers at greater ranges than those currently planned. The development of ASBM, such as the DF-21D, and other weapon systems capable of pinning forces down at ranges that make current weapon systems unviable in deterring aggression in these regions requires inspired evaluation. Air systems, *inter alia*, which are capable of operating at ranges outside of these threats, potentially unsupported, are necessary. At whatever distances from bases, against an adversary with an air defence capability, control of the air will continue to be a fundamental prerequisite for all conventional military operations.

Powered unmanned aircraft have been operating almost as long as powered manned flight. Along with the trend towards single-seat aircraft operations, doctrine and tactics have evolved to take advantage of the transformation evolution that technological advances have allowed manned flight to utilise. Other than the actual act of flying an aircraft, historically, navigation has been deemed critical to mission success. Navigation accuracy and the precision of weapon delivery, both air-to-air and air-to-ground, is currently the predominant requirement for combat air power. As technology has developed, the role of the navigator, and other associated airborne professions, has become less crucial. Using the same rationality, the fact that pilots have traditionally been required to fly aircraft that facilitate achieving the requisite military task should not be a driver for future doctrine, tactics or procurement. Technology now allows greater time, effort and resources to be focused on systems that will not require a human interface in an aircraft or, potentially, even monitoring weapon systems.

Existing UCAS programmes focus on detecting and destroying TST, utilising ISTAR and SEAD roles – the air-to-surface part of the counter-air task. Most military forces consider the air-to-air component of counter-air warfare, a true TST issue, as the main pillar of air power, or, at least, 'the first amongst equals'. Significantly, there is a paucity of research into the air-to-air capabilities and requirements for future UCAS. The importance that situational awareness plays in warfare, particularly in control of the air, is vital. From World War I to modern air warfare, situational awareness has proven to be the key enabler in gaining control of the air; pilots, and other aircrew and personnel, have, of course, been vital, but would be ineffective if they did not possess situational awareness. NEC is pivotal in establishing consistent and reliable battlefield situational awareness. Along with the negating portion of the kill chain, this is the critical node in all the domains of warfare.[3] Could the same systems that give the F-22 Raptor and future F-35 JSF operators' situational awareness be utilised by UCAS? Could UCAS properly see and sense what an adversary is doing now, not just where it is? Using NEC to gain situational awareness will allow an integrated UCAS to take the fight to an adversary at ranges that are not currently obtainable by manned counter-air systems.

If viewed dispassionately, there is nothing particularly difficult in conducting the air-to-air role, if situational awareness is adequate and weapon systems are effective. It is relative, however; viewed as a three-dimensional chess game, air combat has stressed the capabilities of modern air systems and aircrew. Nonetheless, even in the most complex visual air-to-air engagements, there would be a finite number of possible decisions. If the 'unknowns' are 'known', it is essentially a case of completing a set of prescribed manoeuvres and decisions that, although complex at times, should be programmable. Situational awareness is the key. If only partial situational awareness exists, a logical pattern of actions should still be programmable. In any case, it is arguable whether visual air combat, requiring highly manoeuvrable aircraft, will be required by 2040.

Given any counter-air scenario, a human, with the correct training, being in the right frame of mind, and having the required skill and situational awareness, could make the correct decisions. Because most humans are affected physically when operating high-performance aircraft in dynamic and stressful environments, assimilating information is extremely difficult without taking some time to do so; they might make potentially wrong decisions or take decisions too late. If the process were automated to a level that did not require human input, then the outcome would probably be fundamentally improved. The days of fighter pilot versus fighter pilot in visual air combat may not be over, but they will surely continue to follow the trend since the Vietnam War.

To some, the term 'autonomous' is emotive. I am of the view that UCAS would only truly be autonomous if communications links were lost, and then only in the sense that these systems will be operating in a highly automated mode, with no supervision by a human. UCAS would use the algorithms within their pre-programmed systems, using lookup tables that would contain all conceivable eventualities; computing processing technology should continue to advance, allowing systems to conduct operations to the level of a human, but faster and more accurately. AI programs, such as Agent software, could be used to aid the decision process, but only within a defined set of rules. Autonomous systems would not make random decisions without the constraints that would normally be placed on humans. Data fusion of information collated through NEC, allowing the employment of kinetic effects, such as AAM or DEW, could be utilised on UCAS or manned systems. With a high level of automation/autonomy and situational awareness, the 'system' could make all the appropriate decisions on required tactics, leading to successful engagements. Development of these systems should allow the appropriate effect to be obtained before the visual arena is entered – or at least to an extent that does not warrant development of close visual combat systems that require the air vehicle component to be highly agile. The gun and, since the 1950s, AAM have been used in aerial conflicts; however, there have been no known Western or Israeli air-to-air kills requiring classic air combat manoeuvring since the Vietnam War. This covers almost 40 years of military aviation – a significant portion of the total history of aerial combat. The requirement for what is known as a 'knife fight in a telephone box' by fighter crews would be negated by the use of HOBS weapon systems with a high-kill probability, whether AAM or DEW, aligned with NEC. The utility of the AAG also has to be questioned. 'It will never be required' cannot be guaranteed; however, the question of whether it is worth the cost of developing certain weapon systems and aircraft manoeuvrability requires stringent examination.

The effect that political, legal and ethical issues of using UCAS might have upon decision makers is an important consideration. This should not be underestimated, particularly in terms of politicians' willingness to deploy such systems at little, if any, risk to their own military personnel. Although ROE constraints and political necessities may initially militate against full autonomy, the development of AI and HMI technology should offer a level of integration enabling a greater degree of certainty when conducting CID and CDE than that of HITL systems. It would also allow missions to be planned and then executed using on-board decision-making – with a HOTL monitoring the system and taking action only when necessary, and perhaps autonomously, if this is deemed desirable.

The LOAC calls for the responsibility of a HITL when decisions are made for release of weapons. The 'Nuremburg Principle' requires that someone always be held accountable for an action that is taken that falls inside or outside of international law – that is, they are legally and morally accountable. Is it against the LOAC if UCAS are used without a human at least 'on the loop'? If responsibility is taken within the command chain, at all levels of decision-making, then no laws are broken. It could be argued that it is the software programmers who write the code for UCAS that are ultimately responsible. However, this is not the situation with extant weapon systems that are autonomous (highly automated). Air-to-surface missiles, SAM, cruise missiles and AAM are all examples of weapon systems that have this capability. Military commanders and politicians have satisfied themselves that the level of risk that these weapons pose in causing collateral damage is acceptable within the LOAC. The same logic would apply to UCAS. It is straightforward – if the legal criteria could not be met, then UCAS would probably not be utilised autonomously.

It was fundamental to ensure that this research had merit. The questionnaire used established that the research methodology was appropriate and that the subject warranted investigation. Many of those interviewed had relevant experience in counter-air operations. Ninety-eight per cent believed UCAS could gain control of the air by 2040. These are pilots, navigators and counter-air specialists with an understanding of all the relevant strands and many vagaries that the fundamentals of air-to-air combat have traditionally entailed. It seems counterintuitive, but none was tempted to protect the man in the cockpit; none had the 'pilots/aircrew are gods' attitude which has prevailed in air forces around the world, ever since aircraft were first used as weapons of war. Eighty-six per cent of interviewees have no ethical concerns with the use of UCAS. This does not mean that consideration is not required when developing training for personnel; a potential lack of understanding of air power should be taken into account if these personnel have not themselves been immersed in the philosophy of warfare or, indeed, in combat operations. There may also be a risk of detachment when authorising weapon release, perhaps leading to a lack of emotional connectivity with the battlespace. These aspects will require particular attention by military leaders.

Persistence and endurance are important constituents of air power, allowing weapon and sensor effects capabilities to be maintained for long periods. Autonomous AAR, potentially with unmanned tankers, together with advanced power sources will enhance this capability. These technologies will take time to acquire, but should be within the reach of the Western defence/industrial apparatus by 2030–2040. The physiological constraints faced by aircrew today are unlikely to be mitigated in the coming decades. Separating aircrews from their platforms is a factor in increasing range and endurance, not so much in allowing more fuel to be carried but by at least negating the requirement to sustain a human for periods that are considered unviable. Similar to manned aircraft, a future UCAV may use stealth characteristics and defensive measures to penetrate hostile airspace; EA capabilities would also be a fundamental requirement. However, although UCAS could deploy over great distances and with a reduced logistic chain, their operating tempo may stretch any manned airborne supporting system. If the cost of UCAS means that these systems are treated as HVAA, the result may be that manned fighters, themselves valuable airborne assets, are required to protect them, constraining these UCAS to operate within range of manned fighters, thereby negating any advantage that these systems offer. It is important, therefore, that UCAS are capable of operating independently of other HVAA, with a high chance of survival; that is, UCAS should be able to gain and maintain control of the air.

My research indicates that an unmanned counter-air vehicle will need to have some of the characteristics of the current USAF's F-22 Raptor – namely, EA and stealth technology tailored to combat X-band (fighter) radars aligned with high speed and height capabilities. A UCAS, or any manned system for that matter, would not require being as manoeuvrable. The effectors for gaining control of the air combine the C2, NEC, sensors, aircraft, weapon systems, personnel and the logistics chain. Effective ISTAR, SEAD and general air-to-surface missions will require all of these current enablers, which have proven to be effective in most conflicts since the Vietnam War. There is doubt, however, in the effectiveness of some current air-to-air enabling assets – that is, the sensors and weapons currently utilised. AAM have not fulfilled their initial promise. While statistics since 1991 show that the kill probability of AAS has significantly improved, these have not developed to the extent that they offer a guarantee of winning an air-to-air battle against a peer adversary. Future negation systems offering a high kill probability are required.

When countering an adversary with numerical superiority, the quality of own weapon systems, aircrew training and C2/NEC are paramount. When opposing an adversary that has superiority both in numbers and in weapon systems, and whose training and C2/NEC is adequate, then control of the air cannot be guaranteed.

Whether there will be major conflicts between nation-states in the coming decades can be debated. However, at the very least, force structures and capabilities will be required to deter potential aggressors. The best way to win a war is to prevent it happening. Diplomacy, sanctions and ultimately the threat of force are all traditional tools in international relations. Future conflicts between major powers may follow the same deterrence route. Conflict may be averted if it is clear that one side has a major strategic advantage over another. However, the deterrence and escalatory policies of some states may not follow accepted norms. The A2/AD strategies that countries such as China and Iran are evolving will test current Western doctrine and strategy and, not least, the planned manned air-breathing weapon systems envisaged to implement policy. These strategies will strain the capability of seaborne forces to operate within current planned distances of adversary centres of gravity and target sets. Land-based forces may face similar constraints. Systems that are capable of operating from ranges and for periods hitherto not required, and that also offer a potent deterrence, are needed to counter these new emerging strategies; as Bernard Brodie observed: 'It is a truistic statement that by deterrence we mean obliging an opponent to consider, in an environment of great uncertainty, the probable cost to him of attacking us against the expected gain thereof.'[4]

The potential of UCAS conducting missions totally autonomously, semi-autonomously or as part of a swarm, controlled or monitored by a single pilot in a fighter or operator in a large aircraft, such as an AWACS, or from a stationary C2 node, should be assessable. This will take time and funding, with technological advances informing decisions based on a series of connected trials, programmes and academic analysis. Until novel systems, not currently conceived, are available, it will fall to air-breathing systems to take the fight to the enemy. Ultimately, it may be possible for a large COMAO formation of combat and support aircraft, combining manned aircraft and UCAS, or made up entirely of UCAS, to operate together or autonomously. This autonomy may permit quicker and more accurate decisions, enhancing the probability of survival, while achieving the desired mission objectives. UCAS would use automated flight and mission management systems, which could also be utilised by manned aircraft. If these management systems reach the capability that allows them to be trusted to an acceptable level, it is axiomatic that the HITL would not be required for other than legal considerations, if this was indeed required. Using the autonomy levels based on NASA's FLOAAT and the Defence Evaluation and Research Agency PACT concept, Level 4 would be the normal envisaged operating mode, with a HOTL only intervening if required. Level 5, giving full autonomy, would be implemented if communications links were lost and the importance of the mission was deemed crucial enough to warrant the potential risks that this may involve.

A radical approach is required if current strategic doctrine remains extant, with the emphasis on the 'AirSea' concept for counter-A2/AD warfare. Against potential adversaries with this strategy, current and planned weapon systems will be tested by the necessity to operate at extended ranges and with adequate persistence. It is the economics and operational effectiveness of such systems that are likely to affect decisions on procurement and capability. Although there is understandable doubt as to their future efficacy, development of UCAS may reach the stage where it can be demonstrated to commanders, both military and political, that there are no adverse risks. With situational awareness, gained through NEC/NCW, there are no technical reasons why UCAS cannot carry out the full range of combat air tasks currently undertaken by manned aircraft.

This book has examined the advantages of extended range and endurance, and the potential for swifter and more efficient actions, that UCAS bring to warfare. The utility of UCAS warrants full investigation, including that of gaining control of the air, in its entirety. There is currently a lack of synergy and clear thought on their future effectiveness, particularly within the UK, which requires cogent and informed input. There are few reasons why UCAS should not be considered for the counter-air role. The debate appears to have stalled; this book will help take the debate forward, allowing value to be added to the procurement process and helping to inform future policy decisions over the manned versus unmanned debate. If unable to control the air, at whatever range is necessary, all other military operations are drastically curtailed. Ultimately, unless there is some other programme capable of achieving control of the air in a peer-on-peer conflict, one in which A2/AD doctrine is dominant, I believe that the development of UCAS able to conduct this task is essential. These systems would offer a potential revolution in the way warfare is conducted in the 21st century.

Notes

1 Introduction

1 For example, while acknowledging that current US UCAS programmes do not meet requirements for an air superiority fighter, Lt Col Devin Cate believes UCAS have the potential to become a future generation air-superiority fighter by 2025. See generally, Lt Col Devin L. Cate USAF, *The Air Superiority Fighter and Defense Transformation: Why DoD Requirements Demand the F/A-22 Raptor*, Master's Degree, USAF Air University, 2003. See also, Travis J. Gill, *Carrier Air Wing Tactics Incorporating the Navy Unmanned Combat Air System (NUCAS),* Master's Degree, Naval Graduate School, Monterey, CA, 2010. Gill evaluates a scenario in which F/A-18 Super Hornets and F-35C Lighting II aircraft are supported by UCAS in gaining control of the air.

2 See US Department of Defense, *Unmanned Systems Integrated Roadmap FY 2011–2036*, Washington, DC, 2011, p. 17. Also see, Office of the US Secretary of Defense, *Unmanned Aircraft Systems Roadmap: 2005–2030*, Table 6.2-1, p. 74, and US Department of Defense, *United States Air Force: Unmanned Aircraft Systems Flight Plan 2009–2047*, p. 39.

3 Development, Doctrine and Concept Centre, *Joint Concept Note 3/12: Future Air and Space Operating Concept*, Shrivenham: Ministry of Defence, 2012, p. 4. See also, 'House of Commons Defence Committee, Remote Control: Remotely Piloted Air Systems – Current and Future UK Use: Government Response to the Committees, Tenth Report of Session 2013–14, Volume II, Written Evidence', The Stationery Office Ltd, London, 2014, Ev w2, para 2.13.

4 See UK Ministry of Defence, *Joint Warfare Publication 3-63: Joint Air Defence*, 2nd Edition, Shrivenham: Joint Doctrine & Concepts Centre, 2003, p. 1.6.

5 Ibid.

6 All acronyms are used for both the singular and plural sense.

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10 See 'House of Commons Defence Committee, Remote Control, Vol 2', which is inconsistent with regards to UCAV terminology. For example, Ev w61, para 13, describes Predator and Reaper UAS as UCAV, while Ev w2, para 2.12 describes UCAS as being able to operate in contested airspace when necessary, but such a capability does not yet exist.

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12 United States Air Force Scientific Advisory Board, *Operating Next-Generation Remotely Piloted Aircraft for Irregular Warfare*, HQ USAF/SB, Washington, 2011,

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13 Air Chief Marshal Sir Glen Torpy, 'Foreword', in *Air Power – UAVs: The Wider Context*, Owen Barnes (ed.), Shrivenham: Directorate of Defence Studies, 2009, p. 2.

14 Caitlin Harrington Lee, 'Armed and Dangerous', *Jane's Defence Weekly*, 10 August 2011, p. 38.

15 Jeremiah Gertler, *CRS Report for Congress: U.S. Unmanned Aerial Systems*, Washington, DC: Congressional Research Service, 2012, pp. 47–48. A RAND report prepared for the US Navy, contends that UCAS will not be suitable in the air-to-air role in the 2025 timeframe. See Brien Alkire and others, *Applications for Navy Unmanned Aircraft Systems*, Santa Monica, CA: RAND Corporation, 2010, p. 44.

16 QinetiQ, 'UK Taranis UAV Passes First Major Milestone', 2010.

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2 Research Interviews

1 This interviewee was a founder member of Exercise Red Flag, which started in 1975. Aggressor instructors use adversary tactics and doctrine, and sometimes equipment, to teach US and coalition forces how to counter these threats – see S. Davies, *Red Eagles*, Oxford: Osprey Publishing, 2008, pp. 34–36.

2 Ibid., pp. 34–37.

3 Interestingly, the current UK MOD view is that the operation of weapon systems will always be under the control of a human – see 'House of Commons Defence Committee, Remote Control', Ev w2, para 2.13.

4 TPT is the ability of a system/platform to effectively use information from another system/platform, in order to conduct its mission – instigating delivery of weapons from the system's own vehicle, or from another system, and, in certain scenarios, guidance of weapons.

5 These sorties are Large Formation Employments exercises, such as Red Flag, Tactical Leadership Programme and other COMAO exercises.

6 Details of all interviewees are in the bibliography.

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AAM, which is the range inside which an adversary cannot escape a threat's AAM by manoeuvring, normally at 9 G, sustaining the same speed, although this can vary – see Brian T. Schreiber, William A. Stock, and Winston Bennett Jr., *Distributed Mission Operations within-Simulator Training Effectiveness Baseline Study*, Mesa, AZ: Lumir Research Institute: Air Force Research Laboratory, 2006, Appendix G, pp. 27–32.

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14 ACM Sir Glenn Torpy RAF – former Chief of the Air Staff (Interviewed 11 October 2011).

15 AM Christopher Nickols RAF – Chief of Defence Intelligence – 2011 (Interviewed 12 September 2011).

16 ACM Sir Simon Bryant RAF – Commander-in-Chief RAF Air Command – 2010, (Interviewed 30 March 2010).

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19 Colonel Gaillard Peck USAF (Retd) (Questionnarie completed electronically and sent by email, 3 August 2010).

20 Major General Lawrence Wells USAF (Postal Questionnaire, dated 11 January 2013).

21 Interviewed under the Chatham House Rule, on 17 November 2011.

3 Overview

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104 Ibid., p. 9.
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15 Burton's analysis has only one BVR RF AAM kill in each of the 1973 and 1982 Israeli conflicts (1 per cent and 4 per cent, respectively) – see Burton, 'Letting Combat Results Shape the Next Air-to-Air Missiles', slides 4–5.
16 Attinello, *Air-to-Air Encounters in Southeast Asia: Volume IV*, p. 92.
17 Ibid., p. 98.
18 Ibid., p. 93.
19 Burton, 'Letting Combat Results Shape the Next Air-to-Air Missiles'; slide 3 gives 117 kills during 1965–1968, with 22 per cent from RF AAM, and during 1971–1973, 73 kills with 41 per cent from RF AAM; slide 5 details a total of 918 RF AAM launched during these periods.
20 Ibid.
21 See Grant, 'The Bekaa Valley War', p. 61, which cites 82, while Burton states 77 were shot down – see Burton, 'Letting Combat Results Shape the Next Air-to-Air Missiles', slide 3.
22 Burton, 'Letting Combat Results Shape the Next Air-to-Air Missiles', slides 3 and 5.
23 See ibid., slides 3 and 5. Burton states that 10 per cent of RF AAM firing attempts were BVR.

24 Ibid., slide 5.
25 I have used analysis from a number of sources: Burton, 'Letting Combat Results Shape the Next Air-to-Air Missiles', slide 3; Stillion and Perdue, 'RAND: Project Air Force', PPF.25; *Project Red Baron III: Air-to-Air Encounter in Southeast Asia, Volume III: Analysis – Part 1: Tactics, Command & Control and Training*, p. 55; Eliot A. Cohen, *Operations & Effects and Effectiveness*, Washington, DC: U.S. Government Printing Office, 1993; and Air Force Historical Research Agency, 'USAF Aerial Victory Credits'.
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30 See Burton, 'Letting Combat Results Shape the Next Air-to-Air Missiles', slide 12.
31 Watts, 'Doctrine, Technology and War', Chap. 4.
32 See Burton, 'Letting Combat Results Shape the Next Air-to-Air Missiles', slides 3 and 5. Of the total of 918 RF AAM launched, 10 per cent were beyond 5 nm, achieving 2.7 per cent of 73 kills from 1971 to 1973, and 0 per cent of 117 kills from 1965 to 1968.
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37 Ibid., p. 41.
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39 Ethell and Price, *Air War South Atlantic*, pp. 61–67.
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43 Cohen, *Operations & Effects and Effectiveness*. See also Watts, *Six Decades of Guided Munitions and Battle Networks*, p. 146. Thirty-eight Iraqi aircraft were destroyed in air combat with weapons; 24, including 1 from a Saudi F-15, with AIM-7 AAM, 12 with AIM-9 AAM, 2 with an air-to-ground gun, while 3 flew into the ground while manoeuvring – see Cohen, *A Statistical Compendium and Chronology*, Table 206, p. 653.
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Southeast Asia, Volume III: Analysis – Part 1: Tactics, Command & Control and Training, p. 55; Ethell and Price, *Air War South Atlantic*, pp. 214–215; Stillion and Perdue, 'RAND: Project Air Force', PPF.25, 27–28; Grant, 'The Bekaa Valley War', p. 62; Cohen, *Operations & Effects and Effectiveness*; Air Force Historical Research Agency, 'USAF Aerial Victory Credits'.

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8 Conclusion

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Responders to Questionnaire

The interviews and questionnaire responses were conducted under King's College London's Research Ethics mandate. The interviewees were made aware of the use to which the interview derived material would be put, and were given the option of providing anonymous feedback, under the 'Chatham House Rule'.

Military

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Major General Lawrence Wells USAF: F-16, Pilot; Commander, US 9th Air Force, Air Combat Command – email response, 2 December 2012.

Air Commodore Richard Atkinson RAF: Tornado F-3/F-4 Phantom, Pilot; Qualified Weapons Instructor, Air Officer Scotland and Station Commander RAF Leuchars – interviewed 10 August 2009.

Air Commodore Gordon Moulds RAF: Tornado F-3/F-4 Phantom, Navigator; Commander British Forces Falkland Islands – interviewed 1 July 2009.

Air Commodore Richard Powell RAF: Tornado F-3/F-4 Phantom/F-14 Tomcat, Navigator; Qualified Weapons Instructor, Station Commander RAF Waddington – interviewed 11 November 2009.

Group Captain Simon Hindemarsh RAF: Tornado F-3/F-4 Phantom, Navigator; Qualified Weapons Instructor, Chief of Staff, Falkland Islands – interviewed 29 May 2009.

Group Captain Tony Innes RAF: Tornado F-3/F-4 Phantom/Typhoon, Pilot; Qualified Weapons Instructor, Station Commander RAF Leeming – mail response 1 April 2010.

Group Captain Paul Taylor RAF: Tornado F-3/F-4 Phantom/E3-D, Navigator; MOD Operations Directorate – interviewed 5 November 2009.

Group Captain Alan Vincent RAF (Retd): Buccaneer/Tornado GR1, Navigator; Group Leader DSTL – email response 2 April 2010.

Colonel Gaillard Peck USAF (Retd): Phantom/F-15 + Aggressor, Pilot; USAF Weapons School Instructor – email response 11 April 2010.
Wing Commander Jeremy Attridge RAF: Tornado F-3/F-18C/Typhoon, Pilot; Qualified Weapons Instructor, MOD Capability Theatre Airspace – Interviewed 20 December 2011.
Wing Commander Andrew Dickens RAF: Tornado F-3, Pilot; RAF Air Warfare Centre, Head of Trials and Tactics – interviewed 15 May 2009.
Wing Commander Hugh Griffiths RAF (Retd): Tornado F-3, Navigator; Qualified Weapons Instructor; Director – Inzpire Ltd – mailed response 28 March 2010.
Wing Commander Mike Humphreys RAF (Retd): Tornado GR1/4, Navigator; UAS Business Development Director BAE – mail response 6 April 2010.
Wing Commander Richard Knight RAF: Tornado F-3, Navigator – interviewed 1 May 2009.
Wing Commander Mike Lumb RAF: Tornado GR1/4, Navigator; DSTL Military Adviser – interviewed 1 April 2010.
Wing Commander Chris Thirtle RAF: Tornado F-3/F-15E, Pilot; MOD Chief of the Air Staff's UAS Strategy – interviewed 12 January 2010.
Wing Commander Mark Wakeman RAF (Retd): Tornado F-3/F-4 Phantom, Navigator; Qualified Weapons Instructor – interviewed 9 January 2010.
Wing Commander Paul Wallace RAF: Buccaneer/Tornado GR-1/4, Navigator; UCAS Analyst – email response 25 February 2010.
Squadron Leader Dr Richard Birchenall RAF: Communications Engineer and IADS Specialist – interviewed 14 October 2010.
Squadron Leader Ian Brain RAF: Tornado F-3/F-4 Phantom/Wessex, Navigator – email response 19 February 2010.
Squadron Leader Edward Burrows RAF: Tornado F-3, Pilot; Qualified Flying Instructor – interviewed 13 January 2010.
Major Charles Ware USAF: Aeronautical Engineer – interviewed 5 June 2013.
Squadron Leader Steven Davis RAF: Nimrod R1/2, Air Electronics Operator; IADS Specialist – interviewed 24 August 2010.
Squadron Leader Jonny Farrow RAF: Tornado F-3, Navigator; Qualified Weapons Instructor – email response 24 February 2010.
Squadron Leader Sue Freeman RAF: Tornado F-3, Pilot; Qualified Flying Instructor – interviewed 13 June 2009.
Squadron Leader Adam Grindley RAF: Buccaneer/Tornado GR1/4, Navigator; DSTL Military Adviser – mail response 6 April 2010.
Squadron Leader Fredrick Grundy RAF (Retd): Tornado F-3/F-4 Phantom, Pilot; Qualified Weapons Instructor – interviewed 25 October 2009.
Squadron Leader Martin Higgins RAF: Tornado F-3, Pilot; Qualified Flying Instructor – 17 June 2009.
Squadron Leader Steven Kilvington RAF: Tornado F-3, Navigator; Qualified Weapons Instructor – interviewed 3 February 2010.
Squadron Leader Andrew Miller RAF: Tornado F-3, Navigator; Qualified Weapons Instructor – interviewed 25 April 2009.
Squadron Leader Matthew Nicolas RAF: Tornado F-3, Navigator; Qualified Weapons Instructor – interviewed 22 October 2009.
Squadron Leader Kenneth Reeves RAF: Tornado F-3/F-4 Phantom, Navigator; Qualified Weapons Instructor – interviewed 11 August 2009.
Squadron Leader David Richards RAF: Tornado F-3/GR-4, Navigator – interviewed 3 December 2009.

Squadron Leader David Smith RAF: Battlespace Manager – interviewed 20 January 2010.
Flight Lieutenant Mike Hearnshaw RAF: Tornado F-3, Pilot – interviewed 27 April 2009.
Flight Lieutenant James Hunkin RAF: Tornado F-3, Pilot – interviewed 25 April 2009.
Flight Lieutenant Russell Jones RAF (Retd): Tornado F-3/F-4 Phantom, Pilot – interviewed 10 April 2010.
Flight Lieutenant Roy MacIntyre RAF: Tornado F-3/F-4 Phantom, Pilot; Qualified Weapons Instructor – email 19 April 2009.
Flight Lieutenant Gerard McCormick RAF: Tornado F-3, Navigator – interviewed 28 April 2009.
Flight Lieutenant Andrew Shaw RAF: Tornado F-3/F-18 Pilot – interviewed 29 April 2009.
Flight Lieutenant Jonathan Skinner RAF: Tornado F-3/Typhoon, Pilot – mail response 24 March 2010.
Flight Lieutenant Jonathan Smith RAF: Tornado F-3/F-22 Raptor, Pilot; Qualified Weapons Instructor – interviewed 3 February 2010.
Flight Lieutenant Jennifer Trafford: Tornado F-3, Navigator – mailed response 22 March 2010.
Captain Michael Mashoe USMC, Ground Air Defence Commander – interviewed 2 April 2010.

Aviation Analysts

David Bromley: MOD UAS Aviation Analyst – interviewed 15 June 2011.
Alan Brooke: Home Office Scientist; UAS Specialist – interviewed 3 May 2010.
Professor Tony Gillespie: UCL Professor/DSTL Scientist – Autonomy and Artificial Intelligence – email response 1 April 2010.
John Keirl: DSTL Scientist; UAS/UCAS Lead – interviewed 27 November 2009.
Harjit Lota: DSTL Scientist; UAS and Weapons Specialist – interviewed 3 May 2010.
Dr Simon Lovell: DSTL Scientist, Future Air Systems – interviewed 4 March 2010.
Keith Payne: Aviation Engineer – interviewed 16 December 2011.
Dr Jon Platts: Artificial Intelligence and Autonomy Specialist – mailed response 20 December 2010.

Civilians

Alan Bell: Engineer – interviewed 3 April 2010.
Callum Murray: Retired Royal Marine Officer/Businessman – interviewed 8 March 2010.
Polly Murray: Bespoke Furniture Designer – interviewed 8 March 2010.
Stephen Oxnard: University Student – interviewed 8 April 2010.
Angus Paterson: Student – interviewed 9 April 2010.
Myles Paterson: University Student – interviewed 9 April 2010.
Lynne Todd: Certified Engineer and Materials Scientist – interviewed 3 April 2010.
Marie Young: Retired Financial Consultant – interviewed 6 March 2010.
Raymond Young: Retired Engineer – interviewed 6 March 2010.
Oliver Waghorn: Special Adviser to the Secretary of State of Defence – interviewed 24 June 2011.
Joanne Wills: Business Development Consultant – interviewed 31 January 2010.

Chatham House Rule

Five interviewees chose to respond under the Chatham House Rule, including an RAF pilot, an ex-Senior Responsible Officer for the MOD's Information and Superiority capabilities, an aviation consultant and a USAF army officer specialising in counter-air systems.

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