ROYAL AIR FORCE

# Air and Space Power Review

Volume 22 Number 2 Summer 2019



A Peer Reviewed Journal by the
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# RAF Air and Space Power Review

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Director of Defence Studies (RAF)
Room 202, Greenhill House
Shrivenham
Swindon
Wiltshire SN6 8LA

**E-mail:** enquiries.dds@da.mod.uk

**ISSN:** 1463-6298

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**Photographs Courtesy of:** Air Historical Branch (RAF)
**Print:** CDS

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Centre for Air and Space Power Studies

# Foreword

by Group Captain James Beldon

**To mark the renaming of the publication to the *Air and Space Power Review*, published to coincide with the Chief of the Air Staff's Air and Space Power Conference 2019, this special edition focuses on the importance of space and the specific contemporary and historical opportunities and challenges that this increasingly important operating domain presents.**

The opening viewpoint written by Dr Bleddyn Bowen reflects on recent developments in space warfare and their relevance to British military capabilities, and comments on the emerging Defence Space Strategy. A lecturer in International Relations at the University of Leicester, Dr Bowen identifies that, despite the Space Age being nearly 60 years old, perhaps it is only now that wider society is realising the associated exploitation and influence on politics, economics, warfare and critical infrastructure on Earth.

A specialist in artificial intelligence and cybersecurity, Dr Mark Chang examines the constraints faced by UK military space budgets for the development and application of Next-Generation Military Satellite Communications. The article focuses on the increasingly crowded and contested MILSATCOM environment, linking offensive space assets and technological innovations, which in turn impact space-enabled defence affordability. Anti-satellite capabilities are the focus of the edition's second viewpoint by Alexandra Stickings. A research fellow in space policy and security within the Military Sciences group at RUSI, Stickings explores how the strategic balance in space could be influenced and normalised by the acquisition of anti-satellite capabilities by other actors, including rogue states.

Artificial intelligence is heralded by some as the next Revolution in Military Affairs. Squadron Leader James Waller and Dr Phillip Morgan co-author this article, which opens with an historical summary of artificial intelligence, before going on to discuss recent exciting developments and identifying some of the potential implications for the air domain.

The operation of high persistence lightweight air vehicles, often referred to as High Altitude Pseudo-Satellites (HAPS), is the focus of our next article. Flight Lieutenant Lilie Weaver explores the benefits and challenges associated with the record-breaking operation of Zephyr, Airbus' HAPS technology demonstrator, linking in facets of UK MOD involvement within the programme.

Wing Commander Keith Dear offers a thought-provoking viewpoint addressing the rise of big data, which he suggests is fundamentally re-shaping modern warfare. The author argues that the opportunities presented by the exponential increase in data volume and fidelity should make us re-think the way in which decisions are made, and explore whether the right people are charged with making them. Multi-domain operations (MDO) and the RAF's recent re-formation of No 11 Group as a dedicated MDO Group are explored by Wing Commander Jamie Meighan. The article develops to consider the legacy of 11 Group during the Battle of Britain against contemporary future operating contexts in which MDO are likely to play a vital part.

In this edition's final article, Wing Commander Bryan Hunt explores a detailed history on the application of the V-2 and the post-war British exploitation of existing German long-range rocket technology. An intriguing insight into Britain's wartime exposure to astronautics through being targeted by ballistic missile attacks, Britain's subsequent exploitation of Nazi rocket technology in the pursuit of its own rocket programmes is enlightening.

Our first book review, *Reaper Force: Inside Britain's Drone Wars* by Dr Peter Lee, provides a unique insight into the Reaper Force's personnel (and their families) operating from RAF Waddington and Creech Air Force Base in Nevada. The author emphasises the need for continued awareness that any military service is only as good as its people, neglecting the 'human dimension' at its peril. The second book review *The Man who took the Rap: Sir Robert Brooke-Popham and the Fall of Singapore* by Peter Dye provides a superb biographical insight of this highly influential, yet controversial, senior commander, whose many achievements have been overshadowed by the somewhat exaggerated blame that was attached to him for Britain's defeats in East Asia following Japan's entry into the Second World War.

The theme of Remotely Piloted Air Systems and operations continues in *Limiting Risk in America's Wars* by Philip Meilinger. A concise account of the employability of technological advances delivered through air power to enhance the reduction of civilian casualties, the author provides an interesting analysis of the application of the military instrument set against the broader political context. Finally, in a book that some have described as the best book yet written on the conflict, *Vietnam, An Epic Tragedy 1945-1975* by Max Hastings provides some staggering insights into a war that continues to influence the application of military force well into the twenty-first century. The lessons of Vietnam continue to resonate – as the chapters of this book will too.

Enjoy reading this edition, and remember that we are always in search of new perspectives that advance the Royal Air Force's conceptual development, irrespective of rank or experience. Additionally, I should highlight our Facebook and Medium pages, with which you can interact directly via the following links:

https://www.facebook.com/RAFCASPS/

https://medium.com/raf-caps

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Viewpoint

# A Familiar Frontier: British Defence Strategy and Spacepower

By Dr Bleddyn Bowen

**Biography:** Dr Bleddyn Bowen is a Lecturer in International Relations at the University of Leicester, and is an expert on space policy, space warfare, and strategic theory. Dr Bowen has published on British and European space strategy, seapower analogies in outer space, and UK space doctrine, and is currently working on completing his monograph on spacepower theory.

## Introduction

Spacepower's time has come. In 2018 the political, economic, and military uses of outer space – spacepower – enjoyed a level of publicity and policy attention like never before on both sides of the Atlantic. Such attention has exposed what was once a niche policy, industry, security, and military activity and academic specialism to mass media coverage and general policymaker scrutiny. Despite its being 60 years old, perhaps it is only now that wider society is realising that we are living in a Space Age, where the exploitation of Earth orbit is influencing the way we conduct politics, economics, warfare, and critical infrastructure on Earth.

It is telling that, in my scholarly disciplines of International Relations, Strategic Studies, and Intelligence Studies, the explicit and dedicated study of spacepower is still a rare specialism, especially outside of the United States. This is despite the fact that spacepower has been at the forefront of the most technically demanding military and intelligence activities throughout the Cold War and into the post-Cold War era. Today, spacepower is seemingly at the forefront of the emerging post-hegemonic international system. The proliferation of high-quality space technologies and space industrial companies continues within and across major powers such as the EU, India, and China. Several non-NATO militaries are modernising their defence industries towards space-enabled terrestrial warfare and long-range reconnaissance-strike capabilities. This viewpoint outlines my own professional views of and reflections on the shifting international context of spacepower as MOD personnel will surely engage with policy and strategy in space more as the years progress. The military services will require more space-literate personnel to implement the DSS and provide the necessary spacepower support to UK and allied missions, as well as critical infrastructure resilience.

## British spacepower

The story of British spacepower has been one of integration, characterised by a binary system between Europe and America.[1] In the world of intelligence and military satellites, the UK has integrated itself into American space systems with its *Skynet* communications satellite constellation being an exception to this rule. Scientifically, commercially and industrially, the UK's space activities have integrated into the European system – through the European Space Agency (ESA) and the EU for the most part. In the last 20 years, the EU has become a more significant hard power, or security actor, in space. Britain looks set to lose influence on the one side due to Brexit, and the UK may seek to reduce its dependency on the other through the pursuit of new defence assets in space. At present, both sides of the Atlantic are witnessing significant changes with Trump's reorganisation of space in the Pentagon and the EU's desire to set up a new EU space agency alongside ESA and the rupture of Brexit. This binary system and how Britain has long been integrated in both of them should condition any discussion on UK space strategy and defence policy.

Following the founding of the UK Space Agency (UKSA) in 2010 to coordinate industrial and scientific space activities, Whitehall has increased the prominence of space policy for decision-makers. 2013 saw a revision of the RAF's AP 3000 doctrine into the Joint Services JDP 0-30 Air and Space Power Doctrine, where air and space were conceptually separated for the first time. 2014 and 2015 saw the first ever UK National Space Policy and National Space Security Policy, respectively. 2017 saw the second edition of JDP 0-30 which expanded on several aspects of the first, fleshing out more basic assumptions of the MOD's principles in space.[2] For many years, the UK has been participating in the United States' Schriever space wargames, with allied states becoming increasingly prevalent within them. 2018 saw the signing of the UK Space Industry Bill into law, creating a framework for further commercial space legislation. 2018 also saw two significant and unresolved events: the first was the very public rupture of UK space policy with regard to the EU's Galileo satellite navigation programme, and the first hints of the contents of the MOD's Defence Space Strategy (DSS).

In Spring 2018, the procurement competition for the next phase of Galileo satellites – the EU's global navigation satellite system (GNSS) – was due to be finalised in a European Space Agency (ESA) Ministerial Council. As a result of Brexit, British companies were no longer allowed to bid for the contracts to develop the systems involved in Galileo Public Regulated Service (PRS), which is Galileo's secure and encrypted high-precision signal which is only available to approved EU state security and military users. Although implemented by ESA, Galileo is an EU-funded project. As British-based companies, which had to date led the work on the navigation payloads of the Galileo satellites, would soon be outside of the EU, EU security regulation and space industrial policy was clear that any significant contracts and security-relevant work could not go to companies outside of the EU. The former UK Defence Secretary, the Right Honourable Gavin Williamson MP, decided to contest this in public with the support of 10 Downing Street by supporting the notion of a UK replacement programme for Galileo and threatening to block EU access to UK terrestrial sites for ground support,[3] whilst other government departments threatened to withhold important ongoing work from the EU.[4]

Though there is considerable doubt as to the feasibility, desirability and opportunity costs of building a replacement system for Galileo, it has put UK spacepower and the importance of the UK's satellite industry on the political map and in the public consciousness. I have critiqued the UK's stated desire to seek a GNSS programme of its own elsewhere, including providing oral testimony to the UK House of Commons Exiting the EU Select Committee.[5] The Galileo replacement decision – which seemingly has pre-judged the outcome of the £92m 'feasibility study' – is the opposite of what rational and responsible space capability planning should be. The MOD is likely to still have access Galileo's PRS as intended in future, and on the same level of passive usage as the MOD has done with the American GPS military signal since the late 1980s. Michel Barnier, the EU's chief Brexit negotiator, has stated that subject to a functional agreement, the MOD may be able to access PRS signals.[6] British belligerence during the procurement rounds at ESA last year may have helped accelerate the EU's plans to finally set up a rival space agency from the core of the European GNSS Agency (GSA). The EU currently contracts ESA to implement its major space projects and policies and the EU may seek to further limit ESA's decision-marking power over EU-funded and ESA-implemented projects.[7] Regardless of the future trajectory and form of European space integration, Galileo became front-page news in the context of Brexit, and the issue of the lack of sovereign UK spacepower in several areas became talking points in mainstream media.

It was already high time that Britain considered whether it needed to expand its sovereign space capabilities and provide public investment to support the UK's niche strengths in the global space economy – small satellites and downstream applications. The considerations and choices facing the MOD, and in particular in the DSS, would be virtually the same even if Brexit was not happening. Such gaps in capability and strategic planning pre-date Brexit by many years. The DSS is expected to outline a focus on expanding the MOD's capability in space-based ISR and other tactical and operational space systems for deployed military forces on Earth. Recently, the MOD has invested funds into Carbonite-2, (a live video ISR small satellite in low-Earth orbit), NovaSAR, (a synthetic aperture radar small satellite), and has released tenders for Project Oberon which is another synthetic aperture radar satellite programme. The UK Government is also supporting a small-satellite vertical and horizontal space launch capability for Sun-synchronous and polar orbits from UK territory, yet the £50m set aside for this task is smaller than the 'feasibility study' for a Galileo replacement system.

Often these new investments are described in the media as linked to, or in spite of, the Galileo-Brexit debacle. But the reality is that these capabilities simply are not the same and many within the space security community in the UK have been calling for British ISR space capabilities and small-satellite spaceports for many years. Seeing these decisions as making up for the withdrawal of the UK from the EU's space programme is making a virtue out of necessity. Even if Britain were to remain a member of the EU and a leader in its GNSS technology, there would still be a persuasive case for British investments in small-satellite and ISR assets. British space-based ISR would be able to provide new capabilities as a priority for UK military needs without having to rely almost totally on allied assets as it currently does, and unlike navigation signals, friendly ISR assets can be overburdened with excessive tasking and British needs can be pushed down the priority list for allied ISR tasking and analysis. This will be increasingly true as British allies increasingly modernise their own forces to become even more dependent on space systems, reducing the amount of 'bandwidth' available for allies on-demand. In addition, if the MOD and British intelligence agencies were to become major clients of the UK small satellite space industry (coupled with the potential for a small-satellite vertical spaceport on UK soil), this new stream of revenue would likely stimulate a very successful British industry and could help generate a new virtuous circle for the industry. A stable stream of launch requirements from the UK's defence and security organs would help build a market base for UK space launch services. Unfortunately, such possibilities are absent in the current iteration of the Government's Industrial Strategy.

In all its endeavours, the British military cannot do without space support. When considering likely deployments, involving naval power projection, aerial bombardment and close air support, as well as light infantry and ground operations, space systems are only going to become more relied-upon as the MOD attempts to make up for a lack of terrestrial platforms and units with better efficiency and information dominance. Lighter Special Operations Forces (SOF) would be extremely reliant on spacepower for their survivability, mobility, coordination and efficiency, making up for their low numbers and depth, particularly in engaging with unmarked or proxy militias in low-intensity conflict. The DSS, if it brings about new space-based ISR for the UK, will have implications for the intelligence agencies as well. Convincing the intelligence agencies to buy into the systems may be necessary. For example, GCHQ consumed most *Skynet* bandwidth during the Cold War, especially before the advent of fibreoptic transatlantic cables. Like *Skynet*, a British ISR capability could provide London with more secure channels of support and information from space for covert intelligence and special forces operations further afield, independent of friend and foe alike.

The direction of travel in the UK is for more space capabilities, not fewer. Yet spacepower, like any major capability and geostrategic environment, requires a large coalition of stakeholders to provide the direction and funding to realise their benefits, beyond individual parliaments and cabinets. A key problem for Britain to address, regardless of the exact capabilities invested in and which dependencies are to be accepted, is the recruitment of personnel with the necessary technical skills and intelligence analysis brainpower. There is a general shortage of science, technology, engineering, and mathematics (STEM) graduates, and the MOD must not only face this issue but also compete with the attractiveness of working for the intelligence agencies and the commercial space industry.

Any major investment in British space capabilities, whether in space or on the ground such as with dedicated space radars for enhanced space situational awareness (SSA) capabilities, will require functional demarcations of responsibility within the MOD and across the intelligence agencies. The MOD's space capabilities and responsibilities are currently discharged across the RAF, Joint Forces Command (JFC) and Defence Science and Technology Laboratories (DSTL). These entities will also need to clarify their relationship with UKSA, particularly if Britain wants to retain an ostensibly civilian face in space and to provide some degree of a cordon sanitaire between civilian space science and commerce and the military-industrial complex. In addition to deciding who should 'do space' in the MOD and across the organs of the British state, the integration of such new assets and personnel will need to also look outward into the allied and Five Eyes relationships. Britain has traditionally relied on others for the bulk of its space capabilities – it is only reasonable to return the favour to our allies, especially the United States, and consider how best to make Britain in space useful to its friends.

## Space Force and the international context

Across the Atlantic, President Donald Trump has decided to focus some of his energies on the reorganisation of the US military space bureaucracy. He has championed the notion of an independent 'Space Force' as a sixth branch of the US military and will re-create the US

Space Command as a new combatant command on the same level as the other geographic commands and US Strategic Command – essentially undoing the Bush administration's changes in 2002. The latest space policy directive from the White House has seemingly reduced its ambitions and effectively requested that Congress legislate for what bipartisan consensus already had been pushing towards for many years in the House of Representatives, under the advocacy of Representative Mike Rogers – a 'Space Corps' within the US Air Force to have the same degree of autonomy as the Marine Corps does within the US Navy's architecture. However, it is still referred to as Space Force in writing, which disguises its non-independent nature. Regardless of the form, Congress must still legislate for a Space Corps or Force to come about. It is not yet a foregone conclusion as there is considerable hostility within the Senate towards any more independent space cadres within the Pentagon.

At the time of writing, it is still unclear what problem a new Space Corps or Force, and a US Space Command, is trying to solve. There are good reasons for considering a space-orientated service, as I have argued elsewhere.[8] But the Trump administration is tight-lipped as to their rationale for a new service. Claims of Chinese and Russian threats are valid – but these are chronic rather than acute threats. There is no explanation of how the Pentagon has failed to address these issues satisfactorily due to the current organisational structure of US military space. Indeed, Chinese and Russian modernisation are beyond the control of any US military service. There are also complaints that go back decades that the US Air Force does not allow military space culture to develop, or underfunds its space mission, or that the current acquisitions and procurement processes for space are not fit for purpose.[9] Another front in this changing bureaucratic landscape is the new Space Development Agency. Though details are scant at present, it is meant to allow the Pentagon to tap into off-the-shelf space technology and assets in a much faster fashion than current procurement procedures allow with built-to-order space systems, similar to the UK MOD's hopes with small-satellite ISR capabilities using commercial technologies.

These complaints or rationales for reorganisation are not debated in any depth in public – particularly as issues over procurement remain highly classified – and therefore communicating and justifying a Space Force or Corps to Congress and the electorate may be a challenge without getting into the detailed rationales for setting up a new service. The Trump administration must explain what does not work in the current set-up – and by a matter of course will have to criticise the US Air Force's stewardship of American spacepower in the process. This complicates the USAF's life-long effort to retain majority control of US military space and its budget. At the time of writing, there are no new major acquisition programmes beyond long-running capability modernisation and incremental improvements in the US military space community. Discussion of a Space Force should therefore not become bogged down in discussion of US space weapons policies and doctrines. The 'space warfighters' of the US military are, after all, personnel watching computer monitors in windowless bunkers and facilities, responsible for the optimal utilisation and deployment of American space-based infrastructure. Whatever the form the new mould of American spacepower is set, the UK, Five

Eyes states, NATO and Asia-Pacific allies will have to ensure they remain well-integrated within it. The Space Force will mostly be about support to warfighters, not warfighting itself.

A serious discussion of how best to organise military spacepower, and which sorts of assets are required, is a welcome and necessary one on both sides of the Atlantic. China and Russia have either deployed or re-activated kinetic anti-satellite (ASAT) weapons programmes and continue to modernise their terrestrial military forces with supporting space infrastructure which mimics American successes with so-called 'net-centric' or precision warfare since the 1990s. As China and Russia become greater threats in space for space-enabled military forces, they themselves are becoming dependent on space systems for their long-range strike, surveillance, and command and control capabilities. Space is therefore an increasingly target-rich environment for any state seeking to employ soft (e.g. electronic warfare, computer network attacks) or hard kill (e.g. kinetic or explosive) ASAT weapons during a time of open hostilities.

Over 70 states are significant stakeholders in space, with their own space infrastructure and capabilities that are deployed for their own mix of objectives for war, development and prestige. Not least among these are European states and the EU, India, Japan and Israel. With so many states and a myriad of private actors using space, there is an increasing need for international regulation on how to establish 'normal' everyday behaviour and standard operating procedures in space that minimise the risk of accident and unintentional harm or interference. The previous drive at this effort – the EU's International Code of Conduct for Space Activities, is currently in the doldrums of the UN's General Assembly.[10] Despite this stalled effort, there is an increasing desire among some in the private sector and many states for some form of standardisation of behaviour in outer space, particularly in the guise of a space traffic management system. If successful, this will have a far-reaching impact on the way humanity uses Earth orbit and will steal the diplomatic initiative and momentum away from Russia and China's stalled space weapons ban proposal, the PPWT.

Britain must find its place in this evolving diplomatic, strategic and economic landscape. Britain can contribute much for global governance debates on these issues, particularly if it is set on increasing its sovereign space capabilities. A possible area for Britain to gain leverage in these discussions is to invest in SSA capabilities, going beyond RAF Fylingdales and developing essential SSA data that any space traffic regime will need. As well as being necessary for British intelligence and security needs, it would be useful for wider diplomatic and 'good citizen' duties in the global space community by sharing space tracking data. This raises another issue for the UK's future planning in space if it were to pursue more capabilities with regard to the division of responsibilities. Whether or not the military is the best place for a greater British SSA capability is an open question. Traditionally, SSA data is often not as transparent or timely when controlled by the military, and especially if integrated in the American Space Surveillance Network as current British SSA capabilities are via RAF Fylingdales and RAF High Wycombe.

A dedicated civilian UK SSA may be able to provide more flexibility over the data and its sharing to suit London's diplomatic interests as the EU itself seeks to increase its own SSA network.

## Conclusion

British space is going through many changes and has never faced as much public and government attention as before. Yet the same is true of the global astropolitical landscape. Spacepower is proliferating horizontally and vertically, with an increasing number of middle and small powers investing in space technology for the needs of war, development and prestige. British economic successes in space are not guaranteed to continue, and will face an increasingly competitive global space market. There are increasing threats to UK assets in space, and for terrestrial military forces which depend on space, which makes for a potentially bright future for space defence acquisition in the years ahead. Whether new defence assets should be procured off-the-shelf, designed in-house, or new standards of hardening against jamming, spoofing and cyber-intrusions imposed on UK space industry are decisions that Whitehall must make soon. Britain needs to discuss carefully where to invest in capabilities and personnel, and where to rely on and integrate with others. Most importantly, Britain will have to consider how it fits into the binary system of US and European spacepower, as the old historical balance may no longer work given Europe's increasing military space capabilities.

Space is a rather familiar frontier: Britain will continue to struggle to come to terms with the perennial problems of a budget that never meets its lofty rhetoric. Resources are scarce not just in finances, but in personnel. The Space Age is full of promises, and despite access getting easier, the international competition over profit and security in space will increase demands on Britain to keep pace with the larger and comparable economic powers of Earth. Britain's space ambitions have to meet its capacities and hard decisions need to be made on which niches are worth investing in, and where dependencies and allies are indispensable, and not engage in projects of national vanity. Such an argument is not new in discussion of British defence policy and grand strategy, that what we do in space is determined by and reflects upon politics, economics, and strategy on Earth;[11] space warfare is the continuation of terrestrial politics by other means.

## Notes

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[9] Michael V. "Coyote" Smith, 'America needs a space corps', *The Space Review*, 13/03/2017, http://www.thespacereview.com/article/3193/1 (accessed 15/03/2019).
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# Protecting Next-Generation Military Satellite Communications with an Innovative Disaggregation Approach: Delivering Major Gains through Business Change

By Dr Mark Chang

**Biography:** Dr Mark Chang is an aerospace, artificial intelligence and cybersecurity specialist at PA Consulting. He has been deeply involved in the space sector over the last 20 years. He has worked with major suppliers of deep space and Earth centred space missions for communications, navigation and observation in the UK, mainland Europe and the USA Mark led the engineering for three high capability satellite missions for the ESA, a satellite constellation for the private sector and the first 14 Galileo GNSS payloads. He is currently supporting the MOD's SKYNET 6 programme.

**Abstract:** The Military Satellite Communications (MILSATCOM) environment is more crowded and contested than ever, with 500,000 space debris items on one hand and over 40 space-faring nations on the other. Technological innovation has ushered in an era of offensive space assets, presenting a new type of Space Race. Yet UK military space budgets remain constrained with no foreseeable economic boost likely to relieve this. New architectures must respond more resiliently than before. To mitigate budget risks, we must examine defensive options: active (shoot back, escort), passive (e.g. hardening), rapid replacement or strategic disaggregation. Most choices are inflexible or limited in effect, except strategic disaggregation – where capabilities are made difficult to target by dispersing systems. A disaggregation dominated approach will improve system interoperability between allies, industry and the UK; strong interoperability disincentivises competitor threats.

## Introduction

Satellites provide a strategic advantage for the UK defence establishment and it is of prime importance to continually re-examine the vulnerabilities and resilience of the nation's constellations. We propose that disaggregated systems, coupled with host satellite partnering at an allied nation or commercial company level, will yield greater survivability, robustness and resilient capabilities for defence force elements in the face of modern threats while retaining the key requirement of affordability. It can also provide a method to insert essential technology improvements in a controllable manner, which is an option not available currently.

## The role of space capabilities

Sixty years ago, the Soviet Union launched the first man-made satellite[1] into orbit. In the following decades, space systems matured to provide critical capabilities to the military in the delivery of defence tasks. Nowadays they are a mandatory part of our modern national defence complex. Acquiring and deploying these systems in a timely and affordable manner is of crucial importance to UK national security.

In the early military space era, Western powers' space systems were focused on supporting strategic missions such as intelligence and nuclear command and control, with tactical missions very much an afterthought. The UK did experience an epiphany when it made effective use of Military Satellite Communications (MILSATCOM) in the 1982 Falklands Conflict.[2]

The global watershed moment for the use of space-based capabilities in tactical support of force elements undertaking conventional operations came during the 1991 Gulf War.[3] Use of the combination of Beyond-Line-of-Sight (BLOS) communications, precision navigation and timing in synergy with weapons systems formed a new set of abilities that demonstrated the unparalleled strength of the West's air and space power.[4]

## The current MILSAT environment

The use of space during the Cold War era was dominated by the superpowers. The strategic détente that emerged between these two competitors created a no-conflict zone in the space domain which held throughout that period. The extension of destructive conflict into space was viewed as unlikely but, at worst, a certain prelude to a full-scale nuclear confrontation. Thus the UK's third and fourth generation military satellite capabilities (SKYNET 4 and 5) were developed and deployed into a relatively uncrowded and safe space domain.

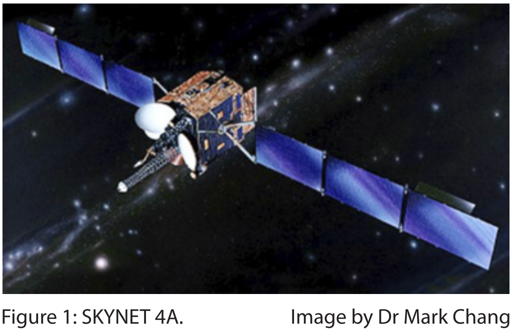
Figure 1: SKYNET 4A. Image by Dr Mark Chang

Today, space is no longer a sanctuary for the UK military capabilities.

Since the end of the Cold War, the Earth-centred space domain has seen a huge increase in activity. There are more than 1,950 active satellites[5] and a plethora of other trackable man-made objects in Earth orbit, where the majority of this is debris. Almost all nations depend on space capabilities for civilian applications like weather forecasting and navigation, and just over 40 nations have assets in Earth orbit. Some two-thirds of the active satellites are used for BLOS communications; most of these systems belong to commercial operators.[6]

The increase in the number of space-faring nations from a handful prior to 1980 to over 40 now has led to a congested and crowded domain.[7] An example of this problem is the first collision involving an active satellite occurring in 2009, when the inactive COSMOS 2251 and the operational Iridium-33 satellites impacted on orbit, creating thousands of pieces of debris in low-Earth orbit.[8] A second example highlights the potential threat at ground level: in 2016, the loss of control of the Chinese space station Tiangong-1 caused worldwide concerns over a two-year period, though it eventually burned up in the Earth's atmosphere, with the glass and titanium remnants falling into the oceans.[9]

This situation is set to worsen as a new Space Race has recently taken shape, this time driven by tech start-ups and private businesses spearheaded by billionaire entrepreneurs. All indications are that these private sector initiatives (SpaceX, Blue Origin, Bigelow Airspace, Virgin Galactic, Boeing, Lockheed-Martin, PlanetLabs, Rocket Lab for example) are not only growing rapidly but are also quickly 'besting' their government-sponsored competitors, irrespective of measure used; but, most importantly of all, in the time-to-service. The barriers-to-entry in the space sector have also decreased, the clearest measure being the number of satellite deploying launches.[10] In 2016 it was 169 while in 2017 it was almost double that number, at 310. In effect, a 'democratisation' of the costs for access to space is underway.[11]

Beyond congestion and crowding, other nations' defence establishments have taken note of the distinct advantages space capabilities provide and have developed counter-space challenge capabilities. In a highly visible demonstration, China successfully tested an anti-satellite (ASAT) weapon in 2007, destroying a malfunctioning weather satellite in low-earth orbit (LEO). The action was swiftly followed by the USA, which successfully destroyed a defunct, de-orbiting surveillance satellite by ASAT in 2008. Most recently, India[12] conducted a controversial ASAT test in March of 2019, dubbed 'Mission Shakti', destroying a 740 Kilograms (Kg) satellite which had been launched into LEO specifically as a target. In another notable milestone, China launched a quantum experiment on a satellite nicknamed Micius (or Mozi in Chinese), designed to transmit hack-proof keys from space in 2016, thus demonstrating further advances in possible competitor counter-space systems.[13]

Moreover electronic, cyber and physical attacks against the ground infrastructure used by space systems are increasingly concerning because the technological barrier-to-entry for these threats is falling, attacks are less attributable and the technology itself is more easily proliferated. From the perspective of third nations, UK and allied military space capabilities are weapon systems, and space is a domain of warfare that can and will be contested.

## Understanding the UK need for military space capabilities

The UK has eight military satellites for communications (MILSATCOM) in current operation.[14,15] The MOD has not yet directly acquired any other satellite capability class other than as demonstrators, be it intelligence, surveillance and reconnaissance (ISR), navigation, meteorology, signals intelligence, early warning or space situational awareness (SSA).

Figure 2: SKYNET 5. Image by Dr Mark Chang

While it appears that the UK lags in military satellite deployments (in the first tier the USA has 134, while in the second tier Russia has 81 and in the third tier China has 31 satellites), it is important to realise that these numbers are deceptive. Space systems are unlike many other weapons systems because they cannot be matched to comparable adversary systems to determine who has the upper hand. More or better tanks may create an advantage in a ground domain combat theatre. This logic does not necessarily hold true in the space domain as military space systems are part of a global infrastructure delivering core force element capabilities, such as precision attack or global power projection. Having a greater number of satellites or more capable satellites than an adversary does not mean there will be enough space-based capabilities to support forces. The value of military space systems is ultimately a function of how they contribute to winning the nation's wars.

A direct consideration of the numbers and types of satellites is therefore not a useful metric for the military competition in space. What matters are the BLOS capabilities these satellites enable for combat forces in other domains and the threats these systems face.

In short, the UK does not need numbers of space assets greater than its potential adversaries. Rather, the nation needs reliable, robust space capabilities that enable both freedom of action and operational advantage. In other words, we must have the right space capabilities at the right time to enable other weapon systems to be superior to those of an adversary in contests where the mission is important to the UK's interests. The use of the MOD's Skynet 5 capabilities by allied nations shows that this constellation achieved the right balance of priorities for its generation.

## Threats to MILSATCOM

We highlight how the changing threat environment affects the capabilities needed in the next-generation architecture for MILSATCOM as a focus, although the same principles apply to any other satellite capability class.

MILSATCOM provides core infrastructure services upon which other weapon systems depend. Force elements at all levels are dependent on MILSATCOM for reliable BLOS communications in the air, sea and land domains. The key type of protection for UK systems developed in the Cold War was nuclear survivability, an implicit assumption being that in conventional conflict deterrence would hold and space-based systems would not be attacked. Limited space domain threats combined with the high cost of launches in the Cold War also encouraged the creation of 'Battlestar Galacticas', which concentrate multiple MILSATCOM capabilities in a very small number of systems, to be able to address a variety of defence missions rather like a Swiss Army knife.

In the post-Cold War era, potential adversaries may not have symmetric vulnerabilities, in that they do not rely on MILSATCOM systems yet can reach the space domain, making deterrence in space difficult to enact. The legacy of Cold War decisions has left the UK's space systems vulnerable to counter-space operations in an anti-access or area denial (A2/AD) situation. In the next sections, we examine the vulnerabilities of MILSATCOM systems to inform the future space domain architecture argument.

## Physical threats

MILSATCOM satellites are vulnerable to kinetic attacks, like ASATs, be they ground launched or initiated from co-orbit. These types of strikes tend to be catastrophic and will create space debris that affect the satellites belonging to owners not directly involved in the conflict. Such threats are widely accessible internationally and legacy deterrence strategies are the only mitigations for now.

Non-kinetic (directed energy) attacks, such as lasers, can temporarily or partially degrade a satellite or its payload with less risk of debris. The targeting is far faster than kinetic platforms, though the effects do not need to be immediately evident (so attribution may be problematic). Enacting this threat requires costly technologies that are not widely nor easily available currently.

All Earth-centric space system architectures are comprised of the space segment and a ground segment. The ground segment is also at risk of physical attack. While they can be disrupted, they can be repaired in days to months; as such, we choose to focus on the space segment in this article.

## Electronic threats

The use of electromagnetic energy to interfere with communications, commonly known as jamming, is an attack vector that can be recovered from. For example, as soon as the jammer has disengaged, communications can be restored. Jamming can be done on the uplink to the satellite or on the downlink. An uplink jammer should be about as powerful as the signal it is attempting to jam and must lie within the footprint of the satellite antenna it is targeting – signal power dominance then becomes the game. There are other methods for uplink jamming which are more sophisticated, but the impact is the same: uplink jamming effects are generally broad, across many satellite operators.

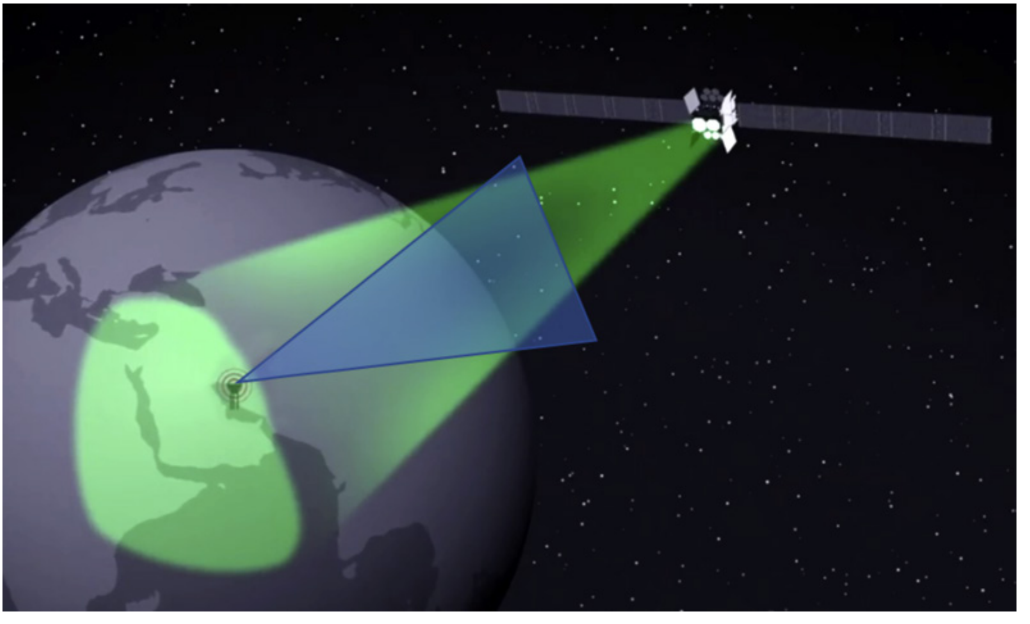

Figure 3: An illustration of uplink jamming. Image by Dr Mark Chang

In Figure 3, green areas represent the satellite footprint while blue areas represent the jamming signal.

Conversely, a downlink jammer needs to be only as powerful as the signal being received, but it must also be within the field of view of the receiving terminal's antenna. Thus, there is a limit to the number of terminals that can be affected by a single downlink jammer. Such jammers are more localised in impact.

It can be difficult to detect and distinguish jamming activity from accidental interference. It is also difficult to attribute a jamming instance to an identified source. Even where attribution is possible, neutralising the source of the jamming can present challenges.[16]

## Cyber attack threats

MILSATCOM systems are also vulnerable to cyber attacks, which can intercept data, corrupt data or take control of systems for malicious purposes. Unlike electronic attacks, which interfere with the physical transmission of data by the electromagnetic spectrum, cyber attacks target the data itself and the systems that use this data. Any data interface in the system is a potential intrusion point, including the antennas on both the satellites and terminals and the landlines connecting ground stations to terrestrial networks. Cyber attacks can target satellites, ground control stations, and terminals – successfully attacking any one of these segments gives the adversary the chance to launch additional attacks on the other segments through the vulnerability. The effects of a cyber attack on MILSATCOM systems could range from local disruption to whole network disruption and potentially the permanent loss of a satellite. Attribution for a cyber attack can be difficult, if not impossible, because attackers can use a variety of methods to conceal their identity. Cyber attacks range over eavesdropping, denial-of-service, deploying a botnet, spear-phishing, ransomware, man-in-the-middle and spoofing activities, all of which are tactics that are used more generally in our society.

Like physical and electronic attacks, cyber attacks in the space domain are already occurring. In 2009, it was discovered that insurgents in Iraq and Afghanistan had been intercepting video feeds from US Predator unmanned surveillance aircraft after copies of the videos were found on insurgents' laptops. Because the video feeds were transmitted without any protection or encryption, insurgents were able to use commercially available software to intercept the data.[17]

## Budget Environment

A maxim in defence planning is 'the enemy gets a vote', meaning an adversary's decisions will affect your plans. This can be extended to include the acquisition process itself because MILSATCOM systems are just as vulnerable to cost overruns, funding instability and programmatic problems as they are to physical, electronic, and cyber attacks. Any of these can prevent a satellite from getting off the ground.

Budgets have risen and fallen in irregular cycles in response to changes in the political, economic and security environment. As plans for the next generation MILSATCOM architecture get underway, affordability becomes a major concern.

## Key cost drivers
## Space Segment

The main cost components of the space segment are the satellite bus (the platform, ie. the structural frame, propulsion, power, control plus any intersatellite link equipment) and its payload, and the launch vehicles used to orbit them. The cost of the satellites varies significantly depending on the type of system. For communications, in general, the bigger the satellite is the lower is the cost per data bit carried. There is a reduced satellite size needed for assets in low-Earth orbit (around 800 km altitude) compared to geostationary orbit (around 36,000 km altitude) because less power is needed to close the communications link as the satellites are closer. However, large constellations of satellites are needed to enable global coverage from low-Earth orbit.

Launch costs are also an important consideration for MILSATCOM systems. One reason MILSATCOM satellites have typically been large and highly aggregated is that the launch cost per unit mass tends to decline as the mass of the satellite increases.

Protected satellites are more expensive because the satellite bus and payload are more complex and have many unique military requirements. Naturally, the more complex and multifunctional the satellite is, the fewer there are likely to be, so more needs to be done to provide military protection per asset.

## Ground Segment

The MILSATCOM control segment includes ground systems that control the satellite bus and payload.

The total cost of the control and terminal segments is difficult to quantify because the systems are funded through many different sources, some of which overlap with other programme costs. The control segment is typically funded in part through the satellite development program and is often not reported separately. The cost of the terminal segment is more complicated to calculate because the costs are spread across multiple terminal acquisition programs in all branches of the military.

Moreover, the costs of terminal antennas and integration are sometimes funded in whole or in part by the platforms in which these terminals are used.

## Programmatic challenges
## The Vicious Cycle

MILSATCOM acquisitions are complex with long development and production schedules and relatively small procurement quantities. These factors reinforce one another in a 'vicious cycle of space acquisition'. That is, higher costs lead to smaller constellations and longer production times; smaller constellations require more capabilities to be packed into each satellite; and packing more capabilities into each satellite drives up complexity, leading to even higher costs and longer production times.

The key risks for MILSATCOM satellites appear to be programme instability, leading to breaks in production, and unique military requirements on the satellite bus and payload. These risks are detrimentally reinforced by the UK's intermittent approach to MILSATCOM acquisitions – from both a production point of view (which impedes the existence of economies of scale) and from a perishable specialist skill set within buyer and supplier organisations (which affects the ability to specify, buy, design, build and launch into service a military satellite).

## Synchronisation between ground and space programmes

Another programmatic vulnerability for MILSATCOM is synchronisation across the space, control and terminal segments. Synchronisation is the alignment of schedules among interdependent programmes to deliver capabilities efficiently and effectively. This is important in MILSATCOM because all three segments (space, terminal and control) are needed for the system to be operational. Satellites have a finite life on-orbit: fuel is consumed for station-keeping, parts degrade from the harsh environment of space, and technology becomes obsolete with time. When one segment of the overall system is behind schedule due to funding shortfalls or development issues, other segments might be forced to delay their schedules as well.

A further complication is the spread of programmes and associated budgets that fund the three segments of MILSATCOM across the Services. Delays in a satellite programme can cause a ripple effect of delays across the terminal programmes managed separately by different Defence organisations. Likewise, delays in separate terminal programmes could lead to decisions to delay the launch of a satellite, so as not to risk placing an under-utilised asset on orbit.

Satellite programmes are also keenly dependent on other elements of the space enterprise, such as launch vehicles. A delay in the launch segment, whether due to funding, political or technical issues, can have far reaching effects across MILSATCOM acquisition programmes. Because current MILSATCOM architectures rely on a relatively small number of satellites acquired over long periods, a loss of even one satellite on launch could have severe consequences.

## Defensive options for the future MILSATCOM architecture

Improving the defences of MILSATCOM systems makes it harder for an adversary to attack these systems and disrupt or degrade the ability to communicate.

Defences must cover the space, control and terminal segments. Depending on future architecture, a level of launch segment defence may also be necessary. Ultimately, the protection of an overall system is only as strong as its weakest link.

The current MILSATCOM architecture divides systems into protected and not protected, with many of the requirements for protected MILSATCOM focused on the strategic mission. Separating the architecture distinctly along these lines is somewhat arbitrary because protection is not 'all or nothing'. There are varying degrees of protection and different types of protection depending on the threat risks to a system.

To determine how best to improve MILSATCOM defences, four fundamental questions need to be answered:

1) What current and evolving threats does the system need to be defended against;
2) What is the weakest part of the system relative to these threats;
3) What level of protection is enough; and

4) What level of protection is affordable?

There are several approaches that can be adopted in response to protecting space capabilities within the environmental spectrum ranging from benign to contested or even nuclear. We emphasise that no single response will suffice to cover all conditions. Nevertheless, there is an approach that will do much to mitigate the risks present in current programmes.

For our favoured response, we identified a series of primary causes arising from the 'vicious cycle of space acquisition' problem and found five impacts that need to be disrupted.

| Programmatic Vicious Cycle Primary Causes | Impacts & thus Challenges |
|---|---|
| Aggregated Requirements | 1. Aggregated, concentrated architectures |
| Complex & inexecutable baselines | |
| Funding & Requirements instability | 2. Systems vulnerable and not technologically advanced with little ability to deal with changing threat environment. |
| Large, complex, expensive systems with no spares | |
| Long schedules with no risk tolerance | |
| Low risk launch requiring huge, slow review process | 3. High costs of launch. |
| Expensive launches lower launch rates, which drives up costs | |
| Lengthy acquisition approach leads to instability in the industrial supply base | 4. Controls limiting competition & partnering.<br>5. Space capability acquisition mindset shaped by legacy approaches: Top down redesign and re-optimisation for new requirements & hesitancy to use leading edge technologies. |

The challenges can all be addressed by adopting the approach of buying more, and smaller platforms to provide space-based capabilities. The key word is platforms, and not simply satellites. Moreover, each of the primary causes listed will be successfully addressed by the adoption of a 'disaggregation-of-monoliths' approach.

## Resilience and Disaggregation

Our innovative approach in response to a rapidly changing security and fiscal environment is to make MILSATCOM system elements more difficult to threaten or be interfered with by

1) disaggregating capabilities: so multiple missions do not depend on the same satellite constellation; and
2) disaggregating systems: payloads are distributed across a larger number of satellites in different orbital planes.

In a disaggregated architecture, each satellite is smaller and less capable than current

'Battlestar Galacticas', thus individually less expensive. The overall cost of the constellation will still depend on many factors, so would need to be carefully implemented.

This 'disaggregation of monoliths' approach enables threats to be avoided and ensure the survival of critical capabilities despite hostile action. It also creates the capacity to rapidly reconstitute, recover or operate through adverse events should robustness fail.

## Attributes of Disaggregation

Disaggregation is a strategy to affect multiple elements of our overall space architecture. Its purpose is to provide options to drive down cost, increase resilience and distribute capability. It brings other benefits too – allowing systems to be less complex, more maintainable with lower per-unit production costs. An emergent outcome should also be the ability to improve the stability of the industrial base, which is not something that occurred when the current generation of monolithic space systems were fielded.

It is important to observe that, while this paper is focused on the space segment, disaggregation is an enterprise level approach. All connecting nodes, ground systems, command and control and launch vehicle architecture will benefit similarly.

Disaggregation offers an enduring ability to keep pace with advancing technologies, sustainment of the space sector's industrial base, achieving affordability and deterring adversarial action.

## The Payload-Centric Model

One approach to facilitate disaggregation within the space segment is to adopt a payload-centric acquisition model. Rather than designing and building satellites from the top down with a defined set of capabilities, a payload-centric approach would focus on specifying the capabilities of the payload first and then finding a satellite bus to host the payload. Using this approach, the payloads could be designed from the outset to be hosted by a wide range of satellite buses.

It would also separate the procurement of satellite buses from satellite payloads and create greater options for MOD payloads to be hosted on non-MOD satellites.

Hosting MILSATCOM payloads on the satellites of other nations, a dispersal method allowed by disaggregation, could be used to complicate an adversary's calculus. While such an arrangement would require overcoming various political and operational challenges, the potential benefits are high and worth exploring. From the UK allies' perspective, this approach would improve interoperability with the UK military and give them access to a global constellation at a much lower cost than fielding an equivalent capability on their own. From an adversary's perspective, this would greatly complicate planning because an attack on the hosted payload (whether physical, electronic, or cyber) would be an attack on both the

UK and the host nation, creating the risk of horizontal escalation in a crisis. Thus, the approach provides an incentive for good behaviour in space.

## Make Systems Easier to Replace

Another aspect to address the vulnerabilities of MILSATCOM systems is to make the systems easier to replace after an attack. The current space segment architecture is difficult to reconstitute because existing military satellites are large, complex, expensive, and procured over long periods at low production rates. A more easily reconstituted architecture using the approach outlined will result in UK MOD assets that are smaller, less expensive, and procured in larger numbers at a steady production rate.

Obviously, the most basic option is to have spare satellites in storage and ready for launch, but that brings with it the risk of a large logistical infrastructure cost. Two key limitations in this simplistic spare satellite approach are cost and schedule. The spare satellites would have to be sufficiently inexpensive to allow for the procurement of reserves and they would need to be ready for launch within a short timeframe. Even with satellites sitting ready in storage, it would take weeks to months to integrate them with launch vehicles, launch them, and move them to the desired orbit. Right now, the time-to-service for a MILSATCOM space asset from early development is about 14 years.

The options for making systems easier to replace overlap in many ways with the options for disaggregating the architecture. A payload-centric approach makes the system easier to replace. The military could have extra payloads ready to launch on hosts to replace degraded or lost space assets. While the limitations mentioned above still apply, the magnitude of costs and schedule impacts can be mitigated by aligning with the most competitive part of the space enterprise: the commercial satellite bus market. This market has consistently produced satellites in 24 to 36 months at much lower price points than the dedicated MILSATCOM sector. The technology to package militarily useful capabilities small enough to be hosted (or to make use of smaller launch vehicles) has been demonstrated and is publicly documented by the Hosted Payload Alliance.[18] Robust commercial encryption standards and components can be effectively leveraged to define protected communications waveforms, payloads and terminals that are small, less complex and more manageable than current UK MOD systems. In the unprotected realm, commercial wideband communications supporting Remote Piloted Aircraft (RPAs) and Airborne Intelligence, Surveillance and Reconnaissance (AISR) have been in use for over a decade. These capabilities can be secured and packaged as a payload or a dedicated platform, in turn enabling options for both hosted payloads and smaller, less complex satellites. Reducing the complexity of the capabilities provides options to recover terminal programmes that are suffering from slippages.

## Security and Commercial SATCOM

Rather than designing, building, and launching its own unique satellites for unprotected communications, the military can and does lease SATCOM services from commercial providers.

Commercial SATCOM (COMSATCOM) provides several advantages, including no development costs and the flexibility to expand or reduce capacity as needed. COMSATCOM has proven invaluable over the past decade of operations in Iraq and Afghanistan, where front line demand for high-bandwidth applications has grown.

In general, COMSATCOM systems are not designed for a contested communications environment. In the main, they offer no protection from physical attack and will not have any nuclear hardened designs. On the other hand, they do have degrees of protection against electronic and cyber attack as these affect business critical capabilities.

Moreover, security is a highly significant concern for commercial satellites because they can be owned or operated by a foreign entity, may connect to ground stations in foreign countries, and may be used simultaneously by a foreign government or foreign-controlled entities.

We suggest that the security risks can be managed through an 'assured capability' process aligned with explicit recognition of the MILSATCOM mission. 'Assured capability' can be broken down into five steps:

1. Develop the MILSATCOM mission ecosystem taxonomy.
2. Risk assess each element of the ecosystem.
3. Determine the acceptable level of risk for each element.
4. Identify the level of assurance below which the MOD is not prepared to tolerate compromise of the mission capability, even in the face of mitigation activities.
5. Specify and audit assurance requirements, informed by a framework of assurance categories.

## Changing our acquisition approach

To effectively and efficiently implement a distributed architectural strategy, the UK's military space acquisition strategies will have to change. Designing and procuring satellite capabilities to optimised top-down requirements will not be compatible with the highly interchangeable and interoperable view that we recommend. Uniquely designed and manufactured components must be dispensed with as much as possible; a more flexible model of commoditised capabilities and making use of economies of scale should be the concept for the next generation architecture.

We should consider a wholesale focus shift of current UK MOD space system development efforts towards mission payloads. By designing a payload to provide the core capability needed by force elements, supported by commercial buses, the ability to make use of both the commercial bus market and hosted payload, opportunities blossom. Acquiring the mission payloads as the core element of a mission-domain architecture allows a product to be created with the ability to fly on either a dedicated bus or as a hosted payload with minimal changes to the production baseline.

This focus shift allows for a mirroring of commercial practices such as competition for satellite bus procurement. Hosting payloads need not be, and should not be, a bespoke exercise requiring heroic efforts to gain approvals, modify products and meet schedules. It should be an inherent part of the national defence strategy to deploy capabilities in orbit. Adjustments to make use of hosting opportunities can be made by matching the timing of payload production with the host satellite assembly, integration and verification (AIV) schedule.

By tailoring the amount of capability that goes into a single payload, additional opportunities are created to synchronise the space and ground segment strategies. More payloads mean that terminals can be uplifted at a more regular drumbeat than the present once-every-15 years, giving opportunities to insert new technologies in a predictable fashion. A direct comparison between this proposed approach and that of commercial mobile telephony can be made to further understand and quantify the benefits.

## Conclusion

Disaggregation, coupled with host satellite partnering at an allied nation or commercial company level, will allow the UK MOD to realise a more affordable and resilient set of capabilities for defence force elements. The involvement of commercial companies can be managed by providing a strong assurance wrapper to ensure the security of capabilities. By disaggregating battlespace awareness and other tactical MILSATCOM missions from core nuclear-hardened, strategic capabilities through a payload-focused acquisition strategy:

- Complexity and cost are reduced, allowing more predictable, controllable and executable programme baselines;
- Requirements are stabilised by creating a process for capability insertion;
- Operational and economic consequences of vehicle loss are reduced;
- A regular and shorter replenishment cycle is established;
- More launch and deployment opportunities are generated; and
- Any adversary's calculus with A2/AD actions are complicated, if not undermined, in any conflict.

We end with a comparison note: the precedent has already been set with both Galileo and GPS II (and III) GNSS systems. These are distributed, disaggregated assemblies of individual payloads. Taken together, the components form a robust, affordable and resilient architecture which has an established production line permitting routine insertions of new technology.

The UK has a need and an opportunity to seek affordable, resilient, survivable space capabilities in ways which keep up with the incredible pace of technological change and adapt in the face of evolving threats. Equally, a strong supply base which offers buyer choice and vendor competition is essential to control costs while protecting perishable skills and specialised logistics.

The mission-led, payload-centric disaggregation strategy that we are proposing can achieve all these aims – the time is ripe to harness this vision.

## Acknowledgements

With sincere thanks and acknowledgements to colleagues for their valued inputs:
Harpal Singh*, James Bates*, Andrew Creber*, Nick Newman*, Peter Dingley#
Andrew Parsons## [*PA Consulting (https://www.paconsulting.com/); #PDRF Ltd, ##SVGC Ltd].

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Viewpoint

# The Normalisation of Anti-Satellite Capabilities

By Alexandra Stickings

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## Introduction

**The 2007 destruction by China of one of its own defunct weather satellites brought to the fore discussions about the dangers of anti-satellite (ASAT) weapons,[1] recently fueled following the test by India in March 2019, in which it also destroyed one of its own satellites.[2] Although both the United States and Russia (both at present and during the Cold War) have long-established research and development (R&D) programmes for ASAT technology, the entrance of a new actor, and one with well-publicised space ambitions, into this small group caused global concern.[3] As well as creating a significant amount of debris, a potential danger to all satellites, China's test was seen in many quarters as an overt demonstration intended to signal capability to destroy a satellite belonging to an adversary. India's test was similarly seen as a demonstration of capabilities, and although it also created significant debris, it was not met with such a strong reaction within the international community.**

Such ASAT capability is, at present, primarily limited to these three major space powers – the United States, Russia and China – with India still not considered to be a major space power, albeit with ASAT capability. Traditionally, ASAT technology involved direct-ascent missiles used to destroy a satellite kinetically – it was this method used in the 2007 test. Yet states have recognised that other methods make proving attribution in space is difficult. There has therefore been a move towards the development of non-kinetic capabilities that can disrupt or disable a satellite while leaving it physically intact. This not only negates the resulting debris creation of a kinetic strike but also allows the operators of such platforms to function beneath a retaliatory threshold. Such capabilities include lasers that can be used to dazzle optical sensors and the use of microwave frequencies to interfere with electronic circuitry. Similarly, recent years have seen the development and trial of technologies to remove debris from orbit, and commercial companies are looking to exploit the benefits of on-orbit servicing, where satellites are used to fix or extend the life of others. While these will be developed with the primary purpose of ensuring the sustainability of orbit, they could potentially be used to damage or remove from orbit satellites belonging to another actor.

As a result, the democratisation of space and the proliferation of technology is increasing the number of actors who could potentially develop or acquire ASAT capability, whether purely as an offensive means or of a dual-use nature that could be used for adversarial purposes. Yet with the focus, particularly in the United States, on the activities of the Russian and Chinese space programmes and the potential dangers therein, there is little evidence that Western militaries have looked at the possibility of other actors, including rogue states and terrorist groups, of acquiring these capabilities. The purpose of this viewpoint is to assess the various types of ASAT capability within the context of the changing space environment and attempt to answer the question of whether this is leading to what may be termed the normalisation of ASAT capability, and, further, how this may affect the strategic balance in space.

## A brief history of ASAT Capabilities

The concept of ASAT capabilities goes back to the beginning of the first Space Age. Both the US and Soviet Union, fearing the actions of the other and the potential strategic advantage of orbiting satellites and space-based nuclear weapons, began researching and developing methods to destroy satellites. Indeed, as early as 1957 the US Army had proposed converting an anti-ballistic missile into an ASAT weapon,[4] and by the 1960s the Soviets had developed the Istrebital Sputnikov (IS) co-orbital system consisting of a launch vehicle and a kill vehicle.[5]

As a result of the technologies available at the time, ASAT capabilities initially were limited to kinetic missiles, either ground- or air-launched or co-orbital. There is an obvious drawback to kinetic attacks, however, and that is the creation of space debris. It is estimated that the 2007 Chinese demonstration created an additional 3,000 pieces of debris in Low Earth Orbit (LEO).[6] The Indian test, carried out at an altitude of 282 kilometres in part to minimise debris, (in comparison to the 865 km of the Chinese test), nevertheless created approximately 400 pieces of debris reaching as high as 2,222 km; some of which is estimated to remain in orbit for one to two years.[7] Such debris is an equal danger to all satellites within a particular orbit, regardless of ownership. Any state or commercial operator that wants to benefit fully from the opportunities that space presents will have a desire to protect the sustainability of orbits through the minimisation of debris and avoid contributing to what could become a worst-case scenario – the Kessler syndrome, in which orbital debris creates a cascade of further collisions, leading to the orbit becoming unusable.[8]

Yet there is a further drawback to kinetic strike that is more closely related to how states view the role of space in military matters. Space is a unique environment, and its relative inaccessibility and remoteness mean that attribution to some activities can be difficult to prove. It is clear that if a state were to use a direct-ascent or other kinetic ASAT missile to destroy another's satellite there would be little hiding place. Retaliation would be expected, as would international condemnation and accusations of 'weaponising' or even starting a new conflict in space. However, if a satellite simply stops functioning, it is not always possible to determine the reason, let alone discover the responsible actor even if there is sufficient evidence to suspect a deliberate action rather than a natural hazard. There has consequently been a move towards the development of non-kinetic counter-space capabilities which exploit technologies that allow for a satellite to be disabled (either permanently or temporarily) or its communications disrupted while leaving it physically intact. These capabilities include lasers that can be used to dazzle optical sensors, the use of high-powered microwave frequencies to damage electrical components, cyber-attacks and the jamming of frequencies. Despite its public ASAT missile test, evidence suggests that it is this area in which China is focusing its efforts.[9]

There are many benefits to states in developing these non-kinetic methods, particularly in terms of desires to deny adversaries' access to their satellites. The potential ability to interfere with a satellite with little to no risk of getting caught but with the opportunity to cause a significant amount of trouble allows states to operate in what is often known as 'grey zone' or 'sub-threshold' warfare.[10] This type of warfare is associated with destabilisation of a state through affecting its critical infrastructure or political processes and is achieved by operating beneath the level of actual conflict. It is these methods that also lead to the use of the term 'counter-space', where, in addition to ASAT activities, they also affect the usage of space and the information that is derived from it.

The way that these capabilities are used also brings into question the definition of a 'weapon' in space. It has often been said that in space, anything can be a weapon. Although this phrase has become somewhat overused, there is a ring of truth to it. It is because of this that when compiling a list of all types of ASAT capability, it is important to include those technologies that have dual-use applications. Many actors, including states and commercial companies, have recognised the dangers of orbital pollution and have been working on technologies to remove debris and repair and extend the lives of satellites through on-orbit servicing.[11] These are, of course, beneficial in nature but do provide operators the capability of acting in an adversarial manner. For example, a satellite that can manoeuvre to a defunct satellite or piece of space debris, attach to it and drag it into the atmosphere to burn it up could also do the same to a functioning satellite. Similarly, satellites with the same manoeuvring capability that are intended to repair or refuel satellites can equally use their abilities to break one. It is because of this that there has recently been much worry over the proliferation of these developments.[12]

The rendezvous and proximity operations (RPO) that these programmes use have been seen in other ways. In August 2018, a US government representative highlighted concerns over the 'abnormal' behaviour of a Russian satellite.[13] Such manoeuvring capabilities could, as well as the uses described above, allow satellites to approach others with the intention of jamming or intercepting their communications, disrupting their abilities and performing surveillance.

It is clear, then, that the nature of ASAT capabilities is diversifying and adding confusion and complexity to what is already a complicated topic. The three major space powers are seeing these developments as potentially threatening the already precarious strategic balance in space. However, it is important also to note that this diversification of ASAT capabilities may also lead to their acquisition by additional actors. The question, therefore, will be what impact this will have on international space security.

## New Actors, New Threats?

As has been noted, ASAT capabilities are primarily associated with the three major space powers. There is potential, however, for others to develop in this area. India, for example, has decades of experience in space, and although this has been for civilian purposes, this could potentially be repurposed for ASAT capabilities.[14] The nascent space programmes of Iran[15] and

North Korea[16] have also been under the microscope in recent years, particularly because of the technical crossover with ballistic missiles. Should these states prove capable of developing fully functioning counter-space programmes, this will have a significant effect upon the balance of power in space as well as on considerations regarding terrestrial relationships. The ubiquity of space support to military operations is leading other states to create sovereign capabilities, even if these are limited at present. More and more countries are developing national space programmes and will be looking to ensure their assets are protected, including some sort of counter-space capabilities if they feel under threat.

It is important to think about why these states would look to develop such programmes. With smaller military budgets, and consequently less funding for space programmes, one might think that available resources would be best placed being spent on programmes that reap the benefits of space, both in terms of information and possible economic gains. This is not to say that such programmes are not going ahead. Smaller states see great advantage in becoming space actors and becoming part of this new, more democratic space; there is a fear, in part, of being left behind and missing out on the benefits. There is also the issue of national pride, with recognition of how the 1969 Moon landing by the United States made it the true leader in space. As such, many countries without indigenous space programmes are procuring satellites from others or joining international partnerships. For example, a number of Latin American countries now have satellites in orbit through partnerships with China.[17]

Of course, any space activity is also a demonstration of technological capability. This indeed can be seen as one of the reasons there was such a strong international coverage of the January 2019 landing by China of a rover on the far side of the Moon.[18] Although presented as a mission principally concerned with exploration and scientific advancement, it also led to claims that China was now at the forefront of a new 'Space Race' and had become the dominant country in space.[19] Interestingly, while indeed an impressive feat, the reaction far outweighed those associated with the European Space Agency-led mission that successfully landed on a comet in 2014[20] or the more recent Japanese mission to an asteroid,[21] both of which were covered primarily in the science sections of media outlets. Neither of these provoked commentary of space dominance or military space capabilities, which seems in the West to be reserved for countries considered to be adversaries. The success of the Chinese mission has had an impact on space defence discussions and it is likely that similar will happen with the future activities of others who are deemed to potentially pose a threat through their space activities.

There is, of course, nothing definite that more states will actively pursue ASAT or counter-space programmes. They will need to balance these activities with their more general space ambitions. However, their increasing usage of space for military and national security and ability to gain technical knowledge through international partnerships does raise the possibility that such capabilities could proliferate.

Of course, it is not just states that should be of concern when thinking of the proliferation of ASAT capabilities. Non-state actors have already thought to have been involved in cyber-attacks against US satellites.[22] These, however, are likely linked to states. What may be more worrying is non-state actors with no links to countries and more importantly with no space assets of their own to protect. Despite the differences in national regulatory frameworks, it would be nearly impossible for such a group to operate its own satellite. They would therefore be most likely focused on cyber-attacks or attacks against ground stations.

## The International Legal Framework

Any concerns with the proliferation of ASAT capabilities need to be looked at within the international legal framework for space. The 1967 Outer Space Treaty (OST)[23] is the bedrock upon which international space law sits, with perhaps its most well-known proclamation being the ban on placing weapons of mass destruction (WMD) in orbit, specifically nuclear weapons. However, the OST is also a creature of its time. Created during the Cold War, when the fear of nuclear weapon proliferation and use was at its height, it was written at a time before technologies such as RPO and debris removal were thought of, not to mention cyber. It is therefore determined to be limited in its ability to prevent states from developing and deploying new technologies that could threaten satellites, and as such there have been calls to update, replace or add to the treaty to ensure that 'weaponisation' of space does not occur.[24] It is interesting, however, that those pushing for new treaties, laws or regulations are also those who are most associated with possessing ASAT capabilities. Russia and China have together proposed language for a new treaty through the discussion on Preventing an Arms Race in Outer Space (PAROS) negotiations, a move not supported by the US.[25] It can be argued that because the OST does not take into account new technologies, it provides cover for states who want to develop ASAT capabilities without fear of sanction or other punishment.

It has been argued in some quarters that should there be no agreement on a new treaty it would be possible to turn to customary international law (CIL) to impede the development of ASAT capabilities and ensure space security.[26] For example, the international laws of conflict and international environmental law may be useful when considering kinetic strikes and the creation of space debris, respectively. While this does provide another option to the international community it may be limited in the case of non-kinetic attack when attribution is not easily identified. Discussions are therefore occurring in some parts that look at creating a set of norms of behaviour for states to follow that would include the development and use of technologies with ASAT potential. The difficulties, of course, are in developing language that covers the current situation as well as future potentialities and ensuring that the norms are adopted by all (or even most) space users. Any new language must also take into account that ASAT capabilities may be developed by additional actors who may see norms as stifling their ambitions.

While there is no doubt benefit associated with the development of new treaties, agreements and norms regarding activities in space, the possibility of covering all eventualities and finding a way to limit ASAT capabilities of proliferating both technologically and in terms of number of users is slim. It may be that a better path is to accept that ASAT capabilities will become normalised and instead develop language that covers their use, both in limiting that use and in what those users can expect in terms of reaction.

## Conclusion

The security and sustainability of space is currently finely balanced upon the actions of the three Tier 1 space powers. The common pronouncement that space will play a central role in the next Great Power conflict[27] means that the focus when considering space and military activity continues to be on the activities and capabilities of the United States, Russia and China and the extent to which they are provoked by each other's activities. Yet, as has been shown, notwithstanding the hazards such as debris and space weather, the threats to satellites are diversifying, as are the actors who may eventually possess these capabilities. It is therefore essential that states take these potential eventualities into consideration when creating space policies and looking at the protection of their space assets.

There is another consideration, however. The current international legal framework moves towards the creation and implementation of norms for responsible behaviour,[28] as well as the proliferation of dual-use technologies and the vulnerabilities of space systems to other forms of attack, suggest that finding a way to fully account for all ASAT capabilities will be practically impossible. This is also because some actors with ASAT capabilities will not be operating within the international framework and either unwilling or unable to become parties to treaties or other agreements.

It can therefore be concluded that the near-term will see a normalisation of ASAT capabilities, where such technologies are able to be developed or acquired by a range of actors. The question is what Western militaries need to do to counter these potential threats and ensure their continued access to space. The first step could be to accept that this will happen regardless and that there is little chance of creating a situation where ASAT capabilities are limited to a few states and if used, within the construct of Great Power competition. It is likely that space systems will more frequently come under attack from a range of actors whose motivations will be more varied. Protecting existing assets and ensuring continued access should therefore be the primary goal with regard to space, but the West should also use this as an opportunity to think carefully about its relationship with the space environment. The normalisation of ASAT capabilities means that space cannot be seen as a sanctuary, if, indeed it ever was – one must not forget that the first ventures into space were driven by military competition and as such space has since been a militarised environment. Countries can no longer expect to be immune from attacks against their space infrastructure. These additional vulnerabilities and associated costs suggest that more is needed to diversify the infrastructure and ensure that reliance on space is matched by resilience and mitigation. As ASAT capabilities normalise, the balance of power in space will likely shift. It is essential that space strategies are shifted to match this new paradigm.

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ROYAL AIR FORCE
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# Putting AI into Air: What is Artificial Intelligence and What it Might Mean for the Air Environment

By Squadron Leader James Waller and Dr Phillip Morgan

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**Abstract:** Artificial Intelligence (AI) is heralded by some as the next Revolution in Military Affairs (RMA), a technology with the potential to offer decisive strategic advantage and revolutionise military tactics and force structures. Development of AI within the commercial sector continues at a galloping and, in some ways, alarming pace, and the academic community[1] has begun to consider the role AI could play within Air Power. This article begins with a brief history of AI, discussing some recent developments in the field and highlighting why there is currently so much excitement around the subject. We also discuss how our understanding of human sensory and cognitive processing limitations advocate a strong need for AI in the form of augmentation and decision support systems in several settings, whilst highlighting unique human abilities to adapt to and process information in different ways (that an AI currently cannot achieve). Based upon the areas where we believe AI will offer an edge to a human operator in the future, we propose a framework for assessing the key attributes of AI and discuss some of the implications for air warfare in the future.

## Introduction

*We can only see a short distance ahead, but we can see plenty there that needs to be done.* [2]

Alan Turing wrote those words nearly 70 years ago, and yet they remain as prescient in 2019 as they did in 1949, perhaps more so. Within the subject of Computer Science, Turing is renowned for his eponymous 'Turing Test', where he first famously asked the question 'Can Machines Think?' and founded the discipline that is known today as Artificial Intelligence (AI).

Turing is also famed for his work at Britain's Second World War code-breaking centre at Bletchley Park and the contribution it made to the outcome of the War. Many consider that AI will have a comparable revolutionary effect on the future of warfighting, so much so that US policymakers have previously decreed that AI will form the bedrock of a '3rd offset'[3] strategy, insisting that AI is a technology with the potential to offer such decisive strategic advantage to its possessor that it could 'offset' the balance of power.[4] This momentum appears to be building: Artificial Intelligence appears over 60 times within the UK Ministry of Defence's analysis of global strategic trends[5] and is firmly considered one of 2019's key 'tech trends'.[6] It goes without saying that it is highly relevant to air power too: the US Air Force has announced that it will invest $100M in AI technology.[7]

Technology has always had a profound impact on the way in which wars are fought. However, it remains a truism that innovation is not confined to the technology alone, and current MOD thinking is clear that the innovation should not just be confined to the technology itself, but in how emerging technology is employed on the battlefield.[8] This is an idea neatly summarised within the introduction of the UK MOD Joint Concept Note[9] on Human/Machine Teaming:

> The winner of the robotics revolution will not be who develops this technology first or even who has the best technology, but who figures out how to best use it. [10]

'Figuring out how best to use AI' is at the heart of this article which is structured in two sections.

The first section will start with a discussion on the concept of AI, with a brief look at some key ideas and recent developments to establish what is and isn't hyperbole, but more importantly it will explain why AI is so important now. Using the examples of computer mastery of chess and language translation the article will illustrate how much the field of AI has achieved and how it is likely to be employed within the air domain. This section will conclude by recognising that AI is likely to complement human activity posing the question: 'What will a human be able to do better in the air war of the future?' The second section of the article will then examine what this means. By considering the likely limitations of the human brain and cognition, we will propose that AI possesses three core, interlinked, attributes which make its employment within air power desirable. These attributes are speed of cognition, ability to process large volumes of information, and ability to access physical spaces which are impossible for a human. The article will examine each of these attributes in turn and highlight possible implications for the air environment.

## AI: A brief history and why the excitement now?

It is worth stating from the outset that this article is not about AI taking over the world, nor does it suggest that computers could immediately gain sentience and possess a decisive strategic advantage over humanity, a proposal which actually can be traced back to Alan Turing.[11] The phrase 'intelligence explosion'[12] has been coined to reflect Turing's original idea that once computers achieve a certain level of intelligence they will simply be able to redesign themselves iteratively, quickly surpassing any level of intelligence achievable by a human, referred to as Artificial General Intelligence (AGI).[13] There is credible academic literature which explores this fascinating idea,[14] however this article will not do so for two fundamental reasons. First, if humanity does develop AGI, it would be such a significant development that it could revolutionise virtually every aspect of life, not just warfighting. Debate on how this could affect air power would probably be low on humanity's priority list! Secondly, and more importantly, however, the academic community is divided on how 'soon' we will achieve AGI, though the broad consensus appears to be that it will take at least decades rather than years.[15] Instead this article focuses on the types of cognitive tasks within the air environment where AI is likely to perform as well as (or better than) a human in the near future.

The other significant area this article will not explore in detail is the ethical dimension of employing AI in warfighting, though it will recognise that this is a hugely important subject.[16] The reasons for this are twofold: first, like many novel technologies, there will always be the less scrupulous adversary who will employ the technology without regard to ethics. Secondly, many of the developments in AI are being pioneered by sectors outside of the defence industry; we will increasingly see AI technology being developed for one purpose not associated with Defence which will subsequently be employed for warfighting.[17] Therefore, regardless of ethical stance, it is important to consider the possibilities that AI could bring to air power. This article aims to explore the potential for AI to be employed in the air environment, agnostic of the ethical debate, though by doing so hopes to better inform it.

So, what can AI do now and what is it likely to be able to do within the next 10 years? To answer these questions, it is worth considering that, over the course of its short history (and like many novel technologies), the field of AI has been beset with 'overpromising and underdelivering' with several false starts, leading to 'AI Winters'.[18] A general theme is that computers are becoming increasingly proficient at activities provided they remain 'narrow', compared with humans who, despite numerous limitations (see examples later in this article), can process wider sets of tasks and are far more adaptable. For example, there have been significant developments in creating a machine which is comparable to a human in language translation or chess; however, at this time, there is not a machine that can do as well as a human at both. Humanity still retains 'general' intelligence i.e. a human can master both chess and language translation[19] or indeed any combination of other complex tasks. The crucial advantage a human possesses is that they can more readily be adapted to any complex tasks requiring a high level of cognition without requiring the level of extensive rebuilding and reprogramming in the way a computer currently requires.

However, this crucial distinction is changing, and a fundamental reason for this is that advances in hardware are now allowing AI programmers to experiment with AI techniques which previously were impractical due to hardware limitations. In spite of several research attempts to produce AI-capable hardware in the last century, it was ironically the video game market which aided this breakthrough.[20] During the early part of this millennium, market forces reduced the cost of multi-processor graphics cards known as Graphics Processing Units (GPUs) to support gaming. However, as a fringe benefit, GPUs are also well-suited to implementing some particular advanced types of Artificial Neural Networks, which had been previously just theoretical possibilities.[21]

An Artificial Neural Network mimics the human brain and, in its most basic form, consists of several processing elements (neurons) which have links between each other (synapses). The route from input through to output is referred to as a 'path'. When solving a problem, a neural network will process input data through possible 'paths' and if this produces a desirable output then the neural network will favour that path in the future, a system known as 'credit assignment'. Taking the analogy of the human brain, this could be considered learning.

Advances in machine learning are well demonstrated by the computer mastery of chess. A significant milestone was achieved in 1997 when IBM's Deep Blue beat the world champion Gary Kasparov,[22] considered by many to be a major development of AI. Some even considered it proof that a machine could pass the Turing Test.[23] Deep Blue was able to examine 200 million moves in a second, so, for each move, was comparing the positions on the board with a repository containing virtually every chess game and strategy played by every grandmaster through history. Playing Deep Blue at chess was akin to playing a human who, at the start of their turn, could stop time, and then take as long as they needed to consider their next move against the collective wealth of humanity's chess playing experience. Yet even some of the developers of Deep Blue did not consider their machine to be 'intelligent'.[24] Deep Blue was an example of a 'brute force' approach to AI, also known as 'Good Old-Fashioned AI' (GOFAI). The computer was not *thinking* about its next move; it was simply consulting an (admittedly vast) checklist for each move it made. Arguably the 'intelligent thought' was still being applied by the human programmers of Deep Blue, some of whom were chess grandmasters themselves.[25] Essentially Deep Blue had been programmed in advance with a playbook that could anticipate every move that its opponent could make.

Therefore, in this context, a much more significant milestone was reached when, in 2017 Google's Deepmind programme beat Stockfish, the 'reigning champion computer' at chess.[26]

Stockfish used AI technology which was fundamentally the same as that which Deep Blue used to beat Kasparov, a GOFAI style approach. However, Google's Deepmind had no prior knowledge of chess. Using its advanced neural network, it played millions of games against itself to 'learn' to play the game to expert standard in just 4 hours! It then proceeded to beat Stockfish. This was hugely significant. Up to that point, a computer could only beat a human by recalling so much data, and simulating permutations so quickly, that no real cognition was taking place. Google's Deepmind proved that, if a clear end state can be defined (in this case winning at chess), a computer can independently and quickly develop knowledge in a previously unknown subject area which can 'surpass not only one human, **but the collective wisdom of humanity**. In the case of this example, hundreds of years of human experience in playing chess was outmatched by Deepmind in four hours!'.[27]

We are now increasingly seeing the results of such advanced AI techniques in the field of language translation, and the developments in this field have introduced an additional nuance, which is that, increasingly, humans and computers will offer different and complementary abilities to solve complex problems; neither will be 'better' than the other. It is fair to say that currently *Google Translate* is more proficient than the average human with no linguistic ability at translating between languages. This is especially true if we consider a human versus a machine in a contest of learning two languages from scratch and then translating between them. Where many humans still retain the edge is when complex language and nuance must be interpreted perfectly by expertly trained analysts. However, the adage: 'good enough today rather than perfect tomorrow' often applies in warfare,[28] in this example AI could provide a complementary aid to linguists to provide a quick 'sense' of what is being said in an unfamiliar language, perhaps where slang or unknown dialect is used, potentially spotting patterns and linkages that a human mind may miss.

In a similar manner to learning chess, the AI agent behind Google Translate has 'learnt' to solve the problem of language translation by developing its own 'language'.[29] This 'language' is unintelligible to a human and is essentially a computational representation of the fundamental syntax of human speech, agnostic of native language. Google Translate's AI engine has done so largely independently of human input, and in doing so has devised a unique and efficient method of translating languages.

It is both fascinating and alarming that AI is developing to the point where it can solve problems completely independently and with apparently unique and innovative ideas, some of which are beyond the reach of a human mind. This is especially the case with a variant of Neural Networks called Genetic Algorithms, which solve problems by 'competing' different solutions to a problem in a manner reminiscent of natural selection. Genetic algorithms can produce creative solutions to a problem which may not be immediately apparent or even unimaginable. An example of this is 'Hackrod': a racing car chassis designed by AI which combines the optimum balance of tensile strength, aerodynamic performance and weight, acknowledged to be a better design than any professionally trained human engineer could have created.[30]

The above examples show that AI clearly is becoming more proficient at tasks which used to be the sole domain of humans, either as a direct replacement or in providing complementary abilities. Therefore, we must start asking: What are those things that 'only a human can do?', but set against the context of the previously mentioned 'false starts' within the field of AI, and the tendency for pessimists in AI technology to move the goalpost of what constitutes a breakthrough. Forty years ago, the academic community felt that once a computer could beat a human at chess, we would have achieved AI.[31] However, this has now easily been surpassed. Similarly, language translation was seen as a bulwark of human ability, yet arguably AI is now superior in some regards. Therefore, to understand how AI will be used in the air war of the near future, we will need to consider some of the limitations of the human brain where AI is likely to add significant value.

## What does AI mean for the Air War?

The previous section has made clear that AI will not just give an advantage, but could become essential, either as a complete substitute or a subordinate to a human operator. But where might this be the case? Consider the following idea that compares humans against AI:

> On the other hand, [AI controlled devices] rely largely on pre-existing models and algorithms (although a degree of learning will be expected), and are less likely to show creativity, to detect unconventional opportunity in data collection, or data relevance, or a clever deception hidden in the data. [32]

Humans may continue to outmatch AI, certainly in the near future, within aspects of warfighting that require unconventional or creative thought. Where AI could add value in a complementary fashion alongside a human, is likely to be in areas such as augmentation and decision support. This article proposes that AI possesses three core attributes which make its employment in the air environment desirable:

- **Cognitive Speed (Speed)**: AI has the potential to process and respond to events far quicker than the human cognitive cycle can. Take the example of visual attention. When performing optimally, humans are capable of perceiving gist of scene within 20-ms at the neuronal level and the presence of a specific object within 150-ms, despite subsequent motor actions often taking longer.[33] Despite this, human perceptual and attention ability and accuracy can easily be degraded by, for example, increasing the number of distractor items in a visual scene,[34] increasing the presentation rate and decreasing the relative positioning of target events (attentional blink phenomenon).[35] Humans are also susceptible to failing to notice changes in scenes that occur within fairly rapid time delays (change blindness phenomenon)[36] and especially when cognitive processing is constrained and/or when changes are not expected. Thus, as AI becomes capable of handling more complex tasks at millisecond speeds, this could become a battle winning attribute.

- **Ability to process large volumes of information (Volume)**: Only hardware limits the amount of information an artificially intelligent agent can process. In comparison, there is a limit to the amount of information a human brain can process. For example, the classic view of short-term memory is that it can hold 7±2 items[37] for not much longer than 1/3 of a minute, and possibly less if rehearsal is limited, e.g., by interference from other tasks and/or items,[38] although, remembering information over the short (and sometimes subsequently longer) term can be improved through, for example, processing items to a deeper (and more meaningful) degree.[39] There is also evidence to suggest that short-term memory is adaptive, in that items will decay at a different rate depending on the rate of memory updating required due to factors such as the number and rate of distractor items.[40] An extremely important point here is that whilst human information processing abilities such as short-term memory are limited, the human brain is still incredibly impressive at processing particular types of information in a range of ways, and can adapt to task and environmental constraints.[41] At earlier sensory perceptual stages of processing, the retina can transmit up to ten million bits per second into the visual cortex of the brain, which even advanced AI struggles to match in terms of pattern recognition.[42] The key to leveraging this attribute, as previously highlighted, will be using AI in a complementary fashion to humans.

- **Access to physical space for making a decision (Access)**: Perhaps most prevalent in warfare, it may be impossible or too dangerous for a human to achieve the necessary access to the location where cognition is required.[43] This access could be physical or electronic; for example, while communications technology continues to advance, so do methods of intercepting or jamming communications. Furthermore, in the future we may not wish to place a human in the loop with recent evidence pointing to marked susceptibly of humans in detecting malevolent cues in computer communications masquerading as genuine computer updates.[44, 45]

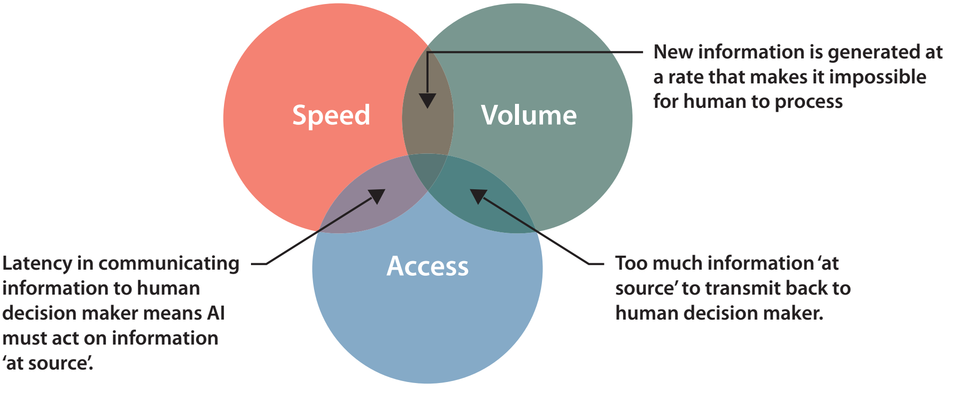


Figure 1: Interaction between Speed, Volume and Access for informing decisions.

All three of these issues could make a case for AI to be employed together with, or instead of a human. Furthermore, they all interlink in a complementary fashion. Practically, where two of the three factors apply this will further make the case *for* employing AI as part of the decision-making process. *Figure 1* illustrates this concept with concentric rings which represent the three proposed reasons for using AI. The areas of overlap present the secondary cases, which are:

- The speed at which new information is generated means the volume is too great for a human to process, or a large volume of information suddenly becomes available and cannot be processed quickly enough by a human to act upon.[46]

- The volume of information generated at the point of physical access is so great that it cannot be transmitted back to a human operator to act upon.[47]

- The transmission time itself from a point of physical access is large enough that it would affect the ability to make a timely decision.

As previously discussed, AI's effectiveness in solving problems diminishes when the problem 'broadens'. Current AI technology is particularly effective if the input variables can be limited and the problem defined in a series of 'values'. This is particularly relevant to air power as it has been suggested that within the air domain there is less complexity in the number of variables. Put simply 'air platforms do not have to dodge potholes in the ground'.[48] Air is likely to be an early adopter of AI technology, and a proving ground for innovative ideas. Consider some of the proposed attributes of AI and how they could affect air power in the next ten years.

## Speed

Speed is an attribute of air power and enables the commander to control the tempo of the battle.[49] It is highly likely that AI will accelerate the speed of air warfare in the future and its use will potentially provide 'decision superiority' to commanders, should it be adopted correctly. This effect will be felt all the way from tactical control of aircraft through to the speed of operational and strategic decision making.[50]

AI taking tactical control of aircraft could be a consideration in the near future. In limited test cases, artificially intelligent autopilots have outperformed human pilots in air-to-air combat[51] and AI enabled, neural network-based autopilots are gaining 'superhuman' abilities for things typically considered the preserve of highly experienced pilots, such as judging landing speed.[52] AI's ability to process and act on multiple sources of information faster than a human are only likely to continue this trend, to the point where it may become, at best, an unnecessary extravagance to retain a human in the loop and, at worst, completely negligent to not allow AI to take over a manned aircraft to perform evasive manoeuvres and save the crew onboard, especially if fighting adversary air forces equipped with AI controlled aircraft.

However, perhaps more concerning will be the effect AI could have on decision cycles for entire aerial battles. To use an analogy based on the previous example, if air-to-air combat can be considered as a game of chess, with a series of defined inputs (i.e. sensor and position data of all aircraft) and desired end state (e.g. zero friendly force kills), then one could argue it is only a matter of time before AI will be better equipped to command and control a fast-paced aerial battle. Consider this alongside the fact that a computer could communicate with an aircraft electronically in an extremely precise manner. There would be no requirement to translate instructions or explain intent; an air force under the control of an artificially intelligent commander would possess a cognitive advantage over an adversary, moving and coordinating as a unified body in a way which would be virtually impossible for its human equivalent, as put succinctly by Scharre:

> forces [will] shift from fighting as a network to fighting as a swarm, with large numbers of highly autonomous uninhabited systems coordinating their actions on the battlefield. This will enable greater mass, coordination, intelligence and speed than would be possible with networks of human-inhabited or even remotely controlled uninhabited systems.[53]

In the first instance this is likely to be a continuum. Initially we are likely to see 'loyal wingmen': AI controlled aircraft which follow a human pilot. This could then evolve to 'flocking' whereby a command aircraft could be followed by a series of AI controlled aircraft, retaining the ability to intervene and control distinct elements of the formation. Finally, we may see 'swarming' where AI controls a fleet of air vehicles and a human can only control the group in aggregate, not individual elements.[54]

## Volume

AI has an ability not only to cope with large volumes of information, which interlinks with the idea that it can improve cognitive speed, but will also enable correlation of data between vastly different raw formats in ways which would be impossible for the human mind. Recall the way in which Google Translate has developed its own 'language'. Now consider the application of this in the field of hyperspectral imaging, a technique which allows a machine to 'see' in both the visible and infra-red ranges of the electromagnetic spectrum and already has proven military application, for example, in discriminating different types of materials and thereby spotting camouflaged military units.[55] An artificially intelligent agent could easily compare and contrast data from a variety of hyperspectral electromagnetic sources, using neural networks to 'learn' what constitutes an enemy aircraft and communicating with other AI enabled analysis platforms using its own 'base language'. A likely subsequent trajectory will be that such AI will be developed to solve the same problems, but with less source data, or against more ambiguity.[56] The key implication for air forces will be that human operators will need to work in a complementary fashion with such AI, ensuring they understand how it works, and crucially where they can add unique value. In much the same way as the previous example, moving from loyal wingmen to swarming. We are also likely to see a continuum of AI being deployed to analyse data. Consider the idea that the future data analyst of tomorrow may spend less time analysing data themselves, and more time training and developing their 'subordinate' AI to do so.

## Access

The final idea is that AI will be able to 'access' locations which a human cannot, and this idea is extremely important as, unlike the other examples it necessitates the deployment of AI, as opposed to being desirable. There are a variety of reasons for AI being preferable to a human operator. Risk is the obvious one within warfighting, but in the future other factors such as physical size may come into play. It may be that battle-winning advantage comes from deployment of aircraft which are simply too small to have a human operator onboard. An obvious point here is that the air war has already begun to encompass this type of technology in the form of Remotely Piloted Air Systems (RPAS). Use of AI to control warfighting aircraft is clearly a contentious proposal and one which goes right to the core of the ethical debate on use of AI and autonomous systems for warfighting. Leveringhaus makes a crucial distinction here, defining RPAS as 'Uninhabited' air systems[57] that are still controlled by a human. In the near future, as air battles take place in '*the most contested areas imaginable, where air, cyber, and the electromagnetic spectrum are all in play*'[58] it is likely to become necessary to design uninhabited air vehicles which can control themselves in the event that communications are lost for minutes at a time.[59] Consider in detail two potential cases where this would be required:

> **Loss of communications with an RPAS**. At the time of writing, Global Hawk is programmed to return to base if it loses communications with its controller,[60] using a basic level of computational intelligence which simply routes the RPAS back to its point of origin using a similar level of sophistication found in autopilots. However, this presents an obvious vulnerability, simply by jamming the communications to the RPAS an adversary could force it to return to base. Even if the jamming were only successful momentarily, it could have a disastrous effect on the prosecution of a mission, with the RPAS changing course to return to base and having to be re-corrected when the human operator regains control. If an adversary were to do this repeatedly, it could effectively deny the capability. Therefore, there is an obvious case for an artificially intelligent agent to be employed to ensure that the RPAS remains on course for momentary jamming, and such AI will likely increase in sophistication to be able to handle longer duration jamming or interception.
>
> **Cyber Attack on an RPAS**: Within cyber operations we will increasingly see artificially intelligent agents responsible for cyber defence. Alexander Kott from the US Army Battle Laboratory proposes that in the near future we will see AI enabled software which can autonomously be deployed within a network or potentially a weapons platform and be left to conduct cyber defence in the absence of an ability to remotely monitor the weapons platform.[61] Kott refers to this type of software as 'bonware' (i.e. the opposite of malware) and proposes that such software will reside in a semi dormant state within

systems, poised to activate in the event of a detected intrusion.[62] The question one must ask here is to what extent should such an artificially intelligent agent be allowed to take control of a weapons system? Clearly this is a question which will be fraught with ethical considerations, and far beyond the scope of this article. However, in considering this question, we should remember that there will be adversaries who will not hesitate to develop malware which will be able to maliciously control a lethal RPAS; AI, or at least AI to augment and support humans, could be the most effective counter to this.

## Conclusions

As stated from the outset, the field of Artificial Intelligence has come a long way in the last 70 years, and while there have been several false starts, we appear to be on the cusp of an exciting, incredible and potentially daunting change. Taking the example of chess, during the 1990s computers had been able to leverage their ability to store large volumes of data and rapidly consider several million moves in a short space of time, however, arguably this wasn't true intelligence but more brute force: the Good Old-Fashioned AI. The accelerated development of Neural Networks has allowed computers to genuinely learn and it is clear that AI will be increasingly able to take on tasks which were typically the preserve of humans in the future. A key point this article has identified, however, is that AI will not necessarily directly replace a human, but will be able to offer complementary and potentially diverse capabilities.

To understand what this would mean for the air environment; this article has proposed three core attributes of AI which make its employment desirable when considered against a human. Each of these attributes have ramifications when considering the speed and ubiquity of air power.

The potentially superior cognitive speed of AI compared with humans could not only affect the tactical speed of engagements between air platforms, but may also affect the speed of C2 in the air environment, especially when considering that AI will enable air platforms to communicate electronically and in an unambiguous manner with each other. AI's ability to process volume of information will clearly revolutionise analysis of intelligence, and it is likely that intelligence staff will be some of the first to benefit from the AI revolution and will be at the forefront of genuine human machine teaming.

However, the final attribute: namely that AI offers a means to apply cognitive analysis and decision-making in a physical space, has perhaps the most significant ramifications for air power. While the idea of ceding a lethal air platform to the control of a computer is ethically sensitive, it is only a matter of time before technology will force the requirement to think about this critically upon us.

Humans will continue to bring unique skills including insight and creativity to warfare. However, those who understand what they will be within the age of AI and how best to harness them will have the decisive advantage. While the distance we can see into the future is probably shorter than it ever has been, there remains plenty to be done.

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ROYAL AIR FORCE
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# Between Air and Space – Zephyr and the Future of High Altitude Pseudo-Satellites within Defence

By Flight Lieutenant Lilie Weaver

**Biography:** Flight Lieutenant Lilie Weaver is currently part of the UAS Test and Evaluation Flight on 56 Sqn, having recently served as a Reaper pilot on XIII Squadron. She has previous experience in Joint Helicopter Command and teaching cadets at Thunderlab, Kabul. Having completed an MSci in Natural Sciences at the University of Cambridge and worked for EADS Astrium before joining the RAF, she combines a background in science and technology with a strong interest in Air Power and history.

**Abstract:** As a consequence of the incremental decrease in weight and simultaneous increases in reliability and efficiency of technologies such as batteries, solar cells and satellite communications, the ability to operate high persistence, lightweight air vehicles in the aerodynamically demanding region of the stratosphere has improved. A class of these vehicles is often referred to as High Altitude Pseudo-Satellites (HAPS). This paper will examine the benefits and challenges of operating these vehicles, which fly well above commercial air traffic and the tropopause. They avoid convective weather but are still subject to low air density and quasi-space weather, as well as the photolytic chemistry, the process by which UV light breaks down atmospheric molecules into damaging free radicals, of the medium to high stratosphere.

## Introduction

**The UK MOD intends to be an early adopter of High Altitude Pseudo-Satellites (HAPS) systems and has already invested in a HAPS Operational Concept Demonstrator (OCD) using Airbus' Zephyr HAPS platform. The Zephyr is a fixed-wing air vehicle (AV) powered by solar energy and rechargeable batteries. It has already broken several altitude and endurance records and looks like a promising programme to convert these concepts from ideas and demonstrators into operational reality within the short to medium term. It is far from the only contender for further investment, however, and air vehicles with similar functionality are being developed all over the world by big aerospace companies such as Boeing, NASA and BAE Systems but also by internet giants such as Google and Amazon, whose applications for the technology include HAPS-enabled internet provision and high-fidelity mapping to remote areas of the globe. The designs of these AVs vary between fixed wing, airships, and balloons.**

HAPS are not a complete step-change from current technologies and concepts, but rather represent an opportunity to 'down cost' expensive subsets of both satellite-based capabilities and lower altitude air breathing platforms. As new, lightweight payloads are developed, HAPS will become useful in areas such as electro-optical reconnaissance, satellite and radio communications re-broadcast (rebro) and signals intelligence (SIGINT). One of the major selling points of HAPS could be described as 'agile persistence', where (with multiple assets) the persistence of a satellite could be achieved, but with the ability both to reposition the asset at will, but also recover the asset and payload at the end of its mission or lifecycle. When thinking about the UK's putative high-altitude network, we will need to consider how best to fuse this new 'mixed domain' to our traditional concept of treating 'Air' and 'Space' as completely separate domains. Above FL600 – around 60, 000 feet, flight is essentially unregulated. Until now, that has not been a problem given the very few users of such high airspace, but this may need to change. Regulators will have to think carefully about 'big stratosphere theory' and how to manage the increasing presence of AVs in this air space, particularly given the lack of manoeuvrability and large altitude block requirements of most of these systems. As an early adopter, the UK may have an opportunity to shape this unregulated space going forward and so consideration as to how to shape and exploit this should begin.

Whilst this paper will primarily address the Zephyr programme, it will also suggest that the future of HAPS is a combination of air vehicles of different types, providing a flexible capability set and 'agile persistence' in a given operational theatre. The benefit of being a very early adopter makes the investment in this relatively new technology worthwhile, buying the UK a 'seat at the table' in developing regulation, but also steering wider programmes to the UK's likely requirements, as well as, eventually, providing a relatively cheap and persistently agile network to support and enable operations worldwide.

## History

The Zephyr project started life as a side project for a group of engineers at Defence Evaluation and Research Agency (DERA), which became QinetiQ, designed as a way to take pictures of QinetiQ 1, a piloted stratospheric balloon designed to break the balloon altitude record. The Zephyr was to remain tethered to the balloon to take pictures. In the end, the balloon never took flight, but the Zephyr project endured, being bought by EADS Astrium in 2013, which became Airbus Defence and Space. But it is not until the last two to three years, with improving battery technology and solar panels that the air vehicle has been able to demonstrate its ability to stay above FL600 consistently through the day-night cycle. The Zephyr programme has gone from strength to strength, breaking the world altitude record in its class (U1.c) in 2010 and then again in 2018, at the Yuma test site in the USA. It still holds that altitude record of 74,000 feet.[1] But challenges remain, not least continuing development in battery technology, to improve life-cycle durability, and, as ever, weight and efficiency. In addition, the atmospherics of the stratosphere are a challenge, with many of the problems of both high-altitude flight and of the increased effects of space or space-like weather. The programme itself has not been without incident either, with crashes at Ascension in 2014 and at Wyndham, Western Australia in 2019, notably both occurring within the climb/descent phase implying that the weather on launch/recovery is likely to be the greatest catastrophic risk during the typical flight profile.

Figure 1: Airbus Zephyr S on launch. 

## Stratospheric Technology

The Zephyr is a heavier-than-air (HTA), solar powered, remotely piloted air vehicle. It uses rechargeable batteries to stay aloft overnight, and ultimately loiters in the stratosphere. The stratosphere starts at the tropopause – the point at which the temperature inversion marks the end of the Earth's lower atmosphere, where temperature decreases with height. This inversion marks the top of convective weather systems and the strong winds associated with the jet streams. The height of the tropopause varies from around 20,000 feet over the poles to 60,000 feet over the equator. Flying above FL600 (approximately 60,000 feet) brings another advantage – under ICAO regulation FL600 marks the transition of Class A controlled airspace to Class E airspace, under the remit of High-Level Flight Rules,[2] and is certainly above civilian air traffic. This is a challenging region to fly in. High altitude weather balloons swell to around 80-100 times their size at the earth's surface, and the air density in the stratosphere is between around 1% and 0.1% of that at sea level. This poses problems for lighter-than-air (LTA) HAPS, particularly in selecting a suitable skin material. HTA vehicles must also be designed for low air density flight. Zephyr 8 has a very high aspect wing, very low weight and fixed pitch propellers that have so much helix angle (to maintain efficiency at high altitude) that they don't provide enough thrust at low speed to get airborne from a standing start, so the Zephyr must be launched by hand, by a well coordinated team of five. The Zephyr 8 has an all up mass of only 67kg, with the main structure weighing in at around 30kg (the rest is batteries and a 5kg payload allowance). This is exceptional when you consider its wingspan of 25m – by comparison, an MQ-9 Reaper has a wingspan of 20m and a max all-up-weight (MAUW) of around 4,800kg![3]

Another feature of the stratosphere is the much higher levels of radiation, specifically, high energy particles (which cause the stratospheric temperature inversion through high energy creation of ozone and its energetic decomposition), which are filtered by the thicker atmosphere of the troposphere. This combined with the high diurnal temperature variation (the air temperature in the low stratosphere is around -50°C but solar radiative heating can cause the skin temperature to exceed this by up to 64°C)[4] contributes to the degradation of skin materials used in HAPS and presents an insulation/heat dissipation problem for the batteries, avionics and payload. With current materials, it is likely that after a 6-month flight, the skin would be so degraded that it would need to be completely stripped and replaced.[5]

Battery technology is another limiting factor. Currently, batteries make up over half of the weight of the air vehicle, and well over half the cost of the entire structure. Even with the most efficient battery technology available, only within the last year has Zephyr been consistently able to demonstrate the ability to maintain stratospheric flight through the day-night cycle. Even now, the battery efficiency over several discharge-recharge cycles is the limiting factor on endurance. The good news is that development of better, lighter and more efficient battery technology is key to the success of many future industries, not least electric vehicles, as well as making renewable power reliable and distributable across periods of high and low generation. Solar cell technology is progressing well also, with many of the same drivers. With current technology, the Zephyr 8 holds the world record for endurance, at 25 days, 23 hours and 57 minutes. In the near future, the Zephyr team anticipate a 3,000hr (roughly four month) flight will be achievable; the ultimate aim is to be able to remain airborne for at least a year.[6]

## Weather

An aircraft as light and flexible as Zephyr is extremely susceptible to the weather. Its cruise speed is just 12 knots indicated air speed (KIAS) – its never exceed speed ($V_{ne}$) is just 20 KIAS. This largely only causes issues for launch and recovery – getting up and down through the higher wind speeds and convective weather to reach the (relatively) calm stratosphere. Turbulence aloft is minimal, and whilst winds in the stratosphere can be as high as 130 knots in the polar vortices,[7] they usually peak at around 30-40 knots in the mid-latitudes and average just 20 knots.[8] This might sound high for a machine which cruises at 12 KIAS, but at 60,000', this converts to 45 knots true airspeed (KTAS), allowing a HTA HAPS freedom of manoeuvre that is greater than would be possible if exposed to tropospheric weather.

Launch and recovery can prove problematic, as can the aerodynamics of a novel airframe. The limiting factor for high altitude/high speed flight is usually flutter, a phenomenon of dynamic aeroelastic instability. With no ailerons to provide positive feedback which exacerbates the simple harmonic motion of flutter, and a highly light and elastic composite airframe, the Zephyr's $V_{ne}$ is based on a static aerodynamic effect. This is basically a divergence speed where, as the angle of attack (AOA) decreases towards zero (operating AOA is 16 deg!), the wing bends up and either reaches structural failure or the aircraft enters a regime of dynamic instability in pitch. In turn this can flip the aircraft or cause structural damage due to out of limits excursions in speed. In 2003 NASA's Helios demonstrator (another record breaking solar/fuel cell HAPS demonstrator) broke up at low altitude in 'normal' turbulence due to this effect,[9] and Facebook's (since abandoned) Aqulia HAPS project suffered a similar fate on final approach in 2016.[10]

## Control

The Zephyr can be flown via satellite, or via a direct line of sight control, using S-band frequencies. On the satellite link, the aircraft flies semi-autonomously, and is given instructions by text message on a waypoint system with a latency of around 2 minutes. In S-band, the aircraft control system can share 10Mbps of bandwidth with the payload, or the payload can stream its data on a ROVER[11] -like link. Communication with air traffic agencies is all done by telephone from the ground station. Each ground station can control up to 4 aircraft over two terminals, offering a potentially personnel-efficient way of controlling very long-term missions.

## Other HAPS in development[12]

## Airship – Thales-Alenia's Stratobus

Thales Alenia Space is designing a HAPS airship, capable (unlike a balloon) of reliable self-positioning through solar powered motors (much like HTA HAPS). But it is a much larger structure and is currently predicted to carry a payload of up to 250kg. The technology is unproven though, with a test flight scheduled for 2020 or 2021. Other HAPS airships have been plagued by budget overruns[13] and problems developing the technology required – most often cited as problems developing the fabric for the skin, which, unlike balloon projects, usually contains the solar cells, and which must be able to maintain a rigid, aerodynamic shape. It must also be able to survive at least six months, if not several years, in the punishing solar environment of the stratosphere. The cost of a HAPS airship is likely to be an 'order of magnitude more' than HTA HAPS.[14]

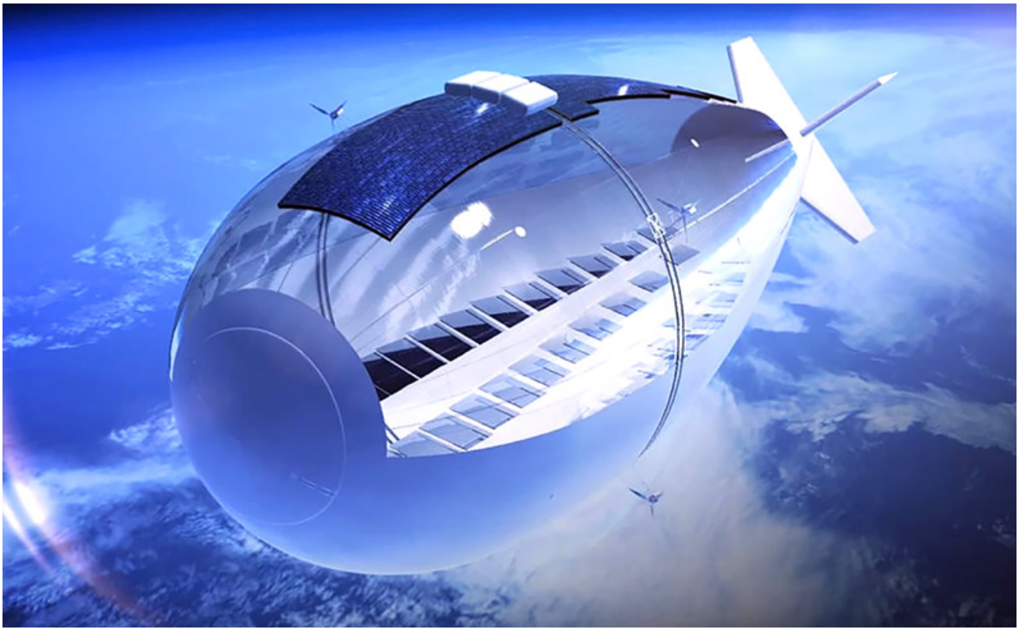

Figure 2: Thales Alenia's LTA HAPS Stratobus. Copyright © Thales Alenia Space

## Balloon - Google Loon

The Loon balloons are a civilian project, designed to attempt to bring broadband internet to inaccessible areas, and those with poor native infrastructure. The balloons are not steered, rather they must 'catch a ride' on stratospheric winds and their operation relies on detailed weather planning, ascending or descending to find an area with winds in the required direction. The project is at an advanced stage with plans to start operating commercially in Kenya in 2019. The balloons can carry a 10kg payload and have a small array of solar panels generating 100W of power during the day, with rechargeable batteries powering the craft overnight. The estimated service life of a balloon is 100-200 days, and the payload is designed to be recoverable. The project has experienced a number of structural failures yet is already capable of delivering internet on a temporary basis to, for example, disaster hit areas. Costings are not freely available, but the skin material (similar to a weather balloon) is relatively low cost, and the payload is small, made of commercially available components, so it is likely that the unit cost in full production could be quite low. Notably, the programme seems to rely upon low unit costs of both the balloons and the payloads, and the assumption that at the end of life, either the balloon's steering or material will fail, and the payload must either be recovered or abandoned.[15] This may work well for a civilian application in an area with low population density but must be considered carefully for military application.

Figure 3: A Google Loon balloon on launch. Copyright © Loon

## Doctrine

Project AETHER is currently being run within UK Defence to investigate what type of solution the MOD should invest in to meet an 'agile ultra-persistent' requirement; with HAPS as one potential solution. As this is a globally new concept, it is important to take time to get the concept of operations right, without having the advantage of observing others' mistakes. Current Air and Space Power doctrine says little about the details of what the MOD should be investing in, so perhaps more attention should be paid to this area, as HAPS are not only a potential force multiplier, but also a networked-force enabler. The Joint Concept Note from DCDC, 'Future Force Concept', devotes only one paragraph to HAPS, identifying that they 'offer the advantage of being more readily upgradeable than their true-satellite counterparts and can be re-tasked to different geographic areas more easily'. It also observes (but not in relation to HAPS) that 'all air platforms have potential to be … network nodes.'[16]

Joint Doctrine Publication 0-30.2 devotes slightly more space to Zephyr as a UK MOD asset, but says virtually nothing about *how* it should be employed. The United States Air Force (USAF) says little more in its doctrinal documents, although it re-emphasises the importance of all future RPAs/UAVs being interoperable. The USAF paper also identifies a modular approach to payloads as important in preventing the proliferation of custom-built air vehicles for each mission or even mission subset, which is extremely inefficient.[17] The authors propose two examples of HAPS applications on the battlefield, 'extreme persistent ISR', and 'near-perpetual battlefield communications node'.[18]

There is little academic work available on military uses of HAPS – most papers focus on civilian applications of HAPS or are so old as to be outdated. Some of the civilian applications can be re-interpreted for military application, such as the concept of internet (or network) dissemination in remote locations,[19] and HAPS-HAPS/HAPS-satellite integration to minimise expensive satellite bandwidth and increase the efficiency of satellite operations by acting as a surrogate download station, with a much longer communications window with a low-earth orbit (LEO) satellite than a ground station would have.[20]

## Capabilities and Integration

HAPS capabilities are largely thought of as being ISTAR related (Intelligence, Surveillance, Target Acquisition and Reconnaissance), but in addition, it could be argued they could be considered as a J6 asset too – a persistent, deployable network that can be taken to a Theatre of operations and used to enable and improve the networked capability of other ground and air based assets, in conjunction with Space comms. This vision is still a long way off, technologically speaking, and relies on ongoing investment in different types of air vehicle, but, if new systems are procured using relatively straightforward principles of modularity and interoperability, it is possible the MOD can multiply the value of its investment in this area.

## HAPS as Imagery Intelligence (IMINT) providers:

Electro-optic/Infra-red (EO/IR) imagery is perhaps the most straightforward and mature aspect of HAPS' capabilities. The technology is relatively well explored through a combination of high-quality imaging pods for fast jets, Medium Altitude, Long Enurance (MALE) RPAS, and other airborne ISTAR assets, and imaging from LEO satellites (see Carbonite-2 and others, below). The challenge is to get an imaging payload down to a low enough power consumption and weight to fly on HTA HAPS – which are the current front runners in the race to become operational. On the Zephyr 8S, for example, the payload must weigh around 5kg. With a total air vehicle average power production of between 50W and 2kW the payload power consumption is likely to have a limit of around 50W (day) and 15W (night).[21] OPAZ is an Airbus payload which has been designed to meet this requirement and can provide 20cm resolution imaging from an altitude of 20km.[22] It is not yet reliable enough to produce imagery on demand, but nonetheless, it shows the potential that exists within those weight and power constraints. Synthetic Aperture Radar may be another payload feasible for HTA HAPS, although the speed profile and altitude of the platform may prove a challenge. In a recent study, Baumgartner calculated that the navigation solution would have to provide a relative position accurate to within 0.4cm to achieve 1m resolution at HAPS representative heights and speeds.[23]

LiDAR (Light RADAR, or Laser Imaging, Detection and Ranging) is another good prospect for carriage on an HTA HAPS. Lightweight LiDAR payloads are already in development.[24] Using a laser-based imaging array could have an added benefit, as it may be possible to use the same equipment to support optical communication,[25] a high bandwidth, highly directional option for future HAPS communication. The disadvantage of EO imagery collect is of course weather obscuring the target. This is something overcome by SAR, but not LiDAR. Larger platforms, such as Thales' Stratobus could carry much larger imaging equipment, but, since these are likely to cost an order of magnitude more than HTA vehicles,[26] it would be questionable whether they would offer better value for money in the imaging arena than, say, a constellation of LEO satellites or an air-breathing, high-altitude asset such as the U-2 spyplane or dedicated SAR platform such as the RAF's Sentinel.

## HAPS as SIGINT platforms:

Another area where HAPS capability could likely be usefully utilised is SIGINT. Due to its sensitivity, there is little in the public domain about the nature of any SIGINT payloads being developed for HAPS, although Airbus does appear to be developing one for Zephyr.[27] The advantage of using HAPS for SIGINT is their persistence, allowing long-term coverage and/or tracking of a target. Weight will, of course, be an issue, especially with HTA HAPS – and the high altitude might also present a problem in terms of signal strength, and the design of the payload is likely to be specialised (rather than taken from another aircraft) due to HAPS' slow flight profiles and high altitude. From a military perspective, one of the challenges of SIGINT on HAPS will be integrating the payload. This depends on the commercial model chosen for the operation of HAPS, since one model (given the long flight times and specialist skills required to operate and monitor HAPS) could be to lease the capability from a commercial company, bolting on a payload and instructing the company where to fly. This is likely to be most challenging in the area of SIGINT, where the MOD will require assurance that the aircraft systems cannot interact with the payload in any meaningful way.

## HAPS as communications and network nodes:

One of the key areas where HAPS may offer a step change in the way the UK military conducts operations is analogous to one of the most spoken about civilian applications of HAPS – networking and communications. On the scale of a ground operation, the footprint of a HAPS (estimated 500km maximum horizon,[28] but a 200km useful operating radius at 20km altitude)[29] would enable one air vehicle with a communications re-broadcasting payload (comms rebro) to act as a point node and, for example, allow beyond line-of-sight (BLOS) radio communications for the troops on the ground. One step further would then allow the broadcast of friendly forces layout, a recognised air picture (or both) from an HQ or C2 node based within that footprint. The next step up would be processing and broadcast of a large-scale C2 picture including elements outside the HAPS' footprint, via direct communication with another HAPS, a geostationary satellite or a distant, air-breathing C2 asset. Large-scale processing of air and ground-based assets is likely to require the ability to carry a relatively large payload. Northrop Grumman's Battlefield Airborne Communications Node[30] (BACN) is operated by the USAF on E-11As. BACN was designed to overcome the fact that different units use different networks to communicate and spread situational awareness and intelligence. The US Army uses Enhanced Position Location Reporting System, to integrate with Situation Awareness Data Link (EPLRS/SADL) on close air support platforms. Most aircraft use Link-16 to contribute to and receive a Recognised Air Picture (RAP); the Common Data Link (CDL) is used to transmit imagery. All of these are available on BACN, along with voice and data rebro.[31] It was realised early on that operating BACN at high altitudes offers the best BLOS coverage – in Afghanistan, NASA's WB-57s (developed from the English Electric Canberra) were used.[32]

The RQ-4 Global Hawk can be modified to carry BACN,[33] and a smaller 'Smart Node' pod is available, shown in Figure 4, carried by an MQ-9 Reaper. Whilst no figures are publicly available on its weight, it looks unlikely to be within the current weight limits of HTA HAPS. Airship HAPS would be a natural fit for carrying larger comms network capability – perhaps for the 'full fat' BACN capability, providing a persistent intelligence picture to all participants in an operation, along with extended range voice and IP comms. A key technology enabler to make full use of this ever-increasing plethora of information will be high bandwidth platform-platform communications. A promising option for this, especially for high altitude platforms like HAPS would be 'free space optical' – i.e. lasers.[34] A full treatment of this technology is outside the scope of this paper but remains an area that should be watched closely to maximise the value of HAPS.

Figure 4. Smart Node Pod on an MQ-9. Copyright © 2014 Northrop Grumman Systems Corporation

## HAPS in practice:

For a small-scale operation, two Zephyrs, could be launched (or redirected)—one for pre-deployment imagery or a live image feed, (albeit at 20cm resolution) and one for UHF/VHF re-broadcast (rebro) ensuring that tactical communication can be maintained beyond line-of-sight (BLOS).

Remote locations, such as the South Atlantic Islands, could benefit from long endurance internet rebro from a friendly country in the region, improving communications both for the civilian population of the Falkands, but also the remote research stations of Rothera and scientists based seasonally on South Georgia and the South Sandwich Islands. It would also lower the cost of expensive satellite communications between the South Altantic islands and the UK. A good selection for this long-term, static rebro might be an airship, which can carry a larger payload—such as Thales' Stratobus, which is designed to carry up to 250kg.

For an enduring Operation, such as SHADER one solution could be to use several HAPS balloons or airships to provide satellite rebro (or even an alternative to satellite BLOS) for MALE RPAS and a wide area tactical picture (something like BACN), along with VHF/UHF rebro. A fleet of Zephyrs could provide imaging prior to a compound assault, for example, in EO, IR, or LiDAR, and could provide 'night before' on-demand pattern-of-life for pre-planned targets. This would leave the MALE RPAS such as Reaper free to operate as a close air support platform and do the more detailed and responsive target development, and it would help free up capacity in telecomms satellites to provide the ever-increasing bandwidths needed for high definition remote video feeds and SIGINT payloads.

## What about Space?

Are HAPS going to replace Space based capability? In a word, no. Large satellites or satellite constellations, such as AlphaSat, or the MOD's Skynet network are bespoke designs for large, very high bandwidth platforms and can cost hundreds of millions of pounds. The cost of launch is high – up to 75% of total cost[35] (although this may decrease with the anticipated increase in capacity, driven by commercial demand over the coming years).[36] These large satellites are designed typically to a 15-year lifespan, requiring (usually) at least triple redundancy in key areas, to maintain functionality in spite of bombardment with high energy particles (which can damage the semiconductor components of even space-hardened microchips – and the smaller and more modern the chip, the more vulnerable to space weather it is, due to the reduced component size and energy).[37]

There are three main orbit types relevant to this discussion: geostationary or synchronous orbit (GEO and GSO), medium earth orbit (MEO) and low earth orbit (LEO). Each of these orbits brings benefits and drawbacks but once reached, a satellite cannot change between them. LEO is where many imaging satellites are positioned, due to the increased proximity to Earth's surface but also for better access to the poles when they are in offset orbits due to their low orbital period (approximately 90 minutes).

Satellites are rapidly reducing in price, thanks to development work in small, low unit cost 'CubeSats', already tested by the European Space Agency (ESA) and others.[38] The industry is also working towards offering a 'plug and play' capability – again driving down the cost and increasing the certainty that payloads will work as expected when in orbit. With CubeSats and HAPS developing rapidly and on similar timescales, this gives us an opportunity to think about the best way to integrate our capabilities all the way down the stack from GEO at 22,000km, to LEO at roughly 500km, HAPS at 20km (60,000' plus) and MALE RPAS/manned platforms mostly below FL 600.

For the foreseeable future, there will be a need for large satellites. Positioning satellite constellations (GPS, GLONASS etc) sit in MEO, offering the orbital stability to offer nanosecond[39] timings and therefore global position indication. Large GEO or GSO telecomms satellites such as AlphaSat offer positionally stable, wide area, high bandwidth broadcast and communication. LEO imaging satellites offer very high persistence (but not immediate), wide area mapping or environmental observation (RADARSAT 2 for example).[40]

So what about small satellites? The RAF recently invested £4.5m in Carbonite-2, a small satellite imaging demonstrator, capable of delivering 1m resolution HD video in 5km swathes.[41] From design to launch, this programme took ten months, a truly rapid capability. The key here is commercial off-the-shelf (COTS) components, very little redundancy and 'good enough' design. The aim is to launch a fleet of smaller satellites to offer increased coverage and better revisit times for the same cost as a medium or large size imaging satellite would have cost. Currently, this technology is largely aimed towards replacing large imaging satellites in LEO, but it is conceivable that the same principles will be applied to communications satellites in the near future. COTS and the improvement in 'plug and play' satellite super-structures means that it may become feasible to launch a satellite or constellation on a timescale of six months to a year, from design to being operational.

## Cost comparison

Carbonite-2 cost approximately £10m[42] of which the RAF contributed £4.5m.[43] It is estimated that the future cost of small (approx 50kg) satellites could be as low as $2m a piece, in a production run of around 20-40.[44] Based on a similar system, a constellation of roughly five LEO satellites is enough to give once-a-day coverage of any particular area, plus the time taken for the imagery to be passed back via a ground station. The design life of a low-cost, non-redundant satellite like Carbonite-2 is around five years[45] (based on space weather), but may be significantly longer or shorter than that; Carbonite-1, built to a similar specification, was launched in 2015 and is still operational after nearly four years.

Currently, a Zephyr 8S (i.e. the single-tailed model) costs around £3m, but Airbus are in the process of ramping-up production at their facility at Farnborough, and it's realistic to project that a unit cost of somewhere around £1m (still with £500,000 being spent on batteries at current technology prices) would be feasible in the near to medium term.[46]

## Integration of HAPS and Space

One of the issues with LEO imagery is not just the revisit time, but the time required to then download the image – and the location of the ground terminal. The transit time of a LEO satellite over a point on Earth is short: the orbital period is approximately 90 minutes, and visibility to a ground station is approximately 20-30 minutes.[47] Even if a ground station was co-located with the area of interest, there would not be time to take the images and then download them. If you wanted 'instant' imagery of the theatre in which you were deployed, for example, you would likely need to wait for the satellite to image your area, then wait until its orbit passes one of its ground terminals, then wait for the image to be transmitted back to you, in theatre. With HAPS, since they are able to keep line-of-sight with the LEO sat for a lot longer than a given point on the ground (visibility of around 2.5 hours a day),[48] it would be possible to use a HAPS as a surrogate ground terminal, and access LEO imagery without waiting for a revisit, or for the LEO to pass overhead a ground terminal somewhere else in the world.

In the same way, a network of HAPS could free up bandwidth on MEO or GEO satellites by acting as a local re-broadcast station, allowing users within the same HAPS footprint to communicate directly, and passing information through the satellite channel only when required, thus acting as a 'filter' to minimise the use of expensive satellite bandwidth.[49] Platform-platform visibility could be as much as 1,250nm at 65,000 feet,[50] meaning that if a stable HAPS-HAPS communications relay could be established, satellite bandwidth could be bypassed altogether, used as a backup, or used for critical parts of the mission, if the remote operating location (which could mean any sort of remote connection – a live feed into a Combined Air Operations Centre (CAOC) from a fast jet; operating MALE RPAS; supplying ground based C2 remotely) and the operational theatre were close enough together. For example, the straight line distance between RAF Akrotiri and Raqqa is approximately 350nm, which could make remote operating a feasible prospect – perhaps even from a tethered aerostat in Cyprus to a HAPS overhead Syria.

## Conclusions:

HAPS show promise over several applications; however, the technology is not yet mature enough to deliver them all. It is, however, advancing rapidly on all fronts, but until the air vehicles can be shown to be reliable and cost effective, they will not enter widespread use. It is nevertheless sensible for the MOD to invest at this early stage, to help develop vehicles and payloads suitable for military use.

HTA HAPS are at the most mature stage of design now and combine a good degree of flexibility with semi-permanent persistence. Their major downsides are extremely limited weight for payloads, limited excess power, and a binary tendency towards either success or catastrophic failure, although, so far, this seems limited to the launch and recovery phase.

LTA HAPS also show promise for investment but are likely to be further away from maturity for military applications. Google has shown that balloons can be used successfully for distributed networking, but careful consideration must be given to whether military payloads would be suitable, given the high 'in-situ' failure rate.

LTA Airships are perhaps the most promising technology from a broadcast and network perspective given their (putative) ability to carry heavy payloads for a long period of time. But the technology seems the least mature, and unless they can be proven to operate successfully in the long term, their much higher cost must give cause for concern over value for money when compared with air-breathing platforms.

Other than the air vehicles themselves, there are certain key technologies that must be developed in parallel to fully exploit the potential of HAPS. Reliable, high bandwidth and interoperable communications are one such example. Building this type of communication network between HAPS, 'air breathers', MALE RPAS and satellites will take many years due to the long lead- and lifetimes of modern platforms. But the framework should be put in place now, to ensure that systems are designed from the bottom up with interoperability in mind.

Lightweight, lower power payload development specifically for HAPS is another key enabler, especially for HTA HAPS. Airbus and the MOD's investment seems to be paying off in this regard, with several novel applications of existing technologies being designed for the Zephyr. This may have some synergy with COTS payloads for small satellites too, as the drivers are similar – driving down weight and power and therefore overall cost.

HAPS could, in the future, be a key force multiplier, especially when considering the provision of wider SA and communications to ground troops. They could also be a force enabler in our technologically reliant air force of 2020 and beyond – driving down the cost of platform-platform (e.g. LINK-16) or platform-operator (e.g. replacing or augmenting Reaper/Protector satellite communication) communication will be key to ensuring our technology remains affordable to operate. Bringing together and being able to disseminate increasingly complex and accurate pictures of the battlefield will be key to whole force interoperability in future conflicts.

| **Conversion table of km to feet** | |
|---|---|
| Kilometres (to the nearest 10m) | Feet (to the nearest 10ft) |
| 1.00 | 3,280 |
| 9.14 | 30,000 |
| 20.00 | 65,620 |
| 18.29 | 60,000 |
| 80.00 | 262,470 |

## Notes

[1] Fédération Aéronautique Internationale: https://www.fai.org/records.

[2] "UAS ATM integration", *European Organisation for the Safety of the Air Navigation*

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ROYAL AIR FORCE
Centre for Air and
Space Power Studies

Viewpoint

# More Science, Less Art: Big Data, The Information Revolution and Decision-Making in the Royal Air Force

By Wing Commander Keith Dear

**Biography:** Wing Commander Keith Dear is currently serving as SO1 Innovation in JFC's Joint Warfare. He is a CAS Fellow, Research Fellow at Oxford's Changing Character of War Programme and Fellow at the Royal United Services Institute (RUSI) where he is also co-executive producer and expert consultant to RUSI's Artificial Intelligence & the Future Programme. He holds a DPhil in Experimental Psychology from the University of Oxford. In 2011 he was awarded King's College London's O'Dwyer-Russell prize for his studies in Terrorism and Counter-Terrorism. He co-leads the Defence Entrepreneurs' Forum (UK) and was founder and CEO of Airbridge Aviation, a not-for-profit start-up dedicated to delivering humanitarian aid by cargo drones.

## Introduction

*Before we work on artificial intelligence why don't we do something about natural stupidity?*

Steve Polyak, Computer Scientist, Psychologist.

The information revolution – the exponential increase in volume and detail of data on almost everything[1] – is fundamentally re-shaping modern warfare, enabling the measurement of effect in war to be infinitely more empirical than ever before. For professional airmen and women, the rise of big data should be driving greater rigour into how decisions are made in organising for war, planning for war, and fighting wars. We are moving from a world in which decisions were made principally qualitatively, on human judgement and intuition, to one in which data science predominates.

If the arguments that follow are accepted, the implications are profound. Orienting the RAF around big data analytics will drive unprecedented rigour into its decision-making. In practice this will principally require the far-reaching adoption of quantitative, statistical, analytics. The primary consequences of this will be felt by commanders, whose decisions will need to be far more clearly derived from evidence and defined assumptions than is currently the case.[2] The secondary consequences are significant too, and will be manifest in how the RAF recruits, trains, educates, structures itself and manages careers. Furthermore, adopting such an approach will enable the automation of many decision-support functions a process that will also require the logic, evidence and assumptions that make up and support the premises underlying decisions to be made much more explicit – both in HQ staff functions and commanders' decisions.

In this viewpoint, I first provide an overview of the scale of the information revolution and demonstrate how this is providing unprecedented insight and foresight, principally through quantitative analytics. Secondly, I show how this is driving doctrinal and organisational change in the RAF. Thirdly, I demonstrate how it will drive greater rigour into, and enable significant automation of, the RAF's decision-making and decision-support functions. Finally, I examine the arguments advocated in the context of previous attempts to conceptualise how Air Forces approach warfare. This viewpoint is written for *Air and Space Power Review*, so the focus here is on the RAF, but many of the insights are just as applicable across all three Services, and indeed across Government more broadly.

## What is the big data revolution and why does it matter?

We live today in a virtual panopticon,[3] in which the volume of data available on each of us is unprecedented.[4] It is estimated that by 2020 this will equate to some 5,200GB of data per person.[5] By my calculations this equates to some 18.5 million books of data on each and every one of us.[6] This is because, as Google's Chief Economist has noted, 'Nowadays there is a computer in the middle of virtually every transaction...' which is enabling 'data extraction and analysis', 'new contractual forms due to better monitoring', 'personalisation and customisation', and 'continuous experiments'.[7] All of this enables data scientists to model and manipulate human behaviour, providing unprecedented insight and foresight, creating what Harvard Business School professor Soshana Zuboff calls 'behavioural futures markets'.[8]

The evidence for the kind of insight Big Data analytics can provide is well-reviewed in Berman, Felter and Shapiro's 2018 book, '*Small Wars, Big Data*'. Between them, the authors combine their military experience in the Israeli Armed Forces and the US Special Forces with doctoral education in economics and political science to turn quantitative analytics to the study of war. They demonstrate how data-analytics have been able to provide metrics demonstrating what works, and what does not, in a range of counter-insurgency operations. They answer with clarity and detail questions like: Do civilian casualties drive violence? What's the relationship between poverty, employment and violence? Does paying for tip-offs work?[9] Furthermore, their decision to focus on what they call 'micro-data',[10] that related to district level activity, clearly provides commanders with more precise, quantitative, detail on the nuances than the staffs I was a part of, or on occasion led, were routinely able to do. For example, in 2008 ISAF intelligence staff were heavily reliant on the Asia Foundation's Afghan Attitudes survey[11] to understand whether the various military operations, security sector reforms, economic, governance and other development initiatives were helping us win the support of the undecided middle, to turn public opinion for the Afghan Government and against the Taliban – something our doctrine made the main objective.[12] The Asia Foundation report aggregates attitudinal data across district, tribal and other boundaries offering categories describing opinion in Central/Kabul, South East, East North, North East, North West, Western, South West, and Central/Hazarjat as if the variances within these huge regions were unimportant or insignificant. Yet this was a war that was so localised such numbers were meaningless. This was highly localised conflict driven by interlocking grievances and feuds overlaid with ideology, ethnicity, and tribalism.[13] Berman et al. report research showing the differential effects of aid across 250 villages in a genuinely randomly selected sample, vice the Asia Foundation's crude regional aggregations (this is not to say these aggregations were without merit in their survey – just that they could not provide the kind of insight we needed and weren't suited for what we were forced to rely on them for). The more detailed data showed that aid projects reduce violence only after 12 months of consistent implementation, only in areas where violence was previously 'moderate' and not in areas where it was high, and that aid improved attitudes to government.[14] They also report a study showing that aid in areas controlled by the Taliban may have brought more stability, but in Government controlled areas aid projects seemed to increase violence.[15]

The nuance, or lack of it, matters. Understanding these various moderating and mediating variables at the local level is critical, it seems, to estimating the likely success or failure of an intervention. Without accurate diagnosis at the right level of detail, decisions taken at a higher level of aggregation might lead to the application of a remedy that helps resolve the problem in some areas but exacerbates it in others. To gain the kind of insight Berman et al. deliver, they recommend staff employ 'theoretically grounded microlevel research'.[16] Their examples are principally quantitative, and dispassionate – starting with the question: What evidence would prove me wrong? In short, they advocate a rigour in the provision of insight that would significantly improve support to decision-making, not just in the RAF, but across UK (and allied) Defence and security organisations.

A raft of primary research demonstrates how living in the virtual panopticon provides not only the unprecedented insight described above, but unprecedented foresight too. The Bank of England has recognised this. Speaking in April 2018, Andrew Haldane, the Bank of England's Chief Economist drew his audience's attention to some of these developments and his vision for their use in ways that merit quoting at length:

> *. . . data on music downloads from Spotify has been used, in tandem with semantic search techniques applied to the words of songs, to provide an indicator of people's sentiment. Intriguingly, the resulting index of sentiment does at least as well in tracking consumer spending as the Michigan survey of consumer confidence.*
>
> *And why stop at music? People's tastes in books, TV and radio may also offer a window on their soul.*
>
> *So too might their taste in games. Indeed, I am interested in the potential for using gaming techniques, not just to extract data on people's preferences, but as a means of generating data on preferences and actions.*
>
> *. . . In time, it is possible these sorts of data could help to create a real-time map of financial and activity flows across the economy, in much the same way as is already done for flows of traffic or information or weather. Once mapped, there would then be scope to model and, through policy, modify these flows. This is an idea I first talked about six years ago. Today, it looks closer than ever to being within our grasp.*[17]

This kind of revolutionary insight is just as relevant to those in defence as it is to bankers. For instance, recent research shows how online contact between groups can be predictive of offline violence,[18] how the 'integrative complexity' of a leader's language – how 'black and white' their pronouncements on a given country are – can probabilistically predict the likelihood of countries going to war,[19] and how flexible – and perhaps therefore effective or ineffective – political and military leaders will be.[20] The former points the way to innovative indicators and warnings allowing much earlier prediction of adversary intentions. Instead of watching for the movement of tanks, recall of personnel or bursts of electronic communications from key headquarters to predict attacks, perhaps, it may be that monitoring videos feeds of political leaders from public TV appearances, via CCTV, webcam, their personal voice communications or video telephone conference data might prove more reliable indicators of future hostile intent. In an age where personality models with high external predictive validity – such as of one's political attitudes,[21] propensity to engage in political activism,[22] violent tendencies[23] or how one is most easily influenced – can be built from social media data,[24] call data,[25] the music people stream,[26] consumer purchase information,[27] banking data,[28] and even from tracking their eye-movements,[29] this kind of early detection of adversary intentions might enable much earlier and effective deterrent activity.

It's not just research either. This science has been, and continues to be, put to practical use by companies and states seeking an edge on their competitors. Witness efforts to influence elections in the UK using social media data,[30] the well-reported activities of Russia's Internet Research Agency in the US (and elsewhere),[31] and China's commitment to influencing public opinion in democracies making it harder for those states to oppose them.[32] Empirical evidence on the extent to which microtargeted political marketing – data-driven influence campaigns that predict who is vulnerable based on personality (or other) modelling of the type described, and then present persuasive campaigns around their target audiences' personalities or other criteria – is limited to correlational data, and inferences from research. For example, Cambridge Analytica have boasted of boosting Ted Cruz's popularity from 40% name-recognition in Iowa (vice Jeb Bush at 85%) to winning the caucus there and going from 5% to 35% support amongst voters in US Republican Presidential primaries, second only to Donald Trump.[33] Other primary research shows the techniques might work, for example, to increase voter turn-out,[34] or to change people's self-perception; to change, in other words, aspects of their identity, and their real-world behaviour.[35] What we can't prove is causality between Cambridge Analytica's claims to have influenced US Presidential primaries, the US election, #VoteLeave's claims to have influenced the BREXIT referendum and the outcomes of those votes.

Talking about how the big data modelling we have described is done in practice twelve months after #VoteLeave had concluded its role in the BREXIT referendum, #VoteLeave's Director, Dominic Cummings described how his team had contributed to the campaign. He noted that they used mathematicians and physicists to model human behaviour based on big data, suggesting that in the future there would be no role in advertising for '… charlatans… [with] …not very good degrees in gender studies or English…'. Rather in the future persuasive campaigns will be run by a '…combination of experimental psychologists and data scientists…'[36] While we can dismiss some of this as hyperbole, there is an important implication to be drawn – the science behind a big-data based approach to influence and decision-making is principally quantitative. As such, those in decision-support and decision-making positions across the RAF are going to need to be much more familiar with quantitative analysis, statistical methodology, its limitations, utility and potential applications. As Cummings makes clear with his colourful language, this is not a role for the enthusiastic amateur. The RAF is going to have to get much more comfortable with training specialists in these areas and finding ways to manage their careers that reward depth as well as breadth of expertise.

## How big data and 'the information revolution' are re-shaping Air Forces

Awareness of what life in the virtual panopticon – the rise of 'big data' and the information revolution – means for Defence is already re-shaping our doctrine, and with it our organisational structure and approach to warfighting.

The RAF's 11 Group was re-formed in November 2018, specifically to enable the RAF to pursue multi-domain operations.[37] Perhaps surprisingly then, multi-domain operations are not currently defined in UK doctrine.[38] But insight into what multi-domain operations might be can be inferred from US attempts to define them. In a 2016 article published in the US *Air & Space Power Journal*, Dr Reilly offered Figure 1 as a way of describing this new concept of operations.[39]

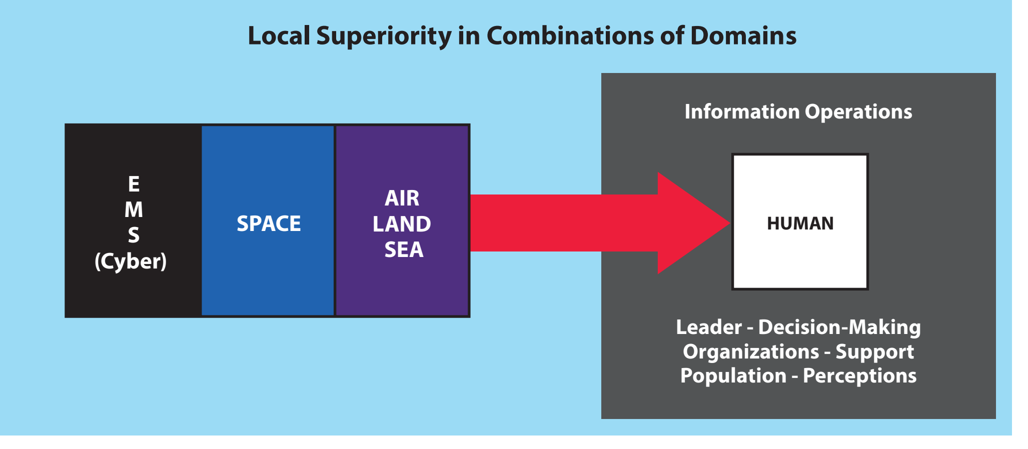


Figure 1: Continuum of domains and their interdependence.

What we see is that multi-domain operations consider actions in the domains of the Electromagnetic Spectrum (EMS), Cyber, Space, and Air, Land and Sea are all in the end about informational inputs to the human domain – that is, to human minds to affect behaviours. Dr Reilly is now leading on the conceptual development of multi-domain operations on behalf of the US Air Force,[40] perhaps suggesting this understanding of war will soon be enshrined in the doctrine of the UK's closest ally. What we have seen in the preceding discussion is that increasingly, the way militaries assess which inputs might work to change behaviours is through the development of carefully designed, evidence-based and falsifiable hypotheses, tested using quantitative analytics. Big data is changing not only how effect is measured in war, and how war is planned for, but how the RAF structures and organises itself for war, and how warfare is conceptualised.

## So What? How will this change the way RAF makes decisions?

Just as quantitative analytics are changing RAF doctrine, how it is structured and ultimately its approach to warfare, so too, will they have radical effects on how the RAF makes decisions, particularly when paired with Artificial Intelligence (AI) that could and should automate much of our information processing.

The volume of data previously described, 5,200GB per person by 2020, or 18.5 million books, is so vast that it will overwhelm human analysts' capacity to process it.[41] Furthermore, with information in these volumes moving at ever-faster speeds,[42] human analysts won't be able to provide insights in anything like real-time – if there is to be a war-fighting equivalent of Andy Haldane's real-time economic modelling, analysis is going to have to be automated.[43] AI is just mathematics, statistical processes, run through a computer program. It is ideally suited to analysing the kind of big data described in the preceding section. In doing so, it will drive rigour even more deeply into our decision-making.

To automate a function, we first have to make explicit the logic and processes we are seeking to automate. Thus, as an intelligence officer, I might explain how I scan the titles of reports for certain key-words or phrases, rapidly triaging say 30-40 reports (on a good day) from the hundreds of intelligence reports received on a given topic (often already filtered by theme such as a region, state, or technology). From there I might skim read and print – or set aside for reading in depth – say 10-20 of those reports, looking for information that is particularly relevant to my geographic or thematic area of interest, that fits or breaks a pattern or that might indicate, usually in concert with other information, that something such as an attack might take place. Conceptually, we can see that this process could, over time, be largely automated, with an AI, (either expert system or machine-learning algorithm), being designed or trained (or teaching itself) to pick out those things that will be of interest – perhaps even able to spot the patterns in the language from which forecasts and inferences can be drawn. In support of this assertion we might look to the example of local newspapers where AI is already being used to write who, what, where, why and when stories.[44] Demonstrating just how advanced language processing is becoming, the non-profit research firm OpenAI announced in February 2019 that it wouldn't be releasing the new language model their engineers had built as it was writing passages of prose so convincing that its propagandistic potential was too dangerous to risk it falling into the wrong hands.[45] Repurposing language models to identify evidence of 'capability, opportunity and intent', the intelligence officers' mantra used to forecast likely attacks,[46] would begin to deliver intelligence reports of immediate value with no human in the analytical loop. The key deduction here is that in applying a methodology that has mathematics at its heart, there is less room for undefined assumption. Thus, intelligence officers have to think much harder about how they do their jobs and be much more explicit about the logic and evidence underpinning their recommendations.

The same will be increasingly true of commanders' decisions. When recommendations are offered with falsifiable hypotheses they are going to have to be more explicit in describing the logic on which they are based. This should already be the case. As T.E. Lawrence once wrote:

> *Nine-tenths of tactics are certain and taught in books: but the irrational tenth is like the kingfisher flashing across the pool, and that is the test of generals.*[47]

Consequently, nine-tenths of a commander's decision ought to be explicitly evidence based, linked to the data, with explicit assumptions, and formulated in a way that allows metrics to be gathered that are falsifiable.

But the application of the irrational tenth is not an exhortation to apply evidence-free assertion. 'Kingfisher moments' are too often an appeal to this irrational tenth as a commander's genius, in need of no explanation. But really what is being talked of is a commander's deliberate incorporation of the unexpected, or the adoption of a seemingly high-risk high pay-off strategy, manoeuvre or tactic into planning – this is not irrational, it's just commanders calculating the probabilities differently to the adversary and received wisdom, or taking advantage of more effective recursive reasoning (I know that she thinks that I will do X therefore I will do Y, etc): therefore, its logic can be made explicit.

Discussion of 'military judgement' is similar, an appeal to intuition – or the accumulated heuristics and biases developed through involvement in previous conflicts. The problem is, in rigid hierarchies, if a senior commander sees 'Kingfisher moments' as creative genius, it is difficult to question the commander's plan without being seen to question that genius. To use a cricketing analogy, it becomes very difficult to play the ball and not the man since the two have become inseparable. It is only by making the logic of a plan explicit, citing for example the precedent on which it is based, or the recursive reasoning, that challenge can be brought to the plan without challenging a commander's authority. Simply put, in calling for falsifiable hypotheses in RAF planning, the argument is for more science in war.

## Whatever happened to the 'art' of war?

To call for more science in decision-making risks setting up an objection from those who prefer to think of war as an art, placing greater weight on qualitative research. But this is a strawman. The most effective analysis weds ruthless transparency and logic in qualitative decision making to the harder edge of big data analytics and probabilistic inference. This is perhaps best exemplified by investment banker Ray Dalio's concept of 'radical transparency', on which the runaway success of his Bridgewater Asset Management was built – it relies on forcing everyone to surface all the assumptions and logic that underlie any decision, in so doing, Dalio ensured Bridgewater could continuously improve by holding quantitative and qualitative analysis to the same rigorous scientific standards.[48] Perhaps the challenge inherent in complex interactive systems require that we continue to make many decisions based on inferences from qualitative data. We should do this on an empirical basis as soon as possible. As my co-author WO1 John Hetherington and I argued in *APR* in 'Assessing Assessments',[49] we are moving in the direction of doing so already, assigning probabilities to language in qualitative assessment and beginning, in some circles, to more closely examine and isolate the attributes of effective predictive intelligence and mark its accuracy.[50] Adopting the approach advocated, would encourage a more rapid and widespread adoption of such rigour beyond the intelligence staff.

One of my own worries in writing this viewpoint was that it might fall into the determinist trap that caught Defence, and air forces in particular, as science and technology delivered unprecedented advance in sensor capabilities during the 1990s and early 2000s 'Revolution in Military Affairs'. From this, and the concept of 'information dominance', we got the hubristic heights of Szfranski's Neo-Cortical Warfare which conceived of the notion that militaries would soon be able to deliver a form of mind control through bombing.[51] So total would the understanding of an adversary be that an Air Force could hit just the right spots predicting perfectly the effect this would have on the enemy's collective brain and making the outcome of conflict certain.[52] A less hubristic, but no less wrong, over-simplification was Warden's five Rings theory, which understood the enemy as a human body that could be blinded, deafened, paralysed, and not as the complex interactive system that it was.[53] The consequence was Shock and Awe, and the spiralling insurgencies in Iraq and Afghanistan that resolutely refused to be blinded or paralysed and, indeed could never be. We had misunderstood their nature, as I argued in 'Beheading the Hydra', mistaking simplified abstractions for the more complex reality.[54]

These criticisms – of over-simplification, and hubristic determinism – were also levelled at Effects Based Operations (EBO), a more moderate version of neo-cortical warfare and Warden's five Rings model, which simply argued that militaries ought to first identify what the object was in any attack, and then estimate the first, second, and third order consequences of this in order to decide what, when and how to attack.[55] It quickly came to be applied as if the prediction to third order effects and beyond could be undertaken with the same precision available in the accuracy of the bombs themselves, contributing to the chaos in Iraq and Afghanistan and, famously, leading the then Commander of US Joint Forces General James Mattis, to publicly ban the use of the term and employment of the concept, insisting on the need to accept the inherent uncertainty of war.[56]

This was a necessary corrective at the time, but I would argue that General Van Riper, who wrote in support of Mattis' decision, was wrong to claim there was no baby in the bathwater.[57] What we threw out along with the concept of EBO was the framework that forced something akin to Dalio's radical transparency.[58] The key difference between Dalio's Bridgewater and the military here was in culture – in the military, predicting the consequences wrongly led to the abandonment of the framework rather than allowing continuous refinement through the exposure of flawed logic, in their attempt to assert an alternative, the US military and allies threw out the model, demanding the embrace of uncertainty.

But, I'd suggest, embracing uncertainty made it harder to learn, and, more importantly, in my experience, meant that some senior officers no longer felt the need to predict the outcome of an attack, nor to surface the assumptions and logic on which their decisions were based. Rather they could fall back on their own 'gut feelings', their 'military judgement', that enabled them to act in uncertainty.

Today, EBO is finding interdisciplinary support for reasons that precisely contradict the basis of which it was abandoned by the military. Looking at what the combination of big data and AI can teach us about decision-making economists have begun arguing that to operate in uncertainty necessarily requires the formulation of hypotheses and predictions about likely outcomes.[59] Similarly, some psychologists now argue that the ability to form probabilistic predictions about the future may be the very foundation of human intelligence,[60] and therefore of sound decision-making. Prediction – hypothesis driven decision-making - was the baby in the bathwater.

The evidence for how militaries have indeed thrown the baby out with the bathwater, in contradiction of Van Riper's eponymous article, is the awkward efforts that have followed in trying to find something to replace EBO. I would assert that neither multi-domain operations nor the UK's 'Full Spectrum Operations',[61] 'Joint Force Advantage',[62] 'Joint Action',[63] or 'Information Advantage',[64] have the merit of the descriptive and conceptual clarity behind EBO. None are so easily explained and understood. This is not to say they are not useful rallying points around which to re-orientate the Royal Air Force and Defence. Their utility is to re-start effects-based planning with an increased focus on cognitive effects and behavioural-outcomes in the human domain, without EBO's baggage – but we should acknowledge the conceptual debt they owe Deptula.

In arguing that for a data-based approach to decision making in the RAF – and Defence more broadly – this article is calling for a third way, between mathematical determinism and obscurantist reliance on gut feelings, a way of probabilistic prediction, and transparent reasoning, the surfacing of assumptions and logic. The greater hubristic danger lies not in adopting the model of a scientific, data-based approach to Air Force decision-making, but in empowering commanders to believe that all is uncertain and their instincts are therefore more valuable than evidence.

If the arguments presented in this viewpoint are accepted, the RAF will need to address shortfalls in quantitative, that is statistical, analytical skills across the force. Career paths for specialists in the application of the human and behavioural sciences, and big data analytics to warfare will be needed. Doctrine will have to capture the requirement for campaign and operational planning to include the formulation of testable hypotheses designed around the desired behavioural outcomes. Automation will be driven far deeper into decision-support and decision-making functions. Commanders and intelligence staff in particular, but all across the RAF, will have to get much more comfortable with exposing the logic and foundations of their assessments, recommendations and decisions. Before the RAF starts introducing AI, it first needs to bound and limit the human propensity for natural stupidity.

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# Multi–Domain Operations; a Review of Contemporary Concepts and an Analysis of Select Capabilities and Actions of Fighter Command and No. 11 Group during the Battle of Britain

By Wing Commander Jamie Meighan

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**Abstract:** The recent reformation of 11 Gp as the RAF Multi–Domain Operations (MDO) Group has refocused efforts to understand, conceptualize and execute the integration of air, space and cyber capabilities. This article explores the path to deliver the renewed vision of 11 Gp, considering current doctrine, future doctrine, and concept development. In parallel, it seeks to understand how adversaries think about MDO. Finally, it applies one of the MDO models being explored by the USAF and applies it to the actions of 11 Gp during the Battle of Britain. There are many contemporary debates with respect to the way ahead for MDO and the future operating landscape, in considering these as well as the legacy of 11 Gp it is hoped that critical analysis and exploration of multiple concepts will assist the RAF in developing a coherent multi–domain operations strategy.

## Introduction

On 11 July 2018, the Chief of the Air Staff, Sir Stephen Hillier, announced the re–formation of 11 Gp as the RAF Multi–Domain Operations (MDO) Group responsible for the integration of air, space and cyber domains. The Air Chief Marshal described the original Group as 'an early demonstration of the power of multi-domain capability', capable of 'fusing aircraft, communications and decision makers across domains to deliver effects'.[1] 11 Gp under the umbrella of Fighter Command did play a pivotal role in the defence of London and the South East of England employing a combination of capabilities in order to bring clarity from complexity for decision makers. On 1 November 2018, a ceremony at RAF High Wycombe reformed No. 11 Gp, with Air Marshal Stuart Atha, Deputy Commander Operations commenting, 'We live in dangerous times and are being challenged in the air, space and cyber domains. This multi-domain threat demands a multi-domain response and that is at the heart of the 11 Group mission'.[2] During the Battle of Britain the actions of Fighter Command and specifically 11 Gp, with the Dowding System within it serve as a powerful reminder of the importance of historical reflection. In this instance, with hindsight the employment of capability and strategy led by Dowding and Park reflect some of the contemporary components of emerging MDO concepts. For we must not forget, 'if there is one attitude more dangerous than to assume that a future war will be just like the last one, it is to imagine that it will be so utterly different that we can afford to ignore all of the lessons of the last'.[3]

The path to deliver the renewed vision of 11 Gp should stretch further than current doctrine on 'cross-domain synergy' and 'Joint Action', extending into future doctrine, concept development and the enhancement of professional education and training. In addressing these issues, this paper seeks to provide a more thorough understanding of UK higher-level concepts as they relate to current MDO thinking as well as an appreciation of how our adversaries see the future operating landscape. This will likely assist the RAF and the contemporary 11 Gp in their development of current and future MDO doctrine and concepts. Furthermore, a thorough consideration of the UK interpretation of MDO, contrasted with the 6-domain construct taught by the Multi–Domain Operational Strategist (MDOS) Concentration at the USAF Air Command and Staff College (ACSC) will provide a contemporary model for analysis. Significantly, when analysed through the legacy of select Fighter Command and specifically 11 Gp activities, critical assessment and discussion may assist the RAF in developing a coherent multi–domain operations strategy. Finally, assessing and understanding 11 Gp actions, the utilisation of the Electromagnetic Spectrum, manoeuvre in the air domain as well as decision making conditions will provide useful insight. Even more useful when compared to Luftwaffe actions, reactions and decisions. In order to set the context, understanding a common set of definitions and a common lexicon will provide the foundation for more detailed and focused conceptual efforts.

First, in understanding the contemporary environment, the current debate in the US and UK is focused on how a nation's armed force can operate in a complex, contested, chaotic environment against peer adversaries, recognising that actions in one domain can and will have multiple effects in others. The characterisation of the contemporary problems faced is not radically different from the environment in 1940. Complex contemporary questions range from 'What is a domain?', 'What is multi-domain?', 'What are domain dependencies?', 'Can airmen recognise domain dependencies?', 'How can vulnerabilities be exploited?', 'How do forces manoeuvre in an MDO environment?', 'How do you construct MDO plans and strategies?', and 'How do you win in an MDO battle?'[4] While contemporary discussion centres on Command and Control within the MDO environment, the conceptual foundations have yet to fully mature. MDOS teaches the concept of a Continuum of Domains, with a domain defined as 'Critical macro maneuver space whose access or control is vital to the freedom of action and superiority required by the mission'.[5] This focuses on MDO as the interdependency of the Electromagnetic Spectrum (EMS), space, air, land, maritime and human domains; or 'continuum of integrated and interdependent domains',[6] as defined by the MDOS Program Director, Dr Jeff Reilly.

This continuum relies upon the notion of 6 domains, with cyber being encompassed into an EMS domain, alongside space, which enables the more traditional domains, with the ultimate goal of impacting the human domain (the 6th domain). Figure 1 refers. This is a concept that has been at times and partially understood and executed periodically throughout history in some form or another and extends beyond the notion of Joint operations and Joint warfare. The case study presented in the later part of this paper; focused on the Battle of Britain, embodies many of the key elements of the continuum of domains. Whilst some of the technologies had not been created in 1940, such as space, historical reflection shows that, maybe unknowingly, Fighter Command approached the Battle as a multi-domain problem.

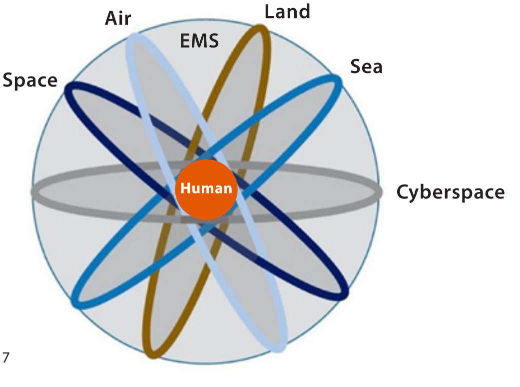


Figure 1: Continuum of Domains.[7]

The concept of a continuum requires critical thinking to deliver effects from, and in, domains, considering and predicting the 1st, 2nd and 3rd order effects of actions and interdependencies, ultimately forcing an adversary to make decisions he would not normally make. Most importantly, it presents opportunities to decision–makers, offering a flexible, adaptive, responsive approach to adversary actions or likely actions that have become more and more unpredictable and non-traditional in scope. Delivering the conceptual art of MDO requires the selection, development and education of specialised personnel capable of using 'combinations of domains to achieve access, control, or destruction of the adversary's interdependence between domains in order to accomplish operational goals'.[8]

In considering the MDOS approach, before considering the historical perspective, we must first consider current doctrinal definitions. In the US and UK, there are currently no agreed definitions of 'domain' and 'MDO'. The definition of a domain does not appear in US Joint Publications, while Multi–Domain in USAF conceptual language within the Air Force Future Operating Concept does not extend beyond air, space and cyberspace combined with command and control.[9] The concept of the continuum of domains extends beyond this interpretation. It sees cyberspace as incorporated into the electromagnetic spectrum. US doctrine defines the electromagnetic spectrum as a 'physics–based manoeuvre space essential for control during all military operations.'[10] The EMS is vital to the enablement of space operations (communications links, Positioning Navigation and Timing GPS–guided munitions, intelligence collection, indicators and warnings), which also directly support air, land and maritime operations. Space includes the earth's ionosphere, magnetosphere and, according to US Joint doctrine, 'electromagnetic radiation, charged particles, and electric and magnetic fields are the dominant physical influences.'[11] The land, maritime and air domains are relatively self-explanatory as the traditional physical dimensions of military operations, built upon with the traditional air, maritime and land services.

Importantly, specialized expertise about each domain should not be seen as equal ownership and control should not be assumed. This stems from the use of the term domain, which itself has links to the term dominance and in broad terms indicates sovereign ownership.[12] Historically, this has been linked to control of land territory, however control of the air, maritime and more recently space and cyber domains presents unique challenges such as environmental conditions, complexity linked to the idea of ownership and access and variations in the use of physical and virtual effects. If we consider the aims and objectives of the Luftwaffe and the RAF, both sought to achieve localized air superiority, in essence seeking to control the air domain. The RAF however, was dominant in the EMS domain. Finally, in this new MDO thinking, the expansion from 5 domains to 6 is a departure from current US doctrine yet should feel very familiar.

The human domain has featured in warfighting for centuries. US AP 3-0 states, 'Fundamentally, all war is about changing human behavior. It is both a contest of wills and a contest of intellect between two or more sides in a conflict, with each trying to alter the behavior of the other side.'[13] Yet no clear definition of the human domain exists. The MDOS continuum of domains concept sees all of the 5 other domains directly impacting the human domain, specifically 'leadership, organizations, and populations in the environment, including their decision making, support, perceptions and behavior.'[14] Through the employment of the strategies of 'deter', 'compel' and 'suasion', winning the contest of wills in the human domain is the only true measure of victory, creating multiple dilemmas for the adversary to attempt to cope with in an attempt to push the enemy into paralysis. This contest of wills was prevalent during the Battle of Britain. Both German and British leadership, as is outlined later, sought to alter behaviors through the employment of capability such as the Dowding system, novel techniques, such as a move from the Big Wing concept and collaborative decision-making and situational awareness seen inside 11 Gp. What then does current UK doctrine offer with regard MDO?

In current UK doctrine, in the absence of the definition of a domain and a clear definition of MDO, it states that the 5 operating domains are air, land, maritime, cyber and space, underpinned by information. Within the information space, activity occurs in the physical, virtual and cognitive domains.[15] A draft NATO definition for a domain is 'Discrete spheres of military activity within which operations are undertaken to achieve objectives in support of the mission.[16] Current and past UK doctrine uses language such as 'Cross–Domain Operations', 'Integrated Action', 'Full Spectrum Operations' and 'Joint Action'. All have varying definitions, some only applying to a single domain.[17] There are undoubtedly elements of the MDO concept in each of these, but none considers or outlines a clear definition of MDO and its components. It is the recent Joint Concept Note 1/17 that provides the best insight into current and UK thinking on MDO–like concepts.[18] From the outset, the narrative highlights the impetus for novel approaches in order to prepare and respond to adversary threats. The focus is on the interdependencies between domains; 'the future force will increasingly need to integrate information and physical activities across multiple domains' that are equally important.[19] JCN 1/17 provides deeper analysis of each of the domains and within this are some encouraging aspects.

In considering the Cyber domain, JCN 1/17 recognises that Cyber and Electromagnetic activities (CEMA) are interdependent, and adversaries will seek to gain advantage using CEMA in all other domains. It also recognises that the freedom to use parts of cyberspace and the EMS will offer 'significant competitive advantage'.[20] This will rely on educated planners and operators capable of integrating CEMA effects and actions, while being able to operate in contested and degraded conditions. In moving towards a clearer UK understanding of MDO, the EMS domain must be at the centre of any future strategy. UK Joint Doctrine Note 1/18[21] provides further insights into the UK's approach in this domain. The UK CEMA vision provides a positive indication of what will be; 'synchronisation and coordination of cyber and electromagnetic activities, delivering operational advantage'. However, a finalised CEMA policy does not currently exist.[22] Any such policy should resist delineating between cyber and EMS, and instead take the opportunity to evolve the concept of a separate cyber domain into an EMS domain in which CEMA happen.

The US has discussed considering EMS to be a domain in its own right. Indeed, the U.S. Navy recently took the unprecedented step of doing just that. In its recognition of EMS, described as 'electronic systems, subsystems, devices, and equipment that depend on the use of spectrum to properly accomplish their function,'[23] it has begun to advance the conversation. There are now senior members of the military and Congress who argue, that, by focusing just on the cyber domain, the US has lost its way in the EMS sphere and must find a way back. As Congressional Representative Don Bacon, (a member of the House Armed Services Committee) has repeatedly said, 'We need to be clear that electronic warfare, the electromagnetic spectrum, is indeed a physical domain. It is a separate physical domain. It's a scientific fact'[24] any future policy should consider the relationship between EMS and Space. As Dr Jeff Reilly points out, the EMS 'empowers space, allowing it to supply key enablers for the domains of air, land and sea, in turn facilitating the ability to influence the human domain.'[25]

Similarly, in the space domain, the UK's JCN 1/7 and JDP 0-30 both recognise how other domains are dependent on space, making it a critical enabler for the three traditional domains of air, maritime and land. Operating within, from and assuring access are all critical components of the space domain in addition to factoring in system resilience and redundancy. JDP 0-30 characterises a 'day without space' as affecting strategic communications, command and control and ISR.[26] While the doctrinal focus on space is encouraging, it fails to present solutions or concepts to meet the challenge of synchronising 'space activity with that conducted in the cyber, maritime, land and cyber domains.'[27] It also outlines offensive and defensive space control measures that it can take to prevent the loss of space capability and maintain space situational awareness. However, it falls short in explicitly highlighting the connective tissue between EMS and space. Without unrestricted access to the EMS domain, the space domain could not function. Without both, the traditional air, maritime and land domains in a future conflict will struggle to operate.

In briefly analysing the traditional domains of air, maritime and land, elements of current doctrine recognise the interconnected nature of actions in and through domains. JCN 1/17 states, 'In their contribution to joint action, maritime forces will support land and air forces with cross-domain logistic support, ISR and power projection as part of a full spectrum approach. The maritime domain is similarly subject to actions from all other domains.'[28] In considering the future operating environment, JCN 1/17 provides an encouraging list of roles and capabilities for maritime projection as well as future systems such as directed energy weapons, hypersonic weapons and autonomous systems.[29] These will all be relevant capabilities in any future MDO peer–on–peer fight. Similarly, JCN 1/17 states that the land domain is a supported and supporting force for the other domains, enabling effective integration and action.[30] Finally, when considering air, JCN 1/7 provides a comprehensive vision of the contested, congested air environment that will be the norm. First, with threat actors gaining access to more disruptive technologies, the prospect of losing control of the air becomes highly likely. Instead, effects and domain awareness inside the air domain will rely upon capabilities from other domains in order to combat complex air defences, passive sensing, hypersonic capabilities and swarming tactics.[31] The delivery of effects will rely on access to, and the ability to mitigate denial within the EMS, as well as sufficient bandwidth to operate.[32] JCN 1/17 designates 'air focus' areas. These are similar to the other domains: operate and command in degraded and denied environments, focus on technologies, seek synergies between platforms and the need for cross-domain integration.[33]

While UK Doctrine does not identify a human domain, it does recognise the importance of influence activities through its approach to Joint Action. Joint Action is a deliberate military approach to 'affect an actor's will, understanding and capability, and the cohesion between them to achieve influence.'[34] A combination of manoeuvre, fires, and outreach and information activities combined can act to deter, coerce, persuade and change adversary behaviour.[35] Recognising this is a key component to a successful MDO, integrated operations or domain superiority will not be sufficient to achieve this. In considering the totality of current doctrine, what becomes apparent is achieving MDO and the integration required on paper is extremely easy to (over) state but in reality is a monumental challenge to execute. Historically the UK has undertaken focused efforts to achieve service integration; Air-Land Integration (ALI) in Iraq and Afghanistan, Air-Maritime Integration (AMI) in Libya, Air Space and Air-Cyber integration as part of the fight against ISIL. Lessons identified from these efforts include a better understanding of co-ordination of forces, command and control, flexibility and tempo, common understanding, effective training and the impact of operating in a contested environment.[36] Sharing Joint doctrine and collaboration with partners and allies to come to common understandings of MDO and an MDO approach is vital, especially now as the UK and its allies must react to an ever–evolving and threatening range of peer and non-peer adversaries.

This transition from a cross-domain strategy to MDO is a reaction to a changing strategic environment. Countries such as China continue to prepare for and deliver elements of their unrestricted warfare doctrine, seeking to use 'all means, including armed force or non-armed force, military and non-military, and lethal and non-lethal means to compel the enemy to accept one's interests.'[37] At the forefront of Chinese thinking is the EMS and the need to dominate it. In 2014, Alan Shaffer, the Pentagon's Research and Engineering Chief, publicly stated that the US had lost its dominance in the EMS.[38] While China in 2015, through its establishment of the Strategic Support Force, formalised its efforts to synchronise activities within the EMS, bringing together Cyber, EW and Space.[39] For the UK, with fewer strategic interests in the Pacific region, China does not represent a competitor state in the same way that the US views it. However, Russia too has invested time and money in EMS, and the UK, with its geographical proximity and its NATO commitments in Eastern Europe, finds itself more relevant to that threat. A report published in September 2017 by the International Centre for Defence and Security in Estonia outlines the challenges members of NATO face as Russia builds on its capabilities in the EMS; a "total package" including capabilities to ensure Russia dominance in the EMS.[40]

Just like China, Russia has embarked on a strategy of maximising the EMS, recognising it as a distinct domain and building structures around it.[41] The UK, like the US, is behind in operating within and maintaining control of the EMS. A recent House of Commons Defence Committee Report has called for additional funding for EMS concluding, 'the UK needs to be in a position to deter and challenge peer adversaries equipped with a full range of modern military technologies who seek to use them in ways that confuse our traditional conceptions of warfare.'[42] In developing a better understanding of the changing strategic environment, EMS as a domain (a combination of Cyber and EW) is surely an urgent necessity. As the then Chief of Defence Staff Sir Stuart Peach articulated, 'to understand, manage and control the electromagnetic environment is a vital role in warfare at all levels of intensity. The outcome of future operations will be decided by the protagonist who does this to decisive advantage.'[43]

With a solid understanding of the contemporary doctrinal and conceptual debates that are ongoing, we reconsider Fighter Command and specifically 11 Gp's employment of MDO concepts consistent with the notion of the continuum of domains. On 1 May 1936, 11 (Fighter) Group re–formed, transferring to RAF Fighter Command on 14 July 1936. In 1940, 11 Gp significantly, was responsible for the Air Defence of London and the South East during the Battle of Britain, using approximately 40% of Fighter Command's assets. This was by far the most operationally active Group during the Battle and therefore provides one of the most complete perspectives when considering MDO. The stated objective of Fighter Command, of which 11 Gp was a key component, was 'to remain in being and offer undiminished and constant opposition, thus denying the Luftwaffe air superiority.'[44] The German objectives were twofold: destroy the RAF as a fighting force and degrade the UK economy by attacking ports and industry.[45] A critical element to meet the objective of Fighter Command and counter the Luftwaffe was the Dowding System, a revolutionary integrated air defence system and ultimately the key element during the Battle of Britain for Fighter Command and 11 Gp from an Electromagnetic dimension.

The Dowding System was the world's first air defensive network, its creation entrusted to Air Chief Marshal Sir Hugh Dowding, Chief of RAF Fighter Command. This system was an interconnected mesh of radars, ground–based observers, barrage balloons, searchlights and anti-aircraft divisions used to provide early warning of incoming air threats flying towards the English coast. In total, nine Chain Home Radar Direction Finding (approximately 30 miles apart), twenty-two Chain Home low–looking radio direction-finding stations, and twenty-four mobile stations were utilised during the Battle of Britain. British scientists had developed these radar systems since 1935. In addition to this, anti-jamming equipment was deployed to prevent German attempts to jam the Dowding system.[46] Integrated into this were sector control rooms, filter rooms, plotter rooms and communication links all directly contributing to 'Fighter Command's situational awareness, survivability, and lethality.'[47] In modern terms, when considering the continuum of domains, Fighter Command and 11 Gp utilised this system as its critical element within the EMS domain to facilitate on–demand access to enable parity of air control. The result was a German leadership that faced frequent decision-making challenges. As German ace General Adolf Galland, who at the time of the Battle was a fighter group commander, stated after the war 'From the first the British had an extraordinary advantage, never to be balanced out at any time during the whole war, which was their radar and fighter control network and organization.'[48]

The assimilation of the data provided to the filter rooms showed the true success of the radar system, heavily utilised by 11 Gp who faced a constant flow of German aircraft from across the channel. In modern terms, filter rooms acted as fusion hubs, combining numerous radar pictures and providing inputs to leverage response options for fighter aircraft. It also had the challenge of determining friendly tracks from enemy ones. Chain radars' maximum range was limited to approximately 120-200 miles, with an average of 80 miles and could provide limited data (range, bearing) for aircraft above 1,000 feet with an approximate 20-minute warning. Chain Home Low radars were limited to 30 miles range and could provide accurate azimuth but not height.[49] Success was much higher during the day then at night. Signals Intelligence and observers acted to pre-empt or confirm the movement of enemy aircraft, augmenting the radar network. Signals Intelligence through the interception of High Frequency radio could provide a 2-hour warning and give insight into aircraft numbers, types and routes.[50] Significantly, the use of Radio Telephony Direction Finding automation from selected friendly aircraft providing ground radar friendly position data contributed to accurate vectoring against the incoming enemy.[51] The employment of the Dowding system, combined with intelligence and fusion in the EMS domain resulted in the ability of Fighter Command and 11 Gp to react and manoeuvre rapidly in the air domain to meet German air raids, employing small formations of assets to affect the enemy, while limiting losses in the air and on the ground. This was a defensive strategy executed by Air Vice-Marshal Keith Park in command of 11 Gp. Park was later described by Air Vice–Marshal 'Johnnie' Johnson, the RAF's leading Second World War ace, as 'the only man who could have lost the war in a day or even an afternoon'.[52] Park executed the defensive strategy laid out by Dowding, partly because of the intimate knowledge of defensive systems and strategy he had gained between 1926 and 1932, while under his command.[53]

In executing this defensive air strategy, focused application by 11 Gp at the squadron level was central to success. The simplicity of the strategy introduced indecision and confusion into the German leadership, sowing seeds of doubt into the German air strategy. The Luftwaffe's tactics from the outset sought to draw the RAF into a decisive battle. Large formations were sent over England with the sole purpose of luring in RAF fighter aircraft, predominantly from 11 Gp. The use of smaller formations of 8-12 bombers with 9-30 escorts sought to achieve this objective.[54] The German leadership had expected a more decisive response from 11 Gp aircraft, but instead faced small but constant piecemeal skirmishes. This approach, with a mere 250 aircraft, had three main objectives set by Park. First, the objectives of his squadrons were to interdict the bomber aircraft destined for airfields and cities. Park recognised that in order to survive, a purely fighter vs fighter campaign would end in disaster. Second, Park recognised that, with limited numbers, his bases in the South were vulnerable and so early and effective interdiction of German bombers was critical. Third, because of a shortage of experienced pilots and recovery means, engagements over land were preferred.[55] Park's strategy was counter to those in command around him (12 Gp for example) who preferred the 'big wing' tactic where numerous squadrons would mass to seek a knockout blow. This, however, was time–consuming and counter to the objective to ensure localised air control, providing just enough to facilitate manoeuvre space.[56] 11 Gp was able to sustain constant pressure on the Luftwaffe through the continuous use of well-directed small-scale packages of fighter aircraft against bomber forces and fighter escorts. In addition to this, 11 Gp had a distinct advantage against the Luftwaffe because the proximity of its airfields to the German threat which had massed in France. Being closer increased RAF reaction time as well as limited the ability of the Luftwaffe to mass large formations before being intercepted or engaged. Through the effective use of the EMS domain (in essence the Dowding System), be that through identification, command and control or jamming, 11 Gp aircraft were able to rapidly concentrate small formations of fighter aircraft, to disrupt German bombers in the air domain, degrade German fighter escorts as opportunity presented, but more importantly strategically delay Operation SEALION, the invasion of the United Kingdom.

In considering the Human Domain, analysis of the distinct leadership approaches and decision-making taken by Dowding and Park in contrast to the Germans' provides useful insight. Dowding and Park shared in their belief about a common strategy and tactical employment of assets based on the assessment that the Luftwaffe would focus its objective on the targeting of Fighter Command. This vision was supported by a fully decentralised command and control ecosystem to support dispersed forces. This was however was not a vision supported by all or communicated well. Additionally, in creating sectors, Dowding thrust Park into a central role with 10 Gp in the Southwest and 12 Gp in the North in supporting roles. The frictions created by this arrangement and lack of clarity in communication by Dowding had the potential to undermine the overall vision. In particularly, Air Vice-Marshal Leigh-Mallory commanding 12 Gp (who had wanted to be 11 Gp Commander) believed he had more time to react and thus could use different tactics to attempt to shoot down as many aircraft as possible. He also believed that his tactics be employed by all Gp's. This was never to be the case.[57]

Because of the tempo and geography of the battle that Park and 11 Gp faced, over the course of the Battle, he issued 35 instructions to his Group a significant number in comparison to his peers and his way of ensuring a common understanding of the operational picture as well as his intent. Significantly, instructions were not orders, as per British military regulation, and therefore were open to interpretation as the operational environment required.[58] This afforded latitude in Mission Command and significantly increased the speed of information sharing throughout the defensive network. Park, supported by this ecosystem, executed a strategy designed to make the Germans 'give up if he becomes convinced that he is getting nowhere.'[59]

In contrast was the German organisation and demeanour. In 1940, the Luftwaffe's Head of Intelligence, Major Josef Schmidt, surrounded himself by staff that he hand–selected but were sub–standard in capability. His team issued a series of reports to the General Staff indicating that the Battle of Britain could not only be won, but would be a total pushover. Reports provided on 2 July 1940 painted a picture of inferior aircraft, limited operational airfields, a small-scale aircraft industry and an inflexible command structure. It also suggested that Britain's air defences were weak, which was a significant miscalculation.[60] Most significantly, on assessing radar, ten separate agencies all contributed to an assessment but failed to share their findings; this was a highly effective system that if not dismantled was likely to create significant challenges to the Luftwaffe.[61] Yet in 1940, the German Luftwaffe lacked a clear air strategy against the UK. Göring and subsequently Hitler provided broad guidance to include targeting aircraft, ground supply, factories, and people in order to gain air superiority. The Luftwaffe was also to be prepared to support Operation SEALION.[62] Even when Göring launched Operation ADLERANGRIFF (Eagle Attack) and issued his initial attack directive, the objectives were broad in nature, undermined by continuous over-estimation of German capability in relation in the RAF. Significantly, this meant an underestimation of the significance of radar and the vital role it would play in preventing German success. As one German officer stated, this lack of clarity about the complexities of a strategic bombing campaign as well as gaining air superiority was just 'romantic warfare'.[63]

It is unsurprising that the German reaction to encountering the Dowding system was disbelief, surprise and upright arrogance. They had anticipated an inflexible system, prone to mass attack. Yet, during the Battle of Britain, the actions of Fighter Command and specifically 11 Gp supported by the Dowding system not only acted as an accelerant to German attrition: they also created havoc in the leadership of the Luftwaffe. Poorly organised for an offensive counter air–fight or a meaningful strategic bombing campaign, and presented with poor intelligence, the German leadership were unable to confirm if its bombing efforts were rendering Fighter Command inoperable or weakening defences in Southern England. It therefore continued to fight.[64] Over–inflated estimates of aircraft destruction aligned with optimism in the early stages that 'the RAF would be neutralised in some two to four weeks', added to the confusion that followed.[65] In contrast to the broad unity of command displayed by Dowding and Park, the German leadership lacked co-operation and co-ordination, and was blighted by rivalry.[66] Officers frequently embellished reporting provided to Göring. Overall, the German leadership in the Luftwaffe did not know what was going on. Significantly, the Luftwaffe did not fully grasp how the UK radar network operated. The inability of the Luftwaffe to destroy radar masts, poor intelligence assessments about sub surface operations rooms and a lack of accurate Battle Damage limited damage to the RAF radar network.

This was not to say that the Germans did not attempt to use the EMS and develop their own radar system. The success that this could have yielded was deeply limited by a doctrinal focus on offensive destruction of the enemy and its aircraft on the ground, vice the employment of a defensive network.[67] Between 1936 and 1938, Germany had tested radar out to a range of 120km. Between 1937 and 1939 they created a coastal chain radar system that could have been highly successful if they had sought active integration into the wider military command and control network.[68] The Germans also attempted to employ radar in France in the initial stages of the Battle, but failed to maximise radar to monitor RAF reactions.[69] In addition to this, the utilisation of radio beam technology called 'Knickebein' sought to improve targeting at night, which initially was extremely effective, although ultimately the development by RAF Intelligence of a means to detect this resulted in the capability being routinely jammed.[70]

Adlertag 'Eagle Day', which began on 12 August 1940, was Göring's effort to refocus on gaining air superiority as well as targeting the Royal Navy in order to set the conditions for Operation SEALION.[71] 12 August 1940 and the days immediately after it, serve as a good example of a specific part of the Battle of Britain in which both sides sought to maximise manoeuvre within the EMS domain, providing cueing for air assets, while seeking to compel the other side to over-commit and be drawn into further air attrition. The Luftwaffe expected this to be 'the beginning of the end of Fighter Command.'[72] A Luftwaffe operational trials wing, Erprobungsgruppe 210, was formed using BF109 fighter-bombers to conduct focused attacks against UK targets, specifically radar sites. Attacks began against the Ventnor radar site on the Isle of Wight, as well as five other airfields including Manston, Hawkinge and Lympne. What followed was a package of almost 500 bombers and fighters (in loose escort) heading for Portsmouth.[73] Yet, radar, whilst degraded, was able to identify and help vector fighters to respond and, more importantly, could be regenerated quickly when damaged. This showed the Luftwaffe pilots that they were detectable from the moment they launched, observed by what some called 'the evil eye of these invisible signals.'[74] While Luftwaffe fighters circled craving a decisive engagement, Park launched attack after attack against bombers with devastating results.

On 15 August, known as 'Black Thursday' by the Luftwaffe, 75 aircraft were lost against RAF losses of 34.[75] The Luftwaffe leadership refused to accept the reality of the situation and, playing into Park's hands, felt compelled to provide a surge of fighter sweep and fighter escort sorties. German leadership called by Göring, fought to explain how Eagle Day had been such a disaster. Attacks by Unit 210 against radar sites failed in planning and execution. It was highly unlikely an attack would destroy a radar site, but persistent daily attack could assist in disrupting it. Attrition rates of the Stuka bomber force further compounded the task. Göring responded by calling for even greater numbers of fighters to protect the Stuka bombers (ratio of one Stuka wing to three Fighter wings) in essence stretching their remaining force even further. He eventually stopped using the Stukas entirely. He provided further instructions that included limiting attacks on radar stations airfields that were attacked on the previous day, as he did not believe the attacks were having a significant effect.[76] On 20 August 1940, orders to the Luftwaffe were to launch continuous attacks against the RAF on the ground, as well as industry and ports in an attempt to provoke the RAF into prolonged battle. The Germans were never able to assess the impact of this strategy, but the losses continued to mount for the Luftwaffe.[77] The Luftwaffe had 25% more aircraft shot down than the RAF as well as seven times the rate of aircrew killed. Inaccurate intelligence assessments further complicated decision-making. Intelligence assessed that by the end of August 1940 the RAF only had 100 fighter aircraft left, when in fact the number was close to 700.[78]

Göring's lack of strategy as well as his overconfidence and egotism had directly contributed to the survival of Fighter Command and 11 Gp.[79] He had also created a divide within his own organisation; tensions between fighter and bomber units, compounded by his own self-interest and preservation, prevailed. In comparison, Dowding and Park had developed a strategy that used EMS to detect aircraft, combined with focused, selective fighter engagement within the air domain mainly against bombers to force a change in behaviour by the German leadership. In England, morale of the population was high, as news of the limited RAF losses of aircraft and pilots spread as well as the mounting German losses. The Germans lost more aircraft in the week of 12 Aug 1940 than in the entire previous month.[80] Validation of the Dowding system was supported by the decision making of Park and actions of 11 Gp. By September 1940, as sortie rates for Luftwaffe fighter pilots rocketed, morale quickly slumped. Unlike the rotations to the north of England that Dowding and Park were able to make for aircrew, there was limited respite for the Luftwaffe crews who began to lose a sense of purpose.[81] In being compelled to surge aircraft, the Luftwaffe failed to stop Fighter Command, failed to gain the air superiority needed for Operation SEALION, and changed targeting strategies.[82] 15 September 1940 now remembered in Britain as 'Battle of Britain Day' reminded the Germans that Fighter command and 11 Gp were alive and well. Park scrambled 170 Hurricanes and Spitfires to meet a raid destined for London.

The actions of Fighter Command and specifically 11 Gp undoubtedly contributed to the ultimate outcome of a German defeat during the Battle of Britain, especially with the majority of air activity taking place in and around London. Figure 2 provides a graphical representation of how the interdependence of domains as part of the continuum model resulted in an effect on German decision-making, the Luftwaffe leadership and operators, as well as the perceptions of the German population. Much has been made of German equipment shortfalls, especially the lack of a strategic long-range bomber.[83] Even with a strategic bomber, bombing accuracy would have remained an issue and more significantly, the tactics and techniques employed by 11 Gp would have remained unchanged. The Luftwaffe failed to concentrate on the relevant Centre of Gravity, which was Fighter Command and specifically the Dowding system, Command and Control, aircraft and pilots.[84] Intense, sustained attacks against radar sites and Sector Operations Rooms may have resulted in a different outcome. However, as evidenced by

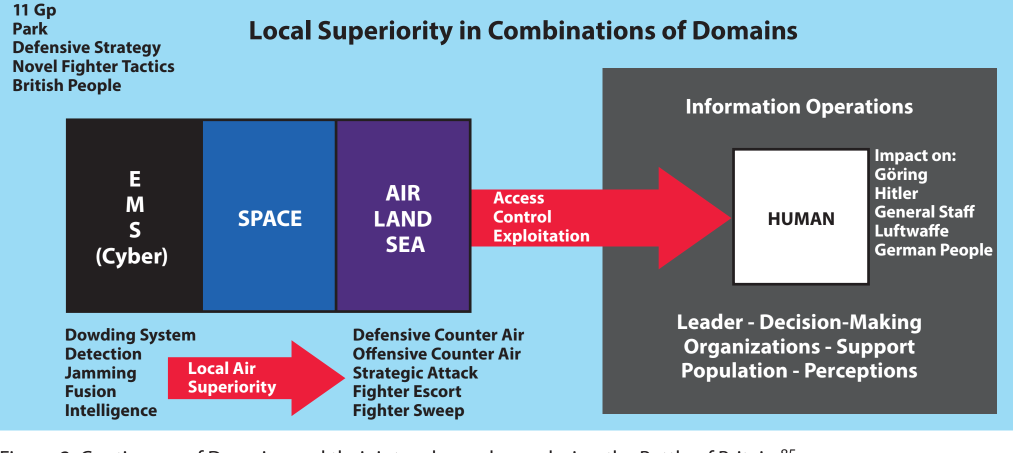


Figure 2: Continuum of Domains and their inter-dependence during the Battle of Britain.[85]

the erratic actions of Göring, a lack of informed strategic decision-making is likely to have been one of Germany's greatest shortfalls. In considering the role of radar within the EMS, employed to facilitate Fighter Command's strategy, the RAF and German leadership made decisions in two very different ways.

The Cynefin Model or framework (Figure 3 refers)[86] helps leaders to determine context to characterize a problem or situation in order to make appropriate choices or decisions.[87] The model makes it possible to try to explain some of the effects that the exploitation of domains had on British and German leaders and organisations within the Human Domain during parts of the Battle of Britain. The Cynefin model, presents five components: simple, complicated, complex, chaotic and disorder. These represent ordered on one side (simple and complicated), unordered (complexity and chaos) the other and disorder in the middle.

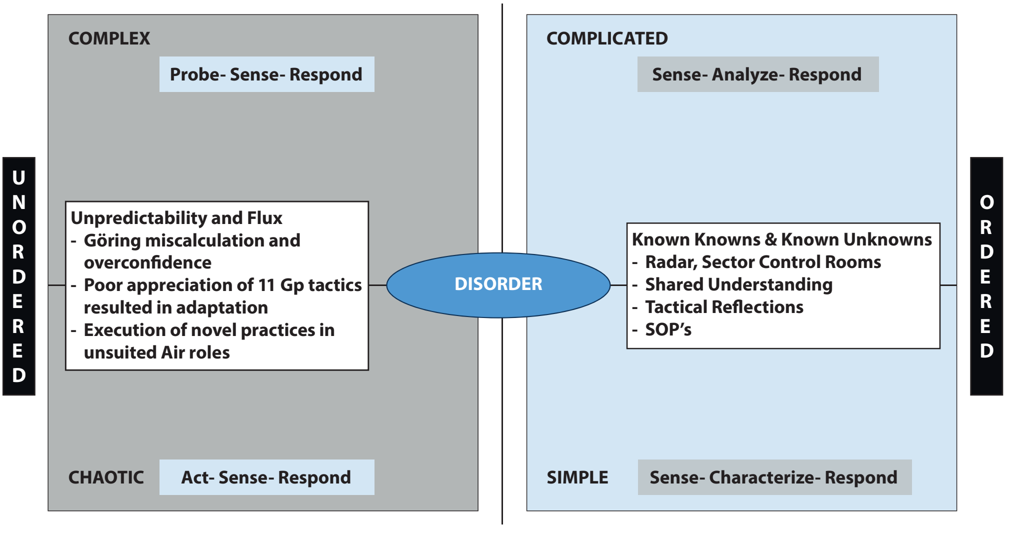


Figure 3: Cynefin Model and decision making during the Battle of Britain.

In considering the actions of 11 Gp and the Battle of Britain, Park, within the human domain was able to retain a high degree of decision making order. If we consider the decisions made within 11 Gp, much of the activity of the network of radar stations, sector control rooms and observers falls somewhere between the realm of simple and complicated, i.e. 'known knowns' and 'known unknowns'. These components are characterized by leaders who 'sense, categorize, and respond' on the one hand, and 'sense, analyze, and respond' on the other.[88] Park and his command of 11 Gp centered upon shared understanding and the ability to respond using established operating procedures and developed practices. In the shadow of particularly demanding days, Park was able to spend time analyzing how the system responded to the German threats and improve best practice if needed. On 13 September, with a period of bad weather, he spent time reading combat reports, synthesizing tactics and communicating his observations to his Sector Station Commanders.[89] The Public Record Office is full of other examples, such as memorandums, communications and tactical reflections shared routinely with units and stations.[90] Park, over a period of five months, was able to anticipate his adversary's moves and react quickly and decisively, earning him the title 'Defender of London'.

In contrast, the Germans lacked insight and knowledge of the RAF and the tactics and techniques that Park would employ. Göring miscalculated the importance of the EMS, specifically radar, in enabling Fighter Command operations. Göring's overconfidence meant a shift away from a tactical support to land role that the Luftwaffe had performed so well previously, to a move toward strategic bombing in which the Luftwaffe had limited training, techniques and procedures. Further compounding these miscalculations was an arrogant, divisive and controlling leadership style in which tactical commanders who were Subject matter experts, were prevented from contributing to the decision making process. Göring viewed the attack on England as his battle, and in preparing for this failed to appropriately analyze and direct what to target, how to target and failed to gain local air superiority to allow the invasion of England to begin. This lack of understanding meant that Göring spent most of the Battle of Britain in complexity, creating 'unpredictability and flux' as well as routinely 'seeking to impose a course of action' on his subordinate commanders.[91] The inability to adapt to the situation as it unfolded, in part because of the actions taken by 11 Gp led by Keith Park, resulted in poor decision making.

From a poor starting point, the Luftwaffe's limited understanding of Britain's defensive network, aerial tactics, nature of targets, knowledge of the aircraft industry, and RAF fighter tactics served to push Göring into crisis mode. As Eagle Day showed, Göring was unable to 'act to establish order' and respond to the situation he and the Luftwaffe faced.[92] He could not identify a way to counteract Park's fighter intercept policy; his bomber force was experiencing high levels of attrition and he was making mistakes. On 30 August 1940, partly in response to the continued bombing of Berlin (itself a response to an accidental German raid on London), Hitler lifted the ban on attacking London with the first attacks on 7 September. Göring had the chance to disagree, but did not. By 15 September, with raids continuing day and night, the Luftwaffe reached a tipping point. By 30 September, because of aircraft attrition, German attacks all but stopped. The shift of focus away from Britain's Centre of Gravity – i.e. Fighter Command, was a strategic blunder, relieving pressure on Dowding's forces.[93] Hitler had not followed the assessment provided by the Luftwaffe Operations Group before the war in which they declared, 'because of the increasing strength of the air defences, no decision could be hoped for by terror attacks on London. On the contrary, such attacks [are] more likely to produce the opposite effect and undesirably strengthen the national will to resist'.[94] Ultimately, the decision to shift focus was in part, because 11 Gp and Fighter Command were able to dominate the EMS, preventing the Luftwaffe from gaining air superiority over the UK and sending the Luftwaffe into disorder. The Luftwaffe showed that once in disorder, sensemaking and decision making becomes extremely difficult to achieve as indicators of disorder are less obvious and if decision makers do not adjust it is easy to remain stuck in ambiguity and uncertainty.

MDO is greater than just the physical elements of fusing information, command and control or providing data to decision makers. Focusing on the physical linkages enabled by technology is the easy part of the MDO journey. Re-evaluating current definitions and doctrine provides an opportunity to understand how to leverage the relationships between domains as a whole, as well as the ultimate goal: to shape the human domain. Renewing the historical vision of 11 Gp during the Battle of Britain through the lens of MDO current thinking shows how air power thinkers have already been considering and exploiting these relationships. Understanding the relationships between domains, how to access, exploit and control dependencies between domains and how to directly affect decision makers, is an art and not a science. There are numerous historical examples of MDO in action. The actions of Keith Park and 11 Gp during the Battle of Britain allow for basic analysis that provides a glimpse of the simplicity and complexity of MDO. Developing a UK, Service-specific, Joint and allied MDO conceptual framework, organisational framework and strategy is not easy. Our adversaries, however, are unlikely to repeat Göring's mistakes. We must therefore accept the challenge just as the leaders of 11 Gp and Fighter Command did in 1940.

## Notes

[1] https://www.raf.mod.uk/what-we-do/centre-for-air-and-space-power-studies/documents1/speeches-apc18-cas-keynote. Accessed on 10 August 2018.

[2] https://www.raf.mod.uk/news/articles/historic-11-group-reforms-for-multi-domain-challenges. Accessed on 10 December 2018.

[3] J C Slessor, Air Power and Armies, (Oxford: Oxford University Press, 1936), x.

[4] The recent Air Forces Association Conference in Sep 18 in Washington DC, focused on Multi Domain complexity. The RAF is currently beginning to explore MDO concepts as part of the establishment of No. 11 Gp.

[5] https://othjournal.com/2018/09/17/defining-the-domain-in-multi-domain. Accessed 13 Jan 2019.

[6] Jeffrey M. Reilly, "Multidomain Operations," Air & Space Power Journal (ASPJ) 30, no. 1 (Spring 2016), 61–73, http://www.airuniversity.af.mil/Portals/10/ASPJ/journals/Volume-30_Issue-1/V-Reilly.pdf.

[7] The online journal Over the Horizon based at Air Command and Staff College has provided permission to print this diagram.

[8] https://othjournal.com/2018/06/27/nato-planning-and-multi-domain-operations-a-german-perspective/. Accessed on 20 November 2018.

[9] U.S. Air Force, Air Force Future Operating Concept: A View of the Air Force in 2035, Washington, D.C., September 2015, 14.

[10] Joint Publication (JP) 6-01, Joint Electromagnetic Spectrum Management Operations (Washington, DC: Office of the Secretary of Defense, 2012), I-1.

[11] Joint Publication (JP) 3-59, Meteorological and Oceanographic Operations (Washington, DC: Government Printing Office, 2016). Accessed October 7, 2018. http://www.dtic.mil/doctrine/new_pubs/jp3_59.pdf. GL-5.

[12] Webster dictionary defines a domain as 'complete and absolute ownership of land'

[13] https://www.otc.army.mil/ADP3-0.pdf, 2. Accessed 20 October 2018.
[14] OTH online Primer https://www.youtube.com/watch?v=NE6BVmxAYMs&feature=youtu.be. Accessed 20 September 2018.
[15] Joint Capability Note 1/17, Future Force Concept. Accessed 10 September 2018. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/643061/concepts_uk_future_force_concept_jcn_1_17.pdf.
[16] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/732503/20180803-doctrine_uk_terminology_JDP_0_01_1_2018.pdf.
[17] There is not an exhaustive list of former and current definitions, although each of these is focused toward integration of effects. Joint Action in JDP 3-00, 3rd Edition, Change 1 is defined as "The deliberate use and orchestration of military capabilities and activities to realise effects on an actors' will, understanding and capability, and the cohesion between them to achieve influence".
[18] Joint Capability Note 1/17, Future Force Concept. Accessed 10 September 2018. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/643061/concepts_uk_future_force_concept_jcn_1_17.pdf.
[19] Ibid.
[20] Ibid, 3.
[21] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/682859/doctrine_uk_cyber_and_electromagnetic_activities_jdn_1_18.pdf.
[22] Ibid.
[23] https://defensesystems.com/articles/2018/10/24/navy-electronic-warfare-williams.aspx?m=1. Accessed 19Jan 2019.
[24] https://breakingdefense.com/2017/11/spectrum-ew-should-be-a-warfighting-domain-rep-bacon/. Accessed 19 Jan 2019.
[25] Jeffrey M. Reilly, "Multidomain Operations," Air & Space Power Journal (ASPJ) 30, no. 1 (Spring 2016), 61–73, http://www.airuniversity.af.mil/Portals/10/ASPJ/journals/Volume-30_Issue-1/V-Reilly.pdf.
[26] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/668710/doctrine_uk_air_space_power_jdp_0_30.pdf. 73.
[27] JCN 1/17, 27.
[28] Ibid, 30.
[29] Ibid.
[30] Ibid, 36.
[31] Ibid, 43.
[32] Ibid, 44.
[33] Ibid, 47.
[34] Ibid, 5.
[35] Ibid, 6.
[36] Examples of this can be found in a variety of publications including:

https://www.raf.mod.uk/what-we-do/centre-for-air-and-space-power-studies/documents1/delivering-effective-air-land-integration-ali-in-the-next-war-what-enduring-lessons-can-uk-defence-draw-from-historical-and-contemporary-operations-to-generate-and-maintain-an-efficient-joint-/.
https://www.rand.org/content/dam/rand/pubs/reports/2008/R4045.pdf.
https://medium.com/raf-caps/integrating-cyber-with-air-power-in-the-second-century-of-the-royal-air-force-bca74b8d42ed.
https://www.airuniversity.af.edu/Portals/10/AUPress/Books/B_0105_BROWN_SPACE_POWER_INTEGRATION.pdf.

[37] Qiao Liang and Wang Xiangsui. (1999). Unrestricted Warfare. PLA Literature and Arts Publishing House, Beijing. Downloaded from http://www.terrorism.com/documents/unrestricted.pdf. Accessed 7 September 2018.

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[39] https://www.c4isrnet.com/home/2017/06/08/dods-annual-china-assessment-shows-growing-cyber-ew-capabilities/. Accessed 7 September 2018.

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[41] Ibid, 10.

[42] https://publications.parliament.uk/pa/cm201719/cmselect/cmdfence/818/81807.htm. Accessed 19 January 2019.

[43] JDN 1-18, 2.

[44] Stephen Bungay, The Most Dangerous Enemy (London: Aurum Press, 2000),192.

[45] https://www.raf.mod.uk/what-we-do/centre-for-air-and-space-power-studies/documents1/air-power-review-vol-18-no-2-battle-of-britain-75th-anniversary-special-edition/. 143. Accessed 26 July 2018.

[46] Bungay, The Most Dangerous Enemy, 65.

[47] Paul M. Kennedy, Engineers of Victory: The Problem Solvers Who Turned the Tide in the Second World War, 1st ed (New York: Random House, 2013), 93.

[48] https://www.rafmuseum.org.uk/documents/Research/RAF-Historical-Society-Journals/Bracknell-No-1-Battle-of-Britain.pdf. 10. Accessed 10 September 2018.

[49] https://www.raf.mod.uk/what-we-do/centre-for-air-and-space-power-studies/documents1/air-power-review-vol-18-no-2-battle-of-britain-75th-anniversary-special-edition, 89. Accessed 26 July 2018.

[50] Tony Devereux, Messenger Gods of Battle (London: Brassey's Ltd., 1991) 124-5.

[51] https://www.raf.mod.uk/what-we-do/centre-for-air-and-space-power-studies/documents1/air-power-review-vol-18-no-2-battle-of-britain-75th-anniversary-special-edition, 92. Accessed 26 July 2018.

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# Lost In Space: The Defeat of the V-2 and Post-War British Exploitation of German Long-Range Rocket Technology

By Wing Commander Bryan Hunt

**Biography:** Wing Commander Bryan Hunt was born in New Zealand. He read hydrology at Auckland University and International Relations and Law at Cambridge University. Following service in the RNZAF he transferred to the RAF as a specialist works officer. He subsequently transferred into defence engagement, serving in Italy, Germany and Turkey, operating in the British Embassy Ankara during his previous tour. He attended Staff College in Rome and Istanbul and served operationally in the Balkans, Middle East and Afghanistan. He has previously written articles on counter-insurgency intelligence, air power and psychological warfare, and on the failed Gallipoli campaign.

**Abstract:** In September 1944 the United Kingdom became the first country in history to be subject to a sustained ballistic missile campaign. The V-2 rocket was the culmination of a 20-year research programme in Germany, but the operational history was less than seven months and had no appreciable impact on the outcome of the war. Countering the missiles was a two to three-year British intelligence priority but despite the seismic technological change the missiles heralded, Britain remained cautiously interested in exploiting the technologies and the scientist behind them. This was, arguably, to cast a long shadow over British space ambitions and strategic capabilities. This paper considers the developmental and operational history of the V-2 from both an operational and intelligence perspective, and then considers the challenges - and outcomes - of taking advantage of the technologies, set against a background of post-war austerity and competing strategic requirements.

## Introduction
## Battle of London is over…sort of

On the evening of 7 September 1944, Duncan Sandys MP, chair of the government rocket and flying bomb countermeasures 'CROSSBOW' committee, confidently announced that the Battle of London, comprising the V-1 flying bomb attacks, was now over and that the public could now relax, and because of Allied advances through northern France, discounted the apocalyptic predictions of 'rocket' (ballistic missile) attacks. The fear of these attacks had caused the Home Secretary, Herbert Morrison (1888 -1965), grave concern because of alarmist intelligence assessments of the size of warheads and predicted scale of attacks.[1] Starting in August 1943, Bomber Command and the US 8th Air Force had bombed research sites in Poland and dropped 120,000 tons of bombs on the monumentally large reinforced-concrete 'large sites' and 'rocket projector' sites on the Cherbourg Peninsula in northern France and in Belgium that were believed to be crucial to the operational deployment of long-range rockets.[2] Allied forces had now overrun the distinctive, curved assembly and launch 'ski site' buildings where V-1 flying bombs had been launched at Britain. The Chiefs of Staff Committee also believed that all potential rocket launch sites were now in Allied hands. However, a scant 24 hours later, a mysterious explosion occurred in Chiswick, west London, killing three people and injuring a further 20. A second similar explosion occurred a few seconds later in Epping, though with no casualties. Described officially as "gas leaks", these explosions heralded the first ballistic missile attack on the United Kingdom. The weapon was the A4, a 46 ft/14 m high single-stage liquid-fuelled rocket carrying a one ton high-explosive warhead. The A4 – *Aggregat* (experimental) Bombardment Rocket and later renamed by the Nazi Propaganda Ministry and universally known as the V-2 (*Vergeltungswaffen* - vengeance or retaliatory weapon) - had been launched from a mobile position in The Hague, in the occupied Netherlands.[3] It took just under five minutes to travel the 200-odd nautical miles to southern England. Although the British Government maintained the story of gas leaks for several weeks on security grounds, it was recognised across Whitehall that this was the commencement of a ballistic missile (code word:'BIGBEN') bombardment that had been expected – and feared - from late 1943.[4]

## Origins of the V-2

The A4 had been developed in great secrecy at purpose-built research facilities at the German Army Rocket Research Centre on the Baltic peninsula of Peenemünde, near the Polish town of Świnoujście.[5] The origins of the A4 can be directly linked to Germany's defeat in the First World War. The Versailles Treaty of 1919, which formally ended the Great War, imposed severe limitations on the rearmament of Germany, including the realms of artillery. To avoid these restrictions, covert research and rearmament commenced in the early 1920s, and contrary to popular belief, a decade before Hitler came to power. However, under the National Socialists, defence research and development 'was accentuated' and disinformation was used to disguise the true purpose of military materiel and technical developments.[6] Encouraged by Hermann Oberth (1894-1990), an astrophysicist and space-flight visionary, who had established links with the National Socialists in Munich in the 1920s, amateur rocketry clubs were formed with state sponsorship.[7] By the 1930s, German scientists and engineers led in the field of ballistic rocketry to circumvent the ban on large calibre/long-range artillery. One of Oberth's students was a talented engineer, Wernher von Braun (1912-1977). On completion of his doctorate on liquid-fuel rockets in 1933 (and through Oberth's influence), von Braun was recruited by Colonel Walter Dornberger (1895-1980), the German Army's Director of Artillery, and put to work developing long-range artillery rockets. The pinnacle of these developments was the liquid-fuel propelled *Aggregat 4* and first successfully launched – after many setbacks – on 3 October 1942. Whilst Dornberger organised the development programme and marshalled military support and resources, von Braun used his charm, his technical knowledge and political astuteness to secure advancement and funding – and ultimately the endorsement from a doubtful Adolf Hitler – to turn an expensive and esoteric research programme into a new weapon of war.

The British Joint Intelligence Committee (JIC) was aware of a nascent rocket programme from 1942 (although intelligence pointing to a rocket weapons programme had been around since 1939) but understanding the extent of the programme and defeating it proved to be challenging. This lack of understanding was down to tensions across the scientific intelligence community, but through a combination of a dedicated intelligence-led investigation, involving photographic reconnaissance and signals intelligence, coupled with heroic espionage by the Polish Resistance movement, "torpedo like objects 38 feet [12m] long" were discovered confirming British suspicions of German development of 'remotely controlled pilotless aircraft", even though the items that were seen were probably long-range rockets.[8] This led to the Royal Air Force (RAF) conducting a devastating 600-strong bomber raid on Peenemünde on night of 17/18 August 1943 (Operation HYDRA), with a loss of 41 aircraft. Unknown to the RAF, Peenemünde consisted of two separate (and rival) research institutions. The V-1 was being developed by the *Luftwaffe* at Peenemünde West, along with rocket powered aircraft such as the ME-163 *Komet*, whereas long-range rocketry at an adjacent and larger site was being carried out by the German Army. Although research laboratories were largely undamaged, the destruction of production workshops and logistics facilities and the loss of several key propulsion staff, along with much of the housing, resulted in the near-immediate relocation of A4 production and some test facilities to underground centres.[9]

After the raid, which RAF Bomber Command thought had delayed the programme by four to six months, research continued at Peenemünde and at sites in Blizna, Poland, about 550 miles/900 km south east of Peenemünde. Although the damage was extensive, Dornberger (by now a Major General) believed that the delay in research and development was only four to six weeks, and elaborate camouflage techniques were applied to make the site appear abandoned.[10] Production moved to a former gypsum mine near Nordhausen in central Germany. A state-owned company was established for production of the V-2, with staff brought in from the engineering companies of Siemens and AEG, under the dynamic, yet deranged leadership of Gerhard Degenkolb (1892-1954).[11] Other major sites included the

Zeppelin Works, near Friedrichshafen, on Bodensee (Lake Constance), with sub-components built across Germany. The Nordhausen mine, which ultimately expanding to include several forced-labour camps, including the notorious 'Dora' camp, was known as '*Mittelbau*' (also known as '*Mittelwerk*'). Here A4 designs were put into industrial-scale production and testing, prior to the completed V-2 missiles being moved to launch sites. Reports vary, but it is thought that between 15,000 and 25,000 slave workers died at *Mittelbau-Dora* due to appalling living conditions and brutal treatment.

After the July 1944 assassination attempt against Hitler, on 8 August, Heinrich Himmler ordered that the V-2 programme was to be taken from German Army control[12] and moved across to the SS, under *SS–Obergruppenführer* Hans Kammler.[13] Kammler then directed production and V-2 operations from September 1944, whilst issuing up to 100 'ignorant, contradictory, irreconcilable' telegrams a day, and in doing so arguably damaging development, production and deployment of the weapon system.[14] From early 1945, Kammler also took over from the German Air Ministry and the *Luftwaffe*, direction of the V-1 programme, in addition to oversight of all jet aircraft production.

## Rocket in a Bottle?

Debate amongst intelligence and scientific circles raged for 18 months, from early 1943 until autumn 1944, as to the size, range and potency of the rockets. This was only partially resolved when the first rocket landed to the west of London. The arguments were fierce and obtuse. Churchill's friend and scientific advisor, with the sinecure of Paymaster-General, was the German-born and irascible Professor Frederick Lindemann (1886 – 1957, later 1st Viscount Cherwell).[15] He was convinced that no single-staged liquid-fuelled rocket could reach out 150 – 200 miles and assumed (and contrary to the scientific intelligence and Allied research and development) that such a device would be launched from a projector – akin to launching a sky-rocket from a milk bottle. His protégé, Dr Reginald Jones (1911 – 1997, known universally as 'RV Jones'), who had been appointed to the Air Ministry in 1939 as a scientific advisor and in February 1941 became Assistant Director of Intelligence (Scientific Intelligence), challenged this and interpolated from scant intelligence and scientific input, that a liquid-fuel rocket could deliver up to a ten ton warhead on London. He was later to revise this in 1944 to a 12-meter-long body with a one ton warhead. Although Jones reported to Assistant Chief of the Air Staff (Intelligence), he combined this role with a more covert position as a scientific adviser to the Secret Intelligence Service (SIS/MI6), giving him immediate and privileged access to intelligence reports from agents[16] and ULTRA decrypts – intercepts of sensitive Nazi radio communications that had been encrypted using the Enigma machine encryption system.

Duncan Sandys MP, a former artillery officer and Financial Secretary to the War Office who led the BODYLINE committee established to counter the rocket threat, used his political acumen to persuade the government and the Chiefs of Staff of the threat. But Lindemann was bullish and to prove his theories on the method of launching long range rockets were right, he convinced the Chiefs of Staff, and in particular, the Chief of the Air Staff, Air Chief Marshal Sir

Charles Portal (1893-1971), probably with the intervention of Churchill, to search for these mythical projectors on the Cherbourg peninsula and around Calais. Many sites were incorrectly identified as rocket projector sites and received the attention of Bomber Command and the USAAF from August 1943 to early 1944. Post-war analysis showed that the heavy bomber campaign had almost no impact on the eventual operational deployment of the V-2, because of the rapid advance of Allied forces through France, coupled with delays in producing an operational variant, the missiles were not to ready to deploy in large numbers – from mobile convoys – until September 1944, and that the vast concrete structures were unlikely to have been used.[17]

Lindemann also remained unconvinced that the German war machine would invest so heavily in what he saw as a grossly inefficient and inaccurate weapon, given competing operational requirements and set against a deteriorating war situation. However, from 1939, the Nazi leadership – principally through the Propaganda Minister Josef Goebbels – had promised 'secret' weapons that would win the war and destroy 'England'. The V-2 was a manifestation of Nazi technological supremacy and a symbol of raw, unfettered power; as the situation deteriorated Hitler, who had initially been unconvinced by the V-2, saw the missile as a panacea to defeat the British, given that there were no defences against it.[18]

In addition to coping with Lindemann's bullying behaviour and his frequent attempts to undermine the BODYLINE Committee, the team had to contend with a dizzying array of conflicting intelligence. For example, a JIC paper on 'German Long-Range Rocket Development' dated 21 April 1943 variously reported that the rocket had been test-launched in South America, had a 100 (or 200) km range and with a five (or ten) ton warhead, was launched from a metal tube projector or could be fired from a ship. One German prisoner of war (POW), a tank expert who had provided otherwise detailed and reliable information on a variety of other technological advances, reported to interrogators a rocket of 120 tons with a 60-80 ton warhead (with a 30 km blast radius), propelled by hydrogen and with a range of up to 1,800 km, and guided by a 'direction finding' beam. Although this POW had provided useful information in the past, his credibility was doubted in a most colourful way by the JIC:

> [POW] 164 gives the impression of a one track, furiously working brain mounted on a neglected over-grown child's body…it is a case of morbid genius close to insanity by ordinary standards.[19]

A later BODYLINE report of 4 November 1943, outlining targets to interrupt the production and launch of the V-2 established that the 'projectile [would be] fired from a mortar tube of considerable dimensions…made up of multiple sections' and that 'the method of operation may require the incorporation in the design of a high-pressure pump or compressor driven by some form of motor of very high horsepower.' This high-pressure pump or compressor would be used to propel the missile from the projector. The source of these 'facts' is unclear but helped to distract the intelligence collection and analysis effort for some months, searching for mythical launch tubes much favoured by Lindemann.[20]

## Defeating the Unknown

Defeating the V-2 operational deployment proved to be very difficult for the British. The destruction by bombing of the huge assembly, storage and launch facilities in the Pas-de-Calais region of France, led to a wider belief that the threat from rockets had been eliminated, even though the Allies had little information to distinguish between the V-1 and V-2 programmes, having never encountered weapons of either type.

Air Chief Marshal Sir Roderic Hill, Air Officer Commanding-in-Chief Air Defence of Great Britain (ADGB) noted that by summer 1943 Ministry of Supply (MOS) scientists, working against a theoretical model of a rocket (as supplied by the BODYLINE Committee), determined that a rocket could be identified by modified early-warning radar during the boost phase and both points of launch and impact could be identified by use of both electronic and mechanical predictors, although the rockets could not be tracked in flight. Hill took over as the Air Defence Commander on 15 November 1943; coincidentally the role of devising counter-measures was moved from the Ministry of Supply to the Air Ministry on the same day. By that time, five radar stations between Ventnor and Dover on the South Coast had been modified to detect rockets fired from northern France, and "operators had been trained to identify the characteristic trace which a rocket was expected to produce."[21] Alongside the radar, the Royal Artillery anti-aircraft units employed sound-ranging and flash-spotting teams to observe for launches, as they were to do in Belgium from September 1944 when the V-2 campaign commenced. From early 1944, however, the rocket threat was assessed by the BODYLINE Committee as reduced, so the radar watch was dropped. Hill, concerned that such relaxation was premature, insisted that the radar operators should remain in place and train others; a further two radar stations were included in the chain from June 1944 as the V-1 flying bomb campaign commenced, in what Hill described in his-post war report as 'an intermittent drizzle of malignant robots [that] seemed harder to bear than the storm and thunder of the Blitz.'[22] Blitz Collier notes that ground-based electronic counter measures were established to jam 'control beams' that had been postulated, but were never employed.[23]

In the meantime, arguments still raged in London over the possible size of the warhead and, in July 1944, the Home Secretary Herbert Morrison urged the War Cabinet to commence the evacuation of one million people from London and the provision of over 100,000 'Morrison' table shelters. His Ministry estimated over 100,000 fatalities a month and, in August 1944, evacuations from London commenced.[24] Fortunately, a stream of intelligence derived from documents and prisoners captured in France independently confirmed that the warhead was about one ton, and *not* ten tons as was previously assumed.[25] Advancing Allied troops in northern France had discovered a number of sites, and as Hill noted, these did not resemble the 'large sites' but were merely rough concrete slabs.[26] But by August 1944 Jones had refined the rocket model and through intelligence – principally photographic intelligence and by examining the remains of two A4s: one crashed in Sweden and recovered by the British Air Attaché, and another that had been launched from Blizna and fell in Poland and heroically smuggled back to Britain by the Polish Home Army. Jones and his team determined the size of the warhead and deduced that no special launch facilities were needed apart from a small concrete launch pad to hold the launch table and missile upright and the distinctive 'lemon squeezer' blast deflector, which sat underneath it; the latter two items had been identified on test stands in Peenemünde by photographic reconnaissance.

Contrary to intelligence reports reiterating the extant threat, but rather based on the assurance from the Chiefs of Staff that the tactical situation meant that there were no suitable launching sites left from where missiles could reach London, on 7 September 1944 Duncan Sandys felt comfortable enough to dismiss a large-scale attack. Five weeks before the JIC had outlined the continuing threat of attack in a Top Secret report:

> "We have no physical reasons preventing the launching of BIGBEN in the immediate future. It may well be that about a thousand of these rockets exist."[27]

The report detailed the training of personnel, launch procedures, the availability of liquid oxygen, anti-aircraft protection for storage and launch sites, and citing a 'senior source' (probably an ULTRA decrypt), that launches against Britain would start in 'mid-September [1944]'. Dornberger, separately, reported that a bombardment campaign would not start until September. Just two weeks before the V-2 campaign was launched – and Duncan Sandys' premature declaration of victory, the Security Service's (MI5) Deputy Director General, Guy Liddell (1892-1958) expressed his grave concern about the imminent V-2 campaign and suggested to the Chief of SIS (MI6) 'C', (Sir Stuart Menzies) that:

> "the uranium [atomic] bomb…be used as a threat of retaliation to the Germans if they used the V.2. 'C' said that he had no reason to think the V.2 was imminent although it was possible to think that it might start in the near future."

Menzies agreed to put the suggestion to the Prime Minister, Sir Winston Churchill, but his reply is not recorded.[28] At any rate, the British TUBE ALLOYS project (which, by now, had combined resources with the US Project MANHATTEN) to develop nuclear weapons was still eight years away from delivering a working British device and the decision to construct a viable warhead was not made until 1947.

Coupled with the worsening operational situation and with little faith in the invulnerability of monumental static launch sites so favoured by Hitler, by August 1944 von Braun and General Dornberger developed mobile Transporter-Erector-Launcher (TEL) convoys (*Miellerwagen*) which were easily camouflaged and practically impossible to locate. Now V-2s could be launched from any piece of open ground, although the movement and storage of the rockets proved to be difficult under the chaotic wartime conditions.[29] As observed 14 years later by

Constance Babbington-Smith, a senior RAF Photographic Interpreter who first identified the V-2 on its launch stand at Peenemünde, "General Dornberger's almost ridiculously simple concept of how the V-2s should be launched defeated Allied photographic reconnaissance."[30]

There was fierce debate in secret over whether to warn the public about V-2 attacks. However, the inaccuracy of the rockets, coupled with the limited warning time raised concerns that the public would soon lose confidence in false alarms. The Home Secretary believed that this would erode public confidence in the system; conversely, given the little warning time, public panic could result in chaos and injuries as people rushed to enter deep shelters. A missile attack warning system was developed with clusters of maroons (signal rockets) positioned across London and the south east of England that would be fired to alert of an impending attack. This, in turn, was the resurrection of an air raid alarm system that was belatedly introduced in London in July 1917, in response to Zeppelin and Gotha bombing raids on the capital.[31] However, the performance of the V-2 was so erratic (operational analysis showed that 50% fell within a 200 square mile/16 x13 mile box) that alerts would be vague and, furthermore, by the time the semi-automated system was activated, the public would have little time to react and public and private shelters offered scant protection in the event of a direct hit.[32] Morrison's other major concern was the event of a missile breaching the underground rail network, leading to extensive flooding and inevitable loss of life, as thousands of people were continuing to spend their nights in the deep tunnels because of the V-1 bombardment. Transport planners anticipated that up to 57 miles of tunnels of the Underground rail network would be inundated at a speed of 15 mph/24 km/h if the tunnels at Charing Cross or London Bridge were breached.[33] On receipt of a radar report of a V-2 launch, ADGB Headquarters at RAF Bentley Priory in Stanmore would alert the London Passenger Transport Board of an impending attack and the Board would remotely close water-tight doors on the underground network.[34]

General Sir Frederick Pile, commanding Anti-Aircraft Command and serving under Hill, proposed on a number of occasions a 'wall of lead' to disrupt the warheads during the terminal phase of flight. Scientific estimates of the number the number of shells, and therefore the number of AA guns, needed to fill the radar-predicted airspace varied widely and the proposal was eventually dropped as the V-2 campaign ended, but it should be remembered as the first attempt to develop an anti-ballistic missile system.[35]

## The Deceptive Role of Intelligence

Intelligence was not only essential to understanding the V-2 and the impact it might have, it was also key to defeating it. MI6 and MI5 devised a complex and highly sensitive deception plan under the jointly-run Twenty or 'XX' Committee.[36] In this plan, 'turned' Nazi agents broadcasted false reports on the impact points and exaggerated the accuracy of the attacks, resulting in the mean point of impact being shifted away from central London, as had been done during the V-1 campaign. The plan also relied on the British press not publishing the rocket attacks in any detail, hence the need for initial official silence about the attacks.

The Ministry of Home Security assessed that a further 1,300 people would have died and a further 10,000 injured if the mean point of impact had not been moved from central London through an elaborate deception plan.[37] In a 1951 interview in the *New Yorker* magazine, von Braun described his unexpectedly pleasant treatment by the British during his visit to London in September 1945.[38] Demonstrating the on-going secrecy of the deception plan, when confronted by the damage caused in parts of London by the V-2, his only concern was the fate of the German agents who radioed damage reports back to the *Abwehr* (German military intelligence) who passed it on battery commanders and to von Braun. The range of the missiles were then adjusted by altering the burn rate and fuel cut-off of the engines, as well as setting the gyros used to tip the missiles, directly under the guidance of von Braun and his team. Even in 1951, he was unaware that all Nazi agents in Britain had been captured, imprisoned, been 'turned' or executed. This deception plan remained secret until the 1970s.

## The RAF takes the Battle to the V-2

V-2 convoys were elusive yet vulnerable if caught in the open but attacking them presented Air Chief Marshal Hill organisational challenges. As part of the restructuring of Allied commands ahead of the invasion of Europe ('OVERLORD'), Fighter Command had reverted to the pre-war title of ADGB in late 1943 and was under the aegis of the Allied Expeditionary Air Force, commanded by Air Chief Marshal Sir Trafford Leigh-Mallory, who reported directly to the Supreme Allied Commander, General Eisenhower. ADGB, in addition to defending Britain's airspace against conventional attack, was tasked to provide air defence over Allied forces when they landed in France, as well as preparing for the expected V-1 attacks. Hill had at his disposal Anti-Aircraft and Balloon Commands, as well as fighter aircraft from Nos 11, 12 and 13 Groups. As the V-1 campaign began in June 1944 (just as OVERLORD landings commenced in Normandy), despite many requests, Hill was unable to draw fully on either the additional resources of Bomber Command or the Second Tactical Air Force to attack possible V-2 launch locations, as both formations had their own target priorities supporting OVERLORD, such as providing close air support to allied forces, paralysing the French rail network as well continuing the strategic bombing offensive. Hill also described his relationship with Air Chief Marshal Sir Arthur Harris, Air Officer Commanding-in-Chief Bomber Command, as being 'less than to be desired', which may have influenced the outcome of ADGB's request for heavy bombers. Hill, instead, relied on several groups of fighter-bombers assigned to ADGB, (Spitfires, Tempests and Typhoons) engaged in armed reconnaissance which could be tasked to reconnoitre possible V-1 and V-2 launching sites and attack targets of opportunity. However, the ongoing strategic bombing offensive across Germany would have had a major disrupting effect on missile production and distribution, as well as a second order effect on fuel and liquid oxygen production.

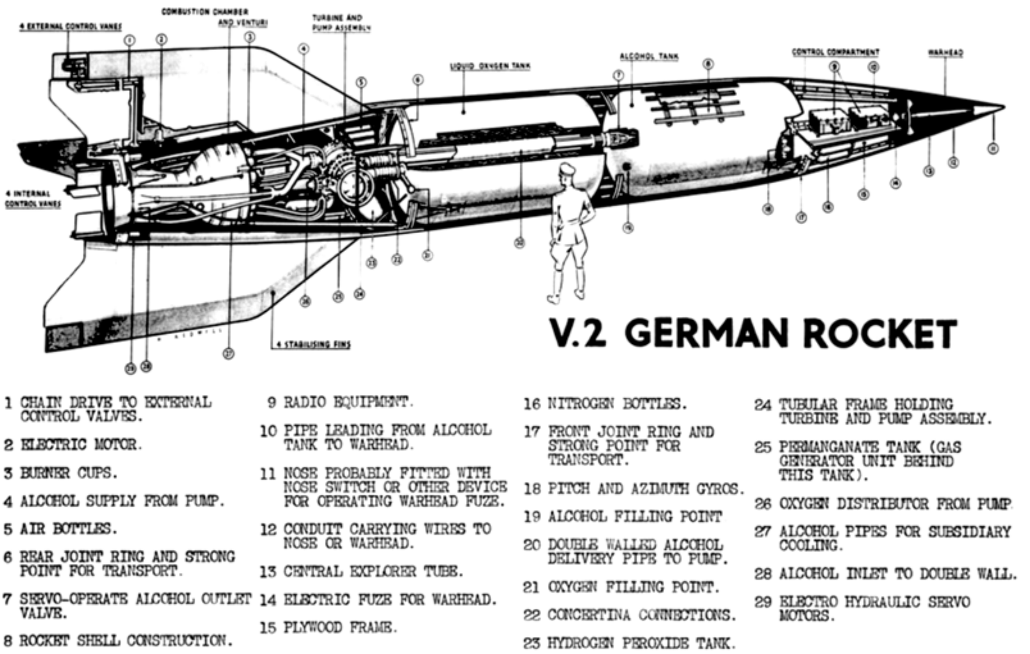
By mid-September 1944, it was clear that the V-2s were being launched from built-up areas in The Hague, so to minimise civilian casualties (and after consultation with the Dutch Government in Exile), his fighter-bombers practised accurate dive bombing in order to attack convoys and complexes believed to house missiles, equipment and personnel. They would be vectored on to possible locations based on radar plotting from a Royal Artillery Mobile Air Reporting Unit, and more frequently, by reports from Dutch operatives. But these attacks only had a limited, short-term effect; targeting was switched to the local rail network and possible storage areas which had a greater, long-term impact. Collier noted that on 7 March 1945 the "German Rocket Organisation in Holland reported its casualties since air attacks began as 51 dead, 117 wounded, and 58 lorries and cars, 11 oxygen-trucks and 48 missiles damaged."[39] Hill also sought assistance from 100 Group RAF, who flew electronic intelligence gathering missions up and down the Channel, with Hill's fighters escorting, in a vain effort to detect both 'control beams' and radio guidance to the rockets.[40] Post-war analysis showed that no such methods of guidance existed, although Dornberger acknowledged that unsuccessful attempts had been made to incorporate such control systems and that a remote guidance system had been installed in an A4 that fell in Sweden and was subsequently recovered to England.[41] This led investigators, including Jones, to conclude that remote guidance would be used.

Allied advances in the Low Countries in March 1945 forced Kammler to withdraw the V-2 batteries eastwards into Germany, where they were then broken up and personnel dispersed. From March 1945 the threat rapidly diminished. A JIC report of 23 April 1945 examining the continued threat posed by V-weapons, pointed out that as "V-weapons were produced in widely dispersed areas, many of which we have overrun…we do not believe that the enemy will be able to continue production on any considerable scale. Moreover, the provision of fuel would be extremely difficult."[42]

## The Campaign – and the Costs

> *There is no siren warning now. No time to take shelter, for this is the most indiscriminate weapon of this or any other war. It is a sinister, eerie form of war.'*
>
> Daily Herald, London, January 1945.

The A4 was 46 feet (14 m) high, vertically launched single-stage liquid-fuelled rocket, with the production variant weighing 12.65 tons (12.85 tonnes), with a one ton/tonne (nominal) warhead, although this was later reduced to 1,650 lbs (750 kg). Maximum range of its ballistic trajectory was about 220 miles (350 km). Monthly production was 300 in May 1944 rising to 616 between September 1944 and March 1945, with a total of circa 6,000 launch bodies produced. Apogee (top of trajectory) was 38 to 60 miles (60 - 96 km) and achieved a maximum speed of up to 3,600 mph (1,600 m/s; 5,800 km/h) and due to atmospheric friction dropping to between 2,200-2,500 mph on impact. The missiles used an early two-dimensional gyroscopic stabilised inertial navigation system, that also fed the stability system. Fuel cut-off, and therefore trajectory and range, was pre-programmed although later (but unsuccessful) attempts of radio control were made. The rocket incorporated most of the design features that are seen in ballistic missiles of today.




Cutaway drawing of a German V.2 rocket. Air Ministry Collection, courtesy of Imperial War Museum. © IWM (C 4832)

Ruined flats in Limehouse, East London. Hughes Mansions, Vallance Road, following the explosion of the last German V-2 rocket to fall on Greater London, 27 March 1945. Courtesy of Imperial War Museum © IWM (HU 88803)

Chinatown (Limehouse, East London) V-2 combustion chamber and venturi which separated from missile on impact. March 1945. http://www.wikiwand.com/en/Limehouse_Causeway

German records show that up until 7 April 1945, 1,190 V-2s were launched against Britain (with a further 169 failures) with 501 of those falling on Greater London. However, the first operational launch was against Paris, on the morning of 7 September 1944, but batteries then withdrew as Allied troops advanced. Antwerp was the target for 1,610 V-2s.[43] Casualty figures vary slightly, but according to British Ministry of Home Security reports, 2,754 civilians were killed in Britain by V-2 attacks with another 6,523 injured. The single largest loss of life in the UK was on 25 November 1944 and saw 160 killed, with a further 108 seriously injured when a Woolworth's department store on New Cross Road in south London was hit. In greater Antwerp, missile attacks between October 1944 and March 1945 left 1,736 dead and 4,500 injured. Thousands of buildings were damaged or destroyed as the city was struck by 590 direct hits. The largest loss of life occurred on 16 December 1944, when the roof of a crowded cinema was struck, leaving 567 dead and 291 injured. The German offensive came to an end at 1645 hours on the 27 March 1945, when the last rocket fell to earth at Orpington, in Kent, with one fatality. The campaign had lasted seven months.[44]

Although the V-2 was a technical triumph over Allied developments and despite the terror imparted and the casualties inflicted, the V-2 had no demonstrable impact on the outcome of the war. Indeed, the expense and scope of the programme diverted resources from conventional weapons production, such as fighter aircraft and surface-to-air missile systems. Furthermore, the synthetic fuel for the rocket required 30 tons of potatoes to distil one ton of alcohol, at a time of chronic food shortages in Germany. The relatively small warhead and a lack of a proximity fuse (to permit a more effective 'air burst') compared unfavourably with the mass effect of conventional bombing. The V-2, delivering a one tonne/ton warhead per missile was set against the Combined Bomber Offensive that could deliver *thousands* of tons of bombs every day – with considerably greater accuracy and effect. Even during the London *Blitz* (October 1940-May 1941), the *Luftwaffe* dropped over 35,000 tons of bombs in 70 separate attacks, equating to some 35,000 V-2 attacks. However, contemporary accounts of the V-2 'Blitz' in London graphically illustrate the fear, horror and destruction these weapons engendered. There was no public warning of their approach thus many casualties were civilians in the open who were unable to seek shelter, and a one ton warhead, travelling at between 2-3,000 mph created massive destruction, albeit localised (because of the deep crater), with the attendant shockwaves creating widespread structural and shock wave damage.[45]

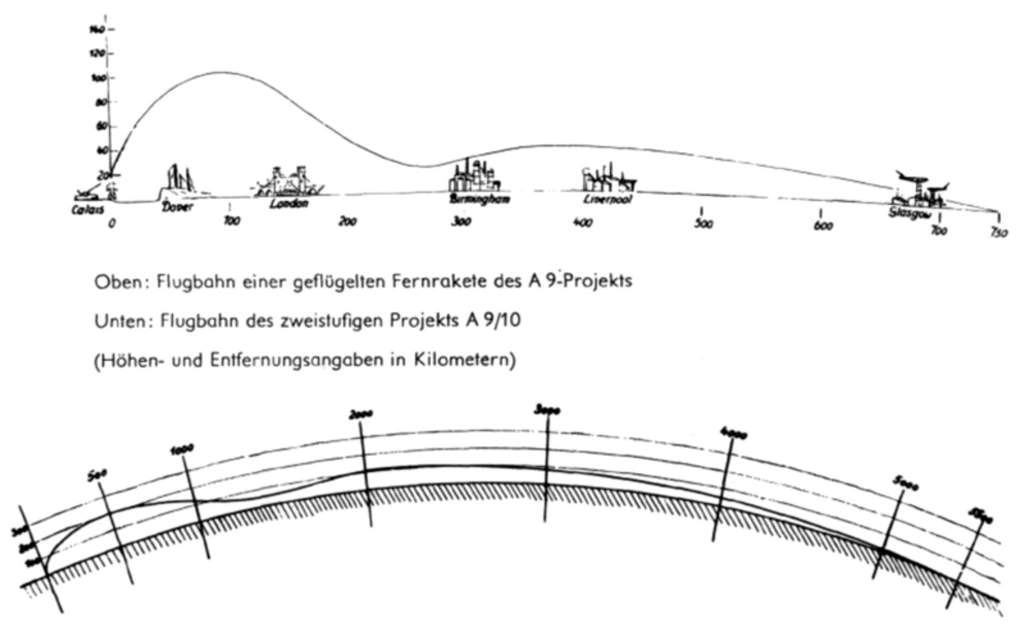
## Long-Range Rocket Development

**Greater Mobility**. Towards the end of the war, even more radical – some might say desperate – weapons were considered by Dornberger, von Braun and their staff, reflecting the changing fortunes of war and Allied air superiority. One proposal – code-named Test Stand XII – envisaged V-2s being launched against New York City and Washington DC from U-boat-towed submersible canisters. In 1943, the *Kriegsmarine* conducted experiments towing up to three 100 ft/30 m long cigar-shaped submersible containers. Dornberger claimed that Bodo Lafferenz (1897-1974), Head of the Institute for Physical Research, visited Peenemünde in autumn 1943 and urged that they examine the possibility of launching the A4 from these floats, with the obvious strategic impact that this development would have.[46] Experiments had been conducted from the decks of submerged submarines (at a depth of between 30-50 feet/10-15 m) firing short-range *Nebelwerfer* solid-fuel rockets.[47] These tests in 1942 had been successful, though never deployed operationally because of the adverse effect on submarine performance and increased acoustic signature underwater caused by the on-deck structures. Further research at Peenemünde determined that a submarine could tow three V-2 missiles in floats - at a total weight of 500 tons - for 30 days at 12 knots. On arrival at the launch area, the canisters would be partially flooded to a vertical position, the gyro-stabilised missiles fuelled (the fuel was apparently to be carried in these cannisters) and then launched. Dornberger anticipated no major problems and he thought the work was promising; however, missile reliability in general (principally premature bursting of warheads)[48] delayed further work on this concept. There are no references to how liquid oxygen would be carried or produced for the missiles, given that LOX evaporates from storage very rapidly; perhaps Dornberger did not include this in his account given that both the US and USSR were attempting to develop submarine-launched missiles, and this would have been a key technical advantage.[49] Research recommenced in November 1944, but the progressive evacuation of personnel, equipment and records from Peenemünde to Upper Bavaria from February 1945, ahead of the Russian advance, stopped further development.[50]

At about the same time, German agents captured in the US revealed under interrogation a supposed plan to deploy V-1 flying bombs from submarines against US East Coast targets; in early 1945, the US Navy launched Operation TEARDROP to counter this technically ambitious yet mythical threat, which had previously been discounted by the JIC in London.[51]

Work had been underway until 1942 to launch the V-2 from special railway wagons, envisaging missiles being prepared for launch in tunnels and then being wheeled out and erected on firing tables clamped on to the tracks. Greater cross-country mobility of the *Meillerwagen* Transporter-Erector-Launcher convoys and the inherent vulnerability of the rail network stopped development, but in late 1944 Kammler resurrected it. Dornberger claimed that he went about the work half-heartedly and the programme was abandoned in January 1945, but not before dry-firing trials from special trains took place.[52]

**Greater Range**. Despite the many setbacks developing a working A4/V-2 missile, von Braun's team had two research strands to increase the range of the A4. One test launch of an A4 reached an apogee of 118 miles/190 km, according to Dornberger, with a scaled increase of range anticipated. Documents and photographs held by US National Aeronautics and Space Administration (NASA), show wings were fitted to the A4, creating the A9 (sometimes designated the A4b) which had an extended range of 500 miles/800 km, with the same one ton




Captured diagram of potential ranges of the A9 and A10 rockets. Courtesy of NASA Historical Office.[53]

warhead. Work had commenced 1940 but ceased in 1943 because of ongoing problems with the A4, but demand for greater range from rockets caused by the deteriorating war situation saw work recommence in January 1945. After one unsuccessful launch, Dornberger reported that on 24 January 145 a swept-wing A4b (A9) with a wing area of 145 square feet/13.3 m² reached an apogee of 50 miles/80 km at 2,700 mph/4,350 km/h. The missile levelled out on the upper edge of the stratosphere at 12-16 miles/19-26 km and flew in a controlled glide, until a wing failed. A captured diagram shows the missile trajectory over the UK and landing just beyond Glasgow.

The final wartime research programme that got underway was the A10, a winged two-stage rocket that *could* have had trans-Atlantic reach of 3,500 miles/5,600 km, taking about 40 minutes to cross the Atlantic. The theoretical design consisted of an A9 carried by a booster with a projected all up weight of 100 tons/tonnes, with an engine delivering 200 tons/tonnes thrust (compared with a mere 25 tons/tonnes of the A4/V-2). The overall height was to be almost twice as high as the V-2 at over 80 feet/26 m but with only a one ton/tonne warhead.[54] As with the A9, there was insufficient time or resources to develop the concept further. Dornberger commented in 1952 on these developments, noting that "we had taken a long stride forward in developing the first intermediate stage preceding the space ship." He also tantalisingly referred to discussions in 1943 with the leading nuclear physicist Professor Werner Heisenberg (1901-1974) on the use of "atomic energy for rocket propulsion" but Heisenberg was uncertain.[55] Another proposal – which has captured the imagination of fantasists - was preliminary research commenced under the orders of Hitler on a 'ten ton' warhead rocket, nicknamed '*Amerika-raket'* – an order of magnitude bigger that those missiles in service. This theoretical work was also carried out in Oberammergau just prior to American forces overrunning the area.[56]

## End of the War

As Russian forces swept into Germany in early 1945, von Braun and Dornberger gathered up 400-500 of their key technicians and engineers, and with their families made their way in stages to barracks in the Upper Bavarian town of Oberammergau by 1 April 1945, under the direction of Kammler.[57] Once established at the 'Upper Bavarian Research Centre', run by the Messerschmitt Aircraft Company (and now the site of the NATO School Oberammergau), his team were engaged on 'make work' tasks and conceptual development – such as the A10 multi-stage rocket - to keep them occupied. von Braun's team also evacuated a reported 16 tons of A4 reports, designs and other documentation from Peenemünde, hiding this archive in another disused mine north of Nordhausen before they moved to Oberammergau. Key research equipment, such as the Peenemünde supersonic wind tunnel, had been moved to a small lake resort town 20 km east of Oberammergau, where there was a hydroelectric plant that could have powered it.[58]

Von Braun was well-known in the nascent rocketry circles in the US and the UK, and secret British Air Ministry Technical Intelligence Summaries from 1943 onwards frequently referred to 'Herr von Braun's' work on ballistic missiles, including references to the hitherto unknown launch of V-2s in late 1943 against Russian targets (although this probably referred to test launches from Blizna, in Poland).[59] von Braun was detained near the Austrian border on 2 May 1945 by US Counter-Intelligence Command (CIC) personnel and taken to Garmisch-Partenkirchen via Oberammergau in what was probably a pre-arranged event.[60] He was treated as a celebrity; in return, he later claimed to have hosted a champagne-fuelled party for his captors at his mountain retreat.[61]

## Exploiting the Technology

**Allied Tensions**. As the V-weapon threat developed, one of the dilemmas facing BODYLINE was what information Britain should share with the Americans about the Nazi long-range rocket programme. In a JIC report of 26 October 1943, the opening paragraph made an appeal:

> "We feel that it is becoming necessary for a ruling to be given as to what information regarding our knowledge of German long-range rockets should be disclosed to the Americans, and by whom."[62]

The report pointed out that US scientists had been consulted by BODYLINE scientists (such as the potential of liquid-fuelled rockets) and that there had been inadvertent leakage from British personnel working alongside US staff; moreover, the US Army Air Force had carried out attacks against 'heavy sites' in France. It was agreed that each Service intelligence chief would brief orally their opposite number, and the respective service attachés in London would be informed by the permanent chairman of BODYLINE, Commander Ian Fleming RNVR. At the same time, although allied military cooperation was increasing, there was the concern of what to tell the Soviet Union. The advances on the Eastern Front meant that Soviet forces would soon encounter A4 test ranges and facilities. RV Jones minuted the Chief of the Air Staff, Air Chief Marshal Sir Charles Portal, recommending that Air Intelligence Officers should be sent to the range at Blizna, and as it was of such importance, Churchill should make a personal approach to Stalin. Stalin agreed in a letter of 25 July 1944, but at that point numerous bureaucratic obstacles were put in the way of the team by the Soviets. Blizna (also referred to as Dębica) was taken by Soviet forces on 6 August 1944 and their scientific teams scoured the site for material of intelligence value. The British team travelled via Teheran but, with visa delays and illness, they were unable to arrive at Blizna until about 20 September. Although the site was well-picked over, the team found and identified a number of components and impressed the Russians who accompanied them with their knowledge on guided missiles. However, crates of salvaged equipment were delayed en-route; when the cases were opened at Farnborough, the contents had been substituted with old aircraft parts.[63]

A curious report of the JIC sub-committee dated 6 February 1945 revealed a personal offer from a Soviet colonel to arrange for an Allied team to investigate the main research site at Peenemünde, once Soviet troops overran it. The colonel had assisted the "Anglo-American team working on the experimental rocket site in Poland [Blizna] last summer [and] had been very impressed by the ability of some of the team members. The colonel had offered to facilitate a similar event in the future if he was approached direct." The sub-committee agreed that Assistant Chief of the Air Staff (Intelligence) would write the Head of the British Mission in Moscow, Admiral Ernest Archer, who in turn would write to the colonel and accept this offer.[64] As an aside, present at the meeting and representing MI5 was Major Anthony Blunt (1907-1983). Blunt was an officer in the Intelligence Corps but had been recruited as a Soviet agent in 1937 and was one of the five members of the infamous Cambridge Spy Ring. It is highly likely that Blunt would have passed this information to his Soviet handlers.[65] In any event, the Russians did not allow access to the Americans or the British when Peenemünde fell to the Russians in May 1945.

**The Race for Space Scientists**. From 1944, British and American planners sought to exploit after the war German technological advances across all fields resulting in the Combined Intelligence Objectives Sub-Committee (CIOS) set up between the US and the British Chiefs of Staff Committees. CIOS also prepared lists of what scientific and industrial intelligence would be shared with the Soviet Union. The British Intelligence Objectives Sub-Committee (BIOS) identified a bewildering range of industrial and scientific intelligence objectives for exploitation on a national basis. To collect this military-industrial technology, an *ad-hoc* organisation of regular army units was established to escort civilian experts, known as 'Investigators', to seize archives, equipment and personnel on a 'Black List' of prioritised targets. Commander Fleming – chairman of the BODYLINE committee - had been the driving force behind the Royal Navy's 30 Assault Unit (30AU) technical intelligence and exploitation team which had operated successfully in the Mediterranean and during the early stages of Operation OVERLORD. Fleming's team was the inspiration for T-Force, which was subsequently developed and directed by BIOS, and commenced work in early 1945. T-Force consisted of several infantry battalions, with Royal Engineer bomb disposal experts and extensive transport support, together escorting teams of civilian 'Investigators' and searched for equipment, archives and personnel. T-Force moved with the front-line and gathered material as they went; on some occasions, T-Force personnel engaged in combat as they got ahead of friendly troops, most notably accepting the surrender of the *Wehrmacht* and *Kriegsmarine* garrisons in Hamburg![66]

**What were the British Prizes?** In the British Zone, there were two great technical prizes. One was the *Walterwerk* complex near Hamburg. Here, under the mercurial engineer Dr Hellmuth Walter (1900-1980), air-independent propulsion systems were developed, principally for the *Kriegsmarine*, such as hydrogen peroxide-powered torpedoes and submarines, but also the turbo-pumps needed to deliver 50 gallons/225 litres of fuel per second into the V-2 combustion chamber. The second great capture was the *Luftfarhtforschungsanstalt Hermann Göring* (Hermann Göring Aeronautical Research Institute), four miles west of Brunswick. Ben Lockspeiser (1891 -1990), Director-General of Scientific Research at the UK's Ministry of Aircraft Production, after visiting the institute (which was a collection of semi-autonomous research establishments), described what he found:

> Aerodynamic, supersonic and high-speed equipment is far ahead of anything in this country…it is probably true to say that in several directions the technical equipment … is unsurpassed anywhere.[67]

He immediately requested a team be sent to Völkenrode to secure the site, equipment and personnel. Lockspeiser and his team realised the vital importance of swept-back wings for supersonic flight. This led him to cancel the UK's first supersonic experimental aircraft project, the straight-wing Miles M.52. According to his 1993 obituary, he was much criticized for this decision as he had been earlier castigated for placing the contract with the Miles Aircraft Company in 1943.[68] Scientists at Völkenrode, and indeed on other research and development sites, were immediately re-engaged in completing their research work and writing up their results in scientific monologues. Most, it seems, were happy to do this as it temporarily guaranteed food and safety for themselves and their families.

Meanwhile, after his capture von Braun was questioned at length at Garmisch about the rocket programme and his National Socialist beliefs by US officers, as well as personnel from the CIOS. On 15 May 1945, von Braun wrote a futuristic report for British investigators, led by Dr William Cook, outlining his aspiration for larger, multi-stage, longer-range, crewed and reusable rockets that could orbit the Earth.[69] Dr Cook (1905-1987), who was appointed in 1940 as Deputy Controller of the British Rocket Projectile Establishment under Sir Alwyn Crow (1894-1965), had agreed with Professor Lindemann in 1943 that a liquid-fuelled missile as proposed by RV Jones was impractical and a solid-propellant rocket would be unfeasibly large. Perhaps still influenced by this prejudice, Dr Cook seems to have reported little of what von Braun had said under interrogation. On 17 June 1945, von Braun was taken back to Nordhausen to locate other members of his team and to recover what equipment they could from the site before it was due to be handed over to Soviet forces. In addition to the archives, over 6,500 tons of equipment, including components to assemble 75 V-2 rockets, were to be shipped to the US.[70]

Von Braun and several of his colleagues were also taken to London for two weeks in September 1945 for further questioning by Ministry of Supply and JIC officials. Sir Alwyn Crow, who also doubted the viability and future of ballistic missiles, interviewed von Braun and reportedly made a half-hearted attempt to recruit him, which von Braun did not accept.[71] Unfortunately, no detailed records of his interviews in London have been found. When he was taken to an impact site in south London, for the first time von Braun was confronted with the damage that V-2s had caused. His observations were of a technical nature and he expressed frustration that debris had been cleared from one site and thus he could not get an accurate impression of the damage the warhead had caused. He seemed to demonstrate little remorse or emotion; this lack of emotion was also noted by von Braun's interrogators in Garmisch.[72] Although not mentioned in biographies of von Braun, during this period it appears that he was also taken to the Hermann Göring Aeronautical Research Institute at Völkenrode, and possibly to Cuxhaven, south of Hamburg. He demonstrated the potency of the A4 turbo pump steam generation components (potassium permanganate and hydrogen peroxide), which had been developed at *Walterwerk*, to British T-Force staff, who subsequently reported on this meeting.[73]

At the end of July 1945, approval was given by the US War Department under Operation OVERCAST (later renamed Operation PAPERCLIP) for von Braun and 350 other scientists, engineers and technicians to be moved to the US and re-commence the development of V weapons for use against Japan. It appears that about 125 of his team in Oberammergau were selected, probably on von Braun's advice, to travel to the US.[74]

Von Braun was to enjoy celebrity status in the United States as a rising star in the National Advisory Committee for Aeronautics (NACA), culminating on leading the Apollo programme, which landed men on the moon in 1969. The US Authorities, although aware of his Nazi party and SS membership (he had been promoted to SS-Sturmbannfuhrer (Major) in June 1943), quietly ignored his background, and accepted his explanation of membership of both organisations 'as a political necessity' and he was granted US citizenship in 1955. He was last investigated about his Nazi links by the Federal Bureau of Investigation in 1971 and in recent years evidence has emerged of his complicity in the thousands of deaths of slave labourers by starvation, execution and ill-treatment at *Mittelbau-Dora*, forever damaging his reputation as the twentieth century's preeminent space scientist.[75]

## Operation BACKFIRE

BACKFIRE was a British plan but authorised in June 1945 by General Eisenhower as Supreme Allied Commander, to test-launch captured V-2s. Under the War Office's Special Projectiles Operations Group, between July and October 1945, 30 unarmed launches were planned to take place at the Ministry of Supply (MOS) Establishment, Cuxhaven (MOSEC), south west of Hamburg. The War Office commented in the official account of the launches:

> [Backfire] might save years of development work, and…it was agreed that the launching and control of rockets was a complicated operation which it was necessary for the German technicians to demonstrate in the near future before they lost their skill.[76]

T-Force were tasked to locate V-2 components, documentation, support vehicles, equipment and technical personnel across the British and US sectors. This took longer than expected and many of the rocket components had been hidden, suffered from poor assembly, looting and corrosion from many months of open storage.[77] US authorities, who had earlier stripped *Mittelwerk* in Nordhausen of most of its useful equipment, delivered the British 640 tons of components by rail. The volatile hydrogen peroxide, used to produce steam for the turbine that drove the fuel pumps, was conveyed from the *Walterwerk* site near Hamburg.

Around 570 German personnel were employed to prepare and launch the rockets. However, competition with US authorities had made assembling the group more difficult. About 130 of the staff had practical experience of launching rockets and another 85 were scientists or engineers who had worked at Peenemünde.[78] The first launch took place on 1 October 1945, but was regarded as a failure, but on 2 October a successful launch over the North Sea was made. A final launch, captured on film by the Army Directorate of Kinematography, took place on 15 October in front of a large Allied audience of senior officers. The film covers the whole process from receiving the rocket from the factory by rail, through its transportation to the technical storage site, preparation and transfer to the *Meillerwagon* TEL, erection on the launch pad, fuelling and the launch. The work was done by German personnel, still in uniform, but under the watchful eyes of the British soldiers, generally standing at a discreet distance.[79] Adverse weather and deteriorating components saw the operation draw to a premature close. The BACKFIRE project was summarised in a five-volume secret technical report and, after the test launches, the remaining equipment and five assembled rockets were shipped to the UK. The BACKFIRE reports noted that the V-2 heralded a new type of warfare, but only if the rocket was able to deliver an 'atomic' warhead to mitigate errors in accuracy.

BACKFIRE: A German V2 rocket at the moment of launch during British tests in Germany, 10 October 1945.
Courtesy of Imperial War Museum. © IWM (BU 11149)

Most of the German workers returned to a US internment camp Garmisch, with a number of them then recruited to work in the US or France. Fifty Germans were retained on site after the launches, but the MOS made it clear that no UK-based employment contracts would be offered. MOSEC wound up on 1 May 1946; in a reversal six days later, the MOS offered 15 contracts, but in most cases the team had dispersed: six joined the French programme, two refused the offer, two couldn't be found, one went to the USSR and only two readily went to the UK, joined by another two who had initially agreed to join the French. General Dornberger also assisted in the test launches, but instead of being welcomed to the UK, he was still held as a Prisoner of War (POW). He was transferred from Garmisch and detained at Farm Hall and Wilton Park detention centres in England, both special camps for senior German officers and scientists thought to be associated with the German nuclear programme. He was interrogated by the British War Crimes Investigation Unit and then held in a POW camp in Bridgend, Wales and not, it seems, offered employment. British and US investigators were particularly concerned that the Nazi regime had hidden nuclear material and had developed nuclear warheads for the V-2 and went to great lengths to find out whether this was the case, under Operation EPSILON.[80] Coincidentally, cubes of uranium isotopes – part of a nascent Nazi nuclear weapons programme - were recovered by US forces in the river adjacent to the barracks in Garmisch, where both Dornberger and von Braun were initially held by US forces.[81] In 1947 Dornberger travelled to the US, ultimately ending up working for the Boeing Aircraft Corporation, and died in Germany in relative obscurity in 1980.

Another Ministry of Supply establishment was set up at Trauen, on the site of the former *Sänger Raketentechnische Forschungsinstitut* (Sänger Rocket Technology Institute) German scientists from *Walterwerk*, Peenemünde and Trauen were assembled there and conducted research into oxidising rocket fuels, producing reports that were subsequently published by the Royal Aircraft Establishment (RAE) at Farnborough.

By the time T-Force was wound up in 1947, it had seized huge quantities of documentation and equipment, which was shipped back to the UK. By the end of the removal phase, over 14,000 tons of equipment was removed to Britain, along with 4,600 volumes of aerospace research from Völkerode and 3,300 reports from the Focke-Wulf library. Anecdotally, it seems much of it was never exploited and was progressively destroyed in the 1950s. Amongst this equipment was a large number of high-speed, high-altitude test facilities which eclipsed anything available in Britain or the US. Most of these were delivered to the new RAE research centre at Bedford.

## The Russian Dilemma

By early 1945, there was considerable hand-wringing in bureaucratic circles about the exploitation of German technologies and its proponents. BIOS noted the technological advantages that German industry and science offered, but there were equal concerns about the 'remunerated employment of ex-enemy aliens' and security aspects of employing former adversaries. The Deputy Chiefs of Staff Committee (DCOS) established in April 1945 Operation SURGEON, under which hundreds of scientists and engineers were held by the British and interrogated about their technical knowledge and their Nazi party affiliations. Yet, those who encountered the Germans – both British and American – noted a willingness to continue their research and work for the West. As the European war ended, the actions of US and British authorities were increasingly concerned with denying scientific knowledge and novel military technologies to the Russians, although this did not appear to become official British policy until December 1946.[82] However, a decision to actively employ 'alien scientists' in the UK was not made by DCOS until 31 August 1945, thus almost four months were lost after VE Day, during which many personnel were recruited by the US, USSR or France. Contrary to popular belief, although millions of German nationals streamed West, justifiably fearing occupation by the Red Army, many scientists willingly accepted very lucrative offers made by the Soviets, who were prepared to overlook previous Nazi affiliations.[83] This caused concern in Whitehall, as revealed by the JIC minutes of early 1946 regarding the disposal of

German scientists, based on the British interrogation of three naval scientists at 'DUSTBIN', the British interrogation and processing centre for senior Nazi officials and scientists detained under SURGEON. Three scientists were questioned by staff from the Directorate of Naval Intelligence attached to the British Naval Gunnery Mission. They were asked about scientists being transferred to the Soviet Union and they claimed that the Russians wanted all German scientists and technicians to work for them:

> "[The Soviets] Employed the Germans regardless of their political creed or antecedents and have placed them in positions of high authority with the right to issue orders to their Russian subordinates. Russians offer enormous monetary attractions in addition to houses and food on the most luxurious scale to the Germans who they need."
>
> "Experts in V weapons are among those whose services the Russians are anxious to acquire…The common belief in England that Russia will have its hands full with reconstruction is incorrect…the low standard of life for Germans in the American Zone and the absence of any unified Anglo-American policy will prove an inducement for the German scientists to seek service under the Russians."

The paper acknowledged that the US had first pick on scientists, and the UK second, but that the Russians were targeting scientists in the UK and US sectors of occupied Germany, as were the French. An 'atomic physicist', Dr Albert Joos, also held at DUSTBIN, stated that he was ready to return to the Russian Zone, and that a Soviet mission, led by a General, to recover a small number of Russian 'displaced persons' within the British sector was actively recruiting scientists.[84] In response to this, in January 1946, the JIC suggested policy options for the retention of key German scientists to the Chiefs of Staff:

1. To return to the United Kingdom for employment there.
2. To keep them under permanent detention in the British Zone.
3. To offer the conditions at least as attractive as those of the Russians and hope they will remain in our Zone.

The JIC noted, not surprisingly, that scientists preferred the third option.[85] A report six months later confirmed further Russian recruitment in the British sector.[86]

Progressively, observers both in Germany and London became concerned about the predations of the Soviet Union. The vast majority of experts in the British and American sectors were not well-treated; most were unemployed or misemployed as labourers and on near-starvation rations. A May 1946 letter from the Royal Navy's Flag Officer Schleswig-Holstein, concerning the loss of great technical knowledge, summed up the problem:

> Nine or even six months ago the idea of working for the Russians or going to the Russian Zone was completely abhorrent to virtually every German of any mental

> capacity in the British of American Zones…Many of the ablest scientists and technicians from the Western Zones have already entered the services of the Russians and many more are clearly contemplating doing so in the near future unless future prospects in the British or U.S. spheres improve considerably for them at a very early date. The food situation on the British Zone will undoubtedly accelerate this Russia-ward trend, but it is doubtful whether the prospects of physical starvation weigh heavily with these men as the virtual certainty of mental starvation if they remain in Western Germany.

From December 1946, coinciding with the 'denial' role of British technological exploitation, contracting of German experts began in earnest, but was a mere shadow of the American and Russian programmes. Numbers were low in comparison. By the end of SURGEON, 87 scientists had been contracted to work in the UK, of which 38 were in rocket-related technology areas.

**Security Concerns**. There was a clear shift in feelings and policy in the immediate aftermath of the War. Whereas there had been an unbridled desire to exploit Nazi technology long before the War finished through CIOS (for the US to potentially use V-1s against Japan), the morality and the security of employing former Nazis was questioned. Within JIC meetings, MI5 expressed obvious concerns about the loyalty of these individuals and the risk that they could return to Germany – or elsewhere – and share their knowledge of sensitive British programmes, and potentially help in covert German rearmament. Moreover, offering 'aliens' (as they became increasingly referred to from 1946) work was problematic. Most scientists in Britain were employed in the public sector across a plethora of civilian-run government research establishments or at universities. Civil Service employment rules specifically forbade 'aliens' from being employed on government work and there was considerable bureaucratic lethargy in having short-term contracts awarded to those scientists who wanted to come to Britain. The contracts were by no-means generous in an austere post-war Britain that was functionally bankrupt, and aliens were paid less than British equivalents and given particularly austere ration books. Those who came to Britain were deliberately separated from their previous colleagues and worked on highly compartmentalised projects. Living conditions could also grim: the Guided Projectile Establishment in Westcott, Buckinghamshire, was typical. Scientists were housed in damp, unheated wooden former-RAF dispersal hutments within a barbed wire enclosure, initially with little freedom of movement. They met hostility amongst the local populace (as recorded against naval scientists in Barrow, Cumbria)[87] yet in work they appeared to integrate well with fellow scientists and engineers.

There was a cultural bias as well, as demonstrated in a report bemoaning the lack of a suitable policy on the employment of aliens on defence work, reiterated in a 1948 report:

> The view of the JIC is that in principle no aliens should be employed on secret defence work unless it is essential to achieve a particular result and no British Subject of comparable ability is available. Aliens are…[an] undoubted security risk."[88]

Referring to an earlier 1947 study on the same subject, the JIC suggested that aliens engaged on defence work could move to less sensitive research-related projects or to "universities in the Dominions", rather than continuing to increase their knowledge of British defence secrets and technical skills that "they could take back to their native country." The report further noted:

> Even if not disloyal most aliens are temperamentally less discreet than British Subjects, while in the UK they tend to mix with and talk freely with their compatriots.

In the same paper, Polish workers were given special attention:

> The employment of Poles on defence work merits special treatment. It is not unfair to say of Poles generally, and particularly of those who are now in the UK that they are temperamentally unstable.

Heads of research establishments had voiced their collective concerns about removing key personnel and the damage that this would do to projects but were advised by the JIC to remove them from sensitive posts as soon as practicable. Nonetheless, a January 1947 report noted that of a group of Germans at the *Völkenrode* research facility who were offered contracts 'most had been members of the Nazi Party, but denazification was passed as a mere formality'.[89]

The MI5 warnings mainly came from Lieutenant Colonel Martin Furnival-Jones (1912-1997), later to become Director-General of the Security Service from 1965 to 1972. He may have been echoing concerns less about Nazi sympathies but more of Soviet penetration of the British establishment. Though not well-publicised at the time, MI5 had been active in breaking up Communist 'entryist' cells in pre-war Britain and remained concerned about Communists in senior government and academic positions.[90] Since the early 1940s, there had been an extremely sensitive Anglo-American programme to decrypt Soviet diplomatic traffic – VENONA – and, through this, by around 1947, a very small group of senior personnel within the FBI and MI5 learned of Soviet attempts to penetrate sensitive Western establishments. As an example, Klaus Fuchs (1911-1988) was a German *émigré* to Britain in 1933 and was recruited as a Soviet agent in 1941. He worked on the British TUBE ALLOYS and the American MANHATTAN nuclear weapons projects and felt a moral duty to share the research with the Soviets. Fuchs was unmasked in 1950, although his espionage had been identified several years earlier in VENONA decrypts.[91]

There was particular sensitivity around the pioneering technology of the V-2 and its accuracy. In a 1946 Top Secret report, a JIC sub-committee recommended that the time and date of particular V-2 falls of shot remained secret:

> "It is known that experiments in V-1 and V-2 weapons are being carried out by a certain Power [USSR] using captured equipment, and possibly, German personnel. It is,

> therefore, important that no information which might assist these experiments should be released."

In referring to the elaborate deception 'XX' plan run jointly by MI5 and MI6:

> "Certain measures were taken during the V-2 attacks to deceive the enemy as to the results of his firings. To conceal the fact that a cover plan was used, it would be necessary to avoid any publication of details which might be a link to a particular shot fired with a particular fall of shot marked [on an unclassified map]."[92]

## Contribution to Astronautics

About 38 rocket scientists travelled to Britain between the end of 1945 and 1948.[93] Most were offered either a six- or twelve-month initial contracts to work in supernumerary appointments in government research establishments. They were split up between four main sites: the former *Walterwerk* staff went to Admiralty Department Establishment Barrow (ADEB), via Vickers-Armstrong, to work on underwater air-independent propulsion systems; five went to Waltham Abbey to the Explosives Research and Development Establishment (ERDE) established on the site of the former Royal Gunpowder Mills; 12 went to RAE at Farnborough; but the majority went to the newly-established Guided Projectile Establishment (GPE) at Westcott, Buckinghamshire. Others may have been directly recruited into industry, but details are scant. By 1950 about 23 were still in the UK. Those on longer contracts were permitted to bring their families to the UK, which led to an improvement in housing.

In 1945, Sir Alwyn Crow, as Controller of Projectile Development, produced a report on the future organisation of 'Guided Projectiles' within the Ministry of Supply. This report outlined areas of research, where it would be conducted and how many staff would be allocated. Liquid fuel rocket research was focussed on hydrogen peroxide systems and 'monofuels' that did not require an external oxidiser. Most of the projects were looking at short-range missiles for the Admiralty, but the General Staff had submitted two requirements: the first was for a long-range rocket with a 100 mile/160 km range with a three ton warhead (and high degree of accuracy); and the second requirement was for a "rocket for use as a strategical weapon" with a range of up to 300 miles/480 km also with a high degree of accuracy and a high rate of fire. A margin comment notes that the Army requirements were under review and that weapons with considerably longer ranges would be specified.[94]

GPE at Westcott was the hub of most British post-war rocket research and exploitation, and was responsible, under Dr William Cook, for guided missile development for the British Army and Royal Navy. The leading engineer was Dr Johannes Schmidt, who had been responsible for development of the 'Walter' rocket engine for the Me-163 *Komet* fighter, which first flew at the *Luftwaffe* Peenemünde East research centre. Unfortunately, there was to be a major setback. In November 1947, a German-designed Rocket Assisted Take-Off unit exploded during a test run, killing two British technicians and decapitating Dr Schmidt.[95] Perhaps the most significant recruit was Walter 'Papa' Riedel (1902-1968) who was employed by the MOS at Cuxhaven and Trauen, emigrated to England in 1947 to work initially for the RAE at, Farnborough and later at the MOS establishment at Westcott, until his untimely (and slightly suspicious) death in a hit and run accident in East Berlin in 1968, shortly after his retirement. From 1937, Riedel had headed the Technical Design Office as Chief Designer of the A4 at Peenemünde and was probably the most senior scientist on the programme after von Braun.

In contrast with Westcott, RAE Farnborough was primarily interested in exploiting German aeronautical and trans-sonic technology, and in 1946, 26 Germans were offered contracts of varying lengths to work at RAE. Accommodation was reportedly better than at Westcott, but the staff were still dispersed and few of their names appear on research papers until the 1950s. However, their immediate impact, following on the cancellation of the M52 straight wing supersonic aircraft, was to design a 55º swept-wing transonic aircraft in 1948. Dietrich Kucheman became more prominent by contributing to supersonic research (in particular the Concorde) and others behind the 'swing wing' variable geometry which resulted in the Tornado design. But few at RAE were involved in rocketry and the Royal Air Force (RAE's major customer) had little interest apart from missiles used in various anti-aircraft and air-to-ground roles. One proposal for a long-range Ballistic Missile – Menace – which may have been the oblique reference to the General Staff requirement of 1945, was abandoned as being patently unaffordable.[96] An indication of the pervading atmosphere of austerity was measuring manpower down to just ½ person labour units in Alwyn Crow's paper on the guided projectile organisation. In contrast, and hidden from Parliamentary estimates until the 1950s, in 1947 the Labour Government committed £100 million to independently developing viable nuclear warheads.[97]

Perhaps the greatest rocket engineering technology transfer was the extensive use of hydrogen peroxide as an oxidiser in the Black Knight test vehicle rocket and the Black Arrow two-stage satellite launch body, which were developed in the mid-1950s. From 1958, 22 successful test launches were made in Australia until the programme was cancelled in 1965. The Gamma power-plants for both launch bodies were derived from an earlier design produced by the German staff at Westcott, under Walter Reidel.[98] The Black Knight was also considered as a launch body for the 'Blue Streak' indigenous Intermediate Range Ballistic Missile, carrying a British-designed thermo-nuclear device. The Blue Streak was derived from Air Staff Operational Requirement OR 1,139 of 1953 from a nuclear-armed ballistic missile with a 2,300 mile (3,700 Km) range, with design work commencing at RAE Farnborough in 1954. At Westcott, the vulnerability of missiles on the ground was studied, with launch options including V-2 styled trailers, floating or submerged platforms, and massive underground silos considered. In 1958 work started on designing 60 silos dispersed at 6 mile (10 km) intervals, ensuring survival of most missiles if there was 20 megaton strike within 800 yards/metres, and at Westcott, a one-sixth mock-up of a silo was constructed.[99] Partial construction of a full-sized silo is thought to have taken place at RAF Spadeadam in Cumbria, where rocket engines were also tested. However, inter-service rivalry, and spiralling costs saw Blue Streak cancelled in April 1960. Smaller, shorter range missiles using a bi-propellant system included the forerunner of the Bloodhound surface to air missile (SAM), Red Duster, and the naval Sea Slug missile, were also developed at Westcott.[100]

## Conclusions

The post-war exploitation of German technologies and scientists by Britain is often regarded as a signal failure compared with the achievements of German teams in the Soviet Union and America. Greater attention was given to the German presence in the US; indeed, von Braun's capture in 1945 was widely publicised in a positive light by the US Army. Similarly, the achievement of the Soviet Union's Sputnik satellite launch in 1957 was ascribed in the West to the contributions of German scientists and engineers; in reality almost all has been expelled in a fit of Stalinist paranoia in 1952. The reasons for the *apparent* lack of exploitation by Britain are many-fold.

Firstly, agency played a role. Professor Lindemann (now Lord Cherwell), who was hugely influential as Churchill's scientific advisor (and to return in the same role in 1951 in Churchill's first post-war government), doggedly saw little practical future in long-range rockets. Even at the height of the V-2 campaign, Lindemann wrote to Churchill and remained sceptical of the future of missiles:

> Although rockets may play a considerable tactical role as long-range barrage artillery … I am very doubtful of their strategic value.[101]

A scant two weeks after the last German V-2 was fired at the UK, Lindemann still remained unconvinced of the value of long-range rockets. Sir Alwyn Crow, Director of Guided Projectiles, like Lindemann, regarded rockets as a very inefficient form of artillery and did little to exploit von Braun and his team. In his defence, Crow focussed on improving accuracy through better guidance mechanisms, though did not exploit German scientist who had expertise in this area. In contrast, RV Jones wrote to the US Army Air Force in late 1944 outlining the potential for two-stage rockets with a uranium bomb (nuclear warhead) that had a range of 3,000 miles – mirroring work that Dornberger and von Braun were undertaking on the A9 and A10 projects.[102]

Additionally, two of the Service ministries showed little interest in the *need* for a long-range rocket system. The Royal Air Force had built a huge strategic bomber force (by this time being replaced by the Lincoln heavy bomber), which by the end of the War could deliver devastating bomb loads with relative accuracy at relatively long range, but the aircraft and crew remained vulnerable. In spite of garnering considerable technical information and assembling a V-2 at Farnborough from smuggled components in August 1944, there seemed to be no attempt to exploit this technology during the war for use against either Germany or Japan, unlike in the US. Perhaps, in Britain, it was seen that there was no need as Germany was all but defeated and the Pacific war was very much dominated by America. The Tizard Report of 1944, whilst urging the development of nuclear weapons, still envisaged that they would be delivered by fast, high altitude jet-powered bombers. Ambitious Air Staff plans, such as Operational Requirement 230 of November 1946, led to the V-Force of nuclear armed bombers; ironically the V-Force would soon become obsolete in the strategic role because of surface-to-air missiles developed by the Soviets using technology in part developed from the German developments (such as the *Wasserfal* surface to air missile designed at Peenemünde). Furthermore, by 1946 given it was known that the Soviet Union was experimenting with ballistic missiles and considering the huge aircrew losses during the wartime strategic bombing campaign, it is equally difficult to understand why the Royal Air Force did not seek a long-range rocket that would be largely invulnerable to countermeasures – especially as the British TUBE ALLOYS nuclear programme was working towards a fission device that could be conceivably carried by a missile, largely obviating concerns about accuracy. It was not until 1953 that interest was shown by the RAF to develop a long-range missile system. The Royal Navy seemed to show even less interest even though the US Navy successfully test launched a V-2 from the deck of a carrier in September 1947. The only interest at the time in a long-range rocket came, as in Nazi Germany, from the British Army's General Staff. However, this interest was short-lived and the Army requirements for a long-range rocket described by the Director of Guided Projectiles in his 1945 report, did not progress beyond discussion papers.

Secondly, by the end of World War II, Britain's financial, industrial and intellectual resources were exhausted and the cost of debt servicing and of maintaining a huge overseas garrison was crippling. There was also a need to replace most key items of military equipment. This, along with US diplomatic pressure, in part, led to the rapid decolonisation of the British Empire. Additionally, an ambitious long-range rocket programme would have been financially demanding on a post-war Labour government which was more focussed on domestic reconstruction and social reform (such as creating the NHS) – but was also prepared to invest covertly in a domestic nuclear weapons programme, relying on aircraft delivery.

Thirdly, there was the paradox that although the Nazis were acknowledged as having advanced technologies, there was official resistance to harnessing them. MI5 were clearly concerned that UK defence technology secrets might be stolen but many reports contain a somewhat patronising view of the Germans, leading the few scientists and engineers to be kept at arm's length and not retained in their war-time teams. Furthermore, the financial inducements offered to scientists and engineers were unattractive compared with those offered by the USSR, USA and France, and coupled with a sclerotic bureaucratic lethargy, few Germans found it attractive. Security concerns about a re-emergent and belligerent Germany were unfounded, as were concerns over extensive Communist penetration of defence research and industrial community. There is no evidence to indicate any of those Germans who were brought to the UK posed a security risk, and the establishment of a 'Positive Vetting' system of assurance, introduced by MI5 in 1951, further mitigated the risk.

Authors Professor Matthew Uttley and Dr John Becklake have produced detailed studies of the net contribution to British aerospace research and development of the German infusion, and paint a more positive picture. In the astronautic and rocketry fields it was primarily in the area of hydrogen peroxide liquid fuel engines, but the value of the intellectual property that was transferred across to the defence sector, is described as 'incalculable'. Dr Becklake, a former RAE scientist who has extensively researched the German contribution to aerospace technology in Britain, has written that although Britain received several very good general engineers they were too few in number, and as seen above, they were often kept at arm's-length, could not collaborate with former colleagues, and were compartmentalised from major defence research programmes. Work at Westcott, where most of the engineers and scientists worked, was focussed on projectiles rather than manned flight. Rockets – including the V-2 – were seen merely as projectile bodies and not aerospace vehicles. Furthermore, industry had little contact with these experts, although captured equipment was transferred to many companies and was often destroyed without exploitation. He believes that, overall, the German input saved "about 18 months R&D [Research and Development], they had little long-term influence on British rocket technology."[103] In sum, although there were significant contributions by German scientists in trans-sonic aerospace research and development and in liquid-fuelled rockets, Britain of the late 1940s had greater concerns. But, in a tired, war-weary and austere post-war Britain, there was no vision; there was simply no perceived need for strategic long-range rockets.

## Epilogue

In a cruel, and rather late, turn of events, in March 1957 Duncan Sandys, now Minister of Defence, produced the White Paper on Defence, entitled the 'Outline of Future Policy'.[104] This paper recognised the parlous economic conditions at home, rapidly emerging military technologies deployed by the Soviet Union and changing geo-political landscape with pre-eminence of the US (especially in the wake of the Suez Crisis) and the importance of alliances such as NATO. The report recognised ascendency of long-range ballistic missiles with nuclear warheads and the vulnerability of manned aircraft to surface-to-air missiles. Sandys proposed progressive replacement of manned fighters with surface-to-air missile systems, strategic bombers to be supplemented by nuclear-armed ballistic missiles and to intensify research collaboration with America to develop anti-ballistic missile systems. In addition to swingeing reductions in the Royal Navy and the Army, as well as overseas commitments (which saw still saw 150,000 service personnel deployed overseas outside of Germany), his report forced the amalgamation of much of the British aerospace industry and cancelled most aircraft development programmes. The report concluded with assurances, in somewhat familiar terms:

> (a) The Government have adopted this new defence plan in the confident belief that it will not only give relief to the country's sorely strained economy, but will produce compact military forces of the highest quality.
>
> (b) All three Services will be provided with the newest weapons. The reduced Fleet will be composed of the most modern vessels; the Army will be equipped with atomic

> artillery and given a high degree of strategic mobility; the Air Force will be supplied with a British megaton bomb; a missile system of air defence will be developed; and ballistic rockets will be introduced to supplement the V-bombers.

As an interim measure before Blue Streak was expected to enter service, in February 1958 the UK and US governments agreed to deploy 60 US 'Thor' SM-75 missiles, which meant that US warheads could reach targets in the Soviet Union. Under code-name EMILY, 20 RAF Thor squadrons were established on wartime airfields the east coast of Britain from Yorkshire to Suffolk, and across East Anglia. The Royal Air Force provided the infrastructure and workforce, but the warheads remained under US Air Force control, with the launch of missiles controlled under a 'two-key' system.[105] The Thor had a range of 1,500 miles (2,400 km) and was designed by a colleague, and later rival, of von Braun from Peenemünde, Adolph Thiel (1915 – 2001). Like the V-2, the Thor missile was fuelled and launched from a transport-erector launcher system, however in Britain they were launched from fixed locations; the TEL and missile were stored under a shelter that would slide back prior to righting, fuelling and launching the missile. The first missiles – designed to be air-portable - arrived in September 1958 and the last left in August 1963. None were ever launched in the UK. The Blue Streak did not enter service; in its stead the British-designed 'Blue Steel' cruise missile was developed to be launched from the V-bombers. It entered service in 1963 (allowing the Thor to be returned to the US) and finally withdrawn in 1970. Subsequent missile programmes relied on US technology with the Polaris submarine launched ballistic missile, introduced in 1968, finally replacing the V-bomber force in the Deterrent role, albeit with a British designed enhanced re-entry vehicle and warhead system, Chevaline.

The reality was that by 1957 Britain was technologically and industrially at least a decade behind the America and the Soviet Union in missile development. Industrial and scientific resources committed to the UK rocket programme were orders of magnitude smaller that the US and USSR. As a hegemonic actor on the world stage, global leadership had slipped away since the early 1940s and Britain had to contend with being a second-order power, largely reliant on the US for strategic research, development and technologies.

## Acknowledgements

I wish to thank Dr John Becklake for his support and detailed knowledge of German scientists employed in the UK after the war. I would also like extend my gratitude to the Mr Kevin Ball of Taylor and Francis Group, who have made National Archives *Secret Files from the Cold War* available on line to assist my research at **www.secretintelligencefiles.com**

## Notes

[1] CROSSBOW was originally the codename for the committee looking at measures to counter the V-1 flying bomb and BODYLINE fulfilled a similar function to defeat rockets. The committees

were merged in November 1943 under the name CROSSBOW, although reports relating to BODYLINE continued to be produced until mid-1944. The term 'Operation CROSSBOW' is a post-war expression.

[2] Collier, Basil (1964) '*The Battle of the V-Weapons 1944-45*' Hodder and Stoughton, pp. 138-150.

[3] In this paper, the experimental models of the long-range rocket are referred to as the A4; operational use by the more recognised name of V-2.

[4] The A4/V-2 was code-named 'BIGBEN' by the BODYLINE Committee, but frequently referred to as 'Big Ben', 'long-range rocket or 'simply, 'rocket'. Hill para 148; CAB 176/2 'Most Secret' JIC/1737/43 'J.I.C. BODYLINE Intelligence Machinery'. The permanent chair of the BODYLINE Committee was Commander Ian Fleming RNVR, later author of the James Bond genre.

[5] Known at the time by its German name of Swinemünde.

[6] CAB/81/132 Confidential JIC(48) 33 report dated 20 Oct 1946.

[7] Biddle, Wayne (2009) '*Dark Side of the Moon*' W. W Norton NY & London, pp. 39 – 42. Oberth worked at Peenemünde during World War II. Between 1956 – 1961, Oberth worked with von Braun at the US Army Ballistic Missile Agency, developing multi-stage rockets.

[8] Constance Babington-Smith (1957) *'Evidence in Camera' Chatto* and Windus, London, p. 204 – 205. Initially Mr Duncan Sandys, Chairman of the War Cabinet Committee for defence against German flying bombs and rockets, led the belief that the V-1 'flying bomb' and V-2 missiles were part of the same programme. Although testing of both took place at Peenemunde, they were separate and uncoordinated projects. On p. 207 the V-1s are also referred to as 'airborne rocket torpedoes' (a direct translation of the German name from signals) revealing – inadvertently - knowledge of the rocket programme through signals interception and code-breaking, which was still 'Top Secret ULTRA' when the book was published in 1957.

[9] For technical aspects of the search for the V-2, see Robert V Jones (1978) *Most Secret*, Hamish Hamilton, London, pp. 430-461.

[10] Dornberger, Walter (1954): *V2*, Hurst & Blacket, London. pp. 151-168.

[11] Dornberger, pp. 79-83.

[12] Dornberger, p. 222.

[13] SS–Obergruppenführer Kammler (General) Dr-Engineer Heinz (Hans) Friedrich Karl Franz Kammler (1901-1945) was appointed by Hitler in July 1944 to be responsible for all missile technology, including the V-2 ballistic missile programme, and was additionally assigned the grandiose term of 'General Plenipotentiary of the Fuehrer for Jet Propelled Aircraft'. This gave him full control over the production, distribution and utilisation of jet aircraft and vengeance weapons. Kammler, a civil engineer, was infamous for directing construction of the gas chambers and crematoria at Auschwitz concentration camp. His rank was an appointment in the SS – he had no military experience and was known for his cruelty. He is thought to have died near Prague in May 1945 (although bonkers pro-Nazi conspiracy theorists suggest that he survived the war and moved to South America – or Antarctica).

[14] Dornberger, p. 224.

[15] JIC papers regularly refer to Professor 'Linstead', rather than Lindemann, perhaps avoiding awkwardness of his German origins. Occasionally his name is given the more Anglicised 'Linderman'.

[16] Known as 'CX' reports.
[17] Collier, p. 147.
[18] Collier, pp. 138-140.
[19] CAB 176/1 J.I.C./492/43 '*German Long-Range Rocket Development*', 21 April 1943.
[20] CAB 176/2 '*BODYLINE Targets in Germany*' 4 November 1943.
[21] Hill, para 152.
[22] Hill, Sir Roderic (1948): 'Air Operations by Air Defence Great Britain and Fighter Command in connection with the German Flying Bomb and Rocket Offensives, 1944-45.' *The London Gazette* Supplement 19 October 1948, para 66. **https://www.thegazette.co.uk/London/issue/38437/data.pdf** accessed 7 Mar 19.
[23] Collier, p. 404.
[24] Andrews, Christopher (2009) '*The Defence of the Realm: The Authorized History of MI5*' Allen Lane/Penguin, London. p. 313.
[25] R.V. Jones (1978): '*Most Secret War*' Hamish Hamilton, London. pp. 447-448.
[26] Hill, para 163.
[27] CAB 81/124 *Imminence of Attack by Bigben*. J.I.C (44) 366 (0) dated 31 July 1945.
[28] Guy Liddell Diary, vol 10, 25 August 1944. TNA KV 4/194 in Andrews, p. 313.
[29] Dornberger's book shows a V-2 being erected into the launch position from special railway wagons (p. 97). Work began in 1942 but it is thought that no operational launches were made; by late 1944 the railway network very vulnerable to Allied air interdiction, both in search of V-2 rockets but also as part of the wider Allied offensive against German forces. Dornberger, p. 235.
[30] Babington Smith, p. 232.
[31] Wright, Jerry (2014) '*Zeppelin Nights: London in the First World War*' Vintage Books, London, p. 250.
[32] This alert system would be resurrected in 1955 and initially operated by the Royal Observer Corps (ROC) and then from 1965 by the UK Warning and Monitoring Organisation – also based at Stanmore (RAF Bentley Priory) - and would be activated by ROC posts who would launch three 'maroons' to warn of the local approach of radioactive fallout. The system remained serviceable until about 1991.
[33] Longmate, p. 128.
[34] Collier, pp. 127-129.
[35] Hill, paras 220-221; Collier, p. 150.
[36] Perhaps the greatest intelligence coup in WW II after breaking the ENIGMA codes was the complete penetration of the German spy network in Britain by the 'Twenty (XX) Committee'. For accounts of the deception associated with the V-2 programme, see John Masterman's official report released in 1972: *The Double Cross System*, Reed, Wellington, pp. 180-183; Keith Jeffrey's official history (2010) *MI6 – the History of the Secret Intelligence Service*, Bloomsbury, pp. 571-572; Christopher Andrew's (2009) *The Defence of the Realm – the Authorized History of MI5*, Allen Lane, London, pp. 310-316. For technical intelligence on the V-2, see Jones, pp. 430-460.
[37] Howard, Michael (1990) '*British Intelligence in the Second World War*' vol 5 pp. 182-3, in Andrews, p. 316.

[38] Biddle, pp. 142-143.
[39] Collier, Basil (1957) '*The Defence of the United Kingdom*' HMSO, London, Chap XXV, pp. 418-419.
[40] Hill, paras 201-220.
[41] Dornberger, p. 248.
[42] CAB 81/128 J.I.C (SHAEF) (45) 18 (Final) '*Ability of Enemy to continue to use V-Weapons*'. 23 April 1945.
[43] Jones, p. 459.
[44] RAF Fighter Command counted 1115 missiles falling in the UK or within sight of shore. Hill, para 223.
[45] For harrowing contemporary accounts of the V-2 'blitz' against London, see Maureen Walker (2004): *London 1945*, John Murray Ltd, London, pp. 17-71.
[46] Part of the German Labour Front, a central economic planning function of the Nazi Party
[47] A short-range mortar-type rocket, normally in a multi-barrel arrangement, initially designed to deploy a smoke barrage. From images available, the tests were conducted using 28/32 cm rockets. http://www.uboataces.com/articles-rocket-uboat.shtml accessed 7 March 2019.
[48] Collier (1957) p. 399.
[49] Submarine Launched Ballistic Missiles typically have solid-fuel engines.
[50] Dornberger, pp. 231-232.
[51] Lundeberg, Philip K. (1994). "Operation Teardrop Revisited" in Runyan, Timothy J; Copes, Jan M. "*To Die Gallantly: The Battle of the Atlantic*." Boulder: Westview Press
[52] Dornberger, p. 235; picture p. 97.
[53] Schulz H.A (1965) '*Technical data on the Development of the A4* V-2' NASA Historical Office, George C Marshall Space Flight centre.
[54] Schulze, p. 54.
[55] Dornberger, pp. 236- 237. The Nazi nuclear programme was, at best, in its infancy and never posed a real threat, although considerable Allied resources were committed to dismantling the programmes and seizing both research documents and fissile material.
[56] Neufeld, Michael J (2007): *von Braun*, Smithsonian Institute, p. 188-189. Piszkiewicz, Dennis (1998) *Wernher von Braun*, Praeger, Connecticut., p. 39.
[57] Neufeld, p. 196.
[58] Biddle (2009), p. 129.
[59] A complete set of weekly Air Ministry Technical Intelligence Summaries are held by the MOD Air Historical Branch, RAF Northolt, London.
[60] During General Dornberger's internment in Farm Hall, Wilton Park and other POW detention centres in England between 1945 and 1947, he disclosed in a secretly-recorded conversation with another German general that he and von Braun had travelled to Lisbon in October 1944 for secret talks with two officials who claimed to be from the General Electric Corporation, about the surrender of all Germany's top scientists to US forces. Although there may have been some bravado on Dornberger's part, and none of von Braun's biographers refer to any visit to Lisbon during the war (an event he was likely to keep quiet), it is most likely that von Braun's

surrender was carefully orchestrated.
[61] Biddle, p. 129.
[62] CAB 81/118 'German Long-Range Rocket Report' JIC.
[63] Jones, pp. 440-442.
[64] CAB 81/93 JIC(45) 9th Meeting Air Intelligence Targets under Russian Control. Para 8.
[65] Andrew, Christopher (2009): '*Defence of the Realm. The Authorised History of MI5*.' Allen Lane, London, p 173. Blunt (1907-1983) was unmasked by MI5 in the 1950s and publically exposed in 1979.
[66] Longden, Sean (2009) 'T-FORCE: The Race for NAZI war secrets, 1945.' Constable, London.
[67] AVIA 15/2216 minute by DSR 11 May 1945. In Uttley, Matthew (2002) 'Operation 'Surgeon' and Britain's Post-War Exploitation of Nazi German Aeronautics' in *Intelligence and National Security, v17 No 2 (Summer 2002) pp. 1-26*.
[68] https://royalsocietypublishing.org/doi/pdf/10.1098/rsbm.1994.0015 accessed 20 March 2019.
[69] Neufeld, p. 205. In Thom Burnett's 2005 work, he is erroneously referred to as 'Colonel William Cook'. British investigators reportedly wore uniform in the field, however Dr Cook never formally served in the British Army.
[70] Longmate, p. 376.
[71] Burnett, Thom (2005) '*Who Really Won the Space Race?: Uncovering the Conspiracy That Kept America second to the Russians*.' Collins & Brown, London, p. 154.
[72] Biddle, pp. 142 – 143.
[73] Longden, p. 273. Von Braun reportedly spent two days at the former *Luftwaffe* airfield at Völkenrode under British guard.
[74] Biddle, p. 142. This group did not include the 'father' of the V-2 programme, General Dornberger, but did include the much less experienced brother of Wernher, Magnus von Braun.
[75] Piszkiewicz, Dennis (1998) *Wernher von Braun*, Praeger, Conneticut, pp. 50-54.
[76] '*Official Report on Operation Backfire*' v 1-5, War Office, London, January 1946, in Becklake, 2014.
[77] Longden, pp. 271-274. The Operation *Backfire* reports noted that the V-2 heralded a new type of warfare, but only if the rocket was able to deliver a nuclear warhead.
[78] Becklake, John (2006): *German Rocket Engineers in Astronautic Acta* V 49, updated 2011, 2014.
[79] https://www.iwm.org.uk/collections/item/object/1060020906.
[80] Much of what was said by the POWs and captured nuclear and missile scientists at Wilton Park and Farm Hall camps was secretly recorded under Operation *Epsilon*, and some of the recordings and transcriptions were declassified in the 1990s.
[81] Sayer, Ian & Douglas Botting (1984) '*NAZI Gold*', Granada, London pp. 239,240.
[82] Uttley, p. 9.
[83] The terms Soviets and Russians are synonymous in the reporting, and this convention is followed.
[84] The Soviet title for their equivalent operation to SURGEON was 'OSOAVIAKHIM', an acronym.

[85] CAB 81/132 '*Disposal of German Scientists and Russian Activities in connection therein*.' JIC (46) 8(0) 18 January 1946.
[86] CAB 81/133 JIC (46) 51 'Russian Attempts to Entice German Scientists and Technicians from the BRITISH Zone of Germany.' 2 July 1946.
[87] Barrow News, 12 January 1945 on Becklake, 2002.
[88] CAB 158/4 JIC (48) 73 (0) '*Employment of Aliens on Defence Work*.' 3 August 1948.
[89] Uttley, p. 9.
[90] Sir Ben Lockspeiser, previously Director-General of Scientific Research within the Ministry of Supply was apparently investigated in the 1950s by MI5 because of pre-war Communist associations.
[91] https://www.mi5.gov.uk/klaus-fuchs accessed 7 March 2019.
[92] CAB 176/11 '*Publication of Details of Fall of Shot of V.1 and V.2 Weapons*.' JIC/953/46 10 July 1946.
[93] Becklake, p. 6; Uttley, p. 9.
[94] CCGP (45)2, November 1945. www.peoplescollection.wales/item/381651.
[95] The Ministry of Supply assessed Dr Johannes Scmidt, amongst others, as an 'active Nazi' during security screening. Uttley, p. 9.
[96] Becklake, p. 10.
[97] Andrews, p. 325.
[98] Hunt, Bryan (2013); '*The Most Beautiful Barracks in Germany' A History of the Barracks in Oberammergau 1935 – 1975*. Unpub MSS; NSO.
[99] Cockrocft, Wayne & Roger Thomas (2003) '*Cold War: Building for Nuclear Confrontation 1946 – 1989*', English, Heritage, Swindon. p. 46.
[100] Uttley, p. 12.
[101] Longmate, p. 377.
[102] Longmate, p. 378.
[103] Becklake, p. 12.
[104] CAB/129/86 1957 Statement on Defence, March 1957.
[105] Cockroft, pp. 47-51. The US designation for the Thor missile was PGM-17.

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Book Review

# Reaper Force: Inside Britain's Drone Wars


By Dr Peter Lee
**Publisher:** John Blake Publishing (4th October 2018) (**ISBN-13**: 978-1786069641), 352 pages

Reviewed by Air Vice-Marshal (Retd) Tony Mason

**Biography:** Air Vice-Marshal (Retd) Tony Mason was the first RAF Director of Defence Studies. He was subsequently the specialist Air Adviser to the House of Commons Defence Committee while holding a personal Chair in International Security at the University of Birmingham. For many years he has published and spoken internationally on air power and related defence subjects.

## Introduction

Dr Lee is Director of Security and Risk Research at Portsmouth University. He moved into Academe after serving from 2001-2008 as a RAF Chaplain. He specialises in air power and ethics in war. Since 2011 he has taken a particular interest in unmanned aerial systems, known colloquially as 'drones'. Between 2015 and 2018 he conducted 90 recorded interviews and many conversations with serving and retired RAF Reaper operators and their partners. In *Reaper Force* he focuses on human issues, but the interviews also reveal many details of the operational environment not hitherto available to the general public.

In the twenty-first century International Conventions have sought to protect non-combatants while belief in the prosecution of a just war has provided ethical grounds for resorting to armed force. Dr Lee reminds us that in the history of air warfare, opponents have always sought technical, tactical and personal advantages. Destruction and killing were normally at a distance while aircrew in World War Two, usually unaccompanied by families, were likely to relax off duty in a local hostelry. Whilst flying, aircrew were vulnerable to both enemy action and the elements.

Through his interviews Dr Lee illustrates the very different operational circumstances of the Reaper Force, with 39 Squadron at Creech AFB in the USA or with 13 Squadron at RAF Waddington in Lincolnshire. The Pilots, Sensor Operators and Mission Intelligence Coordinators work in Ground Control Stations thousands of miles away from their targets and risk of enemy reaction. Yet they may watch their potential targets at very close range for several hours or perhaps even days. They operate under a directive known as CIVCAS: zero civilian casualties. After the assimilation of intelligence from many sources, rules of engagement include meeting seven criteria, with the final decision to attack or not resting with the Reaper captain, a role performed by the pilot. All targets are planned with the option to perform a last-minute attack abort, a procedure that requires the sensor operator to guide the munition to a pre-designated safe area. One pilot summarised one of the fundamental challenges:

> *Using lethal force ...requires a mixture of aggression and patience, of calculated professional discipline and empathetic human understanding because every time you hear 'cleared hot' (for weapon release) you have to get the decision right. Failure to do so puts friendly lives in jeopardy or increases the risk to innocents (p. 284).*

The crew may have to decide between killing or ignoring a human target. They will see at close range the impact of their weapons as part of the battle damage process including human remains and the reaction of witnesses.

At the end of a shift, the crews return to their homes in downtown Las Vegas or to the Lincolnshire countryside, moving directly from the trauma of war to the peace of their families. Unsurprisingly many interviews revealed the impact on personal relationships of accumulated physical, mental and emotional stress, sometimes temporary, frequently longer lasting. Inevitably, some were more resilient than others. The enduring spirit of the Force was, however, summarised by a pilot who confessed to exhaustion but 'would do it all again...because I made a difference' (p. 302).

Unsurprisingly in a Service renowned for its determination, courage in the face of the enemy and willingness to make the ultimate sacrifice, many interviewees were reluctant to reveal the pressures induced by their environment, feeling a loss of self-respect and sensing the disdain of erstwhile colleagues only familiar with 'traditional' combat. Dr Lee's own sensitive reaction to the disclosures is understanding and sympathetic, without ever losing his underlying belief in the legitimacy and morality of the Reaper Force's operations.

Indeed, the operational incidents described by the crews reveal details which repeatedly illustrate the adherence of the Reaper Force to both legal and ethical principles of war from 2008 when Reaper began to carry weapons. Crews progress through categories of combat readiness to final clearance to kill individuals. Failure to apply rules of engagement, for example to overlook a transient civilian risk, would lead to an immediate official investigation, detailed remedial training and possible reduction in Reaper operational category. An authority to fire could be countermanded at any stage in the process from any of the external agencies watching the operation. The crew are in constant contact with friendly forces on the ground as well as their own chain of command within the theatre of operations. Indeed, perhaps the most controversy and severe trauma are generated when the Reaper Force rules of engagement preclude intervention in support of friendly ground forces, especially if they should be taking casualties.

The unique combination of circumstances which distinguish the Reaper Force's way of waging war prompts Dr Lee to reflect on the demoralising impact of a Government announcement in September 2017 of the award of campaign medals for Operation SHADER in Syria and Iraq which did not include the Reaper Force. Yet between August 2014 and December 2018 the Reaper Force flew 3080 missions and released 964 weapons. Criteria traditionally applied to the award of campaign medals have included geographic location in a specific campaign and exposure to the associated 'risk and rigour' in theatre; neither applying to the Reaper Force. In July 2018 however the Defence Secretary announced that the 'Operation SHADER medal will now recognise those making a vital contribution to Op SHADER from outside the conventional area of operations, for example the Reaper pilots taking life and death decisions from back here in the UK' (p. 249). There has been no further amplification of this apparent change in policy.

*Reaper Force* is not an academic source for research on remotely piloted air systems (RPAS) policy, strategy, tactics or personnel. The number of interviews represent only a small proportion of the Force. Moreover, the interviews and conversations were all voluntary with no scientific or statistical basis for selection or evaluation. The well-founded preservation of anonymity precluded the inclusion of details of recruitment criteria, age, experience, rank, gender or psychological predisposition. In seeking to emphasise the human implications of applying deadly force by remote control, the author frequently imposes his own sentiments on interviews. They can be intrusive and impair the objectivity of his conclusions.

But despite such reservations and limitations, *Reaper Force* is a unique and most valuable addition to the lexicon of British air power, easily approachable by the lay reader and thought provoking to the professional.

The RAF is planning to expand its RPAS force with the introduction of the new Protector system. The availability of counselling on Reaper Squadrons and the existence on several RAF stations of medical units specialising in mental health reflect the Service's concern now about more than just physical wellbeing. Dr Lee's 'snap-shots' stimulate many questions which remain unanswered, at least in the public domain. How far can the boundaries between human control and artificial intelligence be expanded? In an air force, how can the interface be managed between those who fly and fight and those who may be engaging similar targets from the security of remote ground locations? By what selection criteria will RPAS crews be recruited? How will their careers be managed? Do current medical categories and procedures require revision to reflect new operational circumstances?

In an Air Force which has always sought technological advantage, *Reaper Force* is a salutary warning that any armed service is only as good as its people and neglects the 'human dimension' at its peril.

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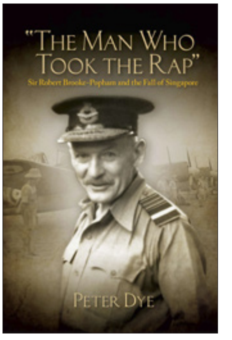
Book Review




# The Man Who Took The Rap: Sir Robert Brooke-Popham and the Fall of Singapore

By Peter Dye

**Publisher:** Naval Institute Press (30th October 2018) (**ISBN-13:** 978-1682473580), 432 pages

Reviewed by Air Commodore (Retd) Prof Peter Gray

**Biography:** Professor Peter Gray retired from the Royal Air Force in June 2008, having reached the rank of Air Commodore (1*). He was the RAeS Senior Research Fellow in Air Power Studies at the University of Birmingham until 2018 and is now RAeS Chair of Air Power Studies at the University of Wolverhampton. Gray spent his early career as a navigator on the F4 Phantom and, more recently, commanded 101 Squadron flying VC10 K tanker aircraft. Gray holds degrees from the Universities of Dundee, London, Cambridge and Birmingham (PhD). He is a Fellow of the RAeS, the Institute of Leadership and Management and the Royal Historical Society.

## Introduction

Air Chief Marshal Sir Robert Brooke-Popham was appointed as Commander-in-Chief Far East in October 1940: Singapore fell to the Japanese invasion in early 1942, an event which is widely symbolised as the end of the British Empire. At the time, Churchill described this in the *Hinge of Fate*, (the fourth volume of his self-serving memoirs of *The Second World War*) as 'the worst disaster and largest capitulation in British History'. In the same paragraph, Churchill stated that he, and Parliament, had taken the view at the time that a Royal Commission into the defeat was not practical. Characteristically, he went on to suggest that his chapter was not a substitute for such a court. At the time, and subsequently, Brooke-Popham was widely condemned and vilified in the Press and in Parliament. The contemporary criticism was regrettable, but possibly understandable in the quest for a scapegoat, or even a villain. The reality was that the empire had been in general decline for many years; or possibly more correctly, British power on the world stage was being eclipsed as the century evolved. The subtleties of such arguments were, and

**are still, easily swept aside. It was far easier to deride Brooke-Popham as a 'nincompoop' or worse. Politicians, and other decision makers of the era, were more than content to let Brookie (as he was more generally known) carry the can than to encourage a deep analysis of their own roles in policy decisions taken throughout the inter-war period when Britain's resources just could not cope with providing a credible defence of possessions in the Far East. Brooke-Popham's sixteen-month tenure could hardly have changed the course of history and more important folk than him would have been in the firing line.**

In *The Man Who Took The Rap*, Peter Dye has sought to offer a more nuanced version of the events leading to the Fall of Singapore and, in some way, belatedly speak on behalf of Brooke-Popham who chose never to do so for himself. The Singapore section of this book makes it essential reading for all students of the conflict in the far east as well as those interested in the wider history of the Second World War. But the book goes well beyond this, and to many readers of *Air and Space Power Review*, it will be the biographical aspects of this leading and highly influential airman which will be of great interest. Brooke-Popham's influence spanned whole generations of air force personnel and included his time as an active pilot on the western front; his tenure as Commandant in the early years of the RAF Staff College at Andover and subsequently at the Imperial Defence College; his preparations for the Air Defence of Great Britain; as Inspector General of the RAF; and as an Imperial Governor. After his retirement, Brooke-Popham was well known to RAF Staff College students at Bracknell for the named essay prize given for the best dissertation. So, this book effectively is a full-scale biography of Brooke-Popham in the context of his life and times and is to be commended for that alone.

In an era of broader contemporary, or modern, history, traditional biographies of great men and women have gone out of vogue. The reasoning behind this goes well beyond the fickle whims of academe. A sizeable portion of contemporary readers of military histories prefer tales of 'derring-do' at the tactical level, of individual 'heroes' or, more often, of groups made up of brave folk often in the face of their incompetent or heartless leaders. A more pragmatic reason for the demise of the traditional biography is the difficulty in shedding the shackles of hagiography. If an author is dependent on access to family archives for research material, it may be necessary to tone down criticism of the subject. It is also all too easy to become immersed in the story, the context and personnel and, at least, exhibit a less than critical sympathy with the subject at hand. It is therefore no surprise that a scholar's library remains full of dated biographies.

In this work, it is clear that Pete Dye did have excellent access to family papers and to the family members themselves; the Foreword by Francis Philip Brooke-Popham is immediate evidence of this. There is also a noted sympathy for the Brooke-Popham himself. But this does not amount to hagiography. Peter Dye writes with too much authority for such a charge to be sustainable. His scholarship, and outstanding deployment of historical sources in support of his arguments, provide him with more than an adequate defence. Furthermore, the same skills shed considerable light on various episodes of British and RAF history that are most welcome. This book is therefore a highly welcome addition to the canon of British air power literature and has considerable further merits to commend it to a wider audience.

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Book Review


# Limiting Risk in America's Wars

By Phillip S. Meilinger
**Publisher:** Naval Institute Press (30th November 2017) (**ISBN-13:** 978-1682472507), 304 pages

Reviewed by Dr Peter Lee

**Biography:** Dr Peter Lee is the Director Security and Risk, and a Reader in Politics and Ethics, at the University of Portsmouth. He has been researching and writing about remotely piloted air operations since 2012. In 2016 Peter was granted unprecedented research access to the two RAF Reaper squadrons for his latest book, *Reaper Force: Inside Britain's Drone Wars* (2018).

## Introduction

**In his latest book, the prolific air power author, academic and former USAF officer Phillip S. Meilinger makes an impassioned and historically-based argument for America to adopt the best available technology to reduce its military and political risk. He also extends the need to limit risk to civilians and infrastructure while fighting adversaries. More specifically, in the drive for asymmetric advantage he advocates for a reorientation of US military policy away from massed land forces towards 'airpower, SOF, indigenous ground troops, and robust ISR' (p. xvii). The latter looks very like the US order of battle in Syria against ISIS.**

The author introduces a helpful, if brief, summary of the key tenets of air power theory since the First World War. This sets the foundation for the aim of the book: to grant air power 'a greater or possibly even dominant role' in US strategy (p. 9). There follows a discussion of the British military historian and strategist Basil Liddell Hart, and the reduction of risk through his 'Indirect Approach' (p. 18) and the resultant 'limited liability' (p. 22).

Having set the context for his main thesis, Meilinger then sets off on a series of historical case studies over several chapters which look at 'second front' operations (p. 31), or indirect approaches, where belligerents seek to defeat or weaken an enemy while avoiding head-on confrontation. In the process he builds his case using incisive analysis of military and political events, consistently drawing upon statistical data that spans costs, troop numbers, supplies, sorties flown, ships at sea, enemies killed, civilian casualties, defence budgets, and much more. The result is a well-argued case for reducing risk in America's wars in the twenty-first century in an almost breathless intellectual journey across modern wars, large and small.

The final two chapters provide a fascinating and provocative culmination to the author's arguments. His tone tends to be more critical of conventional army and Marine approaches to war, attributing greater nuance to sailors and airmen and the way they apply technology. Precision weapons are presented as a particularly beneficial development and their accuracy, 'measured in single-digit feet' (p. 172), is presented somewhat idealistically: 'The consequence has been a dramatic decrease in the number of civilian casualties in wars fought by the United States and its allies (p. 173)'. His statistics point to the benefits of this technological advancement.

From an ethical perspective, I am intrigued by the dynamic that then emerges in Meilinger's argument. On the one hand he advocates for the 'jointness' that emerged from the Cold War: 'To minimise mistakes and confusion, military operations became more centralized and more joint' (p. 171). In contrast, in the discussion about the proficiency of air-delivered munitions which follows reads much more as air power advocacy.

Referencing precision weapons and civilian casualties he is keen to cite the relatively small number of civilian deaths that are attributable to single-service air strikes: 11.3% of 85,000 Iraqi civilian deaths between 2003 and 2008; and only 2.6% of 60,922 Iraqi civilian deaths between 2005 and 2009 (p. 173). The other 97.4% were a result of ground warfare.

If, as Meilinger advocates, the use of indigenous forces on the ground is to be part of America's risk reduction strategy, then the US would not, in fact, be moving away from large-scale joint warfare but merely outsourcing the land element. More pertinently, it would not be reducing *overall* risk in modern war but merely reducing its own risk by outsourcing the blood cost of the ground element. It might even be increasing the overall risk to civilians in modern warfare by supporting indigenous allies whose ground forces are not as discriminating or proportionate as the US Army or US Marine Corps. Surely consistency and morality demands that the US 'owns' the ground casualties caused by the 'friendlies' it supports if those allies are also supporting US strategic interests. If the reader does not recognise this dynamic then they might be left with a distorted view of what air power can achieve in modern warfare.

In addition, as an air power advocate, I surprised myself with the degree to which I felt defensive towards the US Marine Corps General who is roundly criticised for his view that, '… we can't lose our honor by failing to put our own skin on the line' (p. 174). Because for the author, 'Airpower offers a far more intelligent and humane alternative' in limiting 'risk to friendly forces' (p. 174). They seem to be talking at cross-purposes. Despite any shift towards risk-free or reduced-risk warfare – especially to one's own combatants – through the application of technology via air power in particular, if a piece of ground needs to be taken and held it will be a marine or a soldier that does it. The need for honour and physical courage on the battlefield has not disappeared, even if the requirement has changed somewhat in the increasingly political-risk-averse wars that the US has fought over the past three decades.

In what is an excellent, thought-provoking book, there are two areas where I would take issue with the author. The first of these reveals my own bias as much as any deficiency in the text, because drone warfare is only briefly mentioned and is assumed to reduce risk to the crews involved. However, the reduced risk that the author refers to is *physical* risk. The book could benefit from a discussion here about psychological risk to Predator and Reaper crews who see the results of their strikes in increasingly high-definition detail. A brief footnote is scant consolation (p. 179, note 51). I would argue that risk is relocated or redistributed through remotely piloted aircraft (or drone) use, not reduced or removed.

My second query is about the inherent assumption that political goals should be, or even can be, pursued 'at low cost and low risk' (p. 205). Before the 2008 banking crisis, financiers around the world were certain that they had hedged and calculated away their risk to a minimum. Instead it was simply ignored or missed and waiting to blindside the global banking structure, starting with seemingly impregnable US banks. For all the logic of Meilinger's arguments, the approach he advocates contains a number of unstated risks that cannot be measured in either blood or treasure. What is the risk to the collective American psyche if opponents and neutral observers eventually see US political and military risk aversion as cowardice? And what if the unthinkable happens and a population that is schooled in the language of low risk war is called upon to wage a brutal war of truly great national and individual sacrifice? Will the confusion be any less than that of the financial crisis?

Perhaps the greatest legacy of Phillip Meilinger's book will be to prompt exactly this kind of soul searching and critique of past, present and future government policy on the methods and means of war. After reading the book I felt there was something familiar but not immediately identifiable about its message and tone, especially the idealistic and sometimes idealised view of what air power can achieve. Initially I thought of John Warden's 'Five Ring Model' of air power strategy (1995, p. 44).[1] But the connection that I eventually settled upon – and readers will form their own opinions – was to Hugh Trenchard's impassioned arguments for the supremacy of air power over naval and land power after World War I. In reality, Trenchard's air power theory was as much a political argument for the very existence of the Royal Air Force and the prioritisation of its budget, as it was about how aircraft can be used to deliver effect in war. It could even have been called *Limiting Risk in Britain's Colonial Wars*.

[1] Warden, J.A., 1995. The Enemy as a System, Airpower Journal 9(1), 40-55, Available at: https://www.airuniversity.af.edu/Portals/10/ASPJ/journals/Volume-09_Issue-1-Se/1995_Vol9_No1.pdf [Accessed 20 May 2019].

I highly recommend *Limiting Risk in America's Wars* to both the amateur enthusiast and the professional soldier, marine, sailor and air power practitioner. It is informed, provocative, and offers 'risk' as a very useful lens through which to revisit old debates around war and military intervention. I just can't help being concerned that the idea of 'low risk' war might lead to hubris or complacency. War will always be a costly business and someone, somewhere has to pay.

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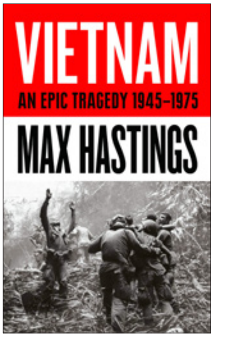
Book Review

# Vietnam: An Epic Tragedy 1945-1975




By Max Hastings

**Publisher:** William Collins (20th September 2018) (**ISBN-13:** 978-0008132989), 752 pages

Reviewed by Group Captain Tim Below

**Biography:** Group Captain Tim Below is a Hercules pilot, experimental test pilot, and a strategist. A graduate of both the Royal College of Defence Studies and the USAF School of Advanced Air and Space Studies, he holds Masters degrees in Defence Studies and in the Art and Science of Airpower. He was the UK's first resident Defence Attaché to Vietnam from 2013 to 2016, and is currently serving as the Air Attaché in Paris.

## Introduction

**In *Vietnam: An Epic Tragedy 1945-1975*, Sir Max Hastings reflects on the real-world dilemma as *Realpolitik* events unfolded in Vietnam during the 30 years following the Second World War. These eventful years saw the fall of the French colonial regime, the inexorable advance of America's foreign policy into the Indochinese mangle, the eventual withdrawal of the United States from South Vietnam (correctly the Republic of Vietnam), and the subsequent – and he postulates by then inevitable – fall of the Southern regime to the communists of the North (formally the Democratic Republic of Vietnam).**

Hastings is a distinguished author, journalist, TV broadcaster, and newspaper editor who has received awards for both his journalism and his books. Vietnam was just one of 11 conflict-ridden countries to which he travelled as a reporter, visiting on numerous occasions during the war from 1970, culminating in his presence in 1975 at the fall of Da Nang and subsequently of Saigon. This book is the product of contemporary interviews with individuals from both the USA and Vietnam, who were involved in events 40 years earlier. Some are critical figures of the era; some fought in one capacity or another; and some were (mainly Vietnamese) civilians whose lives became embroiled in what Hastings entitles an *Epic Tragedy*. By his own admission, he seeks not so much to catalogue the events of the war, but instead to characterise how it felt for those caught up in it.

Throughout this significant work, Hastings repeatedly returns to two themes. First, that far from being founded on the interests of the Vietnamese people, the American commitment to the South Vietnam regime was instead developed, executed, and adapted to serve its own domestic and foreign policy objectives even as these themselves evolved over two decades. Second, and notably from 1968 onwards, that the US leadership (particularly President Richard Nixon and his National Security Advisor Henry Kissinger) gratuitously sacrificed tens of thousands of lives on each side of the conflict by protracting the war in pursuit of 'peace with honour' – even at the height of the 'Vietnamisation' programme – while attempting to conceal the reality of an ignominious defeat from their American electorate. Indeed, perhaps because they constituted such temporally critical influences on policy formulation, Hastings focuses particular and well-presented attention on the significance of the multiple US Presidential elections held during the period.

Hastings' undercurrent throughout his book is that the South Vietnamese regime did not merit being propped up by the United States. US policy-makers regrettably failed to recognise that irrespective of who they installed to lead it, the regime had no political or societal credibility in the eyes of the indigenous Vietnamese people. Yet because he separately finds himself unable to endorse the cause of the communist regime of the North, Hastings is unavoidably drawn to the book's overall conclusion that neither societal regime represented a good national proposition. Moreover, his enduring lament is that following the Geneva accords of 1954, the Vietnamese people found themselves tragically trapped in a military confrontation between these two violently opposed, and independently oppressive idoeologies, a situation which was perpetuated by the self-serving interests and actions of the United States.

Although he does not major on them, Hastings also proffers three air power lessons particularly relevant to the modern twenty-first century commander. First, that however unpalatable it may be, trying to impose a way of government on a resistant nation requires territorial occupation not the underwriting of an inadequate or incapable sovereign government. Second, the use of air power alone to break the will of a relatively simple society which is protected by capable proxy air defences represents a significant challenge in multiple dimensions. And third, that if the conditions of success are maintained only through the air power capabilities of an intervening nation, then upon withdrawal of those capabilities, the conditions for sovereign failure will inevitably recur.

Throughout his book, Hastings adopts a presentational style based on recounting human experiences through the various phases of the war. Some of his accounts appear to be slightly disjointed litanies of various individuals' fleeting recollections, and this tends to result in the reader adopting a posture of a rather dissociated voyeur. However, his excellent and detailed exposition of other phases succeeds in drawing the reader into the world of those engaged in and/or palpably affected by the war at various critical junctures as the events unfold through the lens of their memories. His accounts of the Tonkin Gulf incident of 1964, the Tet offensive of 1968, the lesser-known battles of Daido in that same year, and the battle of An Loc in 1972, are particularly good examples. Elsewhere, Hastings touches on the My Lai massacre of 1969 and the extraordinary confrontation by the Australians at Long Tan in 1966. Yet notwithstanding that Hastings' key theme is one of flawed US policy, those more steeped in this war's history may find the scant treatment which these latter two battles receive to be somewhat surprising.

As a valuable insight from a very human perspective, *Vietnam: An Epic Tragedy* complements Fredrik Logevall's *Embers of War* and Neil Sheehan's *A Bright Shining Lie*, which address the roots of the war with America and Lieutenant Colonel John Paul Vann's contribution to that war respectively. Using abbreviations only for a small number of frequently recurring organisations and expressions, all of which are glossary-listed; signposted through a well-structured and largely chronological presentation of the major events of the war; and with a comprehensive and detailed index; this work is accessible to all, although a prior basic grasp of the war's history will enable the reader to better comprehend the insights Hastings offers through the eyes of those who endured it.

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Established in 1947, the Association's membership comprises highly regarded individuals with a wealth of experience in the air and space power domain and is open to individuals, businesses, military units, consultants and academics. Indeed, anyone who has an interest in air and space power.

Members include serving and retired members of the UK's Armed Forces and from overseas, those engaged in the Media and Communication Directorates of the MOD, Members of Parliament, academics with aviation or associated aviation/defence interests, representatives of the aerospace and defence industries and aviation/defence media.

Throughout the year we hold a series of events that create a platform for members and guests to listen and contribute to the latest developments and trends in air and space power, helping to define today's environment and shape the future.

Discussion is stimulated through conferences, debates, lectures and forums. These include regular 'fireside chats' which give corporate members the opportunity to engage with senior military officers in free and frank discussion. Regular dinners are also held throughout the year including our annual event in the House of Commons. These are attended by senior military and industry leaders, providing the basis for further discussion of the air and space power domains.

The Chief of the Air Staff's Air and Space Power Conference, held in London every July and delivered by the Association on behalf of the RAF, is the jewel in the crown in stimulating an informed and international debate on the future of air and space power. The Association launched the first Defence Space Conference in 2018, delivered on behalf of the MOD, and this biennial event provides a platform for the MOD to debate emerging thinking on a wide variety of Space issues with stakeholders from across the Space community and Defence environment,

With its strong reputation and close relationship with the MOD, the defence industrial base, academia and the practitioners of air and space power and those with a keen interest in the subject, the Association has become a trusted and authoritative voice in the air and space power debate.

**www.airpower.org.uk**

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ISSN: 1463-6298

Produced by Air Media Centre, HQ Air Command. 3401_19AJ


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