Ministry of Defence

Joint Doctrine Publication 0-40

UK Space Power

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Foreword

Space is critical to society, underpinning almost every aspect of life in the Information Age and is a vital component of national security, enabling our military operational advantage. It provides distinctive utility for Defence through the enduring principles of perspective, access, and persistence across a truly global arena. Potential adversaries understand our reliance on space and are increasingly able to exploit vulnerabilities, threatening our access to space and, with that, our strategic stability and security. In parallel, the exponential commercialisation of space means the domain is rapidly becoming more congested, with large corporations driving technological change, where in the past, only nation states had the ability to do.

Space power is rarely used in isolation but forms part of an integrated approach comprising operations across multiple operational domains set alongside cross-government activities. Moreover, due to the nature of the space domain, collaboration with our allies and commercial partners on all space matters is fundamental to our collective success in the employment of space power. It is critical that as we grow our space capabilities, those charged with the employment and direction of space power do so with a common knowledge and understanding. Doctrine provides us with an agreed upon and operationally relevant body of best practices, principles and beliefs that articulates how we fight today. It is our collective wisdom drawn from operational lessons, training, and experimentation. However, it is not, and must not be allowed to become dogma, especially as space power continues to evolve.

Developing independent space power doctrine is fundamental to the UK's operationalisation of the space domain. This first edition of JDP 0-40, *UK Space Power* provides a balanced and comprehensive unclassified understanding of space power which should be considered essential reading for a wide audience across Defence and desirable reading for our partners across government.

This is a pivotal moment for UK Defence as we seek to operationalise the space domain at pace, so please share this widely and provide feedback. Space power doctrine must not be developed in isolation; all operational domains should understand and engage to maximise the opportunity we have ahead of us.

Air Chief Marshal Sir Mike Wigston KCB CBE ADC
Chief of the Air Staff

Preface

Purpose

1. Joint Doctrine Publication (JDP) 0-40, *UK Space Power* is the UK's keystone space domain doctrine. Whilst JDP 0-01, *UK Defence Doctrine* provides the broad principles and philosophy underpinning the use of UK Armed Forces, JDP 0-40 is focused specifically on UK space power. UK space power doctrine was previously encapsulated in JDP 0-30, *UK Air and Space Power*, 2nd Edition, but given the recognition by the North Atlantic Treaty Organization (NATO) and the UK that space is an independent operational domain, it is now appropriate for emerging UK space power doctrine to be articulated in its own publication.

Context

2. While space capabilities have underpinned military operations for many years, the 2021 *Global Britain in a competitive age: The Integrated Review of Security, Defence, Development and Foreign Policy* accorded a priority to UK space operations that has been reflected in the creation of the Ministry of Defence (MOD) Space Directorate and the establishment of UK Space Command. This first edition of JDP 0-40 therefore brings together UK government policy, strategy, higher-level doctrine and enduring space power knowledge and experience to provide a basis for understanding the utility of the space domain in the military context.

3. In line with UK doctrine policy, JDP 0-40 pursues a NATO-first approach. However, given the close ties with United States Space Forces, it is also coherent with current United States space doctrine.

Audience

4. This edition of JDP 0-40 is designed to be a simple and concise explanation of the utility of space power, written at the lowest classification to access the widest possible audience.[1] It sits at what JDP 0-01, *UK Defence Doctrine* describes as the operational level and therefore avoids tactical-level detail. JDP 0-40 should be of value to joint commanders and staffs, the single

1 It should be noted that this precludes detailed reference to some capabilities, practices and procedures.

Services, the broader defence community and other government departments, as well as UK partners and allies. It is designed to appeal to non-specialists and specialists alike. For the former, it introduces the subject and provides signposts to more detailed study. For the latter, it provides a structure for understanding and describing UK military space power that is coherent with our allies and partners alongside a vocabulary of agreed, standardised terms that are a benchmark for wider use.

Structure

5. JDP 0-40 is divided into four chapters with a supporting lexicon. An outline of what is covered in these chapters is detailed below.

a. **Chapter 1 – An introduction to space power.** Chapter 1 sets out the fundamentals of space power. It introduces space and space power before discussing the space domain as a system. It outlines the characteristics and limitations of space power before placing it into a national and global context.

b. **Chapter 2 – The roles of space power.** Chapter 2 introduces and describes UK space power roles alongside the key missions that sit below them.

c. **Chapter 3 – Space command and control, coordination and planning.** Chapter 3 discusses how UK space command and control is conducted. It begins by discussing general principles, before moving on to cover specifics relating to the space domain.

d. **Chapter 4 – The employment of space power.** Chapter 4 sets out how space power is applied within an integrated approach. It discusses the three tenets of JDP 0-01, *UK Defence Doctrine*, sets out how space is integrated with the other operational domains and then considers the role of space power in deterrence.

Linkages

6. JDP 0-40, *UK Space Power* is the UK keystone space domain doctrine within the joint doctrine architecture, sitting below JDP 0-01, *UK Defence Doctrine* and alongside other operational-level domain doctrine, namely: JDP 0-10, *UK Maritime Power*; JDP 0-20, *UK Land Power*; JDP 0-30, *UK Air Power* and JDP 0-50, *UK Cyber and Electromagnetic Doctrine*. JDP 0-40 is

also founded upon current policy, in particular, the 2021 *Global Britain in a competitive age: The Integrated Review of Security, Defence, Development and Foreign Policy* (referred to as the *Integrated Review* throughout this publication) and the 2021 *National Space Strategy*. JDP 0-40 is coherent with NATO's Allied Joint Publication (AJP)-3.3, *Allied Joint Doctrine for Air and Space Operations*. It is also coherent with the Royal Air Force's capstone doctrine, Air Publication (AP) 3002, *Air and Space Warfare*, 4th Edition.

Contents

Chapter 1

Chapter 1 sets out the fundamentals of space power. It introduces space and space power before discussing the space domain as a system. It outlines the characteristics and limitations of space power before placing it into a national and global context.

> "Space plays a critical role in our daily lives. Satellites orbiting the Earth only 160 kilometres above our heads keep us connected with our friends, families, and colleagues. They support our present and future security and prosperity, enabling us to navigate the oceans, keep our troops safe, monitor the climate and forecast the weather."

National Space Strategy, 2021

Chapter 1

An introduction to space power

1.1. With space-based capabilities now a vital part of both everyday life and military operations, space has never been so important. It does, however, remain somewhat of an enigma, acknowledged by all but understood by only a very few. Misconceptions, fuelled by popular culture and science fiction, are rife, leading to misunderstanding and exaggeration of what can be realistically expected from space assets. This chapter seeks to establish common ground, setting out relevant definitions as well as establishing the various factors that affect the space domain, alongside the advantages and limitations faced when operating in, from or through it.

Section 1 – Definitions

1.2. **Space.** While most could attempt to describe 'space', there is no agreement under international law as to the altitude at which airspace ends and outer space begins. From a practical perspective, outer space begins 'above the highest altitude at which an aircraft can fly and below the lowest possible perigee[1] of a satellite in orbit'.[2] This point is commonly known as the Kármán Line: a height approximately 100 kilometres above mean sea level, above which the atmosphere becomes too thin for an aircraft to generate conventional lift without needing to exceed the speed required to achieve orbit. Thus, for practical purposes, anything in orbit or beyond can safely be regarded as being in space.[3] For the purposes of this document, 'space' physically begins at the Kármán Line but its capabilities are enabled by assets on Earth and, therefore, the space domain includes the satellites in orbit and beyond, supporting ground infrastructure and the information layer connecting ground and space.

1 The point of an orbit closest to the Earth.
2 Joint Service Publication 383, *The Joint Service Manual of the Law of Armed Conflict*, 2004 Edition.
3 Ibid.

1.3. **Space power.** Space power is defined as: exerting influence in, from, or through, space.[4] The ability to influence is critical to achieve wider UK government aims. The UK government pursues its goals by leveraging four instruments of national power: diplomatic, information, military and economic.[5] Under the military instrument, Defence considers space to be one of five interconnected operational domains,[6] which together or separately provide options for the employment of the military instrument. Credibility, underpinned by a coherent strategy, plays a large part in the ability to successfully exert influence. This influence is pivotal to the UK's ability to conduct integrated action, seeking to shape narratives as part of an audience-centric, integrated approach. UK space power is inherently integrated, containing military, civil and commercial elements. It can support all of the instruments of national power and, furthermore, while it can be used to influence activities in space itself, it is also used to enable effects and exert influence elsewhere.

1.4. **Space and smart power.** States are engaged in systemic competition[7] both with rivals, who operate within the rules-based international order, and with adversaries, who may not. States use a blend of hard and soft power, the sum of which is known as smart power, to advance their goals and interests. Hard power seeks to coerce opponents to adopt a course of action, which they would not otherwise choose themselves. Soft power, on the other hand, is the ability to persuade or encourage others to adopt an alternative approach. Space power can contribute to both aspects: it can support hard power either directly or by enabling other military action, but it can also take the form of soft power through building alliances and industrial collaborations. Space power can contribute to humanitarian assistance through environmental monitoring, through helping to provide assured positioning, navigation and timing signals or through research to better understand the impacts of space weather on terrestrial systems. Such activity benefits from collaboration, even with competitors or potential adversaries.

4 Joint Doctrine Publication (JDP) 0-01.1, *UK Terminology Supplement to NATOTerm*.
5 See JDP 0-01, *UK Defence Doctrine* for more details.
6 Maritime, land, air, space and cyber and electromagnetic. See JDP 0-01, *UK Defence Doctrine* and the JDP 0-X0 series of operational domain doctrine publications for more details.
7 Referred to by the North Atlantic Treaty Organization (NATO) and the United States as 'strategic competition'.

Space as an operational domain

Space is contested by both state and non-state actors. It is subject to expanding commercial competition and is congested by a growing volume of satellites and debris.[8] Increasing reliance on space, identified vulnerabilities and the perception of challenge in space necessitated a change of approach. The United States (US) formally established its Space Force as a new military Service in 2019. The same year, the North Atlantic Treaty Organization (NATO) formally announced it considered space to be an operational domain.[9] This approach has been endorsed by the UK and is reflected in the *Integrated Review*. The UK has formed the Ministry of Defence (MOD) Space Directorate and UK Space Command, which support the *National Space Strategy*, not least by protecting and defending the UK's space interests.

Section 2 – The space domain

1.5. An exponential increase in space activities has meant that space is becoming increasingly congested and complex. It is, however, critical for both UK military operations and UK society as a whole. In an era of competition, it can therefore be expected to be contested by adversaries.

a. **Congested.** Traditionally, the use and exploration of space was only undertaken by the major powers, who exploited space in support of their national interests. Competition over national prestige drove space exploration and the military was able to exploit the understanding and ideas it delivered, but space was viewed as a niche activity that supported activities in other operational domains. In recent times, technological advances have seen an increase in the available uses of space alongside the traditional barriers and costs associated with establishing space capabilities being lowered, triggering commercial expansion into space on an unparalleled scale. Commercial activity now covers almost all aspects of space operations, including activities such as space launch, that were previously only achievable by the major powers. Developing countries and other organisations no longer

8 *UK National Submission on Space Threats in response to United Nations (UN) General Assembly Resolution A/RES/75/36*, 30 April 2021.
9 Announced following the meeting of NATO Ministers of Foreign Affairs, Brussels, November 2019.

need their own space programmes; capabilities and products can be procured on the open market. Such activities, especially the growth of mega-constellations, have drastically increased the number of satellites which, given they are typically concentrated on the most advantageous orbits, has dramatically increased congestion.

b. **Complex.** The blurring of the lines between civilian and military, government and commercial has drastically increased complexity in space. International collaboration, licensing and commercial considerations make ownership, responsibility and liability (and thus attribution) far less clear. These are compounded by challenges of not just tracking space objects but ascertaining their true purpose and intent, especially when only basic information must be disclosed under the international registration regime for space objects.

c. **Critical.** With provision has come reliance. Technological advances, underpinned by increasingly widespread commercial or dual-use space capabilities,[10] have imperceptibly permeated society and popular culture to such an extent that they are now almost indispensable, but they are nonetheless taken almost completely for granted. Such is the UK's societal reliance on assured access to space, the UK government considers space infrastructure and assets to be linked to critical national infrastructure, 'the loss or compromise of which would result in major detrimental impact on the availability, delivery or integrity of essential services, leading to severe economic or social consequences or to loss of life'.[11]

d. **Contested.** In addition to the changes in the space domain, recent times have seen global geopolitical changes that the 2021 *Integrated Review* describes as a return to 'systemic competition' between states. Furthermore, while the UK competes with rivals who act in accordance with the rules-based international order, adversaries seek to exploit the seams of UK, allied and partner institutions and undermine their cohesion and credibility. Increasingly, such competition exists on a spectrum where adversaries seek to achieve their own goals both overtly and through clandestine methods designed to remain unattributable or to blur their origins and intent so as not to elicit a military response. Many such adversaries have space programmes themselves, can source capabilities commercially or have at least identified space to be a critical vulnerability

10 Such as assured precise timing signals and readily available global navigational data.
11 UK Cabinet Office, *Public Summary of Sector Security and Resilience Plans*, 2018.

of their own adversaries and have taken measures accordingly. Space is now accessible to a larger group of both state and non-state actors whose intentions are not always honourable or benign.[12] Given the identified reliance on space, and the potential threat, a fundamental goal of the UK's *National Space Strategy*[13] is to seek to protect and defend our national interests in and through space. Such defence must cover all three segments (space, ground and link) and not just assets in space. The link segment can be equally contested due to the proliferation of electromagnetic warfare counter-space weapons.

Examples of international threats: Russia and China

Russia has conducted a number of on-orbit activities that have drawn attention and condemnation from both the UK, US and other partner nations. These include contesting the electromagnetic spectrum, targeting the vital link between satellites and ground segments, as well as placing satellites in orbit that can release smaller secondary and even tertiary devices with the possibility that some may have a destructive capability. In November 2021, Russia conducted a test of a direct ascent anti-satellite (DA-ASAT) missile against one of its own redundant satellites. The resulting debris cloud created in the region of 1,500 trackable objects, greatly increasing the risk to satellites in low Earth orbit (LEO) and the International Space Station, which at the time was crewed by a team that included Russian cosmonauts. Russia has also exerted pressure by denying launch facilities to OneWeb satellites, which are part owned by the UK government, in response to wider sanctions imposed following the 2022 Russian invasion of Ukraine.

China has a robust DA-ASAT programme. On 11 January 2007, China launched a direct ascent attack on one of its own defunct weather satellites, the Fengyun 1C, demonstrating that China had the ability to target a satellite and could therefore contest control of space. China also possesses multi-use capabilities on orbit that are necessary for co-orbital anti-satellite weapons as well as a wide range of electromagnetic and cyber counter-space capabilities. China continues to conduct tests of its operational DA-ASAT system. However, China may no longer need to use kinetic tests to prove that its DA-ASAT capabilities can threaten any satellite in LEO, and likely medium Earth orbit and geosynchronous Earth orbits (GEOs) as well.[14]

12 Air Publication (AP) 3002, *Air and Space Warfare*, 4th Edition, 2020.
13 HM Government, *National Space Strategy*, September 2021.
14 Center for Strategic & International Studies, *Space Threat Assessment 2021*, April 2021.

1.6. When seeking to understand space as a complex operational domain, it is best to break out the interconnected system into logical component parts. It should be stressed that the following aspects cannot be taken in isolation: each affects and relies on the others.

Political aspects

1.7. **Diplomatic.** The UK government's *National Space Strategy*[15] recognises that space is of strategic importance to the UK, and it supports the growth of a competitive commercial space sector, which requires a stable and secure operating environment to thrive and to deliver the economic benefits sought. It commits the UK to preserving and promoting the safety and security of the space environment, as well as to cooperate internationally and advance discussion surrounding the responsible use of space. In accordance with the rights and obligations set out in the Outer Space Treaty, space is 'free for exploration and use by all States'.[16] Most international legal and normative frameworks recognise the importance of international cooperation in respect to space activities.

1.8. **International negotiations.** The UK supports international negotiations as a further measure to prevent an arms race in outer space. The UK recognises two broad categories of challenges to operating in space. First, hazards that could harm a space system: these are generally naturally occurring in the space environment or are the result of space activities (such as space debris). Secondly, 'threats', namely those actions or activities using capabilities that threaten the space systems of another state.[17] The progress made by the international community in mitigating many of the hazards has not been matched by international action to deal with threats. The UK tabled a United Nations (UN) General Assembly resolution in October 2020 entitled 'Reducing space threats through norms, rules and principles of responsible behaviours' seeking to take a constructive step in international negotiations. This led to the adoption of UN General Assembly Resolution 75/36 by the First Committee that encourages states to broaden the international discussion on space threats, build states' understanding of threats, seek to reduce the risk of conflict escalation in space, and share ideas on the further development and implementation of responsible behaviours. A further UN General Assembly

15 HM Government, *National Space Strategy*, September 2021.
16 UN Office for Outer Space Affairs, *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies*.
17 *UK National Submission on Space Threats in response to UN General Assembly Resolution A/RES/75/36*, 30 April 2021.

Resolution 76/231 was adopted in December 2021 under this initiative. The decision was taken to convene an open-ended working group to take stock of existing international legal and other normative frameworks, consider current and future threats by states to space systems and make recommendations on possible norms, rules and principles of responsible behaviours.[18] The UK government views international cooperation and its network of partners and allies to be essential to a collaborative space enterprise. This global and national context is discussed later in this chapter.

1.9. **Legal.** As in all of the other operational domains, military applications of space must be in accordance with domestic and international law. These are explained further below.

a. **International law.** The cornerstone of the international legal framework for space is the Outer Space Treaty, although it is not an exclusive statement of the framework applicable to space. The Outer Space Treaty reaffirms that space activities must be carried out in accordance with international law, including the UN Charter. This is important as it affirms that international law governs when a state has a right to use force. The Outer Space Treaty does provide that nuclear weapons and weapons of mass destruction may not be placed in orbit around the Earth, stationed in space or installed on the moon or other celestial bodies. This prohibition does not affect the use of intercontinental ballistic missiles carrying nuclear payloads that merely transit through space and do not necessarily achieve orbit or orbital velocity. At a fundamental level, the Outer Space Treaty establishes that space shall be free for exploration and use by all states, but that space is not subject to national appropriation by claim of sovereignty, by means of use or occupation or by any other means. These broad principles have practical significance and are in contrast to the jurisdictional arrangements that exist in airspace. To illustrate, consent is required for aircraft to enter the airspace of another state. However, consent is not required for satellites in orbit passing over the territory of a state. There is also overlap and interplay between the concepts of responsibility, registration and liability under international space law that have implications for military space operations. The International Telecommunications Union (ITU), through a collection of instruments, governs the allocation and use of both radio-frequency spectrum and satellites in geostationary orbit.

18 UN General Assembly Resolution A/RES/76/231, *Reducing space threats through norms, rules and principles of responsible behaviour*, December 2021.

b. **UK domestic law.** UK domestic law seeks to fulfil a number of functions in the context of space operations. This includes regulating the space activities of individuals and organisations falling under UK jurisdiction and ensuring that the UK complies with its various obligations under international space law. These aims are, in part, pursued by virtue of the Outer Space Act 1986 and Space Industry Act 2018 and associated regulations. Effective regulation is essential to ensure that standards are set to improve safety, efficiency and to mitigate the negative environmental impacts of a rapidly expanding space enterprise. The UK's *National Space Strategy* set the goal of the UK leading the world in modern space regulation. In July 2021, the Civil Aviation Authority was appointed to exercise every regulatory function set out in UK domestic space law. Regulation also exists to control the export of sensitive military and dual-use space technology, a measure that in part seeks to prevent proliferation of capabilities.

Military aspects

1.10. While space has been fundamental to military operations for decades, such is the current dependence that the vast majority of military operations could not be sustained without space capabilities. Operations depend on space, principally for: communications; meteorology; positioning, navigation and timing functions; intelligence, surveillance and reconnaissance; and the ability to operate remotely piloted aircraft at range. In essence, space is a vital part of the Defence Digital Backbone and should be seen as a vital enabling part of the global information network. This dependence has been identified as a vulnerability by adversaries[19] and this has led to some nations building arsenals of counter-space weapons capable of degrading, denying, disrupting or destroying space systems. Such capabilities are discussed in later chapters but can have effects ranging from temporary denial to physical destruction. They may be surface, sub-surface, air or space based, kinetic (such as a DA-ASAT missile) or non-kinetic (dazzling or jamming) and may be targeted against any of the three segments of a space system (see paragraph 1.16).

1.11. As well as dedicated space capabilities, conventional military or espionage activities can have direct effects on space systems. An airstrike on a ground control station or a cyber payload uploaded to a satellite by a saboteur could have a more devastating effect on an overall space system than a

19 For further information, see United States government, Defense Intelligence Agency, *2022 Challenges to Security in Space: Space Reliance in an Era of Competition and Expansion*, January 2022.


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Direct and indirect attacks on objects on orbit may increase space debris

DA-ASAT targeting one specific satellite. Furthermore, direct and indirect attacks on objects on orbit may cause debris, which could compromise the attacking state's own space capabilities. Such an overt attack may also be far easier to detect and attribute to a specific actor than an indirect non-kinetic attack. With adversaries adopting strategies designed to remain below the threshold that would permit a forcible response, it is increasingly likely that threats will be obscured. Traditional defensive procedures such as force protection and vetting key personnel to mitigate insider threats are therefore increasingly important in the space domain.[20]

Economic aspects

1.12. As part of an integrated approach, the UK sees a strong commercial space sector, allied space capabilities and civil and scientific expertise to be vital contributors to UK space power. To put this in context, in 2019–20, the UK space industry produced £16.5 billion in income and directly employed 46,995 people with space employment growing by 6.7% from the previous year.[21] Such ambition is reflected in the 2021 *Defence and Security Industrial Strategy*

20 A detailed open source discussion of current space threats can be found in the Center for Strategic & International Studies' *Space Threat Assessment 2021*, April 2021.
21 BryceTech summary report for the UK Space Agency, *Size & Health of the UK Space Industry 2021*, 13 April 2022.

and the 2021 *National Space Strategy*. UK Defence expects to support the UK space sector to realise the economic benefits from this dynamic and rapidly expanding market, extending the UK's influence in the space domain.

1.13. A thriving commercial space sector is valuable to Defence both for developing innovative projects that offer the potential of delivering decisive military advantage but also to reduce the costs and increase the capacity and availability of existing systems. The growth of commercial and dual-use capabilities provide options to military planners; increasingly, choices can be made as to which capabilities need to be owned on a sovereign basis, which can be obtained by collaboration with allies, and which can be accessed from commercial sources. The UK government has invested US $500 million in OneWeb, a low-Earth satellite communications company that seeks to operate 600 satellites providing global broadband capability. Within the new Defence Space Portfolio, funded concept programmes exist to provide improvements in satellite communications, intelligence, surveillance and reconnaissance and space domain awareness. The UK has also developed a civil sovereign launch capability. LaunchUK, the UK Space Agency's spaceflight programme, aims to establish commercial small satellite launch from the UK.[22] Once this is established, the UK will possess an end-to-end capability able to design, build, launch and operate small satellites. Alongside these opportunities, it is important to be aware that increased space proliferation equates to increased challenges and potential threat vectors. While Defence is tasked to protect and defend space capabilities, this will come with a resource cost and detailed consideration must be given to how this affects commercial and dual-use capabilities. Furthermore, without suitable prioritisation, the pace of change will challenge the military in terms of maintaining relevance in a rapidly changing commercial space sector.

Social aspects

1.14. The UK, like all modern states, depends on space services for day-to-day societal functions such as enabling banking transactions, the effective operation of the national power grid and the use of smartphones. However, the public are often unaware of this, or take assured access for granted, making it difficult to acknowledge our reliance on freedom of access to the space environment. Culturally, space remains a unique fascination and the UK Space Agency is charged with inspiring the next generation, but space remains a subject understood by only a few, with false assumptions and

22 UK government House of Commons Briefing Paper 2021-9202, *The UK Space Industry*, April 2021.

myths commonplace. These are increasingly perpetuated by popular culture and science fiction, which can distort perceptions of what can realistically be achieved in space while drastically underplaying the unique challenges posed when operating in the space environment.

Information aspects

1.15. Technological developments, including the proliferation of dual-use systems, have led to increasingly interconnected nodes and systems, in particular, in cyberspace and the information environment.[23] The free flow of data and seamless functioning of networks are critical for space functions, both for control signals and the operation of payloads. Most satellites depend on cyber technology and this in turn opens up vulnerabilities that can be exploited by potential adversaries. Previously, attacking space assets was only an option for major powers, however, technological advances have lowered this cost barrier so that other actors can now procure technology that can affect or interfere with space operations. In addition, space capabilities, especially timing signals, enable the carriage and synchronisation of information essential for all aspects of modern society. Global navigation satellite systems (GNSS) especially have become 'so prevalent today that they have contributed to a system-of-systems issue, such that even the most vigilant operators of infrastructure and other applications may not be completely aware of the magnitude of their reliance. Even in systems presumed to be independent of GNSS, master clocks and other seemingly independent sources of time … are in fact based on GNSS receivers and therefore hold an unseen dependence.'[24]

Infrastructure aspects

1.16. Unlike the maritime, land and air domains, space power is rarely enabled by human activity within the environment itself but is conducted through human activity on Earth. Consequently, space operations are separated into three segments to aid understanding of the space system as a whole.[25]

23 The information environment is defined as: an environment comprised of the information itself, the individuals, organizations and systems that receive, process and convey the information, and the cognitive, virtual and physical space in which this occurs. NATOTerm.
24 Government Office for Science, *Satellite-derived Time and Position: A Study of Critical Dependencies*, January 2018.
25 Segments are intended as a framework to aid understanding. Some capabilities or features of systems may overlap, for example, inter-satellite links could be considered link or space elements.

a. **Space segment.** The space segment comprises elements of the space system in outer space itself, which are typically satellites on orbit but also other objects transiting through the space domain above the Kármán Line. Satellites comprise two basic systems: the spacecraft itself and the payloads it carries. This differentiation is important as the two can have different software, systems, ground segment elements and tasking chains.

b. **Ground segment.** The ground segment comprises terrestrial facilities that are used to launch, direct and control satellites as well as operate their payloads. The ground segment also includes infrastructure for tracking and monitoring space objects and interfaces to process and use satellite information. The ground segment consists of three distinct sub-segments: the launch and re-entry segment covers all aspects of launch and re-entry operations below the Kármán Line (above which is classified as the space segment); the control sub-segment consists of ground control stations and similar supporting infrastructure; and the user sub-segment which comprises interfaces such as Global Positioning System (GPS) receivers, very small aperture terminals and satellite telephones.

c. **Link segment.** The link segment connects the space and ground segments and comprises both the data itself and the medium used to carry it. Typically, this involves the use of electromagnetic signals, including laser communications.

Physical environment aspects

1.17. Operating in space is intrinsically dependent on the physical environment space provides.[26] Forces that act on a satellite differ significantly from those which affect an aircraft in flight. Furthermore, the environment encountered by a spacecraft on orbit can be extremely harsh, given it lacks the protection afforded terrestrial domains by the Earth's atmosphere. Such factors are summarised as follows.

a. **Orbits and orbital mechanics.** Satellites move predictably according to the laws of orbital mechanics. These determine the parameters of an orbit, including the period (the time taken for one complete orbit), the satellite's speed around the orbit and its track over

26 Further information on the physical aspects of space, including orbital mechanics, space debris and weather can be found in the MOD's *The UK Military Space Primer*.

the Earth. The choice of orbit is a compromise between the: power required for data transmission against total area coverage on Earth; level of detail and sensitivity available; and amount of time an area is visible. A satellite in orbit may freely pass over any point on Earth.

b. **The space environment.** The space environment is extremely harsh and this impacts on the design of spacecraft, mission systems and the limitations placed on them. Typically, the environment has weak aerodynamic forces. While drag still occurs, the laws of orbital motion dominate, making changes to the orbit largely propulsion based. Manoeuvring takes considerable planning and incurs fuel penalties which, unlike aircraft, currently cannot be commonly replenished in flight. Space also exhibits extremely high temperature fluctuations as a satellite passes in and out of the view of the sun. These variations, even those between the sun facing and shaded surfaces of a satellite itself, can be extremely damaging to the satellite and its sensors. Significant amounts of a satellite's structure need to be dedicated to thermal control subsystems, rather than forming part of the payload. Operating in a high vacuum also causes significant challenges for satellite design as the vacuum can cause lubricants to evaporate, metals to weld themselves together and plastics to be completely eroded. Furthermore, high levels of radiation, highly energetic particles and fluctuating magnetic fields can severely impact space capabilities.

c. **Space debris.** There are tens of thousands of objects in orbit larger than 10 centimetres, most of which are items of space debris. The total amount of debris, most of which is too small to be detected, is estimated to be greater than one hundred million objects. Given the speed that these objects travel, they pose a significant hazard to operating in the space domain and their numbers are constantly increasing. Removing debris is technically possible but it is complicated by cost, legal issues and political challenges. An effort by one state to remove a non-functioning object owned by another could be interpreted as a hostile act, raise wider security concerns and complicate international liability considerations. Likewise, an object designed to remove debris could equally be used to damage or destroy a functioning satellite. Space debris continues to be a significant issue, hence the requirement for capabilities to track and monitor such hazards and risks.

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d. **Space weather.** The sun's activity causes space weather through events such as solar flares, coronal mass ejections and radiation storms.[27] Space weather can adversely affect space segment capabilities by disrupting satellite sensors, degrading electronic circuits, corrupting computer memory and by causing damage to solar panels. Enhanced radiation levels also heat the atmosphere, subjecting satellites in LEO to enhanced drag, which shortens their lifetime. Space weather can affect the link segment, since solar storms have the capacity to disrupt communication and navigation system frequencies.[28] It can also create effects on Earth, causing damage to electrical systems such as power grids, pipelines and signalling equipment. Space weather can therefore have a significant impact on a host of military and civilian applications, especially satellite communications and precise navigation. Users of systems that have a dependency on space need to be cognisant of the dynamic space environment and satellites need to be resilient enough to operate effectively in such an environment.

Space weather can have a significant impact on a host of military and civilian applications

27 See the MOD's *The UK Military Space Primer* for more details.
28 Including secure satellite communications and positioning, navigation and timing data, derived from GPS.

The Carrington Event

The Carrington Event, named after the astronomer who observed and recorded it, was a severe space weather event that occurred between 2nd and 3rd September 1859. It remains the largest solar storm on record. One, possibly two, coronal mass ejections erupted from the surface of the sun, causing the Earth to be hit by a vast eruption of magnetised plasma moving at around 1900 kilometres/second. The orientation of the wave was opposite to that of the Earth's interplanetary magnetic field, causing the Earth's magnetosphere to be effectively opened up, allowing the solar plasma in. Upon impact, the event generated ground induced electric currents that caused telegraph systems to fail and, in some cases, cause electric shocks and sparks that went on to cause fires. Such an event may be rare but is almost inevitable in the future: a Carrington-class storm narrowly missed the Earth in 2012. Studies have shown that an event today would have more significant consequences given modern reliance on technology. A reasonable worst case scenario could see severe damage to the electricity grid, satellites, electrical systems, navigation systems and communications systems on Earth.[29] The total economic cost of a similar event to the US alone was estimated by the insurers Lloyds to be between US $0.6–2.6 trillion at 2013 prices.[30]

Time

1.18. While satellites are capable of accessing any area on the planet, for any other than GEO, limitations traditionally existed in terms of persistence, given the revisit times required for an individual satellite to sense a given area of interest. More recently, the proliferation and exponential growth, especially of satellites in LEO, has potentially removed this limitation, albeit universal satellite coverage does not currently equate to universal coverage of all missions and sensors. Time does still have direct relevance to the space domain: solar weather activity varies according to an 11-year cycle. The last solar minimum was in late 2019 with the next solar maximum forecast to arrive between 2025 and 2026. The current growth in numbers of satellites being launched will be paralleled by an increase in solar activity that is likely to affect them. Finally, unlike aircraft, there is currently no commonly fielded ability to refuel

29 Royal Academy of Engineering, *Extreme space weather: impacts on engineered systems and infrastructure*, February 2013.
30 Lloyd's, *Solar Storm Risk to the North American Electric Grid*, 2013.

satellites on orbit,[31] thus every satellite launched has a finite operational lifetime based on the fuel it carries and which it needs to operate its systems and manoeuvre to maintain the orbit parameters it is launched on. Increasingly smaller, cheaper satellites are designed to only have short lifetimes, re-entering the Earth's atmosphere at the end of their lifetime so as to burn up and minimise space debris. These 'disposable satellites' can then be replaced by modernised versions equipped with more modern technology. Larger exquisite satellites are designed to be operated for much longer periods of time, but their fuel resources are still finite: any manoeuvres to reorientate, stabilise or mitigate threats reduces their potential operating lifetime.

Section 3 – Characteristics and limitations of space power

1.19. Space power has distinctive attributes brought about by the characteristics of the environment. These are perspective, access, persistence and versatility, and they are explained below.

a. **Perspective.** As with the air domain, space capabilities exploit the vertical dimension, albeit to a completely different order of magnitude. Such an unparalleled vantage point means that space represents the ultimate high ground. Even satellites stationed in the lowest orbits offer a footprint that can cover thousands of square miles of the Earth's surface. Those positioned in the higher orbits can have a perspective covering approximately one third of the Earth.

b. **Access.** The international rules and norms governing overflight of sovereign states by aircraft do not apply to satellites; space offers unrivalled access to any point on Earth, with no requirement to adhere to national boundaries. This provides significant military utility, as satellites can overcome the difficulties of gaining access to an area of operations, be it due to overflight permission or adversarial anti-access and area denial strategies.[32]

31 Although considerable research activity is focusing on this area.
32 Satellites are not impervious to anti-access and area denial threats, as demonstrated by successful anti-satellite missile tests by China and India. However, the perceived constraints on satellite operations are very much reduced compared to air operations.

c. **Persistence.** Typically, the orbital life expectancy of satellites is measured in years or even decades, so they can overcome the air power limitation of impermanence. A GEO allows a satellite to remain over the same area of the Earth 24 hours a day, providing continuous access to a given terrestrial area of interest. Satellites in LEO can also provide significant persistence if sufficient coverage is provided by a constellation of satellites. However, the higher GEO does not currently afford high-resolution images of Earth and individual satellites in LEO can only provide intermittent coverage.

d. **Versatility.** Space assets are versatile because a single platform can carry a multitude of sensors and capabilities to provide services simultaneously to multiple users. While the MOD has a capability programme to deliver sovereign capability, many UK space programmes are still combined civil-military enterprises, with broad applicability across a range of government policy functions.

1.20. **Limitations of space power.** While providing tangible benefits to Defence, using space power is not without its challenges. The following limitations should also be considered when discussing the space domain.

a. **Cost.** While the traditional cost barriers for space systems have dramatically reduced, they are still expensive. Furthermore, while it is increasingly cheap to launch small satellites into LEO, these are not always suited to all military tasks and capabilities. Larger multi-payload satellites capable of being launched into GEO and which are designed to remain in orbit for greater periods of time can still be vastly expensive undertakings, especially as these systems need to be hardened to cope with both the hazards posed by harsh operating environments and threats from adversaries. Such increased resilience comes at a cost, both in terms of the satellites themselves but also their larger launch platforms. A balance must be struck between these large, exquisite capabilities and smaller, cheaper systems that may be able to mitigate some of their disadvantages through sheer numbers and which can be rapidly replaced with newer more modern systems as technology advances. Regardless, a distinction must also be made between what may be termed financial cost against conceptual cost. The financial cost of a sovereign space system might be vast but the conceptual cost of not having it, or relying on others for it, might mean we are unable to operate across all other operational domains or at least are subject to leverage from a competitor.

b. **Vulnerability.** Space systems possess vulnerabilities across all three segments. Objects such as satellites in the space segment are subject to the harsh conditions found in the space environment as well as from direct threats. The link segment is particularly vulnerable given that weak signals from space will often be vulnerable to more powerful and closer surface-based electromagnetic warfare weapons such as jammers. Ground segment infrastructure may also not be as heavily protected as other military sites, thereby making them vulnerable to a raft of full spectrum attacks. Force protection of critical ground segment sites will be increasingly important in an era of constant competition with adversaries trying to mask their activities given how obvious, and therefore attributable, direct attacks on space-based or link systems can be.

c. **Predictability.** Objects in space do not fly like aircraft, rather they fall in accordance with the laws of orbital mechanics. Satellite orbits are therefore mostly predictable.[33] From an adversary's point of view, it is possible to accurately predict where a satellite will be at a given time. That said, just because it is possible to know **where** something is does not mean one knows exactly **what** it is doing and, thus, not only the tracking, but also the identification and characterisation of space objects is crucial.

d. **Limited responsiveness.** While limited responsiveness is still valid when considering larger exquisite capabilities (which are few in number and take years and sometimes decades to build and replace), increasingly, the ease with which small, almost disposable satellites can be built and launched may mitigate this limitation to some degree. A state with an end-to-end space capability could possess a stock of 'plug and play' small satellites, at suitable readiness levels, to be launched using sovereign capabilities very rapidly indeed. Using these procedures, space could certainly be responsive enough for most operational scenarios.

e. **Orbit congestion.** While space itself is vast, the laws of orbital mechanics mean that certain orbits, especially GEO, are extremely valuable. Orbit slots in GEO are regulated by the ITU. Any actor wanting to launch a satellite into GEO must apply to the ITU for a slot and popular regions have become so congested that few or no orbital slots

33 Exceptions such as the Russian LUCH, Chinese SJ17 and US X37B can manoeuvre in space.

remain. Issues surrounding the filing of orbital slots and the allocations themselves are being examined, not least due to commercial pressures and allegations of 'paper satellites' where an actor submits an application for a satellite that does not exist or may not be built for a considerable time. This in effect captures the slot for the actor's future use but denies it to others. Capturing such prime space 'real estate' may present risks or limitations to an individual actor's future strategic ambitions in space.

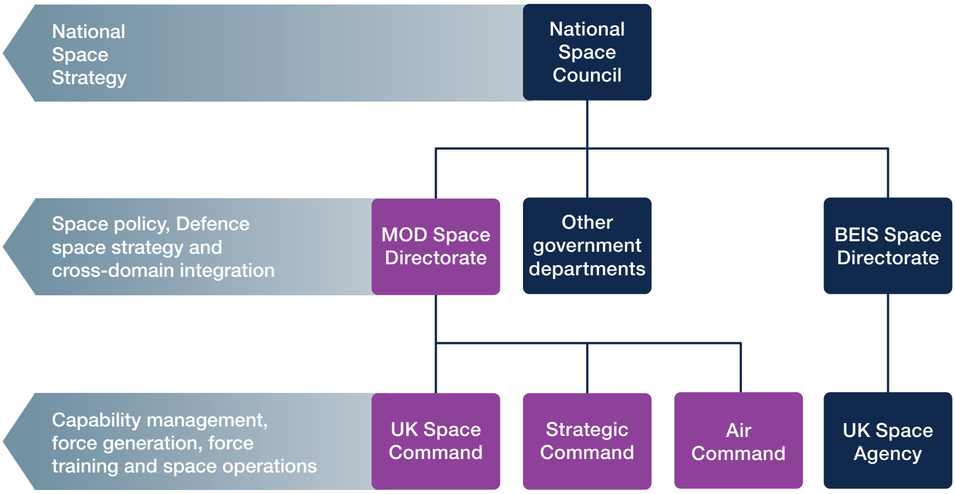
Section 4 – Space power in context

The national context

1.21. **National Space Strategy.** Echoing the 2021 *Integrated Review* and *Defence in a competitive age* (Defence Command Paper),[34] the first *National Space Strategy* set the goal for the UK to become a meaningful actor in the space domain by 2030. The *National Space Strategy* brings together civil and defence activity in an integrated approach to deliver and maintain an end-to-end sovereign capability that can develop, build, launch and operate space systems. As well as providing military advantage, space is seen as a critical area that can promote growth in the UK economy, provide opportunities to expand the UK's technical and research sectors, and create and maintain a skilled workforce. Underpinning this is the need for the UK, and UK Defence in particular, to be able to protect and defend the UK's national interests in space. The *National Space Strategy* is supported by a coherent MOD-specific *Defence Space Strategy*.[35]

1.22. **Defence Space Strategy.** The 2022 *Defence Space Strategy* sets out how Defence will support national efforts to become a meaningful actor in space as well as securing UK interests and ensuring freedom of action throughout all five operational domains. It sets out how Defence will deliver the protect and defend functions of the *National Space Strategy* as well as supporting the objectives of the *Integrated Review*. It also outlines the Defence Space Portfolio of investment into military and dual-use space capabilities as well as clarifying the space organisational hierarchy shown in Figure 1.1.

34 MOD, *Defence in a competitive age*, March 2021.
35 MOD, *Defence Space Strategy: Operationalising the Space Domain*, February 2022.



BEIS	Department for Business, Energy and Industrial Strategy
MOD	Ministry of Defence

Figure 1.1 – UK strategic space hierarchy and core outputs[36]

1.23. **National Space Council.** To integrate space policy across government departments, a new Cabinet committee, the National Space Council, was established in 2020 with the aim of setting the strategic direction for and overseeing the UK government's space activities in line with the UK government's ambition. Particularly close ties are required between the Space Directorates within the Department for Business, Energy and Industrial Strategy (BEIS) and the MOD to deliver on the 2021 *National Space Strategy*.

1.24. **Department for Business, Energy and Industrial Strategy.** BEIS is the central department coordinating responsibility for civil space policy. It is also the sponsoring department of the UK Space Agency and UK Research and Innovation, which are key agencies for the delivery of the *National Space Strategy*. Through its arms-length bodies, it uses satellite-enabled capabilities to monitor land use, deliver accurate weather forecasting and coordinate resilience to space weather.

1.25. **UK Space Agency.** The UK Space Agency develops and delivers UK civil space programmes, based on its deep competence in space science and technology and its partnerships within government, across the UK sector and with international space institutions. It enables delivery of national space

36 MOD, *Defence Space Strategy: Operationalising the Space Domain*, February 2022.

capabilities, invests in early-stage research and development and helps to represent the UK in international civil space cooperation.

1.26. **MOD Space Directorate.** UK military space policy and strategy is the responsibility of the Space Directorate in the MOD. Further information is provided in Chapter 3.

1.27. **UK Space Command.** Established in 2021 at Royal Air Force (RAF) High Wycombe, UK Space Command brings together the three key areas of military space activity[37] under a single 2* military commander. Further information is provided in Chapter 3.

The global context

1.28. Since all states share access to and use of the space domain, and face common hazards and challenges, space is uniquely positioned to encourage cooperation. A broad multinational and multi-agency collaboration, including allies, international organisations and non-governmental organisations, can provide a range of services that most nations could not generate independently. Working together with international partners in the space domain also helps solidify collaboration in wider security matters.

> The UK is leading the global discussion on what responsible behaviour in space looks like. We believe a new approach is urgently needed to increase trust and confidence between countries operating in space to prevent an arms race or a conflict that could have catastrophic consequences.
>
> The Rt Hon Dominic Raab MP, then Foreign Secretary[38]

1.29. **The United Nations.** The UK is attempting to broker an international consensus on responsible behaviour in space through the UN. The UK introduced a UN resolution which was adopted by the UN General Assembly in December 2020.[39] The resolution called on member states to consider how a behaviour-based approach could help reduce threats to space systems

37 Space operations; space workforce training and growth; and space capability.
38 UK government press release, 'UK push for landmark UN resolution to agree responsible behaviour in space', 26 August 2020.
39 UN General Assembly Resolution A/RES/75/36, *Reducing space threats through norms, rules and principles of responsible behaviours*, 16 December 2020.

and prevent an arms race in outer space. It emphasises the importance of maintaining outer space as a peaceful, safe, stable, secure and sustainable environment for the benefit of all and urges states 'to refrain from conducting activities contrary to their obligations under international law, including those that could threaten the ability of all States to freely use and explore outer space, now and in the future'.[40]

1.30. **European Space Agency.** While the UK left the European Union in 2020, its membership of ESA was not affected as ESA is not a European Union organisation. The UK did lose access to the Galileo GNSS programme, but the UK remains part of ESA and is committed to a number of ESA programmes, most notably the Copernicus Earth observation programme, the solar orbiter programme and other programmes designed to increase understanding of space weather.

1.31. **North Atlantic Treaty Organization.** The *Integrated Review* stated that the UK has an unwavering commitment to NATO and remains bound to the requirement for collective self-defence under Article 5 of the North Atlantic Treaty.[41] Accordingly, NATO remains the UK's foremost defensive alliance and is pivotal to the UK's deterrence strategy. At the 2021 Brussels Summit, NATO recognised that attacks to, from or within space present a clear challenge to the security of the Alliance and could lead to the invocation of Article 5 of the North Atlantic Treaty. NATO formally declared space to be an operational domain in December 2019 and the Military Committee approved a Space Domain Action Plan in April 2021. A NATO Space Centre was established at Ramstein in 2020 and plans are at an advanced stage to establish a NATO Space Centre of Excellence in Toulouse, France by 2025. The establishment of space as an official operational domain will require revision of NATO doctrine and standards but plans to put this into practice are still being developed in line with the action plan and will be supported by the new NATO Space Centre of Excellence. UK doctrine policy is to adopt NATO doctrine where possible and therefore the UK will proactively seek to influence the emerging NATO space doctrine.

40 UN General Assembly Resolution A/RES/75/36, *Reducing space threats through norms, rules and principles of responsible behaviours*, 16 December 2020.
41 That an attack on one NATO Ally shall be considered an attack on all.

1.32. **United States.** As our pre-eminent national security partner, cooperation with the US is exceptionally close and the relationship is critical to assure access to a host of space services. The UK was the first nation to join the US-led Operation Olympic Defender. Conversely, the UK operates a limited number of space capabilities which bring mutual benefit to this relationship, not least by providing highly trained UK military space experts both integrated in and directly supporting US space capabilities.

Operation Olympic Defender

The UK was the first nation to join the US-led multinational Operation Olympic Defender. Participating countries are maximising the benefit provided from space and space systems through cooperation across all space missions, preserving the safety of operating in space while enhancing mutual national security. These operations involve partners sharing information and resources as well as coordinating their capabilities. The UK's role is to analyse and share information about space to ensure troops on the ground are aware of threats and their options to maintain access to space services.[42]

1.33. **The Combined Space Operations initiative.** The Combined Space Operations initiative is a partnership of seven nations[43] working together to address threats and shared interests in space. By building on existing alliances, the Combined Space Operations initiative is viewed as a potential route to developing systems that meet the needs of several countries who face similar threats and challenges.[44]

42 As articulated in the *National Space Strategy*.
43 The US, UK, Australia, New Zealand, Canada, France and Germany.
44 House of Commons Library Research Briefing, *The militarisation of space*, 14 June 2021.

Key points

- Space is strategically and economically important to the UK.
- For the purposes of this document, space is viewed as being above the Kármán Line (around 100 kilometres above sea level).
- The space domain is congested by the exponential increase of objects in orbit and made complex by blurred ownership and challenges ascertaining the true function of satellites.
- Space is critical for both military and civilian purposes and is increasingly contested given the return to systemic competition between states.
- Space power provides a commander with distinctive advantages, namely: perspective, access, persistence and versatility.
- These advantages may be offset by limitations such as cost, vulnerability, predictability, a relative lack of responsiveness and congestion on key orbits.
- Space operations can be split into three overlapping segments: ground (launchers, control stations and interfaces), space (objects in or transiting through space) and link (the data and mediums used to connect them).
- Space operations face both threats (human-derived) and hazards (environmental factors) across all three segments.

Notes

Chapter 2

The UK considers there to be four key space power roles: space domain awareness, space control, space support to operations and space service support. These are introduced in Chapter 2 along with the key missions that sit under them.

2

> A comprehensive understanding of activity in the space domain and an ability to protect, defend and integrate, as we have for the other domains, will be crucial in enabling our Armed Forces to respond to future global challenges.

UK Defence Space Strategy, 2022

Chapter 2

The roles of space power

Section 1 – Space domain awareness

2.1. Understanding of the congested, complex, critical and contested space domain is achieved through space surveillance and tracking (SST) and space situational awareness (SSA). Together these feed into the overarching military space power role of space domain awareness (SDA).[45]

2.2. **Space surveillance and tracking.** Space surveillance and tracking is defined as: the detection, tracking and identification of objects in or entering the space domain, using data from sensor observations and satellite operators, sufficient to deliver effective space situational awareness, space domain awareness and missile warning. Note: space surveillance and tracking is delivered for both civil and military purposes. SST includes sensor tasking and management, orbit determination and propagation, catalogue maintenance, launch and manoeuvre detection amongst other tasks.

2.3. **Space situational awareness.** Space situational awareness is defined as: the provision of sufficient understanding of the risks and hazards associated with domain congestion and complexity to enable safe and effective space operations. Note: space situational awareness supports both civil and military purposes. SSA includes SST-dependent tasks such as conjunction analysis, fragmentation analysis and re-entry warning for civil contingency purposes. It also includes launch collision avoidance, laser range clearance, space weather warnings, frequency deconfliction and orbital slot station-keeping monitoring for regulatory purposes and treaty compliance, amongst many other tasks. SSA therefore forms the foundational knowledge upon which successful space operations relies.

2.4. **Space domain awareness.** Space domain awareness is defined as: the provision of security-focused, decision-quality information that can be used to successfully mitigate adversary space effects while supporting the integration of allied space effects into multi-domain operations. Note: space domain awareness is derived from the fusion and aggregation of broader

45 Definitions of SDA, SST and SSA outlined in this section are new UK definitions and will be included in the next edition of Joint Doctrine Publication (JDP) 0-01.1, *UK Terminology Supplement to NATOTerm*.

intelligence and knowledge of the terrestrial domains with space situational awareness and space surveillance and tracking data. SDA includes tasks such as attack attribution, characterisation, jamming analysis, capability and behavioural analysis, and threat modelling. Missile warning also has a critical dependency on sound SDA. SDA builds on SSA to address the threat to UK and allied interests in an increasingly contested domain. It relies on the detection, tracking and identification provided by SST, delivering an increased understanding of the space domain and threats to our critical space systems and services. Knowledge is required of space system ground, link and space segments and the threats to each, both terrestrial and space-based.

2.5. **Military and civil connotations.** It should be noted that the term SDA, being specifically threat focused, has more military connotations than SSA and, accordingly, SSA may still be used by allies, partners across government and industry. An awareness of the differences between SDA and SSA is therefore essential under the integrated approach. In simple terms, SDA provides the 'so what' for military commanders and may form part of critical commanders intelligence requirements,[46] while SSA provides the underpinning understanding necessary to conduct operations in space. Figure 2.1 illustrates the relationships between the different roles required to understand the space domain.

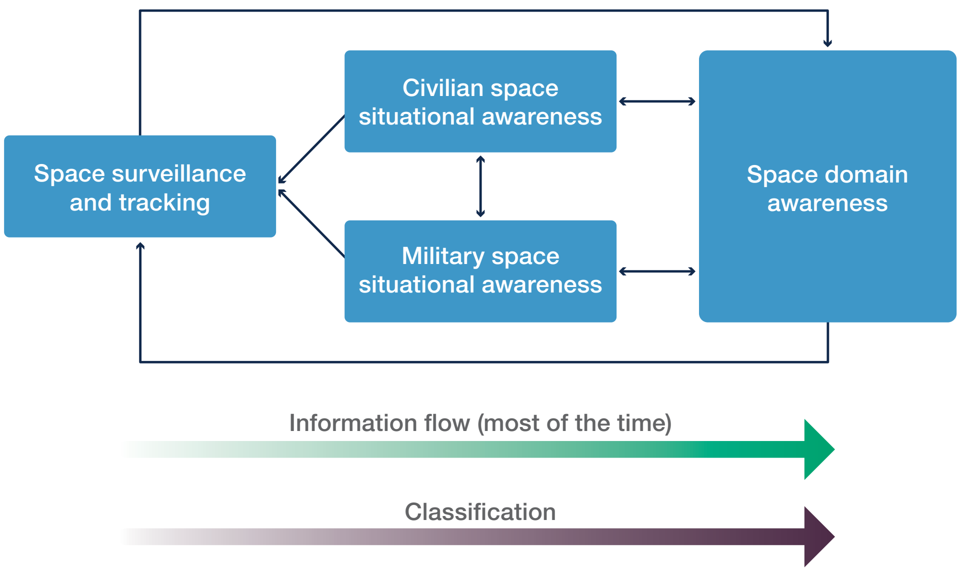


Figure 2.1 – The relationships between space surveillance and tracking, space situational awareness and space domain awareness

46 Allied Joint Publication (AJP)-2, *Allied Joint Doctrine for Intelligence, Counter-intelligence and Security*, Edition B Version 1, July 2020.

Challenges to space domain awareness

2.6. **Detection.** Detection of space objects can be challenging. In low Earth orbits (LEOs), this is typically done by active radar, such as that at Royal Air Force (RAF) Fylingdales. For higher orbits, the power needed to generate a radar beam to the range and fidelity required is often unfeasible, therefore satellites on these orbits are currently identified and tracked by optical telescopes or other sensors using other areas of the electromagnetic spectrum.[47] Depending on the orbits concerned, sensors may only have fleeting windows in which to detect and track a space object before it passes out of sensor coverage. For this reason, multiple sensors placed in different geographical locations can increase the area of coverage and the UK's network of overseas bases and dependencies make it potentially well placed. Furthermore, effective coverage can be increased by sharing information with like-minded allies. Regardless, once the orbit of an object is ascertained, the laws of orbital mechanics can be used to predict the track of an object without necessarily needing to maintain continuity of tracking. However, this can be challenging if an object changes its orbit profile, requiring it to be reacquired and correlated with the existing catalogue of space objects.

2.7. **Warning and assessment.** The ability to predict and differentiate between potential or actual hazards and threats can be challenging but in doing so we seek to protect ourselves while also seeking to identify actors and their activities. For instance, to mitigate the risk of collision, data from terrestrial sensors is used to predict potential impacts and subsequently provide warnings to satellite operators about the hazards posed by other satellites and/or space debris.[48] Such activities are increasingly challenged by the exponential rise in numbers of satellites in orbit combined with the presence of more and more space debris, particularly in LEO. The UK Space Operations Centre (UK SpOC) at RAF High Wycombe[49] provides the UK warning and assessment capability, in coordination with RAF Fylingdales and other government agencies and industry partners, such as the Met Office Space Weather Operations Centre for space weather hazards.[50]

47 Although the planned United States (US) Deep Space Advanced Radar Capability may address some of these issues.
48 The prediction of potential collisions is referred to as conjunction analysis. For more details, see the Ministry of Defence's (MOD's) *The UK Military Space Primer*.
49 In consultation with the US Combined Space Operations Centre.
50 Operational since October 2014, the Met Office operates a fully staffed Space Weather Operations Centre, which issues space weather forecasts, alerts, warnings and advice 24 hours a day.

2.8. **Characterisation.** While space objects can be detected, tracked and identified, in the current complex and congested space environment where adversaries attempt to hide the true nature of their activities, an equally important challenge is to characterise space objects to understand their true purpose. This deeper analysis is pivotal for SDA over and above SSA. Once an object is characterised as a satellite, it is important to determine its capabilities and intent, including detailed characteristics and operating parameters. This process is made more challenging by the exponential increase of numbers of objects in orbit with multiple payloads often being launched from a single launcher. Furthermore, dual-use technology is now commonplace; seemingly innocent satellites may also have military roles, which can provide opportunities but may also present legal challenges for commanders who may wish to apply effects against such a platform operated by an adversary. As well as threats, it is also important to characterise hazards such as space weather events and predict their anticipated effects. This provides decision-makers with the knowledge and confidence to make assessments on how their operations may be affected and any mitigation they may attempt.

Section 2 – Space control

2.9. Space control is defined as: the use of defensive and offensive capabilities to assure access and freedom of action in space.[51] As well as assuring our own access to the domain, this can, when directed, also involve countering an adversary's efforts to defeat, interfere with or attack UK or allied space systems and even target an adversary's own space systems to gain military advantage. While traditionally viewed as a purely military undertaking, in an era of persistent competition, the integrated approach means that achieving a desired degree of space control can also be pursued through diplomatic, regulatory or legal channels. For example, the UK-sponsored United Nations (UN) resolution on reducing space threats notes the 'need for all States to work together to reduce threats to space systems through the further development and implementation of norms, rules and principles of responsible behaviours'.[52] Such diplomatic and potentially legal efforts to reduce space threats contribute to our freedom of action and therefore can be considered an element of an integrated space control strategy. Notwithstanding these efforts, the *Defence Space Strategy* recognises that

51 This is a new definition that will be included in the next edition of JDP 0-01.1, *UK Terminology Supplement to NATOTerm*.
52 UN General Assembly Resolution A/RES/75/36, *Reducing space threats through norms, rules and principles of responsible behaviours*, 16 December 2020.

'in response to our adversaries' increasing offensive capabilities in space, we require credible deterrence and response options to protect and defend our national interests in and through space. This includes a coherent and responsive intelligence-focussed strategy, effective operational space control capability and resilient on-orbit, terrestrial and cyber infrastructure'.[53] In addition to sovereign capability, pledged to be developed under the *Defence Space Strategy* via the Defence Space Portfolio, it also recognises the need for credibility to be enhanced by our behaviour along with our relations with our allies, partners across government and industry under the integrated approach.

2.10. The nature of the space environment is such that total control (as the term is understood in the other operational domains) may not be feasible for any single actor or even alliance. Total space dominance may also be outside a given international mandate, however, given the scale and scope of the environment it may not be necessary, rather it would be sufficient to achieve a degree of control necessary to assure freedom of action in space. Space control is split into two key components: offensive space control (OSC) and defensive space control (DSC), as illustrated in Figure 2.2. It should be noted that the differentiation between OSC and DSC can be blurred. Activity directed against a weapon system targeting a friendly satellite could be considered DSC, but the same activity directed against an adversary high value asset for broader military outcomes could be considered OSC.

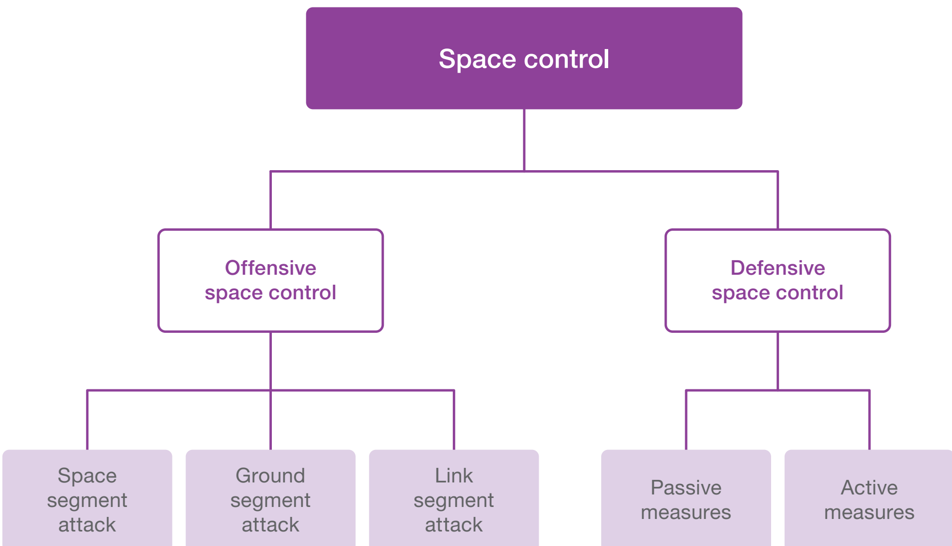


Figure 2.2 – The components of space control

53 MOD, *Defence Space Strategy: Operationalising the Space Domain*, February 2022.

Offensive space control

2.11. OSC operations seek to disrupt, degrade, deny or destroy the space-related capabilities and forces of an adversary. Such operations can be targeted against any of the segments of space activities using kinetic or non-kinetic techniques but need to be carefully considered given the unique legal and ethical complications of deliberately targeting interconnected space systems, especially where dual-use capabilities may be involved.[54] OSC can be subdivided as follows.

2.12. **Space segment attack.** A space segment attack consists of systems and activities used to disrupt, degrade, deny or destroy a satellite in orbit. It can be further divided as follows.

a. **Direct ascent anti-satellite (DA-ASAT) weapons** can be launched from the maritime, land or air domains to hit a satellite either directly or with shrapnel. A number of allies and potential adversaries have demonstrated this capability, but it should be noted that such an activity can be readily attributable and will also create a debris cloud that may affect their own space systems as well as draw condemnation and potentially responses from other actors reliant on the space domain.[55]

Other direct ascent anti-satellite tests

In September 1985, the United States (US) Air Force successfully test-fired an anti-satellite missile from an F-15 Eagle aircraft, from Edwards Air Force Base, California. The missile successfully destroyed a US satellite orbiting 340 miles overhead. In addition, in February 2008, under Operation Burnt Frost, the US intercepted and destroyed a non-functioning US satellite deemed a hazard on re-entry using a heavily modified Standard Missile 3 fired from USS Lake Erie.

On 27 March 2019, India conducted 'Mission Shakti'. A modified anti-ballistic missile interceptor known as the Prithvi Defence Vehicle Mark-II was launched against a test satellite in LEO, destroying it. In this instance, the test was conducted at a relatively low altitude intended to reduce the resulting debris field but ably demonstrated that India now possessed a functional DA-ASAT capability.

54 See Joint Service Publication 900, *UK Full Spectrum Targeting Policy*, Edition 5, Part 2, Annex G, 'Space Control Operations' for specific guidance at the OFFICIAL-SENSITIVE classification.

55 The US, Russia, India and China have all demonstrated that they have the ability to conduct direct ascent attacks on satellites.

b. **Non-kinetic means** of space segment activity can include laser-dazzle attack, cyber effects and electromagnetic warfare techniques. Lasers can be used to temporarily dazzle or permanently blind the sensors on a satellite. They can also cause components to overheat. Other techniques, such as the use of high powered microwave transmitters, can cause permanent damage to a satellite's electronics without necessarily causing the debris field of a DA-ASAT engagement.[56]

c. **Co-orbital systems** may be grouped into rendezvous operations and proximity operations. While these are often grouped together, they are distinct activities. A rendezvous operation involves attaching one satellite to another. This could pose a threat as the intercepting satellite could potentially be used to manipulate, damage or even destroy its target.[57] Proximity operations involve stationing one satellite close to another for a time. While this could be a direct threat, for example, if the intercepting satellite possessed a warhead or powerful jamming device, proximity operations can also be used to conduct a detailed assessment of the capabilities of a satellite to characterise it or to seek to intercept or manipulate signals as part of a link segment attack. More simply, such a satellite may just be positioned to block line of sight to a target area or control signal source.

d. **Nuclear attack.** While prohibited,[58] the detonation of a high altitude or exo-atmospheric nuclear device can create a high radiation environment and an electromagnetic pulse (EMP) that would have large-scale indiscriminate effects on satellites in affected orbits. Such an event would immediately affect satellites within range of its EMP and would also create a high radiation environment that would accelerate the longer term degradation of satellite components on unshielded satellites in affected orbital regimes.[59]

56 While less likely, it should be noted that any attack on a satellite which does not remove the satellite from the space domain could directly or indirectly lead to the break-up or collision of that satellite, leading to an equivalent debris field.
57 Challenges from space debris have led to the development of debris removal technologies, however, these could be considered dual-use technologies given an adversary could develop an OSC capability able to 'capture' target satellites under the cover of a debris mitigation programme.
58 The detonation of nuclear weapons in space is banned under the Partial Test Ban Treaty of 1963. Notably, the UK, US and Russia are signatories but China and North Korea are not.
59 Center for Strategic & International Studies, *Space Threat Assessment 2021*, April 2021.

Co-orbital anti-satellite tests

The US accused Russia of conducting a co-orbital anti-satellite test in July 2020. This test involved a Russian satellite (Cosmos 2542) that contained a smaller satellite inside of it, labelled Cosmos 2543. Cosmos 2542 ejected Cosmos 2543 in 2019. On 15 July 2020, Cosmos 2543 fired a small projectile near an unrelated Russian satellite. US Space Command released a statement that condemned this test and asserted that the small projectile fired from Cosmos 2543 could be used to target satellites. In response, the Russian Ministry of Defence said these 'matryoshka', or nesting, satellites are deployed for routine inspections and surveillance of Russia's own space assets. Since being ejected from its mother satellite, Cosmos 2543 has been very active, conducting proximity operations with several other Russian satellites.[60]

2.13. **Ground segment attack.** A ground segment attack is a practical option for OSC operations because it can be delivered through a kinetic attack on a terrestrial space node, for example, using a combat air platform, cruise missile or special forces. Alternatively, non-kinetic means, such as electromagnetic warfare or cyberattacks, could be used. Ground segments are also vulnerable to insider threats if force protection and vetting activities are not rigorous. Such methods avoid the advanced technological requirements and costs associated with a kinetic attack on the space segment, as well as potentially reducing the risk of generating unwanted space debris.

2.14. **Link segment attacks.** Link segment attacks target a satellite's control systems, mission systems or data transmissions by targeting the link itself or its terrestrial control or receive nodes via non-kinetic means such as electromagnetic warfare or cyber capabilities. Electronic attack can use either space- or land-based jamming or spoofing techniques to target a satellite through signal interference. Cyber capabilities can use the link segment to target satellite control systems, potentially allowing an adversary to take control and either disable or manipulate the satellite to their advantage, such as shifting the focus of the sensors to another area. Conversely, the link segment can also be used as a vector to target ground segment infrastructure, for example, using space-enabled cyber operations. More passive means may involve attempting to capture and either exploit the link data as part of an intelligence, surveillance and reconnaissance (ISR) collect or manipulate and retransmit it to attempt to deceive an adversary.

60 Center for Strategic & International Studies, *Space Threat Assessment 2021*, April 2021.

Defensive space control

2.15. DSC requires a proactive approach but can be both proactive and reactive in nature. It is conducted to protect space capabilities from attack, interference or unintentional hazards. Various methods can be used to maximise the resilience of space capabilities to disruption from malicious activity or hazards such as space weather. Foreign counter-space programmes are becoming increasingly capable, so defensive capabilities must continue to be developed to assure freedom of action. DSC consists of both passive and active measures.

a. **Passive measures** provide a significant level of protection by physically hardening satellites to enable resistance to radiation or electronic attack. Anti-jamming and cryptographic techniques can be used to protect command, telemetry and data transmission links. The protection of terrestrial infrastructure is another important aspect and can be achieved by ensuring that adequate force protection is in place or by using camouflage, concealment and deception techniques. Additionally, strong operations security measures are critical to mitigate the current inability to upgrade or retrofit capabilities within the space segment.

b. **Active measures** include using techniques to counter any kinetic or non-kinetic attacks against a satellite or its mission systems. Examples include manoeuvring a satellite to avoid a co-orbital threat or hazard, reorientating a sensor to avoid a jammer/laser or reducing sensitivity/shutting down a receiver to protect against jamming. All of these activities could result in a temporary mission kill and even a reduction in life of the satellite or mission but may maximise longer-term survival. Additionally, active measures may be used to target adversary threats and prevent them from deploying attacks against space systems.

Challenges to space control

2.16. Satellites typically follow predictable orbits, are difficult to conceal and have a limited ability to manoeuvre away from threats and hazards. This makes them vulnerable to adversaries who have the ability to track and subsequently target them using OSC techniques such as laser dazzling or, in extremis, a kinetic attack.[61] Using alternative surface properties, which reduce a satellite's signature, can complicate efforts to observe and track satellites, noting such

61 Conversely, the orbit of adversary satellites can also be predicted, enabling the conduct of OSC activities or the concealment of sensitive operations or capabilities on Earth.

materials must still be able to function in the space environment. Satellites are also highly dependent on the link segment for control and data transmission, so adequate frequency selection, encryption and anti-jamming capabilities must be used to reduce the chance of them being exploited. However, these measures do come at a cost and some commercial or dual-use capabilities may not have been designed to possess robust security features. Commercial and dual-use satellites may also use agreed international communication and software standards, and often open architecture, which are not designed with security as a requirement and are known and understood by adversaries, increasing the potential for targeting or exploitation.

Section 3 – Space support to operations

2.17. Space support to operations enables and enhances the UK's military capabilities, providing critical support to the combat effectiveness of the joint force. It is divided into five core functions, as shown in Figure 2.3.

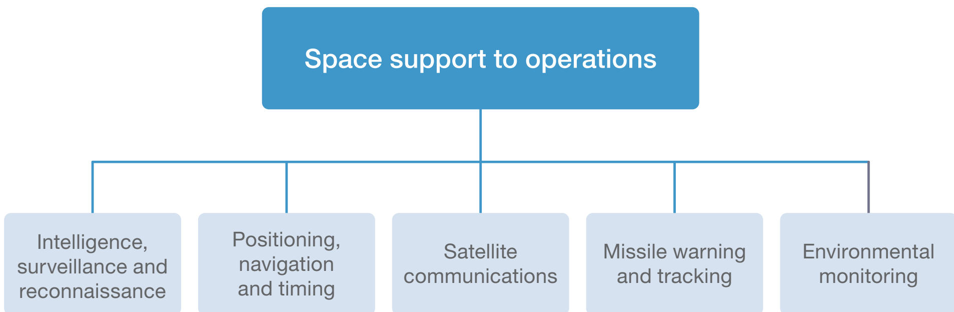


Figure 2.3 – The components of space support to operations

Intelligence, surveillance and reconnaissance

2.18. The ISR role develops situational awareness and enhances understanding, helping shape the conduct of operations.[62] The synchronisation of information collected from space and the subsequent processing, exploitation and dissemination of it identifies trends, linkages and threats. It

62 See AJP-2.7, *Allied Joint Doctrine for Joint Intelligence, Surveillance and Reconnaissance* (with UK national elements) for more details.

supports decision-making by contributing to the identification of an adversary's dependencies, vulnerabilities and strengths alongside understanding the human environment. ISR consists of three linked 'inform' functions.

a. **Intelligence.** Satellites do not directly deliver intelligence but provide timely, accurate and relevant information that is processed and potentially fused with other sources of information before being disseminated to users as intelligence. Intelligence informs political and military decision-making processes and makes a major contribution to assessing the intent of adversaries alongside assessments of when and how specific objectives, or even an end state, might be achieved.

b. **Surveillance.** Surveillance is the continuing and systematic observation of a wide area of interest. The area of interest can be in any one of the air, space, surface, sub-surface, electromagnetic or cyberspace environments, observed by visual, aural, electronic, photographic or other means. It is not orientated towards a specific target but is designed to provide warning of broad adversarial initiatives and to detect potential threats.

c. **Reconnaissance.** Reconnaissance complements surveillance by observing a specific area of interest to gain specific information about specific activities. Intelligence that is critical to the prosecution of current operations is often derived from reconnaissance operations so it should be evaluated and transmitted with minimum delay to those elements that need the information.

2.19. **Benefits of space-based intelligence, surveillance and reconnaissance.** Using space-based ISR, either sovereign, alliance or commercial, as a component of a multi-domain ISR system can have a number of advantages. Some of these advantages are outlined below.

a. The perspective offered by space enables ISR satellites to cover an unmatched area of interest. They can be focused over a wide area or on a specific point of interest and conduct a number of ISR tasks, including passive imagery and electronic intelligence gathering.

b. Advanced sensor technologies have resulted in satellites being able to produce images of a resolution that can match or even eclipse those provided by some air platforms.

c. Despite the potential threat of OSC capabilities, ISR satellites may still be able to overfly hostile areas, which are impenetrable to ISR aircraft. This creates opportunities for fusing complementary capabilities, whereby satellites can plug gaps in other operational domain ISR capabilities and vice versa.

d. High resolution electro-optical and synthetic aperture radar imagery is now commercially available, with civilian assets capable of producing images of a quality that was previously only available at a classified military level. The rise of commercial ISR means that required data can be obtained from commercial sources, not just sovereign or allied capabilities. Commercial products therefore have the potential to plug gaps in capability, coverage or supplement over-tasked allied military capabilities. Conversely, commercial ISR may also be available to potential adversaries.

2.20. **Challenges to intelligence, surveillance and reconnaissance.** There are a number of challenges facing the ISR process. The following should be considered when assessing the value of space-based ISR.

a. The global presence offered by ISR satellites means they can offer an immediate response to a crisis to help build understanding. At the very least, they are likely to be first on the scene. However, their responsiveness, as well as being a strength, can also be limited. Large constellations of ISR satellites can offer significant resilience but there could still be gaps in coverage. There can be a misconception that space can provide persistent, continual monitoring. Space assets can provide persistence, but this is achieved through multiple revisits. It is therefore important to consider whether an area of interest can be covered, for how long and for how often, over a given period of time. This depends on the orbit of each satellite, which may limit responsiveness and coverage time during each orbit over a specific point.[63]

b. Large and exquisite sensors are built to specific requirements and timelines for construction are considerable, so reconstitution of assets can take time, especially for satellites in higher orbits that require larger and more complex launch platforms and procedures. This means that resilient architectures and collaborative arrangements are key for

63 Any orbit represents a compromise between imagery resolution and the dwell time of the satellite. However, depending on the specific task, a low resolution image from a satellite in a higher orbit might suffice.

the current and likely future contested environment. Reconstituting a lost capability can be a long-term project, however, operationally responsive emerging technologies may offer options to meet shortfalls in coverage through the relatively rapid deployment of small satellites, albeit in lower orbits.[64] Equally, responsive technologies could help maintain capability in a degraded environment where spacecraft life is reduced due to adverse space weather or high quantities of debris.

c. As well as space weather effects, it is important to remember that some space-based ISR systems are as susceptible to terrestrial weather as their air counterparts. An electro-optic/infrared satellite system may struggle to penetrate cloud or blown dust in the same way as an aircraft's sensors. Ocean surveillance satellites may struggle in high sea states and high winds have the capability to move satellite dishes out of alignment, potentially compromising data links.

Positioning, navigation and timing

2.21. Positioning, navigation and timing (PNT) is the ability to determine location, time and velocity accurately and precisely. It is vital for civil and military applications, supporting fourth generation (4G) and fifth generation (5G) communications networks and a host of other civil uses as well as supporting defence capabilities.[65]

2.22. Space-derived PNT capabilities, delivered using global navigation satellite systems (GNSS), provide mission-essential data and information, which enable the effective execution of military operations. They provide precision navigation for military platforms and personnel; precision guidance for smart weapons; and precision timing for data links and secure communications. They give an integrated force the ability to effectively synchronise operations, whilst ensuring communications security. The Ministry of Defence (MOD) currently makes use of the US' Global Positioning System (GPS), which provides position, velocity and time information to an unlimited number of users through civilian and encrypted military modes. The timing signal is particularly essential for secure communications and data transfer capabilities, such as data links.

2.23. Given the importance of PNT to military space operations, the US use the term 'navigation warfare' (NAVWAR) to describe 'deliberate defensive and

64 The UK is a world leader in small-satellite technology.
65 HM Government, *National Space Strategy*, September 2021.

offensive action to assure and prevent PNT information through coordinated employment of space, cyberspace and electronic warfare operations'.[66] The mission of the Joint Navigation Warfare Center at Kirtland Air Force Base is to enable PNT superiority for the US Department of Defense, inter-agency and coalition partners; so, while the UK do not doctrinally recognise NAVWAR as part of PNT, the term is broadly used and is therefore included here given how closely UK military space operations are integrated with those of the US.

2.24. **Challenges to positioning, navigation and timing.** Although a GPS signal can be encrypted for military use, the technique used to transmit GPS data means that the power of the received signal is very low. Consequently, the GPS signal is susceptible to jamming or deceptive spoofing and even a low power jammer can prevent the receipt of GPS signals across an area of several square kilometres. Effective mitigation against GPS jamming is available, however, it comes with size, weight, power and cost implications that do not suit all users. The potential loss of GPS signal can also be mitigated by reducing the dependency on the system by developing capabilities and procedures that do not rely on space-derived PNT services or by seeking alternative PNT sources from other operational domains as part of a system of systems approach. Although the majority of UK military capabilities will continue to rely on GPS in the near term, alternative GNSS capabilities are being pursued to improve resilience. Following the decision to leave the European Union, the UK is no longer involved in developing the European Galileo GNSS, but the 2021 *National Space Strategy* states that the UK government is 'evaluating the case for investing in resilient PNT capabilities through a mixture of innovative new terrestrial and space-based technologies'.[67]

Satellite communications

2.25. The ability to communicate and pass increasingly large amounts of data beyond line of sight is an essential military requirement, since terrain or horizon-masking can restrict radio communications. Satellite communications (SATCOM) relay data and voice transmissions through space, providing the ability to establish communications at any point on the globe. They enable communications at a range of classifications, between home bases and deployed forces, even in austere locations with poor infrastructure. They enable the dissemination of operationally critical ISR data and the control of remotely piloted aircraft systems at range. The global reach and effectiveness of the UK Armed Forces is therefore dependent on resilient SATCOM.

66 US Department of Defense (DOD), *DOD Dictionary of Military and Associated Terms*.
67 HM Government, *National Space Strategy*, September 2021, page 34.

Satellite communications relay data and voice transmissions through space, providing the ability to establish communications at any point on the globe

2.26. The UK's secure SATCOM capability is currently provided through a private finance initiative (PFI) with Airbus, managed through Strategic Command.[68] It provides a secure and resilient communications capability through the Skynet programme and other SATCOM resources from other providers. UK partners and allies also use Skynet bandwidth, which bolsters collaborative ties and, similarly, lost or degraded capabilities can be replaced by negotiating access to allies' space services. Commercial bandwidth can provide redundancy for military systems as well as considerable advantages in terms of availability and coverage, but there are potential security risks if military communications are enabled by commercial satellites, which could be more vulnerable to jamming or have data-paths that are routed through unknown ground stations. Commercial satellites may also host foreign payloads. There are also risks in using commercial bandwidth because the terms of service provision could be significantly less than that provided through a dedicated military system. When choosing to use commercial providers, commanders must thoroughly understand the risks and benefits they face. In some cases, for example, using commercial satellite telephones in emergencies, tangible benefits may outweigh some security concerns in a commander's calculus.

68 The PFI is scheduled to end in summer 2022 with the likely replacement being a government owned/civil operated model. This model is not discussed here as at the time of publishing, the exact nature of the new construct is still being refined by ongoing negotiations.

Enhanced Skynet

Skynet is a family of military communications satellites, operated on behalf of the MOD. Skynet 4 and Skynet 5 satellites are currently operational. In July 2020, the MOD signed a £500 million contract with Airbus to extend and enhance the Skynet fleet. This will involve the development, manufacture, cyber protection, assembly, integration, test and launch of a military communications satellite, Skynet 6A, planned for launch in 2025. The contract also covers technology development programmes, new secure telemetry, tracking and command systems, launch, in-orbit testing and ground segment updates to the current Skynet 5 system.

2.27. As well as traditional voice and data transfer, a key element of modern communications is broadband Internet provision, which is increasingly vital for both military and civilian applications. To increase global broadband cover and connectivity, the UK government invested a US $500 million equity share in OneWeb in 2020, a LEO satellite company. It is envisaged that OneWeb will eventually have over 600 satellites in orbit, providing global reach and broadband connectivity while supporting the UK government's aspirations for UK leadership in space-enabled capabilities and services. The availability of such systems may provide further options for military planners.

2.28. **Challenges to satellite communications.** Like all communications, SATCOM capability is often a trade-off between the range and bandwidth desired and the size of antennas, power systems and processors needed to generate it. Compromises also need to be made between frequencies used, which are constrained by the laws of physics, and which are affected differently during their transmission through the atmosphere. Orbits themselves also need careful consideration. Stable geosynchronous Earth orbits (GEOs) provide constant coverage and reduce the need for complex satellite tracking procedures but the cost of launching satellites into this regime can greatly exceed that for those in lower orbits. In addition, coverage from GEO is reduced towards the poles and their higher altitude can increase the time delay or latency of the information passed. While this may be acceptable as a delay on a telephone call, it could be catastrophic when trying to land a remotely piloted air vehicle.[69]

69 Detailed information on SATCOM challenges and the compromises needed to mitigate them can be found in the MOD's *The UK Military Space Primer*.

Missile warning and tracking

2.29. Missile warning and tracking, specifically of ballistic missiles, forms part of the overall concept of integrated air and missile defence (IAMD), which the North Atlantic Treaty Organization (NATO) defines as: all measures to contribute to deter any air and missile threat or to nullify or reduce the effectiveness of hostile air action in order to protect populations, territory and forces against the full spectrum of air and missile threats.[70] Space-based missile warning systems are designed to detect, track, identify and assess ballistic missiles and their flight paths as well as predicting their likely time and point of impact. They form one component of an overall IAMD capability that must also integrate layers of surface-based sensors and interceptors.

2.30. The ground-based ballistic missiles early warning and tracking system at RAF Fylingdales is such a sensor, feeding into a US global system and making a significant contribution to the overall missile warning function. The UK SpOC works closely with RAF Fylingdales to ensure that missile warning details are disseminated. The US space-based infrared system provides a space-based ballistic missiles warning and tracking capability, the output from which is shared with allies, including the UK.

2.31. **Challenges to missile warning and tracking.** Once the sole property of the major powers, recent times have seen a proliferation of ballistic missiles passing into the hands of militias and other organisations willing to use them, making the assessment of the threat they pose more challenging.[71] Combined with this are difficulties in physically locating ballistic missile systems themselves prior to launch, complicating any targeting process. Ground-based and naval systems are highly mobile and certain adversaries now possess the capability to launch ballistic missiles from air platforms. Once airborne, detection, identification and tracking are made more difficult by modern ballistic missiles having reduced radar cross sections and possessing multiple, in some cases manoeuvrable, re-entry vehicles containing a mixture of warheads and decoys.

2

70 NATOTerm.
71 The Yemeni Houthi militia have repeatedly used ballistic missiles to attack Saudi Arabia.

2

Environmental monitoring

2.32. The challenges presented by a changing world climate, with an increased likelihood of population migration and disaster relief operations, have made terrestrial environmental monitoring of pivotal importance.[72] Furthermore, predicted increases in solar activity prior to the forecast solar maximum in 2025–26, alongside the exponential growth in the numbers of satellites on orbit, has meant that the monitoring of space weather is equally crucial. Space assets potentially have advantages in environmental monitoring. The attributes of access and persistence mean that satellites can potentially have enduring global coverage. They can also be used to monitor austere or even toxic environments without endangering personnel. The *National Space Strategy* states that space will be used to tackle global challenges, including climate change and biodiversity loss. As well as these universal challenges, environmental monitoring can provide data that is essential for military operations.

2.33. Data derived from space assets can provide information on meteorological, oceanographic and environmental factors that may affect the planning and execution of military operations, be it from space weather or terrestrial weather. Synthetic aperture radar capabilities can track weather fronts and provide data on ocean waves and a variety of multispectral capabilities can measure humidity, cloud cover and the composition of terrain materials. Increasingly, new technologies such as hyperspectral imaging and LIDAR[73] are also increasing the quantity and quality of information available for scientific analysis. Space-derived terrestrial weather monitoring also contributes to a significant proportion of long-range weather forecasting. This function is therefore a key enabler because it provides operationally significant information on sub-surface, surface and air conditions, which has utility for multi-domain operations. As well as purely defence functions, under an integrated approach, Defence space systems can contribute surveillance data and information to our partners across government for vital tasks such as terrestrial environmental monitoring, disaster relief and infrastructure development.

2.34. **Challenges to environmental monitoring.** While a large number of environmental monitoring satellites have been launched, global coverage in some regions can still be a challenge. For example, changing polar conditions may require constant monitoring but that is not always possible using low orbit

72 MOD, *Global Strategic Trends – The Future Starts Today*, 6th Edition, 2018.
73 A portmanteau of light and RADAR, LIDAR is primarily a technique for measuring distance by laser ranging, the technology can also create a three-dimensional representation of the surveyed environment.

polar-orbiting satellites given their revisit times. While this can be addressed using other orbital regimes, there can be a trade-off between the desired area of coverage and fidelity of imagery. In addition, once a satellite has been launched, constantly recalibrating it to ensure comparable data over time is difficult, potentially compromising the overall information it provides. Finally, environmental monitoring requires simultaneous monitoring of a number of interrelated factors, which can be a challenge for an individual space system with a limited payload. Space-derived data therefore needs to be combined with additional other data from other satellites alongside sensors in other operational domains to provide a more complete picture of the environmental system as a whole.

Section 4 – Space service support

2.35. Space service support consists of operations that launch space assets and maintain and sustain them. It comprises launch operations and satellite operations.

2.36. **Launch operations.** These operations are fundamental to the ability to participate in space-based activities as they deliver satellites, payloads and material into space. Due to the associated cost of this activity, the UK has historically relied on allies and third-party launch capabilities such as those of the US, India and the European Space Agency to deliver UK satellites into orbit. However, the *National Space Strategy* considers space launch to be a prerequisite to acting in space and has committed the UK to possessing a sovereign space launch capability by 2022, capable of launching small satellites through LaunchUK, the UK Space Agency's spaceflight programme. This offers the potential for a responsive launch capability, where satellites with bespoke payloads can be held ready for rapid launch if and when required. Such satellites could also be designed

A UK Skynet 5D satellite is launched on board an Ariane rocket from French Guiana to be easily replaceable should they be lost, become unserviceable or if their payloads required updating. Replaceable LEO satellites could also be designed to degrade their orbits and burn up by re-entering the Earth's atmosphere at the end of their operational life, thus avoiding creating more space debris.

2.37. **Satellite operations.** These operations involve the manoeuvring, sustainment and maintenance of satellites. The MOD currently depends on commercial providers for this function, although this may not be the case in the future.

2.38. **Challenges to space service support.** While LaunchUK will provide elements of sovereign capability, this will be for small satellites on very specific orbits.[74] For larger satellites, or those which need to be placed in higher or less inclined orbits, the UK will still need to rely on allies, partners or commercial entities, raising issues of assurance, security and responsiveness. Such a reliance can be exploited: for example, a number of the UK part-owned OneWeb satellites were intended to be launched by Russia but sanctions over the invasion of Ukraine have led to the launch being cancelled and the satellites impounded in Russia with the resulting potential for their technology to be exploited.

Overlap between roles

2.39. The space power roles, illustrated in Figure 2.4, are a good framework within which to view activity in space; however, they are not absolute and overlap between the roles will inevitably occur. Space control overlaps in a number of areas with SDA and space support to operations. For example, SATCOM electromagnetic interference detection and mitigation could be considered as part of DSC or space support to operations (a combination of ISR and SATCOM). The satellite warning service could be viewed as DSC, SDA or ISR. Given the UK currently splits responsibility (including for development and funding) for the elements of space power between a number of different military commands and civil agencies, some delineation is important. When considering capabilities and activities that overlap doctrinal or domain boundaries, the following delineations may prove useful: SDA provides the information on which operational decisions can be made. Activities and capabilities designed to mitigate threats identified using SDA information are generally classified as space control, which includes the protect and defend mission, while space support to operations may only include the delivery of space services to terrestrial operations and not necessarily address the threats to those services.

74 For more information concerning the impact of launch latitude on orbit parameters, see the MOD's *The UK Military Space Primer*, June 2010.

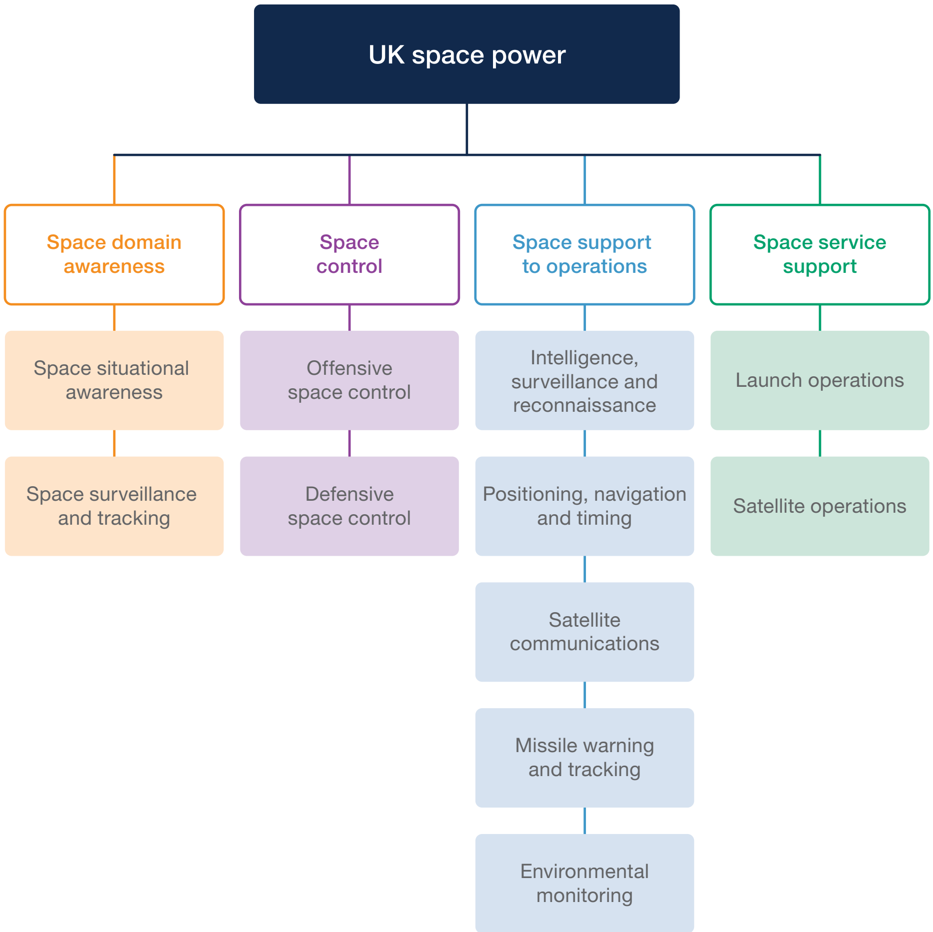


Figure 2.4 – UK space power roles

2.40. Overlap will also happen with other operational domains. For example, targeting an adversary's ground segment infrastructure with carrier-based aircraft could correctly be considered a maritime strike mission, an air attack mission or OSC. No definition can cover all eventualities and therefore if there is a need to differentiate, the mission should be labelled in accordance with the desired effect, rather than purely the means.

Key points

- The UK consider there to be four key space power roles: space domain awareness, space control, space support to operations and space service support.
- Space domain awareness combines situational awareness with surveillance and the tracking of space objects to provide information to assist allied space effects while successfully mitigating those of adversaries.
- Space control is the use of defensive and offensive capabilities to assure access and freedom of action in space.
- Space support to operations enables and enhances the UK's military capabilities, providing critical support to combat effectiveness.
- Space service support consists of operations that launch space assets and maintain and sustain them.

Notes


SPACE OPERATIONS CENTRE
UNITED KINGDOM

Chapter 3

Chapter 3 discusses how UK space command and control is conducted. It begins by discussing general principles, before moving on to cover specifics relating to the space domain.

3

> "This [space] strategy is about more than capabilities. It is about partnerships. Government working as one with industry and international allies."

Jeremy Quinn MP, Minister for Defence Procurement, February 2022

Chapter 3

Space command and control, coordination and planning

Section 1 – Principles of command and control

3.1. Space power is rarely used in isolation but forms part of an integrated approach comprising operations across multiple operational domains set alongside cross-government activities. These actions must be directed and timed appropriately to maximise the effects they can create. Space is a global domain which can overlay multiple theatres and joint operations areas, creating competing demands to prioritise often scarce resources. These resources may be highly classified or owned by allies, commercial entities or partners across government. Effective command and control is therefore the key enabler, without which the fundamental space power roles cannot be delivered effectively, irrespective of the size or nature of an operation.

3.2. **Command and control definitions.** The following North Atlantic Treaty Organization (NATO) definitions of command and control are used in this publication.

a. **Command.** The authority vested in a member of the armed forces for the direction, coordination, and control of military forces. (NATOTerm)

b. **Control.** The authority exercised by a commander over part of the activities of subordinate organizations, or other organizations not normally under their command, encompassing the responsibility for implementing orders or directives. (NATOTerm)

Methods of command and control

3.3. **Unity of command or unity of purpose.** Traditionally, military command and control has been underpinned by the principle of unity of command. In this, responsibility for the conduct of a campaign is vested in a single responsible commander, the joint force commander (JFC), who could reasonably expect to have command and control of all of the military assets allocated to them for completion of the task. Under the integrated approach, however, many space assets and space capabilities will not be under a JFC's direct command but will in fact be owned by other actors who will often have their own separate aims. Instead, therefore, the JFC may need to create the effects and obtain desired capabilities by seeking to align multiple actors through a common unity of purpose. Regardless, several enduring critical elements of command and control endure. A commander must understand and determine the operational context, create their intent to determine the campaign design, provide timely direction and guidance to facilitate effective planning and then set the freedoms and constraints within which subordinates can operate. This may, however, need to be communicated to and negotiated with other stakeholders rather than being simply directed.

3.4. **Centralised control and decentralised execution.** The UK's preferred method of command and control for joint operations is 'centralised control and decentralised execution' where overall control is held centrally by the JFC but responsibility for executing plans is delegated to subordinate commanders at the lowest practical level. In an era of persistent competition, there are benefits of centralised control as many previously tactical decisions may need to be made at the strategic level due to their potential to influence audiences. Maintaining centralised control allows competing demands to be prioritised and apportioned, mitigating the risk of assets being inappropriately tasked by uncoordinated users against impractical objectives or being diluted into smaller packages that lessen their overall effect. In terms of executing tasks, however, no single commander is likely to have the level of situational awareness required to centrally manage all concurrent activities. Decentralised execution delegates execution authority to subordinate or on-scene commanders who have a greater awareness of their immediate situation. It is an efficient method when dealing with complex campaigns, especially where communications may be degraded or denied. It is underpinned by the doctrinal tenet of mission command (see Chapter 4), but it may not always be easily achievable for UK space capabilities given the dispersed nature of space power role ownership, although this situation is improving as UK Space Command matures and adopts responsibility for more of the space power roles.

As UK Space Command matures it will adopt responsibility for more of the space power roles

3.5. **Other command and control approaches.** If centralised control and decentralised execution are not appropriate or even possible in the space domain, two other options exist that can be adopted to suit a specific operation or task. These options are centralised control, centralised execution and decentralised control, decentralised execution.

a. **Centralised control, centralised execution.** Centralised execution authority may be necessary for space command and control where the highest-value space assets are being employed or where there is a risk that the use of a classified space asset may divulge or infer its existence or capability. It might also be appropriate when there is a requirement to closely manage tactical activities that might have strategic effects, accepting this may adversely affect tactical efficiency or responsiveness.

b. **Decentralised control, decentralised execution.** The decentralised control and execution of space power is not routinely envisaged. It exists as an option, should it be required, to improve responsiveness in the event of fallback or if resilience operations are required.

Componency

3.6. The organisational command and control framework employed for UK operations depends primarily on the scale, size and complexity of the operating area. For small-scale, low intensity operations in a non-contested operating environment, command and control provided 'at range' from the UK may be appropriate, often enabled using space-based communications. More complex operations are usually best served by a deployable, or permanent, in-theatre command and control capability, especially when an operation is NATO-led, UK-led within a NATO framework or conducted by a multinational coalition.

3.7. At the operational level, the UK uses the concept of component organisation to cohere multi-domain activity under a JFC, particularly for a deployed joint force. The 2* Standing Joint Force Headquarters (SJFHQ) provides this capability for the UK for small and medium sized operations. A JFC may exercise command and control of integrated operations within a joint operations area from their own headquarters, augmented by component liaison officers and other subject matter experts. It is more usual, however, for the JFC to appoint component commanders for the components of maritime, land, air and special forces. At the current time, the joint force space component commander (JFSCC) function is provided by the UK Space Command Headquarters (see paragraph 3.10).

Section 2 – UK space command and control

Command and control by space power role

3.8. The command and control of UK space elements varies, depending on which space power role is being considered. Military operational command is delegated by the Chief of the Defence Staff as follows.

a. Operational command for space control and space domain awareness (SDA) are delegated to Commander UK Space Command. The UK Space Operations Centre (UK SpOC) is the operational command and control unit for Defence in these areas.

b. Operational command for space support to operations is currently delegated to Commander Strategic Command (UKStratCom) with Defence Digital Operations and the Global Operations and Security Control Centre at Ministry of Defence (MOD) Corsham managing satellite communications (SATCOM) and intelligence, surveillance and reconnaissance (ISR) being managed through Defence Intelligence via the Joint Intelligence Operations Centre at Royal Air Force (RAF) Wyton. While the UK currently does not possess positioning, navigation and timing assets in space, UKStratCom coordinates positioning, navigation and timing considerations while delegating responsibility for operational integration to the front line commands. Environmental monitoring, specifically the use of space to inform terrestrial weather forecasting, is the responsibility of the Joint Operations Meteorology and Oceanographic Centre[75] and Defence Intelligence. The UK SpOC is the Defence customer for space weather with the Met Office under UKStratCom's authority. Missile warning is conducted in the UK by the RAF and at sea by the Royal Navy with the UK SpOC coordinating it at national or global scale.

c. The MOD does not currently conduct command and control of space service support assets. They are conducted by commercial entities and partners across government.

Prioritising space capabilities

3.9. The attributes of space power mean that space assets can often have global effects. As such, a satellite on orbit may physically be able to support several JFCs operating simultaneously in different joint operations areas. Space assets are, however, finite, both in terms of numbers and payload capacity, for example, the bandwidth a communications satellite can carry. In addition, certain capabilities may have additional resource demands that place limitations on supporting multiple customers.[76] To mitigate potential frictions, the responsibility for the strategic prioritisation of UK military space capabilities is retained centrally within the MOD. This allows space support to be efficiently prioritised between potentially competing customers.

75 The Joint Operations Meteorology and Oceanographic Centre is a military joint enabling centre staffed by Met Office and military personnel.

76 For example, the processing, exploitation and dissemination of space-derived ISR may be subject to finite limits in terms of the time and resource needed to provide a product. Analysts and automated systems engaged in one task may not be able to simultaneously support others.

Command and liaison elements

3.10. **Joint force space component commander.** At the current time, the JFSCC function is provided by the UK Space Command Headquarters (see paragraph 3.13), who can provide a JFSCC from OF-5 to 2* rank depending on the scale of the operation and the JFC's requirements.[77] Space effects required by the JFC's headquarters and those of the component commanders are created and coordinated by a network of space liaison officers, overseen by a senior space liaison officer located within UK Space Command Headquarters. These officers are specialist space operations officers who assist their components by increasing the effectiveness and efficiency of forces with regards to ISR, missile warning, space and terrestrial weather impacts, communications, positioning, navigation and timing and maximising the utility of space-enabled technologies. How these mission areas support their host components will vary with each operation and will depend on the space resources available. Liaison officers can be augmented with additional staff if required. They collaborate with other divisions within the component, key allies, commercial mission partners and space operations centres to provide support and products for strategy development, targeting, mission planning and current operations as follows.

a. **Component planning.** The space liaison officer and, if appropriate, their team, assist the component planning process by providing advice on available space capabilities and intelligence on the adversary's space order of battle, including enemy space capabilities, vulnerabilities and centres of gravity, limitations and threats to allied forces. During estimates, the liaison officer determines the requirements for space support, develops a space support plan and writes any relevant operations plan annexes. Additionally, they provide subject matter expertise and advise on the targeting of adversarial space capabilities.

b. **Provide capability.** After determining requirements for space in the campaign, the space liaison officer establishes all available capabilities and processes necessary to execute the space support plan. The plan's execution involves generating and submitting space support requests to the appropriate coordination centre. For UK operations, this will be the UK SpOC but for deployed operations, liaison may be with host nation or coalition equivalents, if appropriate.

77 This is achieved by dual-tasking officers from within the UK Space Command space operations pillar.

c. **Provide awareness.** The space liaison officer provides SDA to the host component in coordination with the SDA team in the UK SpOC. Such awareness typically concerns any significant operational impacts due to events in space, including the degradation or loss of any space capabilities. It should be remembered that due to orbital mechanics, space assets may not be present in, or remain within, a commander's joint operations area; therefore, awareness of any matters that may affect the asset through the whole of its orbital path should be considered.

d. **Execution.** During the execution of operations, the space liaison officer actively participates from the component operations room. They provide missile warning, threat indications and warnings, support to joint personnel recovery efforts and assistance with dynamic targeting processes.

3.11. **Inter-component variations.** While the overall tasks of the space liaison officers are similar, their location, command and control responsibilities and some tasks vary between organisations. Details of the different organisations are as follows.

a. **Permanent Joint Headquarters.** Space support to Permanent Joint Headquarters (PJHQ) is facilitated by a space liaison officer who sits within the J3 Joint Effects Cell. With PJHQ being the MOD's hub for operational-level full spectrum targeting, the space liaison officer also provides space representation on targeting boards and effects reviews.

b. **Standing Joint Force Headquarters.** The UK maintains an SJFHQ to provide a 2* operational-level headquarters at very high readiness that can liaise across government departments, allies and partners as required. It can provide command and control for sovereign, multinational and inter-agency operations. The SJFHQ space liaison officer again sits within the J3 Joint Effects Cell but supports both the SJFHQ and its two subordinate 1* headquarters (Joint Force Headquarters and the Standing Joint Force Logistics Commander) in creating the required effects for Defence. The liaison officer provides support to all elements of the headquarters over a wide range of operations ranging from non-combatant evacuation operations and deployed logistics operations to high tempo sub-threshold multinational operations. SJFHQ also supports two multinational frameworks: the

Joint Expeditionary Force[78] and the Combined Joint Expeditionary Force,[79] as well as integrating across government.

c. **Maritime.** The Royal Navy possess a standing 2* maritime component commander, Commander UK Strike Force, alongside three subordinate deployable 1* staffs (the carrier strike group, the littoral strike group and 3 Commando Brigade). Space support to the maritime domain is provided by the space liaison officer, who currently sits within the carrier strike force joint effects cell. The carrier strike force space liaison officer is used primarily within carrier strike force headquarters, but also provides support to the 2* maritime component commander and the other 1* subordinate units and can be deployed with them if necessary.

d. **Air.** Space support to the joint force air component commander is provided by a dedicated Space Operations Section within its Combat Operations Division. The Combat Operations Division's Space Operations Section is staffed by specialist space operations officers who can be augmented should the operational tempo necessitate it.

Organisations and units

3.12. **MOD Space Directorate.** The MOD Space Directorate was established in September 2019 and is part of the MOD Head Office. It has linkages to the UK Space Agency, Department for Business, Energy and Industrial Strategy, Foreign, Commonwealth and Development Office, Home Office, wider government departments and key allies. It sets the MOD's overarching space policy, strategy and objectives and provides space capability coherence across the single Services to ensure Defence efforts are aligned with the national ambition in space as well as providing value for money. Direction from the government's National Space Council flows through the MOD Space Directorate to UK Space Command and other relevant elements of Defence.[80]

78 The Joint Expeditionary Force comprises: the UK, Denmark, Estonia, Finland, Iceland, Latvia, Lithuania, the Netherlands, Norway and Sweden.
79 The Combined Joint Expeditionary Force comprises the UK and France.
80 While correct at the time of publishing, under the MOD Head Office Review, some functions currently performed by the MOD Space Directorate are likely to be disaggregated: with elements concerning space policy to MOD Security, Policy and Operations; space capability strategic plans to MOD Finance and Military Capability; and other functions being transferred to UK Space Command. The Defence Operating Model 'direct' function is are likely to still be delivered by a Space Directorate in some form, but this structure is currently under review.

UK Space Command is a joint command staffed from across the single Services, the Civil Service and key members of the commercial sector

3.13. **UK Space Command.** Formed at RAF High Wycombe on 1 April 2021, UK Space Command is a joint command staffed from across the single Services, the Civil Service and key members of the commercial sector. When fully operational, it will provide command and control of all of Defence's space capabilities, including the UK SpOC, Skynet satellite communications, RAF Fylingdales and other enabling capabilities. UK Space Command also has extremely close links to UKStratCom and the Defence Science and Technology Laboratory, specifically to examine options for developing new capabilities to enable multi-domain integration and capitalise on the research and development expertise that exists within Defence. UK Space Command also interacts with the UK Space Agency to deliver joint national space capability.

3.14. **UK Space Operations Centre.** The UK SpOC is the primary point of contact for UK Defence space-related matters at the operational level. It delivers the RAF's space control and SDA capabilities and has tactical control authority over RAF Fylingdales.[81] The UK SpOC has an enduring working relationship with the United States (US) Combined Space Operations Centre, allowing significant access to US space-derived information in support of operations. It can also provide expertise to assist component commanders in integrating space capabilities and effects into their own operational planning processes. The UK SpOC areas of responsibility primarily include the following.

a. **Threat warning and attack assessment.** The UK SpOC provides continuous, timely, accurate and unambiguous strategic warning. It also provides ballistic missile attack assessment for the UK and deployed forces.

b. **Space launches.** The UK SpOC routinely monitors and reports all space launches around the world. It is increasingly common for multiple satellites to be placed in orbit using a single launch vehicle, either for efficiency or in an attempt to covertly insert objects into orbit. RAF Fylingdales has the capability to track certain low Earth orbit satellites, providing regular updates on any subsequent manoeuvres that are carried out, which may provide indications as to the nature of the satellite.

c. **Detection, characterisation and tracking.** The UK SpOC is required to contribute to SDA by seeking to understand events occurring in space such as the detection, tracking and potential attribution of any direct ascent or co-orbital anti-satellite weapon. The UK SpOC also seeks to detect any non-kinetic threats, either via its own sensors or by using information derived from those of allies and partners.

81 RAF Fylingdales provides a ballistic missile warning and space surveillance service for both the United States (US) and UK. Whilst ballistic missile warning will remain the priority for the foreseeable future, the phased array radar is able to carry out space surveillance tasks when not being used in this primary role, providing the UK with a significant SDA capability. Forming part of the US Space Surveillance Network, the unit provides data to a catalogue of space objects maintained by the US and shared with the UK SpOC and provides information to both the UK and US on the orbital decay and re-entry of objects.

RAF Fylingdales solid state phased array radar

The solid state phased array radar at RAF Fylingdales can search for, identify and track missiles and other objects over 10 centimetres in size to a range of around 3,000 nautical miles. The radar has a 360° field of view with each of the three faces providing 120° coverage. The radar typically collects data on 3,000 objects a day. There are approximately 22,000 objects visible out to low Earth orbit of which Fylingdales can track around 65%.

d. **Rendezvous and proximity operations.** Increasingly, consideration must be given to the behaviour of satellites known or suspected to be controlled by potential adversaries. Accordingly, the UK SpOC is rapidly developing the means by which to detect and monitor on-orbit threats which approach friendly assets, providing warning and attribution when necessary.

e. **Satellite warning.** As the number of countries with access to satellite-based ISR capabilities continues to increase, there can be a requirement to protect Defence-related activities from being observed by these platforms. In conjunction with Defence Intelligence, the satellite warning service aims to provide an awareness of the overhead ISR threat to aid users in their decision-making processes.

f. **Conjunctions.** Conjunctions[82] can create large debris fields which have the capability in turn to cause additional conjunctions with other satellites in a 'domino effect'. To militate against this risk, the US operates a global network of ground-based and orbital sensors (the US Space Surveillance Network) to track space objects and provide warning of potential collisions. RAF Fylingdales is an integral part of this network. This is especially important when crewed space vehicles such as the International Space Station are involved. With enough warning, some operational satellites, and even the International Space Station, can be manoeuvred to avoid or reduce the risk of collisions. The UK SpOC also has access to the conjunction warnings provided by the US.

g. **Atmospheric re-entry.** All objects in orbit gradually lose altitude and eventually fall back to Earth over time. Although most objects burn up as they pass through the atmosphere, some larger objects can survive the atmospheric re-entry, and impact the Earth's surface. When the UK falls within a predicted impact area, the UK SpOC and Defence Intelligence will issue advisory notifications to government response agencies.

h. **Space weather.** The UK SpOC acts as the UK Defence point of contact into the Met Office Space Weather Operations Centre. They will notify any relevant parties who may be affected by space weather events.

Planning

3.15. Space component planning is conducted by the UK Space Command Headquarters Plans Pillar and the UK SpOC. Given the close relationship between the UK and the US in terms of space operations, the UK SpOC is closely aligned with the US Combined Space Operations Centre planning process. The UK is represented during allied Combined Space Operations Centre planning with the UK contribution set out within an applicable space operations directive and space instructions.

3.16. For national operations, space effects are integrated into the planning processes of their host commands using that command's own planning process, facilitated by their component space liaison officers. Space liaison officers, commanders and headquarters can request space effects via either a

82 Collisions between objects on orbit.

request for information/intelligence to the Joint Intelligence Operations Centre or via space support requests to the UK SpOC. Allied space capabilities can also be requested via the UK SpOC.[83] Support for SATCOM and ISR is requested through UKStratCom and should typically remain domain agnostic: requesters should bid for the effect they desire not a specific capability or platform. For example, a beyond line of sight communications solution might not necessarily be delivered by SATCOM and the type of platform collecting ISR should be immaterial to the requester, as long as the product provided answers the specific request made.

83 A plain-English product catalogue is available from the UK SpOC that explains the capabilities and services available and how to request them.

Key points

- Space power is rarely used in isolation but forms part of an integrated approach.
- Space assets and space capabilities will often not be under the direct command of a military JFC.
- Commanders may need to create effects and obtain capabilities by seeking to align multiple actors through a common unity of purpose.
- UK Space Command Headquarters can provide a JFSCC function from OF-5 to 2* rank as necessary.
- Within individual components, space effects are created and coordinated by a network of space liaison officers.
- The UK SpOC is the primary point of contact for UK Defence space-related matters at the operational level.

Notes

Chapter 4

Chapter 4 sets out how space power is applied within the integrated approach. It discusses the three tenets of UK Defence doctrine, sets out how space is integrated with the other operational domains and then goes on to consider the role of space power in deterrence.

> "We will make the UK a meaningful actor in space, with an integrated space strategy which brings together military and civil space policy for the first time."
>
> *Integrated Review*, 2021

4

Chapter 4

The employment of space power

Section 1 – Space and the integrated approach

4.1. As set out in Chapter 1, the UK government pursues its objectives by leveraging four instruments of national power: diplomatic, information, military and economic. Military forces are therefore rarely used in isolation but are often integrated and synchronised with partners across government. This provides more options for decision-makers to use all of the instruments of national power towards common national goals. This is referred to by the UK government as the integrated approach and it is similar to the comprehensive approach used by the North Atlantic Treaty Organization (NATO).

4.2. Under the military instrument, Defence considers space to be one of five interconnected operational domains,[84] which together or separately provide options for employing the military instrument. While space is now considered an operational domain in its own right, it remains a key enabler for the other domains. As technology advances, it could be argued to be more important than ever given the reliance other operational domains have on positioning, navigation and timing (PNT), satellite communications (SATCOM) and other space-enabled capabilities. As such, space power is most effective when integrated with other components of military power, benefiting from complementary capabilities and exploiting synergies between the operational domains. Such activity has previously been termed 'joint action'; however, this is now considered to be too narrow and too focused on the role of the military instrument rather than considering wider audiences. In addition, joint action focused on integrating the traditional three operational domains of maritime, land and air at the expense of space and cyber and electromagnetic. Accordingly, the new *Integrated Operating Concept* and Joint Doctrine Publication (JDP) 0-01, *UK Defence Doctrine* advocate moving towards three doctrinal tenets.

84 Maritime, land, air, space and cyber and electromagnetic.

a. **Integrated action.** Integrated action is the orchestrated use of a full range of capabilities to change or maintain the attitude and behaviour of audiences necessary to achieve a successful outcome. As such it is audience instead of adversary focused and places understanding the audience as its major consideration. Audiences are increasingly interconnected by technological capabilities in the cyber and electromagnetic domain, which are in turn enabled by and carried through the space domain. Space power therefore enables integrated action.

b. **Manoeuvrist approach.** The manoeuvrist approach is more adversary focused and seeks to operate indirectly, pitting strength against an adversary's identified vulnerabilities to undermine an adversary's will and cohesion. Some aspects of space power, such as space-based intelligence, surveillance and reconnaissance (ISR) may be vital for providing the knowledge necessary to enable manoeuvre by identifying such key vulnerabilities that can then be targeted by platforms operating in other operational domains. The principle of economy of effort can also apply to the space domain – a correctly targeted action can have a disproportionate effect.

c. **Mission command.** Mission command can enable the previous two tenets by enabling operational flexibility. Rather than directing all aspects of an operation, a commander instead clearly sets out their intent but permits subordinates freedom to take the initiative and achieve that intent within set boundaries. It is a form of decentralised execution that can work well in some operational domains but may not always be suited to the space domain. Space assets are typically held at the strategic level given their scarcity and, on occasion, their classification; therefore, delegating their use may risk the capability being divulged or inappropriately used. Many space assets may also not be in the direct command of the military commander but may belong to partners across government or other allies. Effective liaison with these partners and allies is therefore critical to integrating space capabilities.

Section 2 – Integration between operational domains

4.3. Military manoeuvre in one operational domain is increasingly enabled by effects from all of the other four domains. To optimise capability and succeed on operations, stovepipes between operational domains and the levels of operations must be broken down, a concept termed multi-domain integration.[85] Before this can happen, however, current integration between space and the other operational domains must be fully understood.

Integration with the maritime domain

4.4. The maritime use of high-end technology and their pursuit of networked warfare systems, while providing considerable advantages, has also placed a great reliance on space-derived systems and products. PNT signals, often derived from space, are vital for the efficient operation of many systems and subsystems, including secure tactical data links that are often also enabled by space-based timing signals. Maritime platforms are also particularly reliant on beyond the horizon communications systems such as SATCOM, both for command and control purposes and for passing situational awareness data between elements of a dispersed force.

4.5. Of particular relevance to maritime operations is the threat posed by space-based ISR. Traditionally, maritime operations relied on the ability to manoeuvre to avoid detection and therefore achieve an element of surprise or at least pose elements of uncertainly to the opposing commander. The prevalence of increasingly persistent space-based ISR, including commercial ISR, across all aspects of the electromagnetic spectrum (EMS) threatens to limit this advantage. When combined with improvements in the lethality of anti-ship missile systems and over the horizon targeting, space-based ISR becomes a more serious threat to maritime systems. Space-based ISR can also collect technical data on the performance of active maritime sensors, allowing their performance to be deduced. For all these reasons, accurate assessment of adversarial satellite collection windows and capabilities are essential. Therefore, integration with space capabilities such as the satellite warning service provided by the UK Space Operations Centre (UK SpOC) at Royal Air Force (RAF) High Wycombe is vital to provide an awareness of

85 See Joint Concept Note 1/20, *Multi-Domain Integration* for further details. A second edition of this concept is in development.

the overhead ISR threat to aid the maritime decision-making and planning process.[86]

Integration with the land domain

4.6. As land forces increasingly digitise they become even more heavily dependent on space support to operations. Land forces are almost completely dependent on space for their PNT needs, with very limited recourse to non-space-based systems given Global Positioning System (GPS) services are integrated into most land systems, from tactical radios to missile systems. For example, a number of extended range rocket munitions, either currently fielded or in development, rely on GPS to complement inertial guidance while tactical radios rely on GPS for timing to synchronise links. Even at an individual level, many of a soldier's handheld devices such as navigational aids, weapon sights or personal radios all include integrated space-based global navigation satellite system receivers.

4.7. SATCOM provides the bulk of beyond line of sight communication capabilities, often serving to extend the range of tactical communications systems, such as Falcon or Bowman, while providing connectivity to UK fixed telecommunications systems, thereby allowing command and control of land forces throughout the levels of operations. These include capabilities from the Skynet system, such as the Reacher series of deployable ground terminals accessing Skynet X-Band services, or commercial systems, such as Slingshot using Inmarsat L-Tac services. While hardened military SATCOM systems are widely used in any situation, commercial SATCOM systems are particularly prevalent where their benefits outweigh security concerns.

4.8. The land domain's first recourse for ISR or environmental monitoring is invariably from space-based assets, albeit invariably from freely available commercial sources. These systems usually provide sufficient information to conduct an initial analysis and, if required, determine requests for information from higher specification military systems.

4.9. Space power is also critically dependent on land power for protection. Spacecraft are usually controlled from fixed ground infrastructure, which often requires land power to provide elements of its force protection.

86 For more information see Book of Reference (digital) (BRd) 4487, *The Fighting Instructions*, Volume 2.6, 'Information Warfare', February 2016.

Satellite launch operations can also be enabled by air assets

Integration with the air domain

4.10. Air-space integration is considered critical to successfully employing air power. The effectiveness and potency of aircraft operations is closely linked to the effectiveness of enabling space capabilities, such as PNT for aircraft and weapons, or voice and data communications. Satellite-enabled communications are essential for controlling and operating remotely piloted aircraft systems, such as Protector, beyond line of sight of their ground control stations. Equally, air power can be critical to space power, for example, by providing force protection through the air defence of space ground segment infrastructure. Effective air-space integration at the operational planning level can also provide opportunities to make use of complementary capabilities. For example, both the air and space domains offer significant ISR capabilities, which, if coordinated during an operation, can complement one another by ensuring there are no gaps in coverage or by enabling multi-source collection on a target. This allows fused intelligence to be generated, providing a better product to customers.

4.11. Satellite launch operations can also be enabled by air assets, such as the horizontal launch capabilities planned by the UK through LaunchUK, the UK Space Agency's spaceflight programme. For some small satellites aimed into low Earth orbits, launching from an aircraft provides advantages over fixed sites. Horizontal launch facilities can be integrated with existing airport infrastructure, as long as range clearance procedures for launch are articulated and specialist infrastructure for fire and fuel is provided. This may be preferable to the construction of a dedicated vertical launch site. In addition, launching from an aircraft can allow greater flexibility with the launch trajectory of the satellite, an advantage for the UK considering its latitude. Terrestrial weather issues at a launch site can also be mitigated, providing conditions are suitable for the aircraft to take-off.

Integration with the cyber and electromagnetic domain

4.12. Space operations rely on the interaction of the ground, space and link segments, the latter residing almost completely within the cyber and electromagnetic domain. Command and control systems, data and information flows are all conducted through cyberspace via the electromagnetic environment (EME).

4.13. Access to the EME is fundamental to data exchange. The selection of frequency used for data transmission affects beamwidth and transmission range, thereby governing the accuracy and security of transmission of data to and from space vehicles. Frequency selection is further impacted by physical factors such as atmospheric interference (absorption and refraction), as well as the power to transmit data between space vehicles and the relevant segments. Careful consideration of the EME is therefore vital to successful space operations.

4.14. Space systems also rely on software and other elements of cyber hardware to generate and transmit the key PNT data and SATCOM systems relied on in the other operational domains. Secure communication systems enabled by encryption software also rely on these accurate timing sources.

4.15. Space capabilities can also be used to assist other EMS operations, particularly though space ISR assets collecting signals intelligence. The access permitted to space ISR satellites allows overhead sensors to be positioned to detect even small changes in the frequencies produced by adversary ground activity.

4.16. As well as being a vital enabler, cyber and the EMS also provide vectors to target all three space power segments, both as part of an offensive space control strategy and, critically, as a threat to be guarded against. Control and data frequencies are vulnerable to being denied or degraded through interference or manipulation. For example, the low power signals transmitted from satellites can easily be jammed by local electromagnetic transmitters or manipulated through spoofing and rebroadcast systems. In addition, both the ground and space segments rely completely on cyber hardware and software to run, making them especially vulnerable to cyberattack. Integration between the space and cyber and electromagnetic domains is therefore vital to understand and mitigate threats, as well as to seek opportunities to influence an adversary.

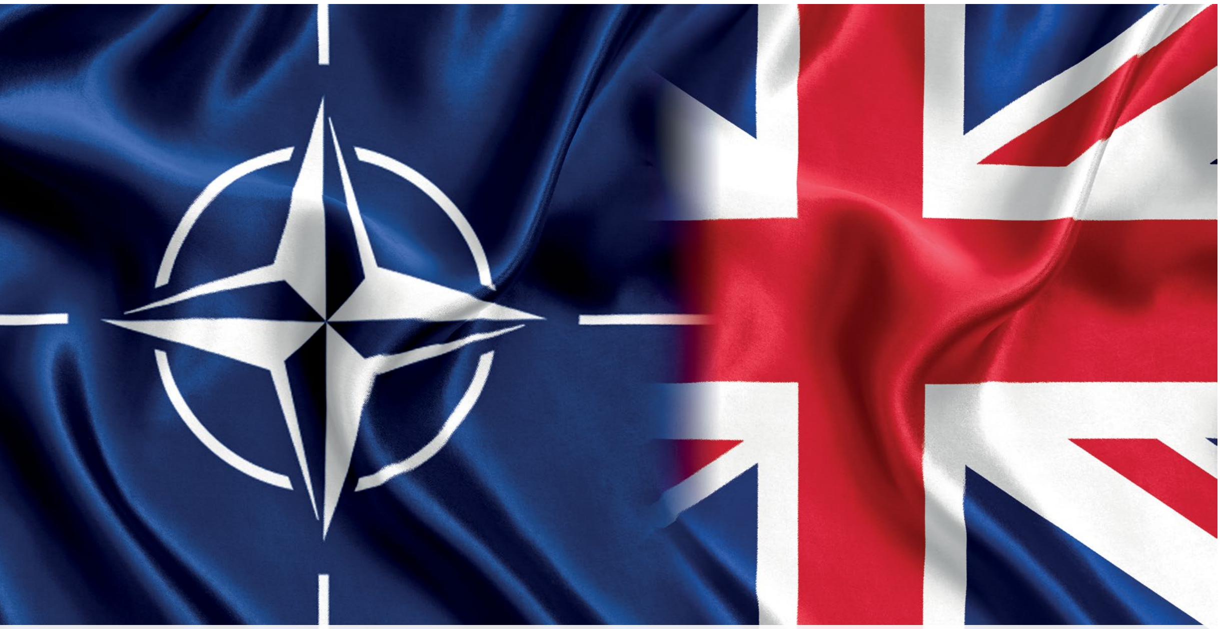
Integration and the space domain

4.17. While it has been articulated how space can enable the other operational domains, it is also important to state that the other domains can enable or facilitate operations in space. This may be as simple as remote space-ground infrastructure being supplied and maintained through air or maritime supply routes, but this can be expanded to include offensive action where necessary. To enable theatre entry of a maritime force, for example, air power could be tasked to locate, identify and prosecute adversary space control capabilities or ground infrastructure processing space-based ISR data. This may also extend to the other operational domains should land or maritime strike be in range of the identified targets.[87]

Section 3 – Space and deterrence

4.18. Given space-enabled capabilities are essential for everyday life, not just for military operations, space has become an increasingly important operational domain, contested by state and non-state actors alike. Reliance on space can be thought of as a critical vulnerability and therefore control of space is sought by actors in the same way that they previously sought control of sea, land and air. Combined with this, threats to space assets, both direct and indirect are increasing, making it increasingly necessary to deter potential adversaries from taking action against them.

87 Specific guidance with regards to space control and the targeting process can be found in Joint Service Publication 900, *UK Full Spectrum Targeting Policy*, Edition 5, Part 2, Annex G.



The cornerstone of the UK's deterrence posture remains enshrined in NATO through Article 5 of the North Atlantic Treaty

4.19. NATO defines deterrence as: the convincing of a potential aggressor that the consequences of coercion or armed conflict would outweigh the potential gains. This requires the maintenance of a credible military capability and strategy with the clear political will to act.[88] There is no universal approach to deterrence: a viable deterrence strategy should be tailored to a particular actor or adversary. Accordingly, deterrence in, through or using space capabilities is not an independent activity but must form part of the wider strategy. It is a whole-of-government activity to which Defence contributes. The cornerstone of the UK's deterrence posture remains enshrined in NATO through Article 5 of the North Atlantic Treaty. NATO resilience is predicated on three pillars of activity:

- layered resilience allowing aggression to be withstood;
- a mutually supporting integrated force to provide options to political leaders; and
- the ability to project stability through activities such as military dialogue, capacity building and operations.

88 NATOTerm.

4.20. The overall objective of deterrence applies to the space domain in the same way that it applies in the other operational domains. Space capabilities also enable other activities that contribute to deterrence. They provide data, in the form of products and services, that is crucial to maintaining activity within all the other operational domains. Space offers political choice through its ubiquity and pervasiveness but is not solely a military, or even state, endeavour, with non-state actors increasingly having a stake in the development and operation of capabilities. Partnerships with civil, industrial, commercial and academic entities are therefore essential to increase resilience, understand the progress of technology in this area and develop further opportunities for deterrence.

Key points

- While space is an operational domain in its own right, it is most effective when integrated with other components of military power.
- The previous term 'joint action' is too narrow and too focused on the role of the military instrument rather than considering the wider audience.
- Space power supports the new UK integrated approach and the doctrinal tenets of integrated action, the manoeuvrist approach and mission command.
- Integrated action involves the orchestrated use of a full range of capabilities to change or maintain the attitude and behaviour of audiences.
- The manoeuvrist approach operates indirectly, pitting strength against identified vulnerabilities to undermine an adversary's will and cohesion.
- Mission command allows a commander to articulate their intent but permits subordinates the initiative to achieve it within set boundaries.
- Demonstrating proven space power capabilities, or enabling capabilities in other operational domains, can contribute to overall deterrence.
- Deterrence must form part of a wider, whole-of-government, strategy.
- In the space domain, partnerships with civil, industrial, commercial and academic entities are essential to increase resilience, exploit emerging technology and develop further opportunities for deterrence.

Lexicon

Section 1 – Acronyms and abbreviations

AJP	Allied joint publication
AP	Air publication
BEIS	Department for Business, Energy and Industrial Strategy
BRd	book of reference (digital)
DA-ASAT	direct ascent anti-satellite
DCDC	Development, Concepts and Doctrine Centre
DOD	Department of Defense (US)
DSC	defensive space control
EME	electromagnetic environment
EMP	electromagnetic pulse
EMS	electromagnetic spectrum
ESA	European Space Agency
GEO	geosynchronous Earth orbit
GNSS	global navigation satellite system
GPS	Global Positioning System
HM	His Majesty's
IAMD	integrated air and missile defence
ISR	intelligence, surveillance and reconnaissance
ITU	International Telecommunication Union
JDP	joint doctrine publication
JFC	joint force commander
JFSCC	joint force space component commander
LEO	low Earth orbit

MOD	Ministry of Defence
MP	Member of Parliament
NATO	North Atlantic Treaty Organization
NAVWAR	navigation warfare
OSC	offensive space control
PFI	private finance initiative
PJHQ	Permanent Joint Headquarters
PNT	positioning, navigation and timing
RAF	Royal Air Force
SATCOM	satellite communications
SDA	space domain awareness
SJFHQ	Standing Joint Force Headquarters
SSA	space situational awareness
SST	space surveillance and tracking
UK	United Kingdom
UK SpOC	UK Space Operations Centre
UKStratCom	Strategic Command
UN	United Nations
US	United States
USS	United States Ship

Section 2 – Terms and definitions

This section is divided into three parts. First, we list new definitions that will be added to JDP 0-01.1, *UK Terminology Supplement to NATOTerm*, followed by already endorsed terms and definitions. Finally, we list unendorsed terms and definitions that may be useful to the reader as reference for this publication only.

New definitions

space control
The use of defensive and offensive capabilities to assure access and freedom of action in space. (JDP 0-40)

space domain awareness
The provision of security-focused, decision-quality information that can be used to successfully mitigate adversary space effects while supporting the integration of allied space effects into multi-domain operations.
Note: space domain awareness is derived from the fusion and aggregation of broader intelligence and knowledge of the terrestrial domains with space situational awareness and space surveillance and tracking data. (JDP 0-40)

space situational awareness
The provision of sufficient understanding of the risks and hazards associated with domain congestion and complexity to enable safe and effective space operations.
Note: space situational awareness supports both civil and military purposes. (JDP 0-40)

space surveillance and tracking
The detection, tracking and identification of objects in or entering the space domain, using data from sensor observations and satellite operators, sufficient to deliver effective space situational awareness, space domain awareness and missile warning.
Note: space surveillance and tracking is delivered for both civil and military purposes. (JDP 0-40)

Endorsed definitions

actor
An individual, group or entity whose actions are affecting the attainment of the end state. (NATOTerm)

adversary
An individual, group or entity whose intentions or interests are opposed to those of friendly parties and against which legal coercive political, military or civilian actions may be envisaged and conducted. (NATOTerm)

audience
An individual, group or entity whose interpretation of events and subsequent behaviour may affect the attainment of the end state.
Note: The audience may consist of public, stakeholders and actors. (NATOTerm)

command
The authority vested in a member of the armed forces for the direction, coordination, and control of military forces. (NATOTerm)

control
The authority exercised by a commander over part of the activities of subordinate organizations, or other organizations not normally under their command, encompassing the responsibility for implementing orders or directives. (NATOTerm)

deterrence
The convincing of a potential aggressor that the consequences of coercion or armed conflict would outweigh the potential gains. This requires the maintenance of a credible military capability and strategy with the clear political will to act. (NATOTerm)

information environment
An environment comprised of the information itself, the individuals, organizations and systems that receive, process and convey the information, and the cognitive, virtual and physical space in which this occurs. (NATOTerm)

integrated air and missile defence
All measures to contribute to deter any air and missile threat or to nullify or reduce the effectiveness of hostile air action in order to protect populations, territory and forces against the full spectrum of air and missile threats. (NATOTerm)

intelligence
The product resulting from the directed collection and processing of information regarding the environment and the capabilities and intentions of actors, in order to identify threats and offer opportunities for exploitation by decision-makers. (NATOTerm)

interoperability
The ability to act together coherently, effectively and efficiently to achieve Allied tactical, operational and strategic objectives. (NATOTerm)

joint
Adjective used to describe activities, operations and organizations in which elements of at least two services participate. (NATOTerm)

joint force
A force composed of significant elements of two or more Services operating under a single commander authorised to exercise operational command or control. (JDP 0-01.1)

multinational
Adjective used to describe activities, operations and organisations, in which forces or agencies of more than one nation participate. (NATOTerm)

reconnaissance
A mission undertaken to obtain, by visual observation or other detection methods, information about the activities and resources of an adversary or to obtain data concerning the meteorological, hydrographical or geographic characteristics of a particular area. (NATOTerm)

space power
Exerting influence in, from, or through space. (JDP 0-01.1)

surveillance
The systematic observation across all domains, places, persons or objects by visual, electronic, photographic or other means. (NATOTerm)

Unendorsed definitions for use in this publication only

defensive space control
Proactive measures conducted to protect space capabilities from attack, interference or unintentional hazards, using both active and passive measures.

geosynchronous Earth orbit
An orbit synchronized to the Earth's rotation, orbiting at the same rate at which the Earth rotates upon its axis. Satellites in this orbit have an altitude of approximately 23,000 miles above the Earth's surface. Within this, a geostationary orbit is an orbit placed directly over the equator at zero inclination, so a satellite appears at a fixed point in the sky to observers on the ground and allows for constant line-of-sight observations within a very large footprint.

global navigation satellite system
A constellation of satellites providing signals from space that transmit positioning and timing to receivers that then use this information to determine location.

Global Positioning System
A satellite-based global navigation satellite system operated by the United States Department of Defense which provides military, civil and commercial users with precise positioning, navigation and timing.

Kármán Line
A height approximately 100 kilometres above mean sea level above which the atmosphere becomes too thin for an aircraft to generate conventional lift without needing to exceed the speed required to achieve orbit.

low Earth orbit
Orbits that are at a height of approximately 1,000 miles or less above the surface of the earth. The average time to orbit the Earth is approximately 90–100 minutes resulting in a satellite in low Earth orbit being in view of a ground user or station for the short period when overhead.

medium Earth orbit
An orbit with no formal altitude (roughly 1,000–2,000 miles above Earth's surface) but is considered to include those orbits between low Earth orbit and geosynchronous orbit.

navigation warfare
Deliberate defensive and offensive action to assure and prevent positioning, navigation, and timing information through coordinated employment of space, cyberspace, and electromagnetic warfare operations.
(US Joint Publication 3-14)

offensive space control
Operations that seek to disrupt, degrade, deny or destroy the space related capabilities and forces of an adversary.
Note: such operations can be targeted against any of the segments of space activities using kinetic, non-kinetic or electromagnetic warfare techniques.

orbit
Any path through space an object follows based on the pull of gravity.

positioning, navigation and timing
The ability to determine location, time and relative direction accurately and precisely.

space service support
Operations that launch space assets and maintain and sustain them.

space support to operations
Space operations which enable and enhance UK military capabilities, providing critical support to the combat effectiveness of the joint force.
Note: it is divided into five core functions: intelligence, surveillance and reconnaissance; positioning, navigation and timing; satellite communications; missile warning and tracking; and environmental monitoring.

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