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What does Protect and Defend mean for a UK National Approach to Space?

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Biography: Group Captain Rayna Owens is in her twelfth year in space-related positions across the Defence Space Enterprise, including as Station Commander at RAF Fylingdales, Space Policy and Strategy within the Air Staff, and helping establish the capability elements of UK Space Command. She has worked extensively across defence, government and with international and industry partners supporting the development of collaborative initiatives and activities such as the Combined Space Operations Initiative, and leading UK participation in US space wargames. She has developed a particular interest in New Space, space future development, space domain awareness and counterspace and has been studying these topics over the last few months mentored by King's College London.

Disclaimer: The views expressed are those of the authors concerned, not necessarily the MOD.

Abstract

The space domain is regarded by many as a global common and often described as the ultimate high ground; however it lacks concepts of sovereignty, national borders or an agreed set of norms of behaviour. The domain has undergone significant evolution within the last seven years, through increasing nations' involvement, and the development and testing of counterspace capabilities, coupled with an exponential proliferation of commercial activities. In parallel, many nations have grasped the nature of their reliance on the space domain for defence, security, and Critical National Infrastructure (CNI), as well as for everyday life. Increasingly collaborative initiatives between nations have helped to build a common understanding of developing threats, operational practices and the necessity to collaborate, as well as refining respective national perspectives.

The UK has been pursuing a unique joint civil-military approach towards development of Space Domain Awareness (SDA) and has been enhancing its UK Space Operations Centre (SpOC) since 2016. Such activity has informed the National and Defence Space Strategy direction to develop a UK National Space Operations Centre (NSpOC). This collaborative way ahead will add a different complexion to UK space developments than if activities were developed separately.

Protection and Defence of UK interests is a phrase that flows from the Integrated Review (IR) and its associated Command Paper, through the National and Defence Space Strategies, to the UK Space Command Mission. The phrase is also reflected in a range of strategies, policies and missions for new space organisations in allied nations. Ensuring the Protection and Defence of UK interests requires the development of a collaborative approach, including working across Defence, Government and internationally with key allies and industry partners. This article examines the major factors which should be considered when developing such an approach, based on the new strategic framing, a Governmental ambition for capability by 2030,[1] civil-military work to develop a NSpOC and to fit with the three elements of national interest outlined in the IR: sovereignty, security and prosperity.

Context

The space domain and its related activities have been characterised by significant change over recent years. Since 2016, an increasing number of nations have realised the strategic benefits to be gained from space, and this has led to the formation of 11 new Space Agencies[2] and space programmes, with many existing space nations increasing their activities. Understanding the prominence of space as part of nations' CNI has also increased as technological use has developed significantly. In the UK this was brought into focus when the Blackett Report: *Satellite-derived Time and Position: A Study of Critical Dependencies* was published in January 2018. This Report stated that the economic impact to the UK of a loss of Global Navigation Space System (GNSS)[3] was estimated at £5.2bn over a five-day period.[4] Similarly, in 2018, the US believed that 14 of 16 CNI sectors were reliant on the Global Positioning System (GPS).[5]

The development of collaborative military initiatives amongst allied nations includes the 2014 Combined Space Operations (CSpO) Initiative, which comprises seven nations.[6] This has enabled regular dialogue between nations' military, operational, capability and policy staffs which has helped seed understanding across governments of the importance of space and its developing threats and hazards. The CSpO nations have developed strong relationships and a level of shared understanding and this activity has deepened collaboration and led to some nations' participation in the US-led space coalition under Operation *Olympic Defender*.[7] There have also been increasingly complimentary public statements from CSpO nations on key activity such as the Russian ASAT test in November 2021, due to shared understanding and interpretation of good and bad behaviour. The CSpO Vision for 2031 was released by participating nations in February 2022 and outlines shared views on the importance of space, guiding principles, objectives, and lines of effort currently in progress.[8] This is further evidence of deepening understanding and increasingly collaborative activities between key space nations.

The domain has also been subject to significant commercial proliferation in the last five years which has seen commerce move into an increasing range of space mission areas. This is likely due to a range of factors, including the increasing options for and reduction in cost of access to space from existing commercial launch providers[9] and the proliferation of new providers, with 15 new launch vehicles due to debut in 2022.[10] The rise of the mega-constellation has brought mass production to satellite manufacturing, where previously each unit would likely have been a bespoke build. Space X (Starlink constellation),[11] Airbus (OneWeb constellation)[12] and Thales (new Telesat constellation)[13] are all quoting impressive build rates which will inevitably drive down unit costs. The so-called 'space billionaires', including Elon Musk, Jeff Bezos and Sir Richard Branson, fuel their space developments with bold strategic vision[14] and this, coupled to an accessible social-media-friendly approach has engendered a level of public interest in space, which has arguably not been seen since the Apollo era. Space is seen as a fascinating and lucrative area to work and invest in, and there has been a surge of interest from Silicon Valley and a significant increase in venture capital investments due in part to Space X and other commercial successes.[15] Estimates value the global space industry at US$350 billion, with an increase to more than US$1 trillion predicted by 2040[16] and the Space Tech 2021 Report states that there are around 10,000 private sector companies and 5,000 leading investors in space technology.[17]

UK Space Developments

UK space developments have increased at pace, with significant Government analysis of the key issues, and the creation of a set of coherent cross-government structures including formation of a National Space Council[18] as a sub-committee of the National Security Council. Space Directorates have also been created within the Ministry of Defence and the Department of Business Energy, Innovation and Skills. Such analysis has resulted in a comprehensive set of evidence as part of the IR, enabling significant additional funding for the Defence Space Programme over the next ten years.[19] Both National and Defence Space Strategies have

subsequently been published, including a coherent approach to delivering three identified strategic themes and a costed plan for the extra funding required for their delivery.

The UK Space Sector continues to be buoyant with the population of space organisations in the UK growing on average nearly 21% per annum since 2012, with 1,293 organisations recorded in the latest version of the UK Space Agency Size and Health of the Space Sector Report. The Report indicated that every region in the UK hosted space organisations, with the South and East and Greater London having the largest concentration. Employment in the sector has enjoyed considerable growth of 6.7% from 2018/19 to 2019/20 with employment tripling since 2000/2001 and an annual growth rate of 6%.[20]

The FCDO work in the UN on Reducing Space Threats through Norms, Rules and Principles of Responsible Behaviours is progressing. The proposed resolution has been adopted and an Open-Ended Working Group (OEWG) has formed, with the first meeting taking place in Vienna in May 2022. This process is likely to take time, as the second OEWG is not scheduled to take place until 2023. However, this is a significant step forward in international space collaboration and is a demonstration of the stated intent for UK continued global leadership on norm-setting.[21]

Protect and Defend

The requirement to protect and defend UK interests is reflected consistently across the IR and within both Space Strategies. The IR articulated the 'Government's 2030 ambition for the UK to have the ability to monitor, protect and defend our interests in and through space, using a mixture of sovereign capabilities and burden-sharing partnerships with our allies'.[22] The National Space Strategy includes Protect and Defend as one of five goals, whilst the Defence Space Strategy includes it as one of three Strategic Themes. Both strategies also reflect direction for work between civil and military elements on the formation of a NSpOC. This level of collaboration between civilian and military elements of government is unique and provides significant opportunity for future development. A single NSpOC covering all UK interests will have a broader mission set than other military SpOCs and will require the development of different relationships and approaches. Collaborative work has been underway since 2016, with the UK Space Agency (UKSA) and the RAF working together on SpOC enhancement. A Commercial Integration Cell[23] [24] was also formed within the SpOC which is enabling the development of relationships and the passage of information with relevant industry partners.

The Defence Space Strategy sets out a three-pronged approach to delivery of the Protect and Defend Theme: 'development of capabilities to deliver effective operational outcomes; identification and attribution of threats to space systems; and responses to hostile activities in a proportionate and coordinated manner'.[25] It identifies key elements as credible deterrence and response options, an intelligence-focused strategy, domain awareness, effective Space Control Capability and resilient on-orbit and terrestrial and cyber infrastructure as well as international

collaboration and commercial partnerships. Plans seek to continue development of existing Space Domain Awareness capabilities, as well as new national additions, and identifies the requirement for collaboration with allies and commercial partners. The requirements to detect, track, characterise and attribute objects in space and build agility into space command and control mechanisms and decision making are identified, as is the requirement to work in partnership with the UKSA, to help establish a NSpOC that will be fully integrated with allies and partners, as well as across Government.

National Interest

While National Interest is a key tenet of international relations, there is no single agreed definition of the term as it is seen as context dependent. However, the IR outlines 'three fundamental national interests; sovereignty, security, and prosperity, alongside shared values fundamental to national identity, democracy, and way of life. These values include a commitment to universal human rights, the rule of law, free speech and fairness and equality'.[26]

Towards a Protect and Defend Approach

Given the establishment of a NSpOC and its associated span of National Interest, the UK approach to Protect and Defend will be broader than military capabilities and support to military operations. Therefore, Protect and Defend is better considered as an approach which will likely include a number of factors including: understanding reliance; building resilience; developing domain awareness; understanding the span of required missions; and the need to develop a comprehensive and joined up approach to assessing and dealing with threats and hazards.

Understanding Reliance

Understanding reliance on space is key to being able to Protect and Defend interests, however given the pervasiveness of space services, developing such knowledge is problematic. The Blackett Report reflects this challenge, stating that 'GNSS is so prevalent today that it has 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'.[27] While GNSS and the timing and location services that these systems provide are of vital importance, they are not the only important areas: missile warning, satellite communications, and a range of earth observation functions are also key to many aspects of defence and security. As the approach to Protect and Defend develops there will likely be a requirement to study vulnerability.

Building Resilience

Given the critical importance of services from space to CNI, Defence and many other aspects of modern life, the hostile physical environment and the increasingly congested and contested domain, there is a requirement to ensure resilience of space systems or key services. The US highlighted a framework for considering mission assurance through resilience in 2011[28] which

considers disaggregation, protection, distribution, proliferation, diversification, and deception as resilience approaches. The level of resilience should be considered at the start of the design process for future space systems or architectures. In 2017 the Aerospace Corporation,[29] laid out a Resilience Taxonomy to consider the trades that could be made to meet mission requirements against a range of factors. This, or a similar type of approach, may be helpful as Space Command matures.[30] Resilience can also be built by considering the development of alternate capabilities that do not rely on space where this is possible. Alternatives also include reversionary modes of accessing information which would normally be delivered by space services, physical or cyber protection measures, space system design, operational usage and procedures, volume of satellites, collaboration and interoperability across systems or nations.

Building Sufficient SDA capabilities

Understanding activity within the domain is fundamental, including what is normal and what is not. This approach is common to the other operational domains, however there are inherent challenges in achieving this within space.

Global space surveillance capabilities, have not matched pace with the growth of satellite numbers, and this situation is compounded by the lack of an agreed lexicon to describe domain surveillance,[31] agreed data standards, formats, interfaces, and modelling tools. Government and national space surveillance systems generally use orbital prediction, updated by sensor tasking, rather than comprehensive continuous surveillance of all orbital regimes. This approach is due, in part, to the vast areas which require surveillance, the legacy of predictable satellite behaviour and sensor and system technology. There is no international mechanism for sharing satellite movements in the way that 'flight plans' denote aircraft movements and there are no internationally agreed norms of behaviour. This means that surveillance, tracking, oversight and understanding of 'normal behaviour' on orbit is not as well developed as in other domains. Therefore, identification of unusual, dangerous, or even nefarious activity is not easy, whilst protocols to discuss activity of concern are not formalised and determination of intent is difficult.

The UK is part of the US Space Surveillance Network, contributing data from RAF Fylingdales, and is in discussion with the US about hosting a US Deep Space Radar.[32] The current UK BMD radar programme could potentially provide additional space surveillance capabilities.[33] Developing discussions as part of CSpO could also foster collaborative approaches between nations on additional space surveillance capabilities. It is anticipated that the own, collaborate, access approach will be fundamental for future capability developments on SDA and in relation to the NSpOC.

Understanding the Span of Mission Sets

The Defence Space Strategy identifies the requirement to detect, track, characterise and attribute objects in space and build agility into space command and control mechanisms

and decision making.[34] However, work to develop the NSpOC is also likely to consider expansion of missions to include exchanging information with relevant industry partners, and oversight of licencing and launch operations. The UK Space Agency is currently running a pilot service, providing Space Surveillance and Tracking information to UK-licenced satellite operators.[35]

Threats and Hazards

The space domain is subject to a range of threats and hazards which for the purposes of this paper are deemed intentionally nefarious activities to impact on or interfere with a satellite or space system; and environmental factors and unintended impacts such as space weather, debris, incompetent operation, or unintentional interference respectively. When considering threats to space capability, all three elements of a space system should be considered, including the ground segment, and the spectrum links used to control a satellite and transfer data or services, in addition to the satellite itself. While consideration of hazards is focused on the space segment, this does not mean that the ground segment will not be subject to hazards.

Threats

Counterspace capabilities can provide kinetic physical, non-kinetic physical, cyber, or electromagnetic effects against space systems which can be temporary or permanent in nature.[36] Year-on-year increases in the number of nations developing counter space capabilities and the increase in pace of the capability developments in some nations, including Russia and China, is causing increasing concern. Regular open-source reporting has developed to cover this area, with the Centre for Strategic and International Studies (CSIS) 'Space Threat Assessment'[37] and the Secure World Foundation 'Global Counterspace Capabilities'[38] reports in their fifth year, while the Defense Intelligence Agency (DIA) 'Challenges to Security in Space' Report is in its fourth year.[39] These documents cover types of counterspace capabilities, track national developments and highlight specific national behaviour.

This year's CSIS Report highlights four key events from 2021: the July 2021 Chinese hypersonic glide vehicle test; the launch and behaviour of a new Chinese geo stationary orbit (GEO) satellite, SJ-21; the November 2021 Russian direct-ascent ASAT test in Low Earth Orbit (LEO); and Russia's GPS jamming in Ukraine.[40] The DIA Report covers the expansion of Chinese and Russian space and counterspace weapons development, combined with the general rise of other foreign space capabilities. These factors are driving many nations to formalize their space policies, to better position themselves to secure the space domain and facilitate their own space services.

Appropriate and proportionate responses to threats to space systems can be delivered from any of the operational domains or may be provided as a multi-national response as such threats are likely to affect more than one nation. Policy considerations are likely to inform any development of space control capabilities.

Hazards

Space Weather

Space weather is the term used to describe a range of phenomena originating from the Sun, including magnetic fields, radiation, particles, and matter, that can impact on the technology used on Earth and on satellites in orbit. Space weather occurs continuously, much like terrestrial weather, and generally has no tangible disruptive effects. However, in its more severe form, space weather can cause significant disruption to GNSS and radio communications, as well as satellites, and the result of this disruption could impact CNI. As a result, space weather has been included in the National Risk Register since 2011 with the Department for Business Energy and Industrial Strategy being the Lead Government Department for managing this risk. The Met Office Space Weather Operations Centre is one of a small number of global forecasting centres who produce space weather services. There is already a linkage to the UK SpOC which generates military space weather predictions. A UK Severe Space Weather Preparedness Strategy was published last year.[41] As the NSpOC matures, the relationship between the Operations Centres and the forecasting and warning activity may well change.

Space Debris

The increasing numbers of satellites being launched is particularly significant. In 2021, it was 1,702, more than the total number of operational satellites in orbit just six years before. Over the intervening period the increase has been significant, including a 20% rise from 2016-2019, and a 30% rise from 2020-2021. Potential future numbers are staggering, with current plans lodged with the Federal Communications Commission (FCC), the body responsible for licencing spectrum in the US, for more than 94,000 satellites on orbit.[42] The debris population has been growing as a result of launches since Sputnik in 1957, as each launch adds to the debris with upper stages, rocket bodies and other items remaining on orbit in addition to the satellite. Added to this there are a number of large legacy rocket bodies from earlier launches which cause specific concerns. Today, nearly half of all catalogued debris are fragments from three major events: China's ASAT test in 2007, an accidental collision between a US communications satellite and a defunct Russian satellite in 2009, and the Russian ASAT test in 2021.[43]

There is no agreed model for calculating the size of the debris problem, however the problem is enormous and growing. One reliable source indicates that as of January 2022, more than 25,000 objects of at least ten centimeters in size were tracked and catalogued in Earth's orbit including active satellites.[44] [45] In addition to this there is a significant amount of currently non-trackable debris, which are objects less than ten centimeters in size. Estimates on this population size range from 600,000 to 900,000 pieces in Low Earth Orbit (LEO).[46] The average impact speed of orbital debris with another space object will be approximately six miles per second (10 km/s)[47] which creates significant potential energy when collisions occur. There are concerns that the increasing debris population could cause a scenario called the Kessler syndrome or Kessler effect, named after the NASA scientist who first proposed the concept in 1978. This is a situation where the density of objects in the LEO grows to an extent that collisions between two objects could cause a cascading effect, generating more space debris,

which, in turn, increases the likelihood of further collisions.[48] Space is not universally and uniformly congested, therefore the collision risk is also non-uniform, with the most significant debris populations in LEO.

Liability and Licencing Responsibility

Liability for space activities is complicated and is covered by two of the 'five United Nations treaties on outer space' [49] which form the bedrock of current space law. The Outer Space Treaty (OST) sets the framework for liability and provides that 'States are responsible for authorising and supervising private activities and bear international liability for any damage or loss arising from them'.[50] The Liability Convention places liability for harm on Earth caused by an object in space or formerly in space, on the launching state.[51] This convention has yet to be fully tested in a court of law as the only invocation of the treaty led to an out-of-court settlement.[52] The UK is a signatory to four of the treaties: the OST, Rescue Agreement, Liability and Registration Conventions, National responsibility is instantiated in UK law through the 1986 Outer Space Act (OSA) and the 2018 Space Industry Act (SIA). The Civil Aviation Authority (CAA) took on the Space Regulator role last year from the UKSA.[53] The UK has developed a progressive and forward leaning regulatory regime, through legislation and associated instruments, to encourage the growth of commercial space activities. Current UK licencing under the OSA or SIA requires applicants to hold insurance for their activities, and indemnify Government, however all operator licences contain a limit of operator liability.[54] As a signatory to the Registration Convention the UK maintains a list of Space Objects.[55]

The number of UK Objects has been increasing year-on-year with a significant increase since February 2019 when OneWeb launched its first satellites, and with 413 satellites on orbit OneWeb now owns represents 83% of UK Objects. Understanding space domain activity and the potential link to UK liability could become important elements of UK interest as UK Objects and debris populations increase and UK launch operations start later this year.

Incompetence

The significant legacy costs associated with satellite build and launch meant that the number of satellite operators was low, and they were highly skilled. However, as the costs of satellite manufacture and launch reduce, the number of launch operators and licencing nations increase, the potential for 'flag of convenience' [56] or jurisdiction shopping for licencing is also likely to increase. This could lead to poor assessment of mission risk and unskilled satellite operations, which could lead to safety issues and even collisions.

Developing a Coherent Approach to Assessing Threats and Hazards

A collision in space, whether caused by nefarious or dangerous activity or by resident debris will likely have significant and enduring impacts which are felt more broadly than by those involved in the incident. Similarly, impact on satellite systems from space weather or liability from UK object activity could all impact on UK interests, UK CNI and other aspects of our defence and security.

Current UK threat assessment processes are well understood and mature. However, the range of threats and hazards in the space domain and the spectrum of interested parties across Government will likely drive discussion about a coherent approach to assessing risks and plans for the NSpOC. Given the broad ranging impacts of an incident in space or involving a UK Object, and close linkages to our CNI, dialogue with the National Security Secretariat focusses upon linkages to Central Government arrangements for crisis response.[57]

Summary

UK Space developments have led, over recent years, to a developing cross-Government structure, additional funding for the Defence Space Programme through the IR and publication of National and Defence Space Strategies which identify activity to meet the National space ambition. The ability to Protect and Defend UK interests is key to delivery of this ambition and central to the UK Space Command Mission. A comprehensive SDA capability is critical to enabling this, as it will enable understanding of the pattern of life within the Space Domain. A Protect and Defend approach has been outlined within the Defence Space Strategy and the Civil and Military approach to developing a NSpOC will be key in bringing all these aspects together. A number of factors will need to be considered as part of this activity, including: understanding reliance, building resilience, developing domain awareness, understanding the span of required missions and the need to develop a comprehensive and joined up approach to assessing and dealing with threats and hazards. This civil-military approach is unique and while there will be challenges to developing a coherent approach across stakeholders, the likely outcomes are expected to deliver significant benefits to the UK.

Notes

[1] By 2030, the Government's ambition is for the UK to have the ability to monitor, protect and defend our interests in and through space, using a mixture of sovereign capabilities and burden-sharing partnerships with our allies.
The Integrated Review 2021 - GOV.UK (www.gov.uk).
[2] Since 2016 11 new space agencies have formed in the following countries: Australia, Costa Rica, El Salvador, Azerbaijan, Greece, Luxemburg, New Zealand, Uzbekistan, Portugal and Turkey
[3] Global Navigation Satellite System.
[4] The economic impact on the UK of a disruption to GNSS: full report - The British Library (bl.uk) accessed 2 Feb 22.
[5] The New Satellite Arms Race Threatening to Explode in Space | WIRED accessed 17 Feb 22.
[6] Australia, Canada, UK, and US, New Zealand, France and Germany.
[7] Building the New Space Coalition - Air Force Magazine.
[8] Combined Space Operations Vision 2031 - GOV.UK (www.gov.uk).
[9] SpaceX has helped to reduce the cost of launch from well over $100 million per rocket to around $47 million through the development of reusable rocket stages. Costs to satellite operators are now as low as $1,400 per kg, having fallen from more than $10,000 per kg before 2000 – Ofcom Space strategy.
[10] Space Foundation Releases The Space Report 2022 Q1 with New Findings on U.S. Workforce,

Insurance Costs and Launch Vehicle Debuts - Space Foundation.
[11] https://www.cnbc.com/2020/08/10/spacex-starlink-satellte-production-now-120-per-month.html.
[12] Revolutionising satellite production for a more connected human race | Airbus.
[13] https://spacenews.com/thales-alenia-selected-to-build-telesats-broadband-constellation/.
[14] Rocket men: why tech's biggest billionaires want their place in space | Space | The Guardian.
[15] How is venture capital affecting the space sector? (filling-space.com).
[16] Investing in Space Exploration | Morgan Stanley.
[17] https://analytics.dkv.global/spacetech/SpaceTech-Industry-2021-Report.pdf.
[18] Leading the new space age: government backs ambitious plans for the UK in space - GOV.UK (www.gov.uk) accessed 18 May 22.
[19] Additional £1.4Bn/10 years.
[20] Size and Health of the UK Space Industry 2021 - GOV.UK (www.gov.uk).
[21] The Integrated Review 2021 - GOV.UK (www.gov.uk).
[22] ibid.
[23] UK space and RAF to establish Commercial Integration Cell for greater military and commercial space collaboration.
[24] The Chief of the Air Staff's speech at the Global Air Chiefs' Conference 2021 - GOV.UK (www.gov.uk) accessed 18 May 22.
[25] UK Defence Space Strategy 2022.
[26] The Integrated Review 2021 - GOV.UK (www.gov.uk).
[27] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/676675/satellite-derived-time-and-position-blackett-review.pdf.
[28] Microsoft Word - TAB B - Resilience Taxonomy White Paper v9.5 (16 Sep 2015) - DASD edits - No Title Page.docx (fas.org) accessed Feb 22.
[29] US Federally Funded Research and Development Centre which supports the DoD, IC and NASA on space.
[30] Microsoft Word - Resilience_WhitePaper_v12.docx (aerospace.org) accessed 15 May 22.
[31] There is a lack of universally agreed definitions however common terms include: Space Surveillance and Tracking (SST), typically a civil term, Space Situational Awareness (SSA) typically a military term and more recently Space Domain Awareness (SDA), first used in US military circles and now more broadly by CSpO nations. The latter term aiming to capture the broader set of circumstances relating to intent of actions.
[32] US wants giant radar in UK to track space objects - BBC News.
[33] BMD radars will normally have latest SDA capability due to similarity of target.
Update: UK approved to buy ballistic missile defence radar (janes.com) accessed 15 May 22.
[34] Defence Space Strategy: Operationalising the Space Domain - GOV.UK (www.gov.uk).
[35] Monitor Your Satellites - Case study - GOV.UK (www.gov.uk) accessed 15 May 22.
[36] 220404_Harrison_SpaceThreatAssessment2022.pdf (csis-website-prod.s3.amazonaws.com).
[37] ibid.
[38] Global Counterspace Capabilities Report | Secure World (swfound.org).

[39] Challenges_Security_Space_2022.pdf (**dia.mil**).
[40] 220404_Harrison_SpaceThreatAssessment2022.pdf (**csis-website-prod.s3.amazonaws.com**).
[41] UK Severe Space Weather Preparedness Strategy (**publishing.service.gov.uk**).
[42] The Meteoric Rise in Satellite Numbers - Union of Concerned Scientists (**allthingsnuclear.org**).
[43] McKnight, D., Matney, M., Walbert, K., Behrend, S. Casey, P., and Speaks, S.; 25 September 2017; 'Preliminary Analysis of Two Years of the Massive Collision Monitoring Activity'; *International Astronautical Congress*.
[44] Union of Concerned Scientists (UCS); 1 January 2022; 'Satellite Database'; **https://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database**. Accessed 19 March 2022.
[45] McKnight, D., Macdonald, J., Arora, R., Pelton, J., Jenniges, J., and Martinez, P.; S2468-8967(20)30006-9; May 2019; 'The Global Risk Continuum (GRC)'; *The Journal of Space Safety Engineering, JSSE 104*, International Association for the Advancement of Space Safety (IAASS) Space Safety Conference, Los Angeles, CA, May 2019.
[46] **https://www.ucsusa.org/nuclear-weapons/ space-weapons/satellite-database**.
[47] NASA - Frequently Asked Questions: Orbital Debris accessed 15 May 22.
[48] *Kessler, Donald J.; Cour-Palais, Burton G. (1978). 'Collision Frequency of Artificial Satellites: The Creation of a Debris Belt' pdf. Journal of Geophysical Research. 83 (A6): 2637–2646*.
[49] The 'Outer Space Treaty' Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, and the 'Liability Convention' Convention on International Liability for Damage Caused by Space Objects accessed 6 Apr 22.
[50] Licensing private outer space activities | Globe Law and Business specialises in producing practical, topical titles for international legal and business professionals.
[51] Kehrer, Trevor (2019) 'Closing the Liability Loophole: The Liability Convention and the Future of Conflict in Space,' Chicago Journal of International Law: Vol. 20: No. 1, Article 5. Available at: **https://chicagounbound.uchicago.edu/cjil/vol20/iss1/5** accessed 19 Mar 22.
[52] The incident in 1978 when Cosmos 954, a Soviet satellite, inadvertently fell to Earth in uninhabited Canadian territory.
[53] CAA takes on space regulator role (**electronicsweekly.com**) accessed 1 May 22.
[54] Spaceflight legislation and guidance - GOV.UK (**www.gov.uk**) accessed 1 May 22.
[55] UK registers of space objects | Civil Aviation Authority (**caa.co.uk**) accessed 1 May 22.
[56] **Flag of Convenience (FOC)** is a business practice whereby a ship's owners register a merchant ship in a ship register of a country other than that of the ship's owners, and the ship flies the civil ensign of that country, called the flag state.[2] The term is often used pejoratively, and although common, the practice is sometimes regarded as contentious. Each merchant ship is required by international law to be registered in a registry created by a country,[3] and a ship is subject to the laws of that country, which are used also if the ship is involved in a case under admiralty law. A ship's owners may elect to register a ship in a foreign country which enables it to avoid the regulations of the owners' country which may, for example, have stricter safety standards. They may also select a jurisdiction to reduce operating costs, avoiding

higher taxes in the owners' country and bypassing laws that protect the wages and working conditions of mariners.[4] The term 'flag of convenience' has been used since the 1950s.

[57] The Central Government's concept of operations - GOV.UK (**www.gov.uk**) accessed 6 Apr 22.