REGULATORY HORIZONS COUNCIL

The Future Regulation of Space Technologies

Plugging the gaps in space

April 2024

“Space is the province of all mankind”
Outer Space Treaty 1967

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Foreword

Tim Peake CMG

Since humans first looked to the heavens, we have found ways of using information gleaned from space. The Sun and the stars have guided us across oceans and continents for millennia, whilst our measure of time is dictated by the orbits of the Moon and the Earth. But when the first human object was launched into Earth's orbit in 1957 – Sputnik – it forever changed our relationship with space. Space now plays a critical role in our daily lives.[1]

Today, over 8000 satellites orbit the planet, providing a plethora of information, from climate and meteorological data to position, navigation and timing (PNT), global communications, scientific research, Earth observation and more. Our assets in space and the information they provide form part of our critical national infrastructure. It has been estimated that a loss of PNT alone would cost the UK economy over £1 billion daily.[2]

As access to space becomes cheaper, safer, and more expeditious, it offers a wealth of opportunity. Space could help solve our climate change and clean energy challenges, increase food production, reduce pollution, and advance our medical knowledge. However, as space becomes more congested, the risk to the space environment and the potential for future conflict increases.

This raises one of the most important questions of our era: how can we protect and sustain the space environment whilst growing the space economy in a way which benefits planet Earth, future generations of humans, and generates economic benefit for the UK?

Regulation is key – and this report is an important contribution to the Government's wider thinking on when, what, and how we will need to regulate domestically, as well as influencing the development of global regulatory systems. There are now over 40 national and regional space agencies and hundreds of private companies developing space technologies, representing an exponential growth since the main international space treaties were created in the 1960s and 1970s. Current regulatory frameworks – international and domestic – will not cope with the breadth and complexity of future space technologies, actors, interests, capabilities, and approaches.

[1] UK Government, National Space Strategy, 2021

[2] London Economics, 'The economic impact on the UK of a disruption to GNSS', Issue 4, August 2023

This report is unique in taking a long-term futures approach to exploring the trends and drivers for space technologies, how technologies may combine into aggregate capabilities, and how we may face very different future scenarios which will affect our strategic choices. It discusses some of the most controversial aspects of future space exploration and highlights the potential for severe – even catastrophic – mismanagement, as well as showcasing some of the potential benefits for humanity.

Commercialisation is both a key driver for space investment and a threat to the space environment. Ever-increasing amounts of space debris could deny access to space or render some Earth orbits unusable. Competition for high value 'real estate' in space and the prospect of mining resources on celestial bodies raises not just ethical questions, but the potential for discord and conflict.

None of these challenges can be addressed unilaterally by the UK, and nearly all the important decisions on how we will use space need to be made collectively by nations representing all of humankind. However, given that geopolitics lags far behind technological feasibility, this leaves a dangerous gap, which private companies, and states with ambitions to profit from space and its assets, are already rushing to fill.

We can hope for a safe, prosperous, and secure future based on international collaboration in space and shared values. Even better would be to plan for it and position the UK as a global honest broker, leveraging our strengths in technology, financial services, law, data science, and assurance. The UK can set out and work collectively towards a future where space is protected, sustained for future generations, and the space economy grows to benefit all. We can be a trusted partner to other states and private companies, at the forefront of developing innovative models and approaches. There are real opportunities here if we move quickly and prudently with a clear vision of the way ahead.

Tim Peake CMG, European Space Agency astronaut

Executive Summary

"Space is the province of all mankind" – Outer Space Treaty 1967

Regulation is how activities and processes are controlled through a range of measures from mandatory rules (law) to guidance, self-regulation, regulatory bodies and inspectorates, together creating the conditions for effective and safe practices. Regulation can enable innovation by providing the framework to experiment safely and give investors' confidence. The Regulatory Horizons Council (RHC) – an independent council of experts created to advise the UK Government on future technologies[3] – was invited to conduct a review of key current and future technologies and how enabling regulation can support their responsible adoption in the space sector. This report was provided to the UK Government, and their response will be published in due course.

The RHC's key finding is that space regulation is mostly 'missing in action' whilst technologies are racing ahead. Given the range and scale of activities likely in space over the next 10 – 20 years, we will need to develop and mature our regulatory approaches both internationally and domestically. Current and future spacefaring nations need to develop together a proportionate and flexible regulatory approach to space alongside, and not after, the technologies which may create future capabilities in space such as debris removal, solar energy generation, mining, and manufacturing. The RHC is concerned that trends towards the increasing militarisation and commercialisation of space could increase the potential for future conflict, and lead to the degradation and misuse of the space environment. Without clear rules and guidelines setting out *who* can do *what* in space and *how*, humanity will fail to benefit from the opportunities of space. All spacefaring nations need to manage the space environment carefully to prevent over-exploitation and pollution, ensure that peace is maintained, and enable everyone to benefit equitably.

The RHC therefore asks the UK Government to continue to work towards a future for outer space that protects the environment and maintains peaceful and equitable uses of space, through developing a sensible, proportionate, and flexible regulatory regime which supports innovation. While the international community need to work together to develop regulatory approaches, the UK can play a key role through our international influence (formal and informal, including: 'science diplomacy' and co-operation), and by leveraging our legal and financial services sector as well as our strengths in key enabling areas such as data science and analytics and in cutting-edge science and technology. The RHC would like more routes for civil society to shape the future of space, ensuring that a more diverse range of voices are heard and embodying the principle that 'Space is the province of all mankind'.[4] Building on the Government's aim that "the UK will lead the pack on

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[3] Regulatory Horizons Council

[4] United Nations Office for Outer Space Affairs (UNOOSA) Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, 1967

regulatory standards, promoting competition whilst ending the wild west nature of space today”,[5] we propose a whole-of-government approach including:

1. In line with the Space Industrial Plan[6], build on existing work to address the challenges of space sustainability especially preventing overcrowding, and in-orbit servicing including removing debris, both through technology development and creating enabling regulations and guidance governing when and how these technologies can be deployed, ensuring both government and commercial actors operate responsibly;

2. Establish the UK as the global centre for space law, arbitration, insurance and financial products and services, and data science/modelling, which will help establish international norms of responsible behaviour and enable effective and safe space operations;

3. Create new mechanisms for public engagement and collective responsible investment in ethical space technologies and capabilities with shared global benefits.

Why does space regulation matter (now)?

For generations, people have looked to space and wondered about how the Universe evolved and our place in it.[7] Humans have been exploring space for decades in pursuit of scientific enquiry: since the initial landing on the moon in 1969, 676 people have journeyed into space,[8] and humans have continuously inhabited the International Space Station since 2000, conducting over 3,000 experiments.[9] Telecommunications have relied on satellites in orbit around the Earth for decades: the first geostationary satellite was Syncom 3, launched on 19 August 1964. Today, people rely on satellites to provide internet, telecommunications, mapping and navigation services, and financial transactions.

The primary international space regulations were developed over the 1960s and 1970s, with the Outer Space Treaty (OST) 1967, the Rescue Agreement 1968, the Liability Convention 1972, the Registration Convention 1975, and the Moon Agreement 1979. The OST is a mix of broad principles, providing flexibility to develop over time, with important rules such as banning nuclear weapons in space. Article 3 of the OST ensures that international law applies in space, including the UN Charter and international humanitarian law which are critical for international peace and security. This provides an important foundation which can be built upon through the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS)[10] and, in the case of satellite telecommunications

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[5] UK Government National Space Strategy In Action, 2023

[6] https://www.gov.uk/government/publications/space-industrial-plan

[7] European Space Agency (ESA) About Space Science February 2024

[8] Astronomy magazine How Many People Have Gone to Space? November 2023

[9] NASA Five Space Station Research Results Contributing to Deep Space Exploration, January 2022

[10] United Nations Office for Outer Space Affairs (UNOOSA), Space Law Treaties and Principles

through the United Nations' (UN) International Telecommunication Union (ITU).[11] While the OST and other international regulations are non-binding treaties between signatories, many have been translated into domestic law by the major spacefaring nations, including in the UK the Outer Space Act 1986, Space Industry Act 2018, and Space Industry Regulations 2021[12], and enacted through bilateral and multilateral agreements such as the Artemis Accords.[13] However, international regulation was developed in an era when nobody imagined the enormous potential for private sector interests in space. Work needs to be done now to develop the governance arrangements which will enable the variety of activities envisaged in future, including environmental protection, managing orbital overcrowding, space 'traffic management', data sharing, Earth observation, space mining, debris removal, energy generation, colonisation, deorbiting, and 'in-orbit asset' trading or managing the ramifications of bankruptcy.

The commercialisation of space is a key trend, with huge potential benefits for medicine, science and more. Over the past decade we have seen the emergence and flourishing of a thriving global space industry ('NewSpace') as costs and barriers to entry have reduced, with ventures such as private launch companies, small satellite constellations, and sub-orbital tourism[14]. Since 2019, SpaceX has launched more than 5,800 satellites into space, making the internet available to 70 countries. On 8 January 2024, a US space company launched the first commercial Moon lander, whose cargo controversially included the cremated remains of at least 70 people, including Star Trek creator Gene Roddenberry, and one dog, thanks to companies which sell people the opportunity to be interred on the Moon (a propellant leak caused the spacecraft to turn around and return to Earth).[15] While commercialisation will yield huge benefits for society, excessive and unfettered profit-driven exploitation could degrade the space environment and pitch competing State and private interests against one another, with unintended consequences such as the *de facto* occupation/ ownership of strategically important space territories and orbital areas.

The other key trend is the potential for increasing militarisation of space. Military organisations have always been part of space exploration and rely on satellites for secure communications, intelligence, surveillance, and reconnaissance (ISR) and position, navigation and timing (PNT) services for ground-based operations. Ukraine, despite not being a spacefaring nation, has made effective battlefield use of space-based communications and ISR to defend itself against the Russian invasion. Over the next decade, defence activities in space are likely to increase. The US, China, and Russia have all created large and well-funded military units specialising in space operations and are ramping up investment in space technologies: the requested budget for the US Space Force in 2024 was over $30 billion. In recent years, China has tested hit-to-kill interceptor missiles, and Russia has conducted successful flight trials of anti-satellite missile

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[11] UN International Telecommunication Union (ITU) Constitution and Convention of the International Telecommunication Union, December 1992

[12] UK Space Agency, Spaceflight Legislation and Guidance

[13] https://www.nasa.gov/artemis-accords/

[14] European Space Policy Institute, The Rise of Private Actors in the Space Sector, 2017

[15] Nature World View, Stop sending human remains to the Moon, 16 January 2024

systems.[16] In February 2024, there were concerns over the possibility that Russia could put a nuclear weapon into space.[17] The issue of potential weapons in space is complicated by the fact that almost any manmade object in space is ‘dual use’ i.e., it could be used for military purposes. Maintaining peace in space in future may become more difficult than it has been up to now, with potentially severe consequences. There is the possibility of an escalating ‘arms race’ in space between states and factions. Many states will feel it necessary to defend their commercial and sovereign interests and assets in space as well as defending themselves from the potential for space-based assets to be deployed by adversaries, for example GPS jamming. There is the potential for irresponsible or reckless behaviours, non-compliance with guidance, and the exercise of ‘soft power’, influence and use of proxies by states and private actors. Making space a dangerous and unpredictable environment will also deter scientific and commercial activities, and investors in non-defence space capabilities, delaying the benefits of space for humanity.

As a result of this expanding use of the space environment, the international treaties and corresponding domestic legislation do not cover many of the activities which are now – or soon will be – possible in space. The treaties which exist are not enforceable, and at present there is no international court for space activities, or formal means for dispute arbitration other than bilateral agreements. Good licensing regimes, compliance and dispute arbitration mechanisms will be critical to manage the future uses of space responsibly. The UN has been clear that the governance of space needs addressing: “The human presence in outer space has fundamentally changed in the past 10 years, and this change is likely to accelerate in the coming decades. We need to develop further the existing governance so that we can sustainably accelerate innovation and discovery.”[18] While good work is already underway, including the UNCOPUOUS[19] and the Inter-Agency Debris Coordination Committee (IADC),[20] which are focused on voluntary measures for managing orbital activities, the lack of international consensus on what the rules should be, weak international governance, and lack of clarity over liabilities, risk slowing progress in deploying key future capabilities such as debris removal.

Like other countries, the UK has invested in growing its space economy and the space sector is now worth over £16.4 billion per year, employing over 45,000 people across the UK. The UK plays a key role in UN and international space policy development, including the Working Group on Reducing Space Threats Through Norms, Rules and Principles of Responsible Behaviours,[21] such as sponsoring the UN General Assembly initiative on space behaviours adopted in 2020.[22] The UK Space Command (part of the RAF) was established in 2021 and was the first formal partner in the US-led Operation Olympic

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[16] Ministry of Defence, Defence Space Strategy: Operationalising the Space Domain, February 2022

[17] New York Times US Fears Russia Might Put a Nuclear Weapon into Space, 18 February 2024

[18] United Nations, Our Common Agenda Policy Brief 7, For All Humanity – the Future of Outer Space Governance. May 2023

[19] United Nations Committee on the Peaceful Uses of Outer Space (COPUOS)

[20] Inter-Agency Space Debris Coordination Committee (IADC)

[21] Aidan Liddle, ‘Responsible behaviours in outer space: towards UNGA 76,’ Foreign, Commonwealth and Development Office Blogs, 8 June 2021

[22] United Kingdom, National Submission on Space Threats, 30 April 2021

Defender, a multinational coalition formed to strengthen deterrence against hostile actors in space and reduce the spread of debris in orbit.[23] Placing sustainability at the core of space activity is the purpose of King Charles' Astra Carta initiative, which aims to convene the private sector in creating and accelerating sustainable practices across the global space industry.[24] There is a lot of excellent work going on across Government, in UK Space Agency, Satellite Applications Catapult, Civil Aviation Authority Space Team and others, and the RHC commends everyone for their efforts and dedication.

What was the RHC's approach?

The RHC's approach to this report explored the opportunities and challenges of 11 current and future technologies which are relevant to space. Technologies themselves are neutral and can be used in many ways across multiple sectors (space is simply a potential application of these technologies), so it is not sensible to develop regulatory recommendations for specific technologies in outer space. The right approach is to regulate the space *capabilities* that the combination and applications of these technologies create, in the wider context of the international regulatory environment and geopolitics. We therefore identified current and potential future capabilities and their benefits and risks, and used horizon scanning techniques to explore future trends, drivers, and scenarios with inputs from industry, academia and government departments and executive agencies. Our recommendations set out where the UK Government can leverage our strengths and opportunities to the greatest effect.

The 'Space 11' technologies identified are:[25]

AI and Machine Learning will improve data analytics and decision-making, and enable innovation in many of the other technologies

Data science underpins many current and future technologies such as AI, automation, robotics, and telecommunications, enables spaceflight and, in future, will help us to optimise bandwidth and orbital capacity

Energy, launch, and propulsion technologies allow spacecraft to take off and manoeuvre in space, and could potentially lead to sustainable solar and other energy sources for Earth

Engineering biology may help us develop novel food and medicines to sustain future human life in space, with spin-out benefits for health services on Earth

[23] Penny Mordaunt, 'Defence Secretary outlines future space programme,' RAF News, 18 July 2019

[24] His Majesty The King. 'The King unveils the Astra Carta seal at a Space Sustainability Reception at Buckingham Palace.' The Royal Family, 28 June 2023

[25] There is no generally accepted definition or groupings of space technologies.

Future telecommunications technologies will drastically improve global connectivity, data sharing and data transmission

Human sciences can inspire us, help us develop the diverse workforce and ethics we need in the space sector, help future human crewed missions operate together, and eventually help us to create new communities in space

Novel materials and nanotechnology will build lightweight, high-strength components for satellites and improve design and performance, and are an enabler for in-space manufacture and recycling

Quantum technologies have the potential to hugely improve communication, computing, and sensing, and may enhance – or undermine – data security and the encryption of satellite communications. Quantum metrology (atomic clocks) would enable more accurate instrumentation and future spacecraft navigation

Robotics, software, and automation activities for uncrewed missions will help us to operate more cheaply, safely, and efficiently, and enable active debris removal and in-orbit servicing, especially when enabled by AI

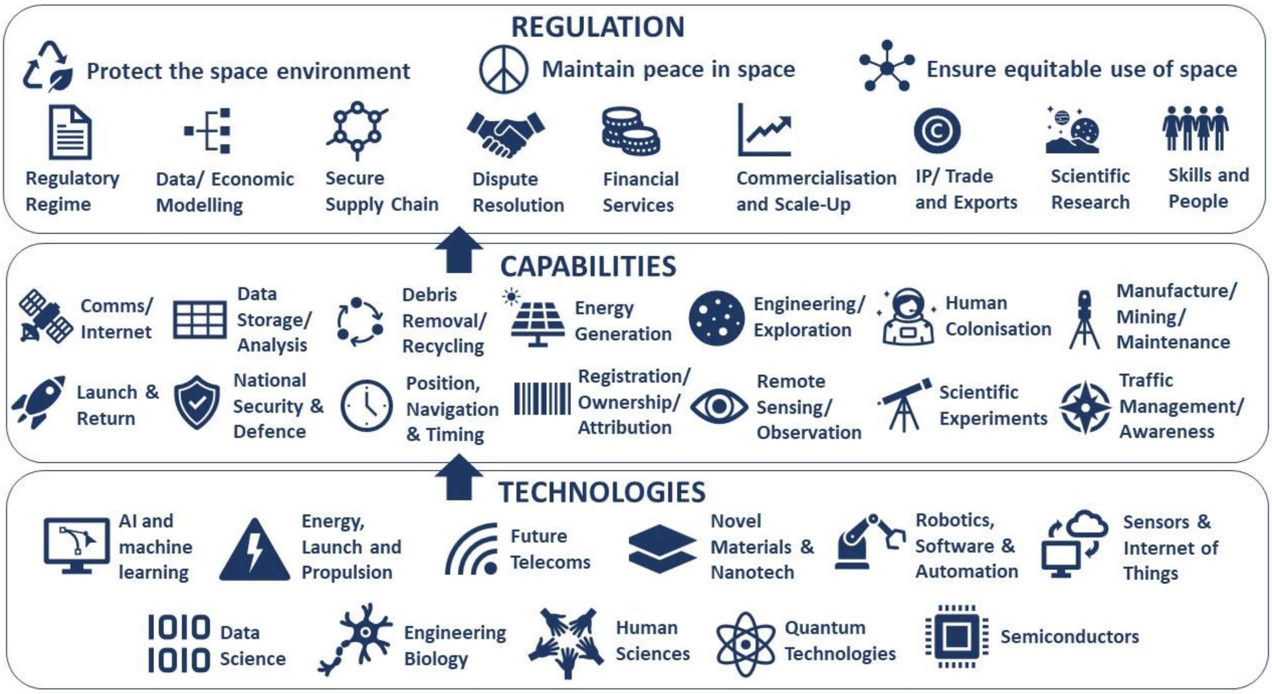
Semiconductors are critical to the Space Sector supply chain and need to be adapted (radiation-hardened) through novel design and materials to enable the breakthrough technologies we describe – especially future communications

Sensors and the Internet of Things will improve our ability to detect and track what is happening, including radio and optical telescopes for astronomy

These technologies together create new and emerging capabilities which will need regulation. Over the next 10 years we are likely to see an expansion of existing space activities such as Earth observation and remote sensing, a broader range of telecommunications capabilities, and new space exploration including tourism. In the next 10 – 20 years, we may see the emergence of novel capabilities in space such as active debris removal, solar energy generation, mining, and manufacturing (including novel medical devices and pharmaceuticals), data storage, new defence capabilities, and more. In the further future, we might see humans reside on spacecraft, the Moon, or other planets.

All these activities will need to be governed by a flexible regulatory regime which covers monitoring and 'traffic management' systems to ensure safe launch, operations, and return and prevent overcrowding or collisions. We will need to have regulation for environmental protections, including requiring operators to properly dispose of defunct equipment and reduce space junk and pollution, and to ensure responsible practices to manage the growing in-space economy, including insurance and in-orbit asset trading. To ensure resilience, regulations will need to cover foreseeable potential situations such as managing emergency situations where a State or another company may have to quickly take over the assets of a company which can no longer operate them. Key areas for future regulation, therefore, include setting out how the international community will protect the space environment, maintain peace in space, and ensure the equitable use of space including creating a flexible and proportionate regulatory regime, developing data and economic modelling tools, securing the supply chain, managing dispute resolution and arbitration, creating financial products and services for the space sector, commercialising and scaling up innovation, further developing the Intellectual Property regime and managing international trade and exports (including restricted technologies), supporting scientific research in and using space, and developing the pipeline of skills and diverse talent needed (Figure 1).

Figure 1: Overview of Technologies, current and future Capabilities and Regulation



Recommendations Summary

The RHC suggest a series of recommendations to:

1. Use the UK's international platforms to advocate for and prioritise environmental protection, peace, and equitable use of outer space;

2. Make the UK the go-to place for space regulation, arbitration and enabling services; and

3. Ensure that the UK is at the forefront of a few key enabling technologies and capability development.

1. Use the UK's international platforms to advocate for and prioritise environmental protection, peace, and equitable use of outer space

Environmental Protection of Space

The UK Government should work with the international community to:

1. Establish strong legal protections for the space environment to limit pollution, mitigate future environmental risks and preserve 'clean zones' for future use
2. Restrict the number of objects put into space to a sustainable level, with agreed quotas for spacefaring nations

The UK Government should:

3. Signal the intention to put into future domestic legislation in 10 years the requirement for space objects and components to be made from materials which meet specified standards for non-pollution and minimise impact on the space environment
4. Rapidly scale up existing work for a national space debris removal and recycling programme and develop associated regulations, guidance, standards and financial investment, insurance, and legal regime to operate them
5. Develop a framework and functions for a future 'Space Traffic Control' system and civil tracking capability

Promote Peace in Space

The UK Government should work with the international community to:

6. Establish a multinational specialist capability ('International Space Safety Organisation') to inspect and enforce internationally agreed regulations
7. Prevent and deter conflicts in and using space through an effective international non-proliferation space weapons treaty
8. Create an international space arms regime based on existing non-proliferation treaties

The UK Government should:

9. Amend domestic terrorism legislation giving law enforcement and intelligence agencies remit and powers to address and prevent planning or intending to carry out unlicensed launches or illegal interference with satellites or satellite communications
10. Develop plans to prepare for and recover from any major future conflict or accident that may occur in space through 'wargaming' and future scenario development
11. Create a space cybersecurity programme with industry, including developing and publishing domestic guidance and standards

12. Develop and publish advice to the space sector on how to manage and respond to supply chain and security threats

Ensure equitable use of space

The UK Government should work with the international community to:

13. Develop an international regime to govern, authorise, and manage future space mining and manufacturing activities
14. Continue to define and promote responsible space behaviours, drawing on multidisciplinary expertise
15. Protect and preserve sites in space of historical and cultural significance

The UK Government should:

16. Establish a Citizens' Space Assembly
17. Explore the potential for public 'Space Bonds' or community shares for ethical investment in space technologies
18. Instil the long-term thinking required to develop space capabilities and mitigate against the risks of short-term economic incentives through multi-year budget settlements attached to clearly defined outcomes

2. Make the UK the go-to place for space regulation, arbitration and enabling services

The UK Government should:

19. Build on the UK's common law approach as the preferred choice of law internationally, and put in place arrangements for the exchange of information between the UK Courts and the UAE Space Court
20. Establish a Space Arbitration Faculty
21. Encourage UK investors to invest in UK space capabilities and accelerate the scale-up of technologies into deployment
22. Further establish the City of London as the global leader for the space insurance industry, including creating a Space Reinsurance Pool
23. Create a positive investment climate for scale-ups and address the gaps in scale-up equity and non-equity funding
24. Implement the recommendations set out in the RHC's report on the *Role of regulation in supporting scaling-up*
25. Develop and mature a comprehensive Intellectual Property regime for space technologies in UK law and create a menu of standard space contracts
26. Define and agree on clear definitions for military, non-military, quasi-military and dual-use space capabilities and create a proportionate classification scheme to manage them appropriately at the lowest classification necessary

27. Extend the remit of the National Security and Investment Act to cover the future in-orbit trade of assets, goods, and services
28. Iteratively develop and evolve a comprehensive regulatory regime for future space activities with appropriate law and associated guidance, authorities, accountability, and enforcement regimes
29. Extend current and future domestic law and push for the extension of international law, to the activities of private actors and consortia operating in space
30. Consider whether the range and complexity of future space activities may require the creation of a separate specialist space regulator
31. Establish clear leadership and accountabilities across Government
32. Agree a legal definition for outer space and definitions and terminologies for different kinds of space areas, environments, and objects

3. Ensure that the UK is at the forefront of a few key enabling technologies and capability development

The UK Government should:

33. Invest in novel semiconductor materials and fundamental design for space, establish an assured onshore integration capability in atomic clocks and timing with a clear assurance approach, and create a terrestrial PNT distribution network.
34. Develop a deployable debris tracking and removal service, a global civil ‘space traffic management’ system, and continue to develop ‘data as a service’ capabilities
35. Commission a programme of work overseen by HM Treasury to develop and publish economic and data modelling frameworks and standards for the space sector and subsectors and establish key datasets providing empirical evidence to understand and predict the evolution of the space environment
36. Create a programme of work with the private and public sector to ensure that the UK Space sector supply chain is secure

4. Investing in Skills and People

The UK Government should:

37. Fund universities to create ‘space bursaries’ aimed at encouraging a wider range of students to take space science and create a Young Peoples’ Panel on Space Futures
38. Explore ‘Space Visa’ exemptions for specialist space technology experts
39. Commission UK Space Agency to create an educational scheme to raise awareness and excite people about career opportunities in the space sector
40. Partner with universities and relevant industries to co-create authentic learning opportunities that are integrated into academic programmes giving students and graduates opportunities to explore and potentially solve mission-led space challenges

1. Introduction

This section introduces the Regulatory Horizons Council and the rationale for this report, its scope, and the approach we took to creating it collaboratively with a range of experts.

About the Regulatory Horizons Council (RHC)

The Regulatory Horizons Council (RHC) is an independent expert committee sponsored by the Department of Science, Innovation, and Technology (DSIT) to identify the implications of technological innovation, and provide the government with impartial, expert advice on the regulatory reform required to support its rapid and safe introduction. The RHC was established in 2019 by the White Paper 'Regulation for the Fourth Industrial Revolution'.[26] The RHC has produced several sector-specific reports, including on quantum technologies, drones, genetic technologies, and fusion energy.[27]

Background to this RHC report

In September 2023, the RHC was commissioned by the Space Directorate in the DSIT to conduct an independent review to identify potential future intersections between the space sector and the five critical technologies identified by DSIT in the Science and Technology Framework,[28] and provide practical recommendations for regulatory reforms that will enable the positive and safe development of these emerging technologies. The review complements the wider cross-government Space Regulatory Review encompassing spectrum and orbital activities and a post-implementation review of the Space Industry Act (2018). The RHC's goal was to provide independent challenge and to influence the government's wider Space Regulatory Review. The work for this report was undertaken between October 2023 and March 2024.

Our approach has been to:

1. Identify the current and future technologies which are relevant to space (Section 3);
2. Explore how these technologies create current and future capabilities (Section 4) and develop potential future scenarios (Section 5);
3. Understand how these capabilities could be regulated and where the strategic priorities should be for the UK (Section 6).

[26] UK Government, 'Regulation for the Fourth Industrial Revolution', 2019
[27] Regulatory Horizons Council reports
[28] Department for Science, Innovation and Technology, 'Science and Technology Framework', 2023

The key activities undertaken were:

1. **Scoping** – we agreed on the remit, timelines, and terms of reference with DSIT and presented to the inaugural briefing event for the Space Regulatory Review.

2. **Alignment with the wider Government Space Regulatory Review** – RHC members participated in the consultation workshops.

3. **Evidence gathering and Horizon Scanning** – the RHC commissioned RAND Europe to conduct a horizon scan and literature review and produce a separate technical report; partnered with Capgemini Invent to organise a Space Futures workshop creating future scenarios for the space sector; and conducted a series of individual interviews with a diverse array of space experts. We convened an in-depth expert workshop with Cambridge Consultants, focusing on five specific technology domains. RHC members attended the UK Defence Space conference in December 2023, the Westminster Business Forum's event on priorities and the subsequent steps for the UK space sector, Wilton Park's Future Space Threats event in January 2024 and techUK's Space Technologies of the Future event in March 2024.

4. **Collective Intelligence** – we used a deliberately 'open policy' approach to gather 'collective intelligence' and invite people to participate in co-creating a shared document. This was disseminated widely using direct emails to stakeholders on LinkedIn, Twitter, and TechUK's website. Additionally, it was shared with various networks such as the Satellite Applications Catapult, Institution of Engineering and Technology (IET), Innovate UK Knowledge Transfer Network (KTN) for Space, the Centre for Research and Evidence on Security Threats (CREST), the Security, Privacy, Identity, Trust in the Digital Economy (SPRITE+) network, and Academic RISC (a subset of the Security and Resilience Industry Suppliers Community or RISC). We received a very good response from a wide range of stakeholders.

5. **Consultation** – we circulated the draft report to selected stakeholders in Government, industry, and academia, and responded to their feedback.

6. **Drafting and Finalising** – we finalised our recommendations and prepared this report for publication, including communications. The RAND Europe report is published separately alongside this report.

Scope

The RHC focused on current and future technologies to deconflict with the wider Space Regulatory Review, and in line with the RHC's wider remit. Our scope included any and all relevant technologies: the five critical technologies set out in the Government's Science and Technology Framework[29] (artificial intelligence, engineering biology, future telecommunications, semiconductors and quantum technologies) are all relevant to the space sector, but so are other technology areas including data science, energy, launch and propulsion technologies, human sciences, novel materials and nanotechnology, robotics, software and automation, and sensors and the Internet of Things (IoT). We therefore expanded our scope of relevant technologies to explore to the 'Space 11'.

Technologies themselves are neutral and can be used in many ways across multiple sectors (space is simply a potential application of these technologies), so it is insufficient to look in isolation at regulatory recommendations for specific technologies in space. The right approach is to regulate the space *capabilities* that the combination and applications of these technologies create, in the wider context of the international regulatory environment and geopolitics. We included in scope any space-enabled capabilities (products and services provided on Earth which depend – or will in future depend – on space). We did not extensively explore the topics of wider deep space exploration or future crewed missions to other planets but focused more on near-Earth and cislunar activities.

In our horizon scanning work, we invited people to consider three broad time horizons: a 'short' time horizon to 2030; a 'medium' horizon to 2040; and a longer-term horizon out to 2050 and beyond.

Throughout, we have taken a UK-centric focus but acknowledged and considered the vital importance of international interdependencies and collaborations.

We took a broad definition of 'regulation' to include law, guidance (mandatory or otherwise) and innovation practices and ecosystems and included international as well as UK legislation. We did not include a comprehensive survey of other countries' domestic legislation other than exploring US International Traffic in Arms Regulations (ITAR) restrictions. We also considered the broader framework and ecosystem for enabling space technologies including incentives, funding, support, training, and access to skills.

[29] UK Government Science and Technology Framework, March 2023

2. About Space

This section defines key terms and sets out why space is important.

What is 'space'?

It is important to clearly define terms: one of the challenges we have found in the rapidly growing space sector is a lack of clarity over terminology and 'missing words' for important concepts. To take one example, a future lunar 'space station' may mean a permanent structure on the Moon, which is different from something in orbit around the Moon (currently the International Space Station – despite being called a station – is in orbit around the Earth). At the other extreme, the space industry already suffers from an impenetrable lexicon, with associated phrases and acronyms, which make it inaccessible for newcomers and lay people to discuss and may contribute to a lack of diversity in thought. There are also multiple terms for similar concepts ('Space Domain Awareness', 'Space Situational Awareness', 'Space Surveillance and Tracking'), and often the same term can be used to mean multiple different things (such as 'protection' and 'sustainability').

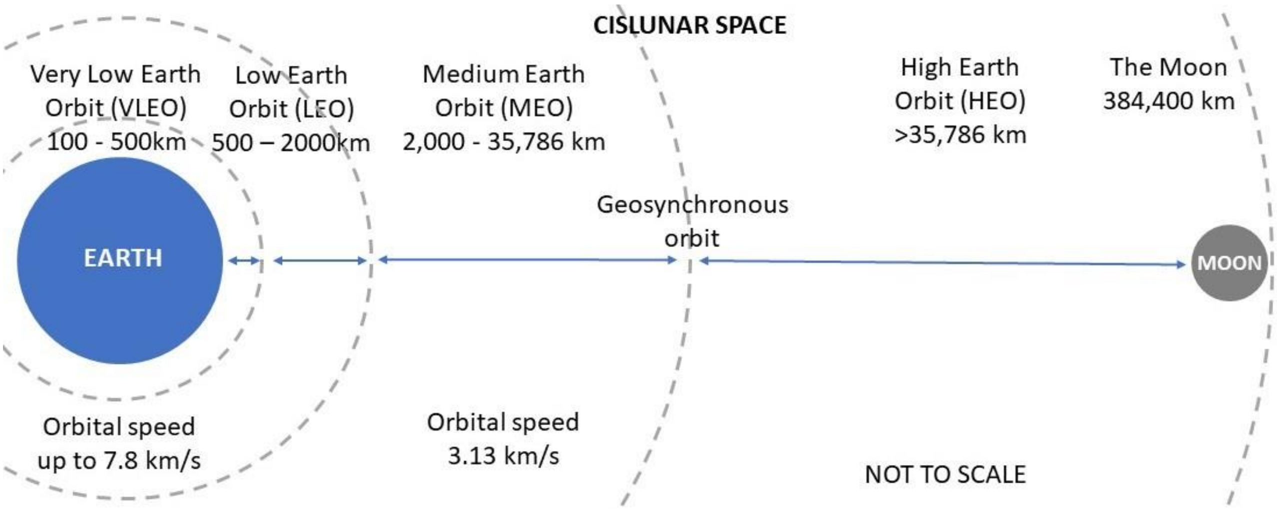
While the term 'space' has many different meanings, in this report it refers to the entire Universe, or cosmos, including the Earth. 'Space and 'outer space' are often used interchangeably; but strictly, outer space means the entire universe outside our atmosphere, excluding the Earth, including our Moon, other celestial bodies (planets, stars, asteroids, comets, meteoroids), and other solar systems. The convention is that outer space begins about 100 km above sea level (the Kármán line) – an imaginary boundary.[30] At this altitude, air density is so low the atmosphere is unbreathable for humans, and oxygen levels are too low to scatter light, making the skies black rather than blue. Outer space is almost a perfect vacuum, with extremely low pressure: sound does not carry because molecules aren't close enough to transmit sound between them. 'Cis-lunar' is used to refer to everything that lies between Earth and the Moon.

An 'orbit' is the curved trajectory of an object around another object, such as the trajectory of a planet around a star, or a satellite around a planet ('satellite' and 'orbit' are semantically circular definitions, in that a satellite is an object in orbit and orbit is the trajectory of the satellite).[31] Objects in orbit are subject to a greater or lesser extent to the gravitational pull of the object around which they circulate (in fact, gravity holds them in orbit and stops them from spinning off): orbits nearer to Earth are much faster than outer orbits. The Earth's orbital area (Figure 2) includes: Very Low Earth Orbit (VLEO); Low

[30] NASA, 'Earth's Atmosphere: A Multi-layered Cake'
[31] ESA, 'Types of Orbits'

Earth Orbit (LEO); Medium Earth Orbit (MEO); and High Earth Orbit (HEO).[32] In VLEO there are benefits such as increasing resolution for satellite images, and less threat of damage from space debris. Most scientific satellites are in LEO; navigation and specialty satellites are in MEO; and weather and some communications satellites are in HEO where there is the best visibility of Earth. A geosynchronous or Geostationary Earth Orbit (GEO) is an orbit 35,786 km in altitude equal to Earth's rotational period, and appears in a fixed position, especially useful for telecommunications.

Figure 2. Types of orbit



The terms satellite, space station, rocket, spacecraft, spaceship, shuttle, and probe are all ‘space objects’ (which can also mean any natural object in outer space). ‘Satellites’ can refer to any natural or artificial object in orbit around a celestial body or another satellite: but in this report, we mean specifically objects or vehicles manufactured on Earth and put into orbit around the Earth, Moon, or other celestial body. ‘Spacecraft’ is synonymous with ‘spaceship’ and is generally used to refer to any man-made vehicle intended for space – large or small – but may imply to some a human-crewed vessel. There is no specific term for satellites/ spacecraft which can land on celestial bodies such as asteroids or planets and can take off again. A ‘space station’ is a large, crewed spacecraft, but in future may mean a permanent installation on a celestial body. ‘Rocket’ is a launch vehicle used to deliver payloads into space; ‘payload’ is used interchangeably to mean both the launch vehicle’s contents (satellites) and a satellite’s instruments. ‘Space shuttle’ is a spacecraft designed to take payloads to and from space. In future, it will matter for future regulatory clarity to define what type of object is in space, whether it is natural or manufactured, whether it is intended to return and be re-used, whether it is crewed by humans, robots, or uncrewed, and so on. Future uses of space will benefit from clearer language and more clearly defined terms, and fewer acronyms.

[32] NASA, ‘Catalogue of Earth Satellite Orbits’

Why is space important?

Why is space important in the first place? The RHC believe there are three key reasons:

1. **Space is – and always has been – an inspiration for humankind.** For generations, people have looked to space and wondered about how the Universe evolved and our place in it. Humans have been exploring space for decades in pursuit of scientific enquiry: since the initial landing on the moon in 1969, 676 people have journeyed into space, and humans have been continuously in space on the International Space Station since 2000. The popularity of science fiction in books, television and movies suggests that these dreams tap into something in many of us. In 2021, the European Space Agency (ESA) received 22,500 applicants to their astronaut programme,[33] and in 2020 over 12,000 people applied to NASA's astronaut programme.[34] In the far future, humans might colonise another planet, ensuring our species' long-term survival.

2. **Space is a driver of human values**: the 'overview effect'[35] of looking back at the Earth from space demonstrates the ultimate perspective on our existence – that we are all connected and together on this planet. Despite humanity's long history of war and overexploitation of the natural world, we have an opportunity in space to do things differently this time: to work together towards a shared space future in a way which is inclusive, diverse, multidisciplinary, and ethical.

3. **Space is an environment and enabler within which current and new technologies will operate.** Many direct and spin-off technology innovations have resulted from space science. Satellites are vital for the global telecommunications system, weather forecasting, navigation, and monitor climate change effects: mobile phones, television broadcasts, and internet services all rely on satellites.[36] Indirect benefits include freeze-drying, remote controlling devices, laser eye surgery, and memory foam – although not, as popular myth would have it, barcodes, biros, Velcro, or Teflon (which have been used in space)[37]. Space technologies have received huge amounts of investment – in 2021, over $10 billion was invested in space companies,[38] with a global space market valued at $433 billion in 2022 – this is expected to rise to $700 billion by 2029.[39] Many of the key technologies of the future – quantum, AI, robotics, driverless vehicles, smart transport systems – will also operate in space, or be dependent on using space assets.

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[33] ESA, 'ESA presents new generation of astronauts'

[34] NASA, 'Become an Astronaut'

[35] Wikipedia, 'Overview effect'

[36] World Economic Forum, 'Six ways space technologies benefit life on Earth', 2020

[37] Wikipedia, 'NASA spin-off technologies'

[38] McKinsey 'A different space race: Raising capital and accelerating growth'

[39] Maximize Market Research, 'Space Technology (SpaceTech) Market: Global Industry Analysis and Forecast (2023-2029)'

3. Future Space Technologies

This section sets out the main current and future space technologies and considers their opportunities and challenges.

Technology is the practical application of scientific knowledge. The RHC has identified the ‘Space 11’ – the 11 key technologies which are the critical building blocks for current and future space capabilities.[40] Many of these technology areas also underpin and overlap with each other, so for example data science, AI and machine learning will be key for robotics and automation. Of course, these technologies will also affect many other sectors, but we have focused on their applications to the space sector, the opportunities and challenges they afford, and the implications for future regulation. It is worth noting that regulation also shapes the future of technology: the choices we make about how to regulate now affect how these technologies evolve in future.

Table 1: Summary of the ‘Space 11’ technology opportunities and challenges

Technology	Opportunities	Challenges
AI and Machine Learning	• Analysis of large, complex data sets • Real-time and predictive spatial awareness • Enhanced decision-making • LLM human/machine interfaces	• Biased/partial training data • ‘Black box’ decision-making • Lack of trust/public concern • Cybersecurity • Need sufficient power source • Resilience and back-up • Standards for interoperability • Issues over ownership, accountability, and liability
1010 1010 **Data Science**	• Enabling key current capabilities including telecommunications and earth observation • Predictive models for navigation and mission planning • Enabler for AI and machine learning, automation, robotics, space ‘IoT’ • Optimising bandwidth and orbital capacity	• Storage capacity • Bandwidth capacity • Need for independent, validated, accurate sources of data • Issues over ownership, data sharing and data protection

[40] https://www.techuk.org/resource/techuk-s-first-emerging-space-technologies-report-is-now-live.html

Energy, Launch and Propulsion	• Limited access to nuclear fuel sources • Potential for dual use • National security restrictions/ITAR • Disposal of nuclear waste • Solar panels would need in-space manufacture due to size	• Safety in take off • Allowing spacecraft to manoeuvre in space • Enabler for space exploration, mining, manufacture, and colonisation • Potential for solar power
Engineering Biology	• Bio-inspired innovations such as novel sensors and imaging • Supporting human colonisation of space with closed-loop ecosystems • Health monitoring of astronauts • Biofuel production in space • In-space oxygen production • In-space drug and medicine production • Novel bioengineered materials for spacecraft, spacesuits and creating structures in space/on celestial bodies • Human adaptation and genetic modification	• Ethics • Development of harmful biology and biological weapons • Biological contamination of the space environment • Returning biological samples to Earth could cause a biohazard
Future Telecoms	• Increased global coverage • Multi-way comms • Increased capacity for communications and web services • Long-distance communications in space using lasers and relays (for interplanetary/multi-space station comms)	• Spectrum limitations • Protection and ownership of data • Costs of data storage • Social implications of global connectivity (extending cybercrime to new populations, for instance) • Cyber-physical effects and manipulation (such as hacking objects)
Human Sciences	• Workforce development across the space sector • Improving human performance in hostile environments • Monitoring crew on spacecraft	• Lack of funding for human sciences in space technologies • Lack of appreciation of value/integration from traditional space science disciplines

	• Building new human communities in space • Bringing diverse multidisciplinary perspectives to develop future space technologies	• Access to people and datasets • Undeveloped research area
Novel Materials and Nanotechnology	• Lightweight, high-strength components enabling improved design and performance • Self-healing materials could increase our ability to travel long distances in space • 'Smart' fabrics can monitor health/detect environmental hazards • Enabling in-space recycling and manufacture	• Expensive and complex to design, create and test • Concerns over safety and reliability • Environmental and health impacts • 'Dual-use' technologies could be used to create novel weapons
Quantum Technologies	• Ability to solve new kinds of computational problems • Precise measurements for PNT • Secure communications	• Cryptography applications currently vulnerable to man-in-the-middle interception
Robotics, Software and Automation	• Safer space exploration (reducing the risk of humans operating in hostile environments) • Space mining capabilities (to identify and extract useful resources) • Building other machines/future habitats • Carrying out scientific experiments/collecting samples	• Reliability and robustness including resistance to dust, radiation and knocks • Lack of power sources • Resilience and back-up • Mobility over rough terrain • Safety concerns if operating near humans • Standards for interoperability • Issues over ownership, accountability and liability
Semiconductors	• Critical technology for communications and satellites • Potential for in-space semiconductor recycling/manufacture	• High cost of manufacture • Acquisition of raw materials • Complex global supply chain • Radiation damage in space

Sensors and the Internet of Things	• Smaller, cheaper, and more sensitive, enabled by novel materials • Enables autonomous systems, safety monitoring and maintenance	• High demand for bandwidth, processing capacity and data storage • Vulnerability to hacking/ spoofing

Artificial Intelligence and Machine Learning

Artificial intelligence (AI) is a category of computer algorithms and systems that perform tasks normally requiring human intelligence, such as visual perception, speech recognition and decision-making. There is no clearly defined boundary between ‘machine learning’ (using the training data to infer the solution to a similar problem using algorithms), ‘narrow’ AI (autonomously performing specific constrained tasks), and ‘general’ AI led by increasing levels of complexity and autonomy (although the real benefit of general AI over hybrid systems of narrow AI and non-AI algorithms is not clear).[41] Edge computing (or edge AI) is opening new possibilities for running AI models close to where the data is collected (as opposed to running them on cloud platforms) which has several advantages, including reducing the need to transmit and store large volumes of data.[42] Reducing the reliance on Earth-based computing capability will be critical to realising the full potential of space for many scientific and commercial activities. As with most computer programmes, AI poses a potential cybersecurity risk.

AI is being increasingly used in a range of applications and industries, but the AI regulatory landscape is immature and there is limited experience of the interaction between regulation and real-life scenarios. Attempts to apply existing regulation to ever changing technologies and concerns ensures technical compliance with the law, but it also encourages users into exploiting regulatory grey areas. The result is a regulatory regime that is applicable to situations that were never contemplated with penalties and consequences ill-fitted to ensure appropriate continued and future use. The lack of appropriate training data and standards for testing AI has resulted in instances of biased AI models appearing to discriminate against specific groups of people[43], an issue which is further compounded by the ‘black box’ nature of AI (making it difficult to understand or explain why the AI model has acted in a certain way).

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41 Alexander Pinhel, ’ Exploring the Boundaries of Artificial Intelligence: A deep dive into AI’s capabilities, limitations (part 1)’, 2023

42 IBM, ’What is Edge AI’

43 Information Commissioner’s Office,’ What about fairness, bias and discrimination?’

The future role of AI in space may not be as grand as the hype suggests. The science-fiction projection of sentient AI controlling spacecraft and becoming a ‘member of the crew’ is unlikely to materialise. Humans have been able to safely launch people into space and onto the moon since the 1960s and spacecraft have always been operated by computer control algorithms; it is not possible for humans to make decisions at the speed required to safely undertake the operations. Early US spacecraft had control panels that could be operated by the astronauts; this gave astronauts more confidence and gave a ‘better’ impression of capability to the press. However, astronauts were strictly instructed never to use them as it would result in their deaths. Spacecraft has always operated in ‘autopilot’ mode; for spaceflight autopilot this does not require the use of AI.

This does not mean that AI will not be useful for space voyages or that AI will not be used to help overcome some of the technical challenges we face. Large Language Models (LLMs) are designed to understand and generate content (text, diagrams, and other data) in the way that a human could, by looking at huge amounts of existing data. Rapid advances mean that this is becoming a standard method for humans to interact with computers in the future. Interfaces using LLMs will be used on future spacecraft to improve the way humans give instructions to highly complex systems,[44] but the LLMs will not ‘make the decision’ about what the instruction means. The output will be used in a reinforcement learning model that will develop the strategy for executing the human’s request; the output of the reinforcement learning model will be inputs to micro-algorithms that will determine the specific changes to be made to control the spacecraft. The micro-algorithms will be traditional, robustly tested algorithms due to the zero tolerance to fault required for safely operating the spacecraft.

Where LLMs are used, ensuring the correct interpretation of humans’ intentions is essential. This is an active area of development in MedTech and FinTech, where misinterpretation can have serious consequences.[45] Similar risks apply to spacecraft operation, and methodologies around AI assurance developed in other fields are likely to be transferable. However, it is not clear when AI assurance will result in an acceptable level of confidence in AI models for the safe use of AI in different scenarios. Without this confidence, it is unlikely that AI would displace the use of human input to traditional algorithms. Regulators need to establish what constitutes an acceptable level of testing and confidence for AI models to be used in different space applications.

AI will support the deployment of Robotics: spacecraft will have AI for proximity operations and manoeuvres[46]– especially as operations take place further away from Earth in new environments and communications become increasingly affected by time delay.

[44] Andrew Myers, AI makes a rendezvous in space, Stanford Engineering, 2024

[45] MedTech Intelligence, ’AI in MedTech: Risks and Opportunities of Innovative Technologies in Medical Applications’, 2021

[46] ESA, Self-driving spacecraft set for planetary defence expedition, 2019

AI models could used to support the design and operation of components and equipment, and to improve robustness and extend life span in the harsh space environment. This includes the use of digital twins for managing larger space infrastructure and designing radiation-resistant semiconductors.[47] But improving robustness does not only lie with the hardware; developing software that is resistant to hardware faults that arise in the harsh conditions of space could also lead to new capabilities. If new AI methods could be developed that can resist and adapt to faults in the hardware arising over time, the life span of equipment could be extended and the need for heavy shielding could be reduced. Developments in quantum computers, which inherently carry some errors that scale exponentially, are likely to lead to fault-tolerant quantum computing approaches that allow scaling of the computational capacity to exceed that possible from digital systems for some types of computation.[48]

A key use of AI for telecoms will be to optimise communication bandwidth use to limit interference user experience given the available resources and propagation environment. AI models will be an important tool for developing appropriate regulations (and reaching international agreement) around spectrum use to establish fair policies that are not detrimental to any group. Other uses of AI in telecoms include modelling distortions in space (caused by the Doppler shift of the moving satellites) which will improve communication channels, control systems for satellite constellations to maintaining fixed satellite position within a constellation and improving satellite reliability and robustness through predictive maintenance and improved design. AI for communications will enable automated network traffic management beyond simple interference mitigation, including bearer management, traffic and user allocation and management, and multi-constellation management.

AI excels in handling large datasets and identifying patterns and correlations over long periods of time, unlike humans (who may not know these patterns/correlations exist). This will be essential to enhance our understanding of Earth and human activities from Earth observation data. As we continue to explore the universe, AI will accelerate our understanding and reduce the effort required to process large and complex datasets.

Data Science

In the dynamic world of modern space technology, the role of data has become increasingly prominent, serving as the backbone of advances in fields like telecommunications and earth observation. The essence of data science lies in its unique blend of mathematical and statistical analysis, advanced computer programming, and the innovative application of AI and machine learning techniques. This

[47] Mark Hennen, 'Digital Twin Showcase: Opportunities for the Space Industry', Catapult Satellite Applications

[48] RAND Europe, Implications of Emerging Technology for UK Space Regulation, 2024, p.9

fusion is critical to uncovering deep insights and intelligence that are not immediately apparent; insights that are crucial to informing decision-making across various aspects of space technology.

One of the most significant contributions of data science in space technology is its ability to enable accurate predictive models. These models are essential to spacecraft navigation and mission planning,[49] especially to address challenges like space weather which poses a risk to sensitive electronics. But the sheer volume of data generated by space technologies presents challenges. From telemetry to environmental monitoring, every aspect of space technology generates vast amounts of data which, while invaluable for training AI models, also creates issues regarding bandwidth and data storage capacity. This situation presents a paradox of having abundant data but constrained resources to store and process it effectively. Unfortunately, much of this data remains underutilised, leading to potential missed opportunities for new insights and advances.

Improvements in data analysis techniques are crucial for making sense of the vast datasets generated by space exploration. Ranging from geological to atmospheric and environmental information, this data is vital in forecasting environmental conditions like wind speeds and solar irradiance. Such forecasting helps improve decision-making and prioritise activities. Data science also facilitates real-time tracking and the prediction of object trajectories in space, thereby optimising the use of orbital capacity and ensuring the safety and sustainability of space operations.[50]

As we venture further into developing a space 'Internet of Things', with increasingly sophisticated AI, automation, and robotics (all heavily reliant on data science), an even greater proliferation of data is on the cards. Better data processing techniques will thus become critical in selecting relevant information. For example, optimising bandwidth by only transferring necessary data and deleting the rest can significantly reduce data storage requirements and increase capacity.

However, advancements in data science are not without challenges. Independent, validated, and accurate data sources are crucial for operational missions and activities like insurance. Issues surrounding data ownership, sharing, and protection are becoming increasingly complex. Such challenges call for a comprehensive and ethical approach to using space data to ensure effective utilisation.

Data pre-processing is another area that presents significant issues. The data collected from space is often noisy and incomplete; managing this noise and missing data is a substantial hurdle. Calibration concerns, which can affect the accuracy and reliability of the data, also pose a big problem.

[49] ESA, 'Artificial intelligence in space', 2023
[50] RAND Europe, Implications of Emerging Technology for UK Space Regulation, 2024, p.9

Despite this, the potential and opportunities offered by data science in space research and exploration are immense. The application of machine learning algorithms in discovering exoplanets has accelerated our search for these distant worlds, for instance.[51] Data science has also revolutionised our understanding of the universe. It has been harnessed in projects like the Sloan Digital Sky Survey, which has mapped millions of galaxies and provided invaluable insights into cosmic structure and the universe's expansion.[52]

In contemporary space missions, the role of data science in data collection, processing, analysis, and interpretation cannot be overstated. It underpins smart choices during missions, such as precise navigation, efficient fuel use, and problem avoidance.[53] Finally, data science has opened new frontiers in crowdsourcing efforts in space research, enabling the creation of astronomical knowledge based on archived datasets.

Energy, Launch and Propulsion

Exiting the Earth's gravitation field requires huge amounts of energy: rockets need to reach a speed of 11 km/s to escape, usually using liquid hydrogen fuel. Once in space, spacecraft need far less energy for thermal control, manoeuvring, to power electrical equipment and for a safe return to Earth. Between the Earth and the Moon (cislunar space), most spacecraft are operated by solar power where there is sufficient sunlight. Missions that travel beyond this point or remain long term (>1 month) in shadow require safe and reliable onboard power systems using nuclear fission processes. If the maximum power requirements are limited to a few kW's, then radioisotopic thermal generators provide decade long safe and reliable power sources. These have been used by more than 50 missions. For higher powers, more elaborate nuclear fission systems (such as Stirling radioisotope generators for nuclear thermal propulsion or nuclear electric propulsion) could be used. Power storage technologies are needed for in-space activity; the batteries used in the LEO satellites are improved upon by fuel cell technologies. Although less mature, fuel cells are candidates for the lunar and Mars missions of the 21st century.

More energy-efficient and cost-effective nuclear fission reactors may be developed in the future, increasing the distance that can be travelled by spacecraft and reducing design constraints.[54] But increased use of nuclear energy to power spacecraft relies on access to nuclear fuel sources. There are also concerns over nuclear energy technology as ‘dual

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51 Jet Propulsion Laboratory, ’New Deep Learning Method Adds 301 Planets to Kepler’s Total Count’, 2021

52 Vavilova and others, ’Machine learning technique for morphological classification of galaxies from the SDSS’, Astronomy and Astrophysics, Volume 648, 2021

53 Data Science Council of America, ’Navigating Uncharted Space: Harnessing Data Analytics in Space Exploration’, 2023

54 NASA, ’Space Nuclear Propulsion’

use' (potentially being used as a weapon, including simply driving the spacecraft itself into another one) and national security restrictions over its use and trade. Restrictions around nuclear technologies make it potentially problematic to remove/ rescue another State's spacecraft without breaching security restrictions, or to trade spacecraft. The disposal of radioactive nuclear energy sources in space could also be an issue – although some think that launching nuclear waste into outer space (including that generated on Earth from nuclear energy plants) may be a solution to expensive, polluting, and hazardous on-Earth disposal methods.

Another approach to reducing the energy required for launch is through horizontal launch, where purpose-built aircraft takes off in the same way as a traditional aeroplane.[55] Once the aircraft has reached its maximum altitude, it either switches to a rocket for the rest of the journey or deploys a rocket-powered space bound section. This approach uses significantly less energy than a vertical launch and can be undertaken from many existing airports. However, space launches disproportionally impact the Earth's biosphere by emitting pollution/ greenhouse gases at high altitude: cleaner space launches are a key aim and much development in sustainable aviation fuels is still required.

Propulsion in space can be provided by a range of technologies, such as beamed energy propulsion using lasers, ion thrusters and microwave electrothermal thrusters. A range of sail concepts have been proposed that use different forms of solar power, such as solar radiation and dynamic pressure from solar winds. Solar sails and electric sails have been deployed on satellites, with varying degrees of success.

Finding ways to generate sustainable power in space at scale is a key enabler for future capabilities such as space exploration, in-space mining and manufacture, and human colonisation.[56] And it could also help us solve our energy challenges on Earth. There is potential for large solar panels in orbit, for example, which could send power back to Earth – but these would need to be extremely large, and therefore would have to be manufactured or assembled and maintained *in-situ* in space which poses significant safety and security challenges.[57]

Engineering Biology

Engineering biology applies engineering principles to biology. It enables the manufacture of novel biological systems, such as cells or proteins, which can be applied across a wide

[55] NASA, 'Horizontal Launch: A Versatile Concept for Assured Space Access', Report of the NASA-DARPA Horizontal Launch Study

[56] RAND Europe, Implications of Emerging Technology for UK Space Regulation, 2024, p.14

[57] European Space Agency, 'Space-Based Solar Power overview', 2022

range of sectors including food, materials, and health[58] such as anthrobots[59] and using AI to design novel proteins that have never been found in the natural world.[60] Completely new bioproducts and processes with novel qualities and capabilities could be created which could disrupt whole industry sectors.

In space, bioengineering could help us feed and keep healthy a future human colony living on the Moon or in a space station. Microbial isolates and communities can be used to degrade and recycle waste to recover important elements such as phosphorus and carbon, recover water from waste, produce oxygen and biofuel, and grow food, organic materials, and medicine.[61] For example, NASA is developing a technology that can convert carbon dioxide and water into organic compounds to enable microbial biomanufacturing of microorganisms for food products, vitamins, plastics, and medicine.[62] The health of space-dwellers could be monitored through biosensors. New pharmaceutical drugs could be developed and tested in space, making use of the microgravity environment to experiment with medicines under conditions not possible on Earth. (The costs of transporting materials and returning the medicines to Earth may make in-space drug manufacture at any scale prohibitively expensive, however.) Bioengineering could allow us to build sustainable closed-loop ecosystems and reduce the need for logistics supply from Earth. This would increase the distance we could travel away from the Earth. Bioengineering could also create novel materials for spacecraft, spacesuits, and grow structures in space or on celestial bodies, reducing the mass of materials needing to be taken into space. It is possible that bioengineered foam or aerogel 'space goo', for instance, could attract micro-particles of debris and prevent them from causing harm.[63] There is also the possibility of using engineering biology to create new bioweapons either in space or on Earth, or of potential accidents in space or when returning space-derived or mutated biological specimens to Earth which might contaminate space/the Earth environment or (very unlikely) cause a lethal outbreak.[64]

Bioengineering activities in the space environment will need highly trained, specialist crews. Their activities could stretch across life support systems, space medicine, bioregenerative systems, bio-fabrication and bioengineering innovation. Where life support, medicine and bioregenerative systems (such as self-sustaining ecosystems to recycle waste, produce essentials for crew) are involved, there will be a need for personalisation and tailoring which would be costly and very challenging.

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[58] Council for Science and Technology, Report on engineering biology: opportunities for the UK economy and national goals 2023

[59] Matthew Hutson, 'Tiny robots made from human cells heal damaged tissue', Nature News, 2023

[60] Fay Lin, 'New Generative AI Model Designs Proteins Not Found in Nature', 2023

[61] Charles S. Cockell, 'Bridging the gap between microbial limits and extremes in space: space microbial biotechnology in the next 15 years', Applied Microbiology International, 2021

[62] NASA, 'Space Synthetic Biology', 2024

[63] Mariano Andrenucci and others, Expanding foam application for active debris removal', 2021

[64] RAND Europe, Implications of Emerging Technology for UK Space Regulation, 2024, p.12

‘Bio-inspired’ (i.e. synthetically mimicked natural structures, properties or functions) approaches to creating novel sensors and imaging systems are a key area for development. Such approaches could be used to provide high-resolution and cost-effective images of the space environment and Earth for industries such as agriculture, environmental monitoring, and national security. Bio-inspired approaches to human-machine interactions might also become important both for crewed space missions and operated space vehicles remotely, for example creating interactive controls using VR, and algorithms used for AI.[65]

Bioengineering could potentially adapt future humans to space, through advanced tissue engineering, augmenting with cyber-biological implants, and DNA manipulation/genetic modification.[66] Tissue engineering could, for example, provide surgical solutions to in-space accidents and emergencies and reduce some of the health challenges of long-term living in space (such as dental health and osteoporosis). For instance, we could create genetically modified lettuce to prevent the loss of bone mass[67] or adapt the genes which cause osteopetrosis (also known as marble bone disease or Albers-Schonberg disease, a rare inherited disorder causing increased bone density) to strengthen astronauts’ bones. These kinds of 'human enhancement’ interventions, while far off in terms of overcoming technical challenges and risks (let alone ethical concerns) could help humans live healthier lives in space and would have huge spin-off health benefits for humans on Earth.

The growth of AI will reshape how we look at biology, especially biology in space. With rapid advances in AI, conducting difficult experiments that require the utmost precision and special environmental circumstances will also become easier and more precise. AI is indeed becoming highly sophisticated, enabling scientists to mimic the exact conditions required for an experiment to be tested.

There are no current UK regulations for engineering biology in space. It would therefore be ideal to start with a risk mitigation assessment and to clearly define the rules around doing biology in space.

Future Telecommunications

Telecommunications technologies include electronic communications (such as mobile phones, television, radio, high-speed internet, emails, and instant messaging over the internet) and the infrastructure which provides these services. Much of the world now benefits from constant connectivity using satellites as part of a global communications infrastructure. While these are already mature and well-established technologies,

65 ’Intelligent Bio-Inspired Robots: New Trends and Future Perspectives’ , Special issue of Machines, 2024
66 RAND Europe, Implications of Emerging Technology for UK Space Regulation, 2024, p.12
67 Alex Wilkins, ’Bone-boosting lettuce could help Mars astronauts stay healthy’, New Scientist, 2022

telecommunications continue to evolve rapidly. In 2040, we are likely to see full global signal and internet coverage even in rural and remote parts of the world, eliminating the need for extensive on-ground physical infrastructure for the user. This will be enabled by satellite backhaul (using satellites to transmit data between terrestrial networks in remote locations and the rest of the world without the need for cables) and using constellations of small low-cost satellites and high-altitude pseudo satellites (HAPS) in non-geostationary orbits.[68] Inter-satellite links are a critical opportunity to enable more flexible, resilient, and timely communications. Future ground segment and waveform virtualisation technologies may transform the requirements for ground infrastructure.

Radio spectrum (spectrum) is the range of invisible electromagnetic waves that enable all wireless technology, from our mobile phones, Wi-Fi and Bluetooth devices to aircraft navigation and satellite applications, among many others[69]. In the space sector, spectrum is an important and valuable finite national resource for the future of mobile telecommunications as well as underpinning satellite communications and controls, PNT and GPS/GNSS, Earth observation and for defence purposes[70]. In future emerging capabilities including space domain awareness, in-space manufacturing and harvesting energy will depend on effective management of spectrum, placing increasing demand on an already constrained resource and requiring, as today, international cooperation and agreements[71]. It is vital that spectrum policy for the UK remains compatible with international norms, supporting the standards and coordination mechanisms offered by ETSI, CEPT, NATO, and ITU and being closely involved with international spectrum policy as technologies evolve to ensure it remains flexible. As with any finite resource, there are concerns over the potential for spectrum interference[72] and competition/ process for allocating licenses[73]. It is possible that AI and new models for combined spectrum use might help ease pressures on spectrum such as the regulatory model proposed by the US Federal Communications Commission[74].

By 2040, we are also likely to see the development and greater availability of telecommunications between multiple locations through electrical signals or electromagnetic waves and increases in space-based global broadband communication and web services through 5G and 6G.[75] There are speculative ideas for using lasers in space and in-space communications relays to transmit messages over very long

[68] International Telecommunication Union, 'HAPS – High-altitude platform systems', 2022
[69] https://www.gov.uk/government/publications/spectrum-statement/spectrum-statement
[70] https://www.ofcom.org.uk/__data/assets/pdf_file/0023/247181/statement-space-spectrum-strategy.pdf
[71] https://www.espi.or.at/wp-content/uploads/2023/10/ESPI-Space-Spectrum-Policy-Report-1-1.pdf
[72] https://www.satellitetoday.com/technology/2019/01/18/spectrum-interference-in-the-new-world-of-space-and-5g/
[73] https://www.datacenterdynamics.com/en/news/european-commissioner-calls-for-spectrum-allocation-shake-up/
[74] https://docs.fcc.gov/public/attachments/DOC-400678A1.pdf
[75] RAND Europe, Implications of Emerging Technology for UK Space Regulation, 2024, p.10

distances,[76] and in-space communications relays.[77] 6G+ communications will enable new business models and even more advanced technologies (such as virtual-reality, augmented-reality, and mixed-reality depictions of entirely computer-generated, or blended with real-world, images) that will be very data-heavy and require high-speed, low-latency networks to function effectively (which advanced satellites could provide).

Telecommunications will benefit from advances in underlying technologies such as AI and machine learning, connected sensors and the emerging Internet of Things. Integrating AI into telecommunications, for example, will help optimise network use and drive down costs.

Human Sciences

Too often, human sciences are forgotten about or treated as an afterthought. But fields including behavioural and social science research into organisational and group dynamics, along with ethnographers, cultural studies practitioners, psychologists, writers, filmmakers or artists have contributed a lot to our understanding of space, including science fiction. Drawing on these disciplines helps us explore how humans might use and even live in space in future (e.g. studying human performance in hostile environments, and developing tools to monitor human performance),[78] and how humans and machines can team. There is much interest in the future development of artificial general intelligence (should AI become sufficiently advanced to count as an autonomous and even conscious ‘crew member’, for example?). As technologies are developed for crewed spaceflight, their design should be informed by principles in line with well-being concerns as well as privacy, ethics, and trust issues. We do not yet know how to regulate or assure technologies such as crew health monitoring, which will become more important with the development of space tourism, longer crewed missions, and potentially permanent human settlements in space.[79]

Human incentives, desires, and cultural framing will be key to how the technology trends play out. They could lead us into more or fewer conflict-driven space activities, depending on how we understand and harness these incentives for a positive human future in space. Human sciences can also help us imagine and be inspired by potential space futures. Speculative literary fiction and science fiction can tell those stories, exercise our moral imaginations, and raise awareness of the opportunities and challenges, shaping not only

[76] Andrew Wagner, ’Communicating via Long-Distance Lasers’, 2020

[77] Lincoln Laboratory, ’Laser Communications Relay Demonstration'

[78] Emma Barrett and Nathan Smith, ‘How can understanding astronaut psychology benefit us all?’, Policy@Manchester , 2022

[79] Nathan Smith and others, ’Off-World Mental Health: Considerations for the Design of Well-being–Supportive Technologies for Deep Space Exploration’, JMIR Formative Research, 2023

space travellers but also the organisations and institutions that are building those space futures. In the shorter term, human sciences can help us understand and build the workforce we need on Earth, develop skills, and attract and retain a diverse range of people in the space sector and associated enabling technology areas.

The wide diversity of human cultures and societies on Earth (including in geopolitical terms) will fundamentally shape how the future of space will play out. It is naïve to imagine one united ‘humanity in space’; rather, we will need to co-create space in a diverse and inclusive way, taking different points of view and interests into account. Colonising space would be a new kind of social challenge. We should take care to prevent the problems witnessed on Earth (inequality, injustice, colonialism, racism, and environmental over-exploitation) from re-emerging in space, and to learn the lessons from this new opportunity and apply them on Earth. There are big questions around how a future human space society would be governed and made cohesive, for example should we consider space as a nation-state, with its own laws and territories? Humanities and social sciences can develop robust research to help us navigate uncertain, negotiated, and contested possible futures.[80] But funding for these kinds of multidisciplinary activities can be hard to come by, as can the people and data needed to undertake this research. UK Research and Innovation (UKRI) should fund multidisciplinary research and development projects on space capabilities which include human behavioural and social sciences and psychology, as these enable other capabilities, such as future human colonisation – noting that considerations might include *whether* to explore space, as well as how.

Novel Materials and Nanotechnology

Materials science is developing rapidly through advances in 3D printing (additive manufacturing) technologies, novel computer-designed materials, materials combining biological and synthetic components, and nanotechnology (manipulating matter on a near-atomic scale to produce new structures, materials, and devices). Novel materials include any substances that have been discovered, engineered, or synthesised which possess unique properties that make them suitable for specific applications. Graphene is an example of a novel nanomaterial with unique properties (extremely strong but simultaneously light and flexible, electrically and thermally conductive, yet transparent) that make it suitable for applications such as biosensing, energy storage, and nanoelectronics. Novel materials may advance many sectors, such as medicine, consumer products, energy, materials, and manufacturing. Advances in nanotechnology in medicine on Earth, for example, could help humans in space live healthier lives and fight disease.[81]

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[80] Space Australia, ’ What role do the humanities and social science have in space’ , 2021

[81] Fan Tong, Yufan Wang and Huile Gao, ‘Progress and challenges in the translation of cancer nanomedicines’, Current Opinion in Biotechnology, 2024

In the space sector, novel materials and advanced manufacturing techniques will create lightweight, high-strength components and coatings for spacecraft, satellites, and space stations. This could reduce light pollution in certain wavebands by making them less shiny, and potentially incorporate biological or synthetic biological materials such as wood (which is lightweight, cheap, and strong, not biodegradable in the vacuum of space, but could be inconveniently flammable in a space station).

Novel materials will increasingly be integrated using 3-D printing, lithography processes, sputter coating, Atomic Layer Deposition and other techniques to enable new designs and improve performance in areas such as heat-resistant and radiation-resistant functional coatings, materials for solar power, and energy storage devices.[82] Self-healing materials, for example, could increase the lifespan of satellites and reduce the need for in-orbit maintenance.[83] Combining materials science with synthetic biology and sensors could develop ‘smart’ materials (such as fabrics which monitor the wearer’s health and detect dangerous chemicals in the environment), or materials which change function depending on how they are being used.

Novel materials can also improve solar panel performance, thermal control systems, and radiation shielding. Design and manufacture of materials and equipment for future recycling in space, could support in-space manufacture and reduce costs. There is a potential to use in-space resources, such as the lunar or Mars regolith, as a material source for additive manufacturing, enabling us to build facilities *in situ* with less need to transport all the materials required.[84] Novel materials in space could also help us address our climate change challenges on Earth. A cloud of cheap microplastic particles in LEO, for instance, would reflect sunlight and cool our planet, while not reducing visibility from Earth or causing damage to satellites. And they would eventually burn up in the atmosphere.

However, the development of novel materials and nanotechnology can be expensive and complex, and testing new materials to demonstrate safety will be crucial. There are concerns over a lack of standards and characterisation, and uncertainties over long-term performance and reliability and the potential environmental and health impacts of disposal. We should be very careful, for instance, before putting untested materials into space which could pollute the space environment in unpredictable and potentially harmful ways. Novel materials could, in theory, be used to create weapons or explosives out of non-traditional materials which would not be detected by current technologies, or to adapt the techniques used to create novel materials with the aim of causing harm.

[82] RAND Europe, Implications of Emerging Technology for UK Space Regulation, 2024, p.15
[83] European Space Agency, ’Spacecraft, heal thyself’, 2006
[84] RAND Europe, Implications of Emerging Technology for UK Space Regulation, 2024, p.15.

Quantum Technologies

Quantum technologies are a group of technologies which rely on quantum mechanics. Quantum mechanics refers to the fundamental properties of subatomic particles, which exhibit wave-particle duality and behave according to the uncertainty principle. The principles of quantum mechanics limit how accurately the value of a physical quantity can be predicted prior to its measurement. Quantum technologies include quantum computing,[85] quantum networks, quantum sensing (radar, lidar, magnetometry, gravimetry, clocks), imaging and metrology, and quantum cryptography, including quantum key distribution and quantum simulation. Atomic clocks are already deployed on global navigation satellite system (GNSS) satellite constellations such as the Global Positioning System (GPS) and Galileo. The RHC has proposed a pro-innovation regulatory framework to develop quantum products responsibly, advocating for the regulation of the applications of the technology rather than the technology itself.[86]In space, quantum technologies could provide secure communications through quantum key distribution (QKD).[87] Several companies are already developing satellite QKD systems, although these are often seen as a stepping stone in quantum satellite communications rather than the end point of the technology's development. Free space optical communication has the potential to provide high-speed communication in remote areas and where it is not practical or possible to lay fibre optic cables. It is a laser-based system that is inherently secure and does not use traditional RF, which means that it sits within the unlicensed spectrum. Free space communication systems are currently being developed for military applications. But these systems require a clear line of light; an increasing challenge in the ever-congested space domain. Quantum communication (using quanta as the media for comms) could be a step change in capacity.

Quantum sensors are among the most developed quantum technologies. The first atomic clocks were launched into space in the 1970s to test navigation techniques. Atomic clocks now form the basis of modern GPS navigation systems but are increasingly under threat from supply chain control (see the introduction of two-way control by China, with little to stop the operator from turning it off for specific users). Other types of quantum sensors are being investigated for alternative navigation, such as magnetometers for detecting changes in the Earth's magnetic field.

[85] Quantum computers use qubits and exploit quantum properties like superposition and entanglement that both significantly accelerate the computer's data processing speed. Superposition means that a qubit is a mix of 0 and 1 but collapses into a specific state when observed. Entanglement is when particles become correlated, so that measuring one determines the state of the other, even at large distances. Source: Salil Gunashekar and others,'Using Quantum Computers and Simulators in the Life Sciences Current Trends and Future Prospects', RAND Research Report, 2022

[86] RHC, Regulation Quantum Technology Applications, 2024

[87] RAND Europe, Implications of Emerging Technology for UK Space Regulation, 2024, p.11

The promised benefits of some types of quantum technology are difficult to realise in space. Theoretically, higher-sensitivity quantum magnetometers can detect smaller changes in the magnetic field (to enable the detection of underwater objects, for example). These changes in the magnetic field are very difficult to distinguish from the background magnetic field produced by Earth and other objects. The signal-to-noise ratio is a major barrier to the use of quantum sensors in space. The terrestrial use of quantum sensors could also improve resilience by providing alternatives to space-based global navigation and positioning systems. The UK has a strategy for realising the benefits of quantum technologies[88] through the National Quantum Technologies Programme.[89]

Quantum computers can perform calculations that are not possible with classical computers. This will open a world of possibilities, even though many tasks will still require classical computers. Quantum computers are not good at handling large datasets, for instance, and are unlikely to help overcome the data deluge problem. However, they will still be useful in helping with optimisation challenges and applications that involve simulating complex relationships (such as natural capital valuation). Connecting multiple quantum computers together requires the sharing of entanglement that is not currently possible as the technology does not exist. Some proposed the concept of a quantum internet, but the future requirements for such a system are not yet clear, and nor is how this will interact with the communication network of the future. New ways of connecting quantum computers will be increasingly important in the future for lunar or non-earth quantum computing networks, where running a fibre cable back to Earth will not be feasible.

Robotics, Software and Automation

Robots are mechanical machines which can be remotely operated or pre-programmed with specific behaviours (automation) such as performing repetitive tasks. It is easy to see how robots may evolve in ways which will allow us to explore and exploit space more effectively. Since robots do not need to breathe and are less affected by radiation than humans (being usually made of steel and silicon), they are the obvious solution to operating in an airless environment that is very hostile to biological life. So far, all exploration of Mars has been done by robots operated from Earth, and the planned Rosalind Franklin rover could be operated remotely from a space station. Robots have taken scientific samples from asteroids, a comet, and the solar wind - and returned them to Earth.[90] In future, robots could be used for mining, maintenance, building other machines, and many other activities, but there is a key challenge in debris generation in close

[88] Department for Science, Innovation and Technology, National quantum strategy
[89] The UK National Quantum Technologies Programme (NQTP)
[90] RAND Europe, Implications of Emerging Technology for UK Space Regulation, 2024, p.9.

proximity operations. Some aspects of these robots' operation may be determined by AI models to enable improved performance in less known conditions (such as traversing the terrain of unmapped landscapes on other planets).

Future robots will need to be much more robust and reliable to manage the hostile space environment (including radiation, temperature fluctuations, rough terrain, dust, and hazards such as space debris). They will also need to be able to perform very touch-sensitive tasks without damaging other equipment. Some areas of robot development include bio-inspired robotics and soft robots, and various ideas for improving mobility, such as multi-legged and limbless robots.[91] Future battery and other power sources will also be very important to power the robots in space. Developing the right software is also key.

Semiconductors

Semiconductors are materials with electrical conductivity between a conductor (such as a metal) and an insulator (such as glass) whose resistivity falls as the temperature rises. Typical semiconductors include silicon, germanium, gallium arsenide and cadmium selenide. Their properties can be enhanced through chemical manipulation and combining materials, creating compound semiconductors. Semiconductors are in most diodes, transistors, and modern electronics; as such, they are essential to space technologies and the supply chain. They are used in the design and manufacture of electronic components for satellites, including microprocessors, memory chips, and power amplifiers, and are crucial to satellite telecommunications. But when used in space, semiconductors are vulnerable to radiation and, therefore, need to be 'radiation-hardened' – usually by strengthening the package materials and with an insulating substrate such as silicon-on-insulator. This process needs to be improved in future through novel design and materials (Radiation Hardening by Design) for a more reliable performance and lower product cost.

Improved semiconductors will create key opportunities, including photonics, lower size, weight, and power, higher speed, and higher resilience. Semiconductors could improve the speed and accuracy of data transmission and analysis, allowing higher volumes of data to be processed between spacecraft or with ground stations.[92] As such, they may contribute to improved GNSS and PNT, and spill-over effects across sectors such as transport, logistics, communication, and national security. Advances in future semiconductor technologies are likely to have significant impacts on space hardware, allowing for miniaturisation and improved performance and making space assets lighter, cheaper, and more power efficient. Smaller and more efficient semiconductors could enable advanced solar photovoltaic cells, improving the solar cells of satellites and allowing them to travel

[91] Hamid Marvi, 'Opportunities and Challenges in Space Robotics', Advanced Intelligent Systems, 2023
[92] RAND Europe, Implications of Emerging Technology for UK Space Regulation, 2024, p.13

further distances. Advanced semiconductors could allow for the creation of space solar farms to harness the sun's energy above the atmosphere and transmit this power back to Earth. Semiconductors could also contribute to improved sensing technologies, enhancing our understanding of celestial bodies and increasing space situational awareness. Advances in semiconductor technologies could improve the accuracy and range of space probes and rovers, enabling deeper exploration of our solar system.

It may be possible to recycle or manufacture semiconductors in space in the future, taking advantage of clean, low-gravity environments for fabrication – especially if raw materials can be found on the Moon or other celestial bodies. However, the benefits of in-space manufacture would be offset by the huge costs of taking equipment and materials into space from Earth and of returning semiconductors (gently) for use on Earth, as well as protecting them from being damaged by cosmic rays and from potential theft. Recycling in space may be useful but would require suitable design and manufacture.

The resilience and robustness of the global supply chain of semiconductors are a concern, as semiconductors underpin so many other key technologies and are hugely expensive to fabricate. The supply chain is increasingly complex, specialised, and multi-stepped, from the acquisition of raw materials in pure enough form (silicon, germanium, phosphorus, boron, indium phosphide and gallium), to design, manufacture, assembly, testing and packing. Over 90% of the world's advanced semiconductors are currently produced in Taiwan, which means that the supply chain is also vulnerable to geopolitical insecurities. The UK Government should invest in novel semiconductor materials and fundamental design for space, drawing on the Harwell test site, as the UK is very well placed to develop this element of a globally significant supply chain.

Sensors and Internet of Things

Sensors are devices that detect and measure a wide variety of parameters. These parameters can include physical properties (e.g. mass, colour), the presence and structure of chemical and biological compounds, the electromagnetic and gravitational field, fundamental particles, and position and time. Improved sensing increases our ability to detect and track what is happening, including radio and optical telescopes for astronomy, novel antennas, and camera technologies. Sensor technology is continually developing, with increasing sensitivity enabling new parameters to be sensed, thanks to advances in novel materials, improvements in data science capabilities and our deepening understanding of the fundamental physics underlying many of these sensors. Trends in miniaturisation, improved power supplies, and a growing number of proven use cases are resulting in sensors becoming smaller, cheaper and more readily available. Sensors are essential to modern life, from the atomic clocks used for GPS systems to thermistors in domestic heating systems.

Many industries rely heavily on sensors to control operations, monitor quality and for safety applications. The ‘Internet of Things’ and ‘Industry 4.0’ have driven much of the development in smaller connected sensors, creating large networks using wireless internet to collect the data generated by the sensors. These connected networks enable greater automation of processes and can improve efficiency through faster responses to the changing conditions detected by the sensors. The networks also create an increasingly ‘cyber-physical’ environment, where activities that increasingly happen online can have a real-world physical effect (and vice versa). This can include both legal and illegal activities, such as cybercrime.

Sensors are just as vital (if not more so) in space where conditions are harsher, with fewer resources and backup options, and no possible escape for humans. Many applications in space will be run remotely or autonomously with robots; sensors are needed not only for the successful operation of these systems, but also for safety monitoring and maintenance. The use of AI for anomaly detection can predict and prevent possible errors and faults. This is essential for space, where undertaking a repair that would be simple to conduct on Earth may not be possible. Space IoT networks are already emerging, allowing objects in space to communicate with one another and with Earth constantly. But all this will lead to even greater demands in data bandwidth, processing capacity and data storage. It is increasingly likely that processing capacity will become space-based for these applications to overcome the bandwidth challenge. It may be possible to hack or spoof the sensors or the connection to manipulate readings.[93]

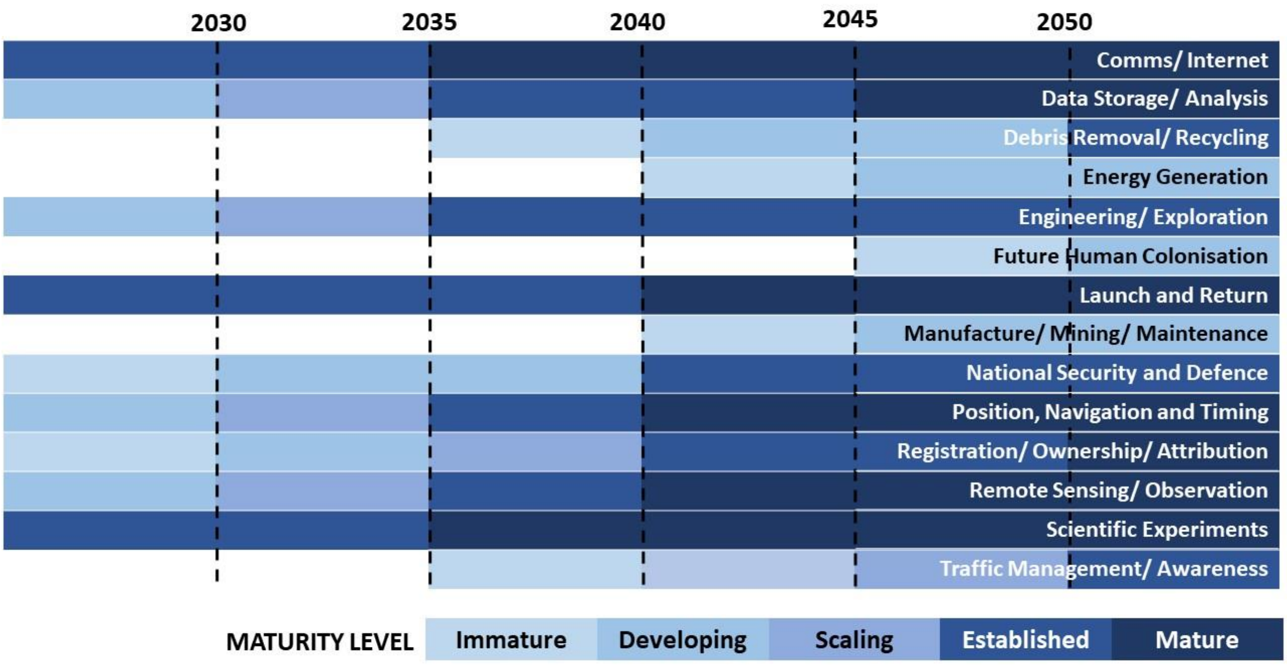
[93] RAND Europe, Implications of Emerging Technology for UK Space Regulation, 2024, p.13.

4. Future Space Capabilities

This section explores potential future capabilities created by one or more technologies described in Section 3 and considers their benefits and risks.

A 'capability' is the power or ability to do something, agnostic of the technology which is being used to achieve it. While different technologies can be developed, combined, and used (or misused) in many ways, what matters from a regulatory and development perspective is the capability that is being created. This will need a much more granular consideration of what such capabilities could mean, their potential for good, or for harm, and what this could mean for developing suitable regulatory regimes for space. "The UN…has painted the future of humanity's interactions with outer space with a broad brush, but now that technology has progressed at an increasingly rapid pace, it's time to consider the smaller details".[94] Mining outer space resources are likely to be a main driver for the future space economy and have significant implications, including for the preservation of the future space environment. However, capabilities will vary in maturity over time as they develop, as shown in the illustrative timeline in Figure 3.

Figure 3. Illustrative timeline for future space capabilities



[94] Lauren Peterson, The future of governance in Space, page 132, 2021

Table 2: Summary of capability benefits and risks

Capability	Benefits	Risks
Communications/ Internet	• Key capability dependent on satellites • Increasing global coverage • Cheaper, more reliable comms and internet • In-space long-range comms for future exploration	• Security of comms and internet from cyber-crime/ hacking • Cybersecurity • Broadband capacity • Nations could find themselves with limited access to spectrum
Data Storage and Analysis	• Key enabler of other capabilities such as communications, AI and Internet of Things • In-space processing capabilities • In-space data centres	• Challenges of access, data sharing and data protection • Need for standards • Vulnerability to debris, radiation, and space weather
Debris Removal/ Recycling	• Preventing and removing debris is a key enabler of other space-using activities • Huge potential opportunity for the UK to take a lead, including regulatory, financial, and legal services	• Technically difficult, expensive • Different solutions needed for different types/ sizes of debris • No regulatory governance for debris removal activities • Security concerns • Payment/ funding
Energy Generation	• Huge potential for solar power to solve the Earth's energy and greenhouse gas emissions challenges • Potential for Helium-3 from the Moon to be a fuel for nuclear fusion	• Logistical and technical challenges • High development costs • Wireless power transmission is possible but not yet at scale • Lack of regulatory frameworks
Engineering and Exploration	• Advancing scientific knowledge • Enabling deep space exploration • Increasingly flexible capabilities • Reusable shuttles	• Potential development of military spacecraft with weapons

Future Human Colonisation	• Support space mining and manufacture • Venues for space tourism • Future human settlements • Potential Space Nation	• Potential for inequality, war, environmental destruction, and social conflict • Claiming territory is currently against Outer Space Treaty
Launch and Return	• Potential for horizontal launch for smaller objects • At-sea launches may be feasible • Increasingly safe and reliable	• Increasing complexity of state and non-state actors • Liability based on launch location may not be a sustainable approach • Risks of unauthorised launch/ ability to prevent it
Manufacture/ Mining/ Maintenance	• Economic benefits • Benefit from space environment (microgravity and vacuum) • Use of abundant natural resources in space • Reduced risk of equipment failure/ increased lifespan • Reducing costs	• High initial costs • Harvesting energy (solar) • Time to travel to sources • Safety and reliability
National Security and Defence	• Space is critical national infrastructure and must be protected from threat • Resilience and national security are important to mitigate potential threats • Space is key to national security and defence – comms, surveillance, imaging • Support decision-making	• Potential for space 'arms race' leading to conflict or war • Most space technology and satellites are 'dual use'/ multi-purpose and could be used for military purposes • Export controls such as ITAR can restrict international partnering
Position, Navigation and Timing	• Fundamental to many commercial services including GPS and banking	• Vulnerable to solar weather and attacks/ GPS-denied environment • Need for a UK sovereign capability

Registration, Ownership and Attribution	• Global registration system • Impossible to hide launch • May be possible to tag space objects	• Need to be able to attribute in order to show liability for insurance, arbitration etc • Potential for in-space economy, transfer of ownership
Remote Sensing/ Earth Observation	• Very valuable market • Key to environmental monitoring • CubeSats increased capability	• Managing and processing data is challenging • No international legislation for remote sensing • Conflicts with copyright law – primary versus analysed data • Need for regulation and protections
Scientific Experiments	• UK strengths in key underpinning technologies • Science diplomacy fosters international collaboration • Counterbalance defence and commercial interests	• Potential to clash with commercial interests • Risky experiments could harm the space environment
Traffic Management and Awareness	• Technically feasible with optical tracking methods • UK could play a key role (like in aviation), potentially as a service • Needs a standardised method for determining position	• Requires detailed regulatory regime including safety, priority, access, control and assurance • Compliance could be an issue

Communications/ Internet

Along with PNT, communication capabilities are our most important dependency on using satellite services in our daily lives. We saw in the previous section how the convergence of technologies, including AI, the Internet of Things, data science, semiconductors, and the trend towards global internet coverage will make future communications more reliable and accessible and increase capacity. However, the use of satellite communications can be controversial, as broadcasting services and telecommunications services of satellites from certain nations may infringe on other nations' territories – if one nation wishes to restrict access to communication, this can cause conflict.

Maintaining and securing global satellite communications and internet capabilities is a key reason to ensure international peace and harmony in space and to manage our collective use of space responsibly – the key international body is the International Telecommunication Union (ITU). There are many lessons to be learnt that could be used to ensure that the challenges we face with communication on Earth are not repeated when building and creating cislunar and lunar space communication networks.[95] International agreements should be made on how to manage non-Earth-based communication networks to prevent conflict and potential harming to the space environment.

In-space communications are also vital for future scientific deep space exploration: the ability of spacecraft to communicate over longer distances without deterioration due to radiation and other challenges of the space environment could enable crewed and uncrewed missions to the Moon and Mars. Improved communication also contributes to humanity's ability to sustain space habitats over the longer term.

Launching space or stratospheric platforms is becoming cheaper and easier, resulting in a shift in the commercial landscape. Incumbent companies are becoming increasingly undertreated by new entrants who have the advantage of being able to leapfrog technology and offer new services more quickly. Spectrum sharing and management will continue to be a challenge. Spectrum is not an infinite resource: there is a risk that nations with less well-developed space economies could find themselves with limited access to spectrum and, therefore, to space. ITU and Ofcom approaches to regulating spectrum use should be refined to encourage the rollout of 6G+.[96] However, there are risks over cybersecurity, and broadband capacity remains a key constraint.

It is difficult to predict what infrastructure the future communication network will use. Quantum technologies will change our capabilities and the requirements of our communication infrastructure, but it is not clear to what extent. Free space optical communications require significant development before it can be used to transmit large volumes of data, but the rate of current satellite launches and the growing space debris around Earth may mean we are never able to realise this capability on Earth. It is essential that 'clean zones; are preserved around the Earth to create open corridors so that we can benefit from technological advances still to come, whether in communication or for safe transport to space.

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[95] Declan Dundas and Daniel Batty, 'Regulatory challenges and the future of lunar communications', 2023; Jeff Foust, 'ITU to consider lunar communications regulations', SpaceNews, 2023

[96] Caio Castro, 'Next G Alliance Plans Expanded Roadmap in 2023', 2023

The UK should work with the international community through the UN to establish strong legal protections for the space environment to limit pollution and mitigate future environmental risks and preserve 'clean zones' to act as open corridors for future use (such as for scientific experimentation, transport, and communications), with a clear regime to manage the environment including exemptions and licenced use. These would be similar to the legal protection already afforded to land, sea, and air. These are not the same as the 'safety zones' proposed in the Artemis Accords to enable small-scale *in situ* resource extraction on the Moon, which may be impractical at scale.[97]

Data Storage and Analysis

While data science is a key enabling technology, we will need considerable capabilities in data processing, storage, access, protection, sharing mechanisms, standards, assurance, analysis, and visualisation (in space and/or on the ground) to make the most of the potential for space data. As data-intensive technologies like AI and the Internet of Things increase in scale and importance, there will be a massive increase in demand for data storage and processing capacity including in space. Some satellites already have data storage and processing capabilities and do not need to send all data back down to Earth to be analysed.

While humanity already generates vast quantities of data stored in giant data centres on Earth (which are energy-heavy for cooling), in future (10 – 20 years), we could potentially see the establishment of large data centres in orbital space, which would have the advantages of low temperatures, solar power and relative security based on their remote location. However, there are significant challenges to overcome, including disruption from debris, radiation, and geomagnetic storms, and the cost/ bandwidth constraints of data transmissions. Spectrum limitations will be a key constraint on future space capabilities.

Debris Removal/ Recycling

In May 2023, satellite tracking listed 7,702 active satellites in orbit around the Earth, an unimaginable number from the perspective of the early days of space exploration. Every launch leads to the potential for more space debris – large or small, including defunct satellites and components. Any accidental collision between satellites could lead to millions of pieces of space debris: in January 2023, a Russian satellite (Kosmos 2499) broke up in orbit, generating at least 85 pieces of trackable debris (over a certain size) 726 miles above Earth, which will stay in orbit for at least the next century before eventually

[97] McKeown, Ben, Andrew G. Dempster, and Serkan Saydam. "Artemis Accords: Are Safety Zones Practical for Long Term Commercial Lunar Resource Utilisation?." *Space Policy* 62 (2022)

falling into the atmosphere and burning up. According to the European Space Agency, there are about 36,500 pieces of space junk at least 4 inches (10 cm) wide and over 130 million objects over 1 mm around our planet. About 50,000 of the largest of those are tracked by the US space agency and the US Department of Defense. Between 200 and 400 pieces of space debris re-enter the atmosphere each year, and mostly burn up before they can reach the Earth's surface. Two faint clouds of space dust called Kordylewski clouds are also orbiting Earth.[98] If a solution were found tomorrow, there is already a substantial legacy of material to deal with.

The high cost of space debris removal is one of the major challenges faced by the market: the estimated costs of developing and deploying a debris removal system range from £millions for removing small (1-10cm) debris using lasers or sweepers, to £billions for large debris by, for example, tugging it into controlled retry, or moving it further out.) Recycling debris may be even more expensive.[99] Active debris removal would be incredibly technically difficult and expensive, involving sensing, far and close proximity operations, navigation, rendezvous and docking,[100] and likely different solutions for large and small-scale debris. Proposed solutions include robotic arms, tethers, nets, lasers, and ion beams (which would be very energy intensive) – some solutions would require spacecraft to have suitable docking and navigational aids installed as standard to facilitate their retrieval. Other ideas could include inert 'space goo' to absorb micro-debris.

Even if suitable technical and financial solutions were developed, either by states or by private companies, they would need international agreements on how to operate, including the liability of the removal company (or the State responsible for its activities) if any damage were caused to third parties/countries, and needing the permission of the owner/ operator/ launch state which, especially if the spacecraft has sensitive or classified technologies aboard or other value, is unlikely to be granted. UN COPUOS guidelines on debris mitigation are 'soft law' and are not legally binding: deorbiting guidelines are voluntary and are often not complied with.[101] Interference with another State's satellite could provoke an international response, and developing, launching, and implementing a system to manoeuvre another space object could be considered a weapon and subject to international prohibition and export controls. The question of payment is complex – possible funding solutions discussed include the 'polluter pays' principle or burden-sharing in the form of a levy on space-faring nations – it may also be possible to create imaginative solutions for public ownership of these kinds of public-benefit capabilities, perhaps through 'space bonds', community shares, warrants or other financial tools.

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98 Pam Rowden, 'Earth's dust cloud satellites confirmed', 2018

99 NASA Office of Technology, Policy, and Strategy (OTPS), Cost and benefit Analysis of Orbital Debris Remediation, 2023

100 OECD Space Forum Secretariat, 'Space Sustainability, The Economics of Space Debris in Perspective', OECD Science Technology and Industry Policy Papers, 2020

101 Lauren Peterson, 'The future of governance in Space, page 147, 2021

Despite the challenges set out above, the UK could place itself at the forefront of an international programme of debris removal in addition to its wider work on space sustainability,[102] as this is one of the key enabling capabilities which will underpin every nation's use of space. The technologies required for successful debris removal are the same capabilities that can unlock the potential for future in-orbit servicing and manufacturing solutions – creating new future market opportunities. The UK Government, through the UK Space Agency, should rapidly scale up existing work for a national space debris removal and recycling capability programme and develop associated regulations, guidance, standards, financial investment, insurance, and legal regimes to operate them. This could attract co-investment from other states and industries in return for reduced rates to use the future services. The programme should set out timelines to rapidly explore, develop, test, scale, procure and safely deploy technical solutions for debris removal, including in-orbit servicing and recycling, using commercial frameworks such as Innovation Partnerships to promote collaboration and co-creation.[103] This programme can include exploring the potential for future smart labelling/ tagging – potentially at a molecular level – and a registration scheme to ensure that space debris (however small) can be attributed to its source, which would also facilitate the future in-orbit trading of satellites.

Preventing debris in the first place should also be a key objective, possibly through the application of novel materials and using materials which will burn up harmlessly on entering the atmosphere – there are concerns about the cumulative impact on the Earth's atmosphere of burning all those materials up on re-entry. Regulation will be critical to ensuring that these principles are adhered to and can also play a crucial role in how these approaches are socialised and funded. The UK Government should work with the international community through the UN to restrict the number of objects put into space to a sustainable level, with agreed quotas for spacefaring nations. This could be managed by a new international body such as an 'International Space Safety Organisation', similar to the ITU's role in managing and coordinating the global use of spectrum.

The UK should also signal the intention to put into future domestic legislation in 10 years the requirement for space objects and components to be made from materials which meet specified standards for non-pollution and minimise impact on the space environment, building on IADC guidelines, and fund research and development of the materials as well as development of the standards for satellite design and development to facilitate ready disposal. Already, a condition of UK licensing operators must have a post-mission disposal plan that is in line with international best practice, as part of the Civil Aviation Authority's (CAA) role in considering debris mitigation measures as part of its licensing and monitoring duties under the Outer Space Act 1986 and Space Industry Act 2018, which are informed by internationally agreed guidelines such as the IADC Guidelines on Space Debris

[102] UK Space Agency, 'UK builds leadership in space debris removal and in-orbit manufacturing with national mission and funding boost', 2022

[103] https://www.legislation.gov.uk/uksi/2015/102/regulation/31/made

Mitigation. In future, all companies operating in space could be required to have feasible and viable plans for the lifetime management and safe disposal of their assets (including recycling), also considering the risks of safety on Earth and on future space stations.

Energy Generation

Solar power is already used to generate energy for spacecraft in orbit, using solar panels to convert the Sun's energy into electricity, and charging a battery to power the spacecraft. Solar power in space is by far the largest potential energy source available. There is the potential for future generation of unlimited clean energy for the Earth using space-based solar power, where energy would be gathered using giant solar panels in orbit and transmitted wirelessly to Earth – potentially solving our energy and greenhouse gas emissions challenges, removing the need for burning fossil fuels or water use while not competing for land resources, and providing cheap, constantly available energy for everyone on the planet in near perpetuity (or at least the 4 – 5 billion year lifespan of our Sun). The provision of global, cheap renewable energy would have huge social and geopolitical ramifications, eliminating one of the major areas of potential conflict and hugely reducing the influence/ reliance on a small number of fossil-fuel-producing countries. While not easy to attack, the concentration of capability in one or more solar panels (which would have to be huge) and wireless transmission networks could potentially be vulnerable to State or terrorist attack, which may become more possible when space launch is cheaper, easier, and more readily available that at present.

The creation of giant solar panels in space would be a huge logistical and technical challenge and very expensive:[104] it would depend on the development of launch vehicles, large-scale in-orbit construction (even if the panels were modular, they would need assembly in orbit) and the challenges of large-scale wireless power transmission would need to be solved – although this is technically possible.[105]

Another potential energy source in space is Helium-3 which is abundant on the moon and could be used as a replacement for fossil fuels and for nuclear fusion. There are significant technical challenges to developing nuclear fusion reactors as well as political and ethical challenges associated with mining on the moon. While there is potential for humanity to benefit from using resources from the moon to create significant amounts of clean energy on Earth, there are many unknowns which could lead to irreversible damage on the Moon.

Significant investment is required to develop the technology and infrastructure for using energy generated in space on Earth, as well as a regulatory framework to ensure the fair use of this energy. As humanity continues to push the boundaries of its physical presence,

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[104] National Space Society, 'Space Solar Power Info: Limitless clean energy from space'

[105] Robert Lea, 'Scientists beam solar power to Earth from space for 1st time ever', 2023

these alternative energy sources will be required even if the energy generation does not prove viable for use on Earth.

Engineering and Deep Space Exploration

Space exploration uses astronomy and multiple technologies to develop and manoeuvre spacecraft and explore outer space, usually for the purposes of advancing scientific knowledge but, in future, potentially also to discover new resources for mining/ manufacturing and for human colonisation. Most space exploration occurs on Earth, through increasingly advanced telescopes. Physical exploration with uncrewed spacecraft is also a way to reach out beyond what can be detected from Earth. Various types of space vehicles have been developed for different types of space exploration, such as fly-bys, orbiters, landers, and rovers and are equipped with various sensors to gather information. In future these could be key for a search-and-rescue operational capability.

The design and manufacture of spacecraft will improve, thanks to technologies including novel materials, better sensors, AI, robotics, better and more efficient energy and propulsion, improved semiconductors, and potentially using engineering biology applications. More reliable reusable shuttles will be developed for launch and return trips to orbit and potentially space vehicles with additional capabilities such as in-space refuelling, space mining, debris removal, and defensive capabilities – for example, to prevent asteroids from hitting the Earth.

Predictive maintenance capabilities will help spacecraft go on longer and extend the lifespan of deep space missions. It may be in the future spacecraft can be made more adaptable and flexible, such as being reprogrammable in space or modular/ capable of disassembly and reassembly and can be designed with future removal/recycling in mind. We may also improve/ invent new techniques for long-term crewed missions into deep space, enabling human colonisation. One potential future development is for military spacecraft with weaponry to defend key space assets or nations, especially once more use is being made of space resources.

Future Human Colonisation

Space is inherently hazardous for humans, but humans have been in space continuously since 2000 aboard the International Space Station, and the record for a single person stands at 437 days. The main reasons to develop permanent human settlements either on spacecraft, or on other celestial bodies such as the Moon, Mars, and Venus are to support space mining and manufacturing enterprises (building an in-space economy), as venues for space tourism, and to continue the human species in the event of Earth becoming uninhabitable or decimated by a deadly pandemic. Some people would also find living in space inspirational and in a spirit of adventure, as can be seen in the number of people willing to pay vast sums to travel into space – while others would see the pursuit of human colonisation of space as an enormous waste of time and money which could be better spent fixing problems on Earth.

It is most likely that the first human settlements in space will be professionals undertaking difficult and dangerous work in harsh conditions and associated medical and psychology staff to support them. As there are no people living there already, initial ethical concerns over colonialisation do not arise, but as more communities exists, this will be a future consideration. We will need to consider the obligations placed on them to provide aid to other space-users and clarify their status as 'astronauts', perhaps with more categories of space-users. As well as health and safety, we will need to consider law enforcement in space, and think about how to defend and keep these people secure. Over time – maybe by the end of this century – we may see the sustainment of entire communities with secondary occupations – support, services, art, leisure – and even new human cultures, languages, and societies. In this future, humans (and animals) are likely to be born in space, and their rights need to be considered to ensure they do not become stranded in the event that humanity must all return to Earth.

The human colonisation of space has huge ramifications for humanity and how we perceive ourselves. The future settlement of the Moon raised many questions at a cultural, psychosocial, ethical, and legal level. There is no clear international agreement as yet on how this could be negotiated (many nations are not parties to the Moon Agreement of 1979), and it may need a specialist international Civil Lunar Organisation for the purpose. Space colonisation is, in one sense, a chance to start over and build new human communities from scratch to reflect the more aspirational, better side of humanity and fix the mistakes we have made historically on Earth. On the other hand, we could export into space communities all the inequality, war, environmental destruction, and social conflict we have seen play out in our history on Earth. An immediate objection is the effective claiming of space territory, which is currently outlawed under the Outer Space Treaty: even then, there were concerns that advancing activities in space could lead to conflicts as both spacefaring and non-spacefaring nations compete to acquire control over strategically and economically significant space assets and resources.[106] The establishment of a new space nation in space could be a positive approach, which could resolve many of the issues around Earth-based nation-states owning or controlling areas of space or celestial bodies. Such a nation could be populated by emigrants from different nations, and then trade with Earth-based nations, and through multilateral agreements with its own government and laws. We will need to start to commission speculative work, research, and public

[106] Lauren Peterson, 'The future of governance in Space, page 111, 2021

engagement on these issues sooner rather than later and start to build consensus over how future human societies in space can establish new patterns.

Launch and Return

The key capability for space is the ability to put spacecraft into outer space (and, increasingly, be able to land them again on Earth or a different celestial body). This is the foundation of most activities in space. Launch has become increasingly safe and reliable, and several space shuttles have now demonstrated the ability to launch and return reliably – however this remains by far the most dangerous part of a space operation. Currently the OST imposes a direct responsibility on states to authorise and continuously supervise the space activities of private actors operating in their territory (this is now customary international law and as such applies to third-party states which are not signatories to the OST) – the only exception to liability is in the case of sabotage. The basic approach of all space activities being effectively underwritten by launching states, who are taking full liability based on the territory of the launch location, is unlikely to be a sustainable approach in future, and hampers the development of effective space law. In future, space objects may be manufactured or assembled from parts in orbit, without ever having been 'launched' and thus fall outside the current approach.

Thanks to the UK's northern latitudes, we are well-placed to reach polar and near-polar orbits using vertical launch. Scotland is the best place in the UK to reach in-demand satellite orbits with vertically launched rockets, and two vertical launch sites are being built: SaxaVord Spaceport, on Unst in the Shetland Isles; and Space Hub Sutherland, in Sutherland, Scotland. Spaceport Cornwall was the site of the first orbital launch from UK soil in 2023, although the payload failed to reach orbit when the rocket's second stage malfunctioned. Spaceplanes and other space transportation can be launched at several aerodromes around the UK. In future, horizontal launch will be increasingly used for launching small things into space and will enable a greater range of organisations and countries to participate in launch. Using existing airport infrastructures, many countries may need to make a few changes to be able to take advantage of horizontal launch capabilities. For small nations, such as the UK, this will reduce reliance on other countries. At-sea launch provides further challenges around where responsibilities lie and the risks this may pose: the UK's Space Industry Act sets out which regulations apply, which depend on whether spaceflight is launched from UK territorial waters or from a UK-flagged ship, or from a foreign-flagged ship outside UK territorial waters by British nationals, UK incorporated company or Scottish firm in which case the UK's Outer Space Act 1986 applies.[107]

[107] Civil Aviation Authority, 'Guidance on duties for all licensees under The Space Industry Act 2018 including monitoring and enforcement by the regulator', 2021

The UK needs to create the right ecosystem to manage regulation with clearly allocated roles, remits, and responsibilities fit for the future development of mature space capabilities. In the UK, all launch activities are regulated by the Civil Aviation Authority (CAA). As the UK's launching capabilities increase, it is essential to ensure the CAA has appropriate requirements and regulations in place, with appropriate means and power to act on potentially harmful launch activities. The UK Government should consider whether the range and complexity of future space activities may require over the next decade the creation of a separate specialist space regulator to shape and enact future regulatory policy and be responsible for pursuing the UK's interests in space in an ethical, proportionate and values-led way, taking over from the current CAA Space Regulator and relevant parts of Ofcom, the UK Space Agency, and Health and Safety Executive, and potentially parts of the Information Commissioners Office (ICO) as the relevance of space data grows. As this would require significant primary legislation and upheaval, the benefits and costs of this need careful consideration, including clarifying how a new space regulator's remit interacts with other regulators' terrestrial remits.

As the costs decrease and technologies advance, the risks of an unauthorised launch by a rogue entity or person increase; while not sabotage, this could leave states liable for whatever activities take place in their territories, whether known or unknown. At present there are no criminal or civil penalties which clearly apply, and it would be difficult for the police to act and to prove who was responsible - depending on the circumstances. If, for example, someone was killed, it could arguably come under murder, manslaughter, or corporate manslaughter law, but also 'astronauts' are specifically exempted from being able to sue for loss of life or injury.

Manufacturing/ Mining/ Maintenance

Manufacturing and mining in space are key drivers for space exploitation and could yield significant economic benefits. We are still learning what natural resources may be available for humans to exploit in outer space through extraction and processing of raw materials (in-situ resource utilisation), reducing the costs for future space missions by reducing the need to launch everything needed from Earth. Raw materials from space can be used to manufacture objects and replacement parts – or even construct buildings – in space, either for use in space, or return to LEO, or to Earth. Metals and metal ores are the most likely sources for in-space manufacture, and many of the techniques used on Earth can be used or modified for space. Mining space resources could solve some supply chain challenges on Earth – for example access to some rare minerals but could also crash the economic value of high-value goods such as gold, silver, or platinum if the market were to be flooded. Hydrogen, helium, and oxygen gases are all present in the space environment, and water is cosmically plentiful, including in the form of ice. Manufacturing oxygen and water in space would enable people to live sustainably on spacecraft or human settlements on celestial bodies – for example, it has been shown that oxygen can be liberated from the lunar regolith by heating to 2,500 °C in a vacuum, although as yet this is an inefficient process.

It is possible to manufacture or assemble in space products that benefit from the space environment (microgravity, vacuum, and high/low temperatures) or could not be made on Earth. Research has been carried out on materials processing in microgravity exploring crystal growth, molten-metal, electron beam welding, 3D printing (including of food), plastic recycling, and the behaviour of liquids (forming spheres), suggesting that differences in material properties in space could have applications for manufacturing: for example enhancing the growth of large high-quality crystals, creating very pure defect-free materials in ultraclean environments (such as for semiconductor wafers), and using the temperature gradient to produce strong glassy materials. One company on the International Space Station (ISS) is pioneering a method to produce artificial retinas in LEO using microgravity and export them back to Earth, potentially reducing the costs of cataract surgery; while another can produce fluoride glass optical fibres (ZBLAN) with zero defects compared to microcrystal defects when produced on Earth. Processing and manufacturing facilities next to mining facilities reduce the need to move raw materials around. There are daunting challenges to overcome, including high initial costs to launch and build facilities, harvesting enough energy (likely solar power) and the time needed to travel to the source – robotics, autonomous systems and AI will help. In the short to medium-term, the high costs of obtaining the resources would make space-derived materials very expensive, but over time, costs would reduce, making in-space mining and manufacture economically viable. Eventually, in-space economies and settlements could be self-sustaining without the need for replenishment from Earth.

Predictive maintenance is the systematic monitoring and analysis of equipment and application trend modelling to predict the potential for equipment failure in order to provide early warning, schedule repairs, mitigate the risks of catastrophic failure and reduce costs. It can also be used to feedback on next-generation design to improve performance. It can be a simple visual inspection, but increasingly sophisticated technology and data science tools are being deployed including AI, sensors, lasers, novel materials and 3D printing, statistical probability analysis, and digital twins (computer models of equipment or systems) to ensure greater accuracy. In space, predictive maintenance can increase the lifespan of spacecraft and equipment and save lives: it can also reduce the costs of transporting spares for replacements – in future, it may be possible to 3D print, grow or self-repair replacement parts, for example, using engineering biology. There are challenges to address regarding safety, assurance, and reliability.

International law is at best unclear on exploiting extra-terrestrial natural resources: “The purpose of space mining activities is considered to be neither an ‘appropriation’ of parts of outer space nor of space resources in situ. Instead, the sole aim of any such activities is their extraction, use and commercialisation, without any territorial demands or titles as to the celestial bodies (or parts thereof) concerned".[108] The regulation of claims to mineral resources has so far been an issue of international agreement rather than an extension of state jurisdiction, given that the OST explicitly prohibits claims of sovereignty to any part of outer space, including the Moon and other celestial bodies. In the absence of international administration and allocation, it falls on domestic legal regimes to authorise and monitor commercial activities,[109] which may make the rules in their own economic favour. The principles set out in the OST are likely to come under strain in future, as state, privately owned and potentially state-backed/ public-private partnerships could seek to assert private property rights in space. The principle has already been established that objects taken from space can be owned, bought, and sold. While the legal status of the Moon and celestial bodies has been detailed in later international regulation, this does not cover extra-terrestrial natural resources or instances such as recycling resources on the spot, accessing water or other resources for immediate use and not extraction, or conversion, such as converting Helium-3 into energy sources which are then transported. There is also the potential to mine defunct spacecraft and man-made objects for parts and materials.

The UK Government should work with the international community through the UN to develop an international regime to govern, authorise, and manage future space mining and manufacturing activities with a holistic and impartial perspective that prioritises environmental protection, peace, and equitable use.

National Security and Defence

Because modern societies are so reliant on space for GPS, telecommunications and other services, space is part of the critical national infrastructure and needs to be protected to ensure resilience. A sufficiently severe attack on these services using anti-satellite (ASAT) technologies could paralyse and cause huge disruption to our daily lives. Ensuring these assets are secure and do not come under threat is a key concern: it is not clear how we could effectively defend satellites against a direct attack in space. Cybersecurity (or electronic warfare) is also a key concern to prevent hacking, hijacking, jamming or other interventions such as using lasers to dazzle. The operators of these key capabilities may also be subject to blackmail with the threat of disruption. Ensuring the resilience of critical space infrastructure is important, including having plans to prepare for and recover from any major future conflict or accident that may occur in space, 'wargaming' and future scenario development, and taking action to reduce the likelihood of such incidents occurring. Domestic guidance and standards for cybersecurity will need to be developed and, where possible, made the foundation for an international agreement, including secure-by-design principles. Organisations and businesses in the UK's space sector and

[108] Tanja Masson-Zwaan and Mahulena Hofmann, 'Introduction to Space Law', Fourth edition, 2019, p.99

[109] The US, Luxembourg and UAE have all take steps towards domestic law on space mining activities

supply chain should be aware of the potential threat of hacking, espionage and spying, including human vulnerabilities (recruiting people knowingly or unknowingly to provide intelligence to hostile foreign intelligence agencies). National security organisations are alert to the threats but need to do more to ramp up specialist expertise and ensure they have the requisite powers and resources to gather and analyse relevant intelligence, develop strategies for deterring and mitigating these threats, and identify hostile groups and actors who may be intent on causing disruption to critical space capabilities.

The UK and international community will need to clarify the many potential jurisdictional and information-sharing issues which could arise from crimes being committed in space, using space technologies, or against space capabilities (such as future space piracy) and plan for such eventualities so that the response is fully developed, proportionate and understood. While Article 22 of the *International Space Station Intergovernmental Agreement (IGA)* sets out principles of criminal jurisdiction (the state of nationality of the alleged perpetrator of a criminal act has jurisdiction to prosecute but if it fails to do so within a reasonable period, the state of nationality of the victim has the right to do so), this has not been tested in court. Future issues could include jurisdiction, mitigation, liability and extradition for future crime, espionage, fraud, terrorism, hacking and other hostile acts. Potential complexities arise over who is considered the victim (one or more nation-states and/or private actors), the burden of proof and the likelihood of obtaining evidence, policing and investigatory authorities and actual ability to investigate, the practicality of returning the alleged criminal to Earth and finding a court whose jurisdiction is recognised.

Space also has a key role to play in delivering national security and defence, through a complex mix of civil and defence interests and infrastructure. Defence uses satellites for PNT, communications, surveillance, and imaging to support ground operations and improve strategic and tactical decision-making, such as weather reports (Intelligence, Surveillance and Reconnaissance capabilities), while national security organisations are interested in signals intelligence (SIGINT) from satellites, and the ability to undertake mapping and some surveillance. Satellite systems have become an integral part of nuclear deterrence by providing strategic warning of an attack, as well as tactical warning of missile launches. Defence also uses commercial space services – and as these services become increasingly sophisticated, countries without their own defence satellite capabilities will be able to take advantage of commercially available services to create nearly equally effective capabilities without needing to invest in their own infrastructure.

Key technical priority areas for defence include: maintaining a sovereign capability in antennas and receivers (especially phased array systems, with beamforming, shaping and null generation capabilities); secure inter-satellite link systems; reconfigurable software processes technology including reconfigurable processing for data traffic routing, and the generation of waveforms; tracking, telemetry and control using UK cryptography solutions and jamming protection; platform resilience against radiation and electromagnetic interference, laser dazzling, and radio frequency (RF) spectrum activity; system integration and testing; data; and sensors including in radar system integration, and passive RF sensing. Maintaining a secure supply chain for all these capabilities is also a key concern. Understanding areas of mutual dependency and, equally, independence or operational redundancy gives defence strategic choices such as undertaking disruption activities without disadvantaging oneself.

The key concern for the potential increasing militarisation of space is the 'arms race' towards weaponisation (either putting weapons into space or using other technologies/ satellites as weapons) – complicated by the fact that any manmade object in space is potentially 'dual use'. Any satellite is itself a potential ballistic missile. The UK's Defence Space Strategy 2021 sets out how space is now seen as an operational domain and the kinds of threats we might face.[110] A nuclear weapon detonated in space would be vastly more dangerous than electronic warfare, laser dazzling, cyber-attacks, or orbital ASATs (anti-satellite weapons). Directed energy weapons, including lasers, could damage satellites or components, and cause debris which could cause further damage. The Defence Space Strategy notes that Russia has conducted on-orbit activities, including contesting the electromagnetic spectrum and targeting the link between satellites and ground segments. Twice in 2020, Russia continued with its series of test launches of Direct Ascent Anti-Satellite weapons and in 2021, Russia conducted a destructive test that resulted in at least 1500 trackable pieces of debris in low earth orbit, which was condemned by many. China has a robust direct-ascent anti-satellite (DA-ASAT) programme, multi-use capabilities on an orbit that are necessary for Co-orbital ASAT weapons, and widely used electronic and cyber counter-space capabilities. The US also has significant military capabilities in space and a separate Space Force: many other nations have created a Space Command or similar.

All nations are mutually vulnerable in space, so alliances between nations have formed to coordinate defence capabilities in space, such as the Combine Space Operations Centre (CSpOC) between the USA, the UK, Canada and Australia. There could be a slippery slope – or potentially rapid escalation – towards in-space conflict, drawing in private actors, especially as ground operations increasingly rely on commercial satellite support – for example Russia saw Starlink as a legitimate military target because it was helping Ukraine. While the 'Space Race' of the 1960s, in which the US and Soviet Union competed to get to the Moon first, undoubtedly drove rapid technological advances, the dangers of future space war, hybrid war or sub-war conflicts are considerable. We could see a future version of a 'Cold War' play out in space, with the development of 'Space Statecraft' exploring nations' mutual dependencies.

In order to protect the interests of national security, export controls are placed on space technologies and components that are considered to be dual-use (e.g. they could be used for military purposes, even if the intention is for civilian purposes). The specific nature of

[110] Ministry of Defence, 'Defence Space Strategy: Operationalising the Space Domain', 2021

export control legislation varies between countries as well as several international control regimes: the US ITAR scheme is widely seen as an inhibitor of innovation and international partnering. While it is important to protect sensitive information and assets, the right balance needs to be struck so that mutually beneficial technologies can be developed and used multilaterally, and scientific information can be shared to enable learning.

Position, Navigation and Timing

PNT capabilities are essential for all kinds of civil and commercial services such as geo-positioning, mapping, and navigation – anything where it is important to know the exact position of an object at a specific time. Precision timing is achieved by an international network of independent atomic clocks on Earth which are synchronised to a series of atomic clocks on satellites in orbit: the time is accurate to a nanosecond. GNSS provide these highly accurate time signals to anyone who needs them: for example, global financial services like traders and banks use them to determine the precise time of trades, because high-frequency trading algorithms mean just a few microseconds can impact the profitability of a financial trade. Financial regulators mandate trading timestamping to at least 100 microseconds accuracy.[111]

Knowing a user’s exact position (latitude, longitude, and altitude) at a precise point in time (using atomic clocks) can be used to calculate other information such as speed, bearing, distance to destination, and provide other kinds of information such as on terrain. The GPS has become ubiquitous in people’s smartphones, smartwatches, vehicles, transport and logistics systems and is accurate to 1 metre: it is provided by 24 satellites orbiting the Earth at an altitude of 20,000 km and transmitting timing services at c. 1.5 GHz at no cost. However, GPS is vulnerable to solar weather and attacks from adversaries seeking to cause harm by disrupting or manipulating the GPS signal by jamming, spoofing or distortion, leading to defence organisations, for example, developing alternative navigational tools for ‘GPS-denied’ environments. Similar satellite systems to GPS in use currently are Glonass, Galileo and BeiDou. Because of the criticality of PNT to infrastructure on Earth on which many other services rely (such as police and fire brigade) the resilience of PNT is an issue of national and international concern. Dependency on GNSS can be mitigated with parallel terrestrial and LEO satellite solutions. In future, we may see improved geolocations for even greater accuracy, fusing PNT payload applications with other data sources and more means to detect and prevent spoofing and jamming.

The UK should seek to establish an assured onshore integration capability in atomic clocks and timing with a clear assurance approach towards the highest precision useful

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[111] Richard Hoptroff, ’GNSS vulnerabilities: securing the future of finance with new PNT solutions’, Finance Derivative, 2023

timing devices - at present, these are optical lattice clocks whose precision is 1.5E-16 - and the architectures by which these precise time signals are distributed. This assurance approach must manage a ‘single version of the truth’ via approved error correction functions, designs, and implementations of holdover clocks/ receivers/codecs. The distribution of time could then be stated as the highest possible standard of reliability and precision through a successful assurance process outcome. Despite the UK's strength in the fundamental science there is no UK sovereign infrastructure, PNT services are provided by other nations. Building on the recently announced crisis plan in the event current PNT services are unavailable[112], the UK Government should create a terrestrial PNT distribution network to further ensure resilience in PNT.

Registration, Ownership and Attribution

In order to be able to manage our use of space safely, we need to know where objects have come from, who owns them and be able to attribute to source in the event of an accident in order to determine liability. While it would be possible to determine the origin of a manmade object from an inspection this is difficult to do *in situ* and is not currently possible for small fragments of debris. In the event of spacecraft or debris falling to Earth or causing damage in space, the ‘victim’ State may not be able to ascertain or prove the origin in order to report, claim damages or initiate recovery. It may be possible to facilitate attribution through smart labelling (even at a molecular level) to ‘tag’ space ‘objects’ ownership to particular countries, or companies. As more and more states have a presence in space, these capabilities will become even more important. More than 80 countries now have a presence in space: the United Arab Emirates has sent a probe to Mars, Israel has (crash) landed on the Moon, and Nigeria has built satellites.

The Registration Convention 1962 requires signatory states to register any space objects launched: this is how we know that at least 2,478 objects were launched in 2023 compared to just 120 in 2010 (however, registration does not cover 100% of what has been launched). It is to every spacefaring nation’s advantage to ensure that such information is collated and shared in an openly accessible register, but the Registration Convention does not specify when information is to be provided and some states launching classified satellites for national security and defence purposes are unwilling to provide registration. States are similarly reluctant to comply with rules on sharing information obtained through Earth observation. However, because it is impossible to hide a space launch (the entire planet has radar and sensing coverage which can track and follow any reasonably-sized space object launch) there is a good ability to know when

[112] https://www.gov.uk/government/news/critical-services-to-be-better-protected-from-satellite-data-disruptions-through-new-position-navigation-and-timing-framework

objects have been launched and roughly where they are (although not what they are for, or plan to do, which can only be inferred if verifiable information is not shared).

The UN Registry could benefit from modernisation and a universal approach agreed on what must be registered and how. Having a clear system for registration, ownership and tagging would also enable the future economy of in-orbit trade of satellites and components, as ownership (and responsibility for operations) can be transferred. Current regulations around ownership and responsibility of artificial objects in space do not provide a standalone framework for the in-orbit trade of satellites and constellations (but so far these have been resolved bilaterally at the Member State level): however as more commercial entities own and operate satellites, there is greater potential for trade or bankruptcy while their satellites are in orbit where ownership would need to be transferred (including operating capabilities). States may also wish to prevent technology they have paid for or consider sensitive from being traded to some other nations. All this could lead to complicated situations arising. The UK Government should extend the remit of the National Security and Investment Act to cover the future in-orbit trade of assets, goods, and services (for example, selling a satellite or components in orbit) and how bankruptcy would be handled for in-space assets.

Remote Sensing/ Earth Observation

Remote sensing is the science of obtaining information about objects or areas from a distance. Remote sensing data is a hugely valuable commodity and one of the space economy's largest elements, with an anticipated market size of $29 billion by 2027. Remote sensing data is used for mapping, meteorology, archaeology, urban planning, military reconnaissance and intelligence, environmental monitoring, ocean topography and managing natural disasters.

Earth observation is a subset of remote sensing but specifically focused on imaging – that is generating pictures of the planet Earth from above, for the purposes of environmental monitoring such as seismic activity, water quality, wildfire, landslide detection, and land and air pollution analysis. Earth observation is becoming increasingly vital for agriculture, transport, logistics and insurance. Earth observation is a key enabler for the regulation of environmental protection.

Earth observation capabilities have increased significantly in recent years due to technical developments in sensor and CubeSats, reduced launch and operational costs (through as-a-service models), and the relative ease with which new entrants can enter this market. There is a wide range of commercial companies providing earth observation services, of varying degrees of maturity and size. As more sectors become aware of the commercial benefit to be gained from the use of earth observation data, new issues arise from lack of fit-for-purpose regulation around data use.

One of the biggest challenges associated with gaining value from remote sensing is the managing and processing of huge data sets. The challenge starts with getting the data back down to earth in a timely manner and then aggregating and standardising it to be able to use it for a given application. Advancements in telecom technology, data science and AI are being used to overcome these challenges. Reducing the barrier to entry for the data analysis will enable more businesses to use the data to gain a competitive advantage, improve operational practices and demonstrate compliance with environmental laws.

There is no international legislation covering the use of remote sensing, but various states have developed a range of legislative, regulatory and policy means to govern access to sensitive data. As remote sensing requires a launch, the launching State is responsible for supervising remote sensing activities and ensuring they comply with State law: however, it is unclear how remote sensing activities can be actively monitored or lack of compliance detected and addressed. The UN Remote Sensing Principles 1986[113] is a non-binding agreement on limited applications for civil purposes – natural resource management, land use, and environmental protection – but does not cover military activities or use (even when the military is purchasing commercial data which is also used for civil purposes). The Remote Sensing Principles set out:

- All States have rights to data collection from space without prior consent or notification;
- States cannot veto another state remote sensing their territories;
- Areas cannot be exempted based on geographic considerations; and
- There are no conditions imposed for sensing capabilities in terms of spatial and temporal resolution;
- Remote sensing shall not be conducted in a manner detrimental to the legitimate rights and interests of the sensed State
- As soon as the primary data and processed data…are produced, the sensed State shall have access to them on a non-discriminatory basis and on reasonable cost terms (i.e. there is no financial privilege for the sensed State)

The Remote Sensing Principles do not impose responsibilities on those who are merely receiving images or data handling, or third parties using the data, and are inadequate for addressing the increasing commercialisation and aggregation of space data. There are no specific obligations imposed on the sensing State for liability for misuse of data or data protection. While the Principles set out that remote sensing cannot be detrimental to the sensed State, it is not clear what the rights of the sensed State are and – given that no

[113] United Nations Office for Outer Space Affairs, 'Principles Relating to Remote Sensing of the Earth from Outer Space', Resolution Adopted by the General Assembly

notification is required – how the sensed State could know it is being sensed, how it could object, and on what evidential basis. There would be no ramifications for the sensing State for failing to comply with any requests to stop on the grounds of detriment. These Principles do not cover remote sensing of the Moon or other celestial bodies, nor of satellites which may not considered the ‘territory’ of the launching state (or a collaboration of multiple states). Furthermore, any potential harm is likely to lie in what is being done with the data being collected – how it is being interpreted and used - rather than in sensing *per se*. Data availability from sensing states is based on good faith: there are no legal mechanisms to enforce them to release data.

There is also the fundamental problem – not only in the space sector – that much of the data is (now) being collected by private companies and State authorities do not automatically have access to the data (either raw or processed) and are not data owners or controllers. The Union of Concerned Scientists has counted over 1,100 active satellites observing Earth, over 550 of which are owned and operated by private entities.[114] An example of the challenges is how commercial Earth observation companies publicly released images of atrocities in Ukraine to the public, prompting Russia to declare the companies legitimate military targets. The situation in Gaza is also being publicly documented by satellite operators. There are issues over data ownership, access, and usage rights (including third-party usage), data privacy, verification, image resolution and how derivatives are handled. The line between civil/commercial and defence interests is blurred, and the lack of clarity over remote sensing data ownership, aggregation from multiple sources, and use creates uncertainty.

The requirement to make remote sensing data available to all users on a non-discriminatory basis leads to a potential conflict – or at least a grey area – with copyright laws. While copyright would apply to analysed data (which has undergone value-add activities) it does not apply to the primary data and may or may not apply to processed data.[115] The lack of clarity here forces database-generating companies to engage in value-add activities (such as adding overlays, labels or combining datasets) in order to assert control over the data they have collected. The EU Database Directive 1996/9 set out legal protection for databases of primary data to protect the copyright of the selection and arrangement of content, and the investment of resources and cost involved in obtaining, verifying, and presenting data: this could be argued to cover the collection of remote sensing data. Overall, remote sensing is an area in need of strong international regulations and protections to provide appropriate clarity and confidence, including public confidence and trust.

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[114] Catherine Amirfar and others, ‘Remote Sensing from Space: What Norms Govern?’, Just Security, 2023

[115] Yi-Ping Chen and others, ’Legal protection and data access of remote sensing and GIS database’, 2007 IEEE International Geoscience and Remote Sensing Symposium, 2008

Scientific Experiments

The UK has world-leading strengths in specific areas of science and technology, which we should focus on developing into scaled products and services. Our strengths in data science and AI, telecommunications, PNT, quantum technologies, semiconductor design, engineering biology and novel materials are all fundamental to developing space capabilities. While the space sector is only one 'lens' to apply to these underpinning technologies, developing the 'space edge' in these areas could give the UK a significant strategic global advantage and a 'seat at the table' in terms of significantly influencing the direction of development in other spacefaring states. The UK can be a thought leader in horizon scanning and developing space capabilities and the regulatory and innovation environment that enables them. The UK Government should sustain and leverage our strong track record of global 'science diplomacy' to pursue the objectives set out in this report.

Throughout the history of space, scientific endeavour – that is, undertaking experiments for the purposes of increasing scientific knowledge – has been a uniting purpose, bringing together multiple nations on the International Space Station (essentially a shared laboratory space) and in joint endeavours. As such, space has significant value as a means of 'soft' diplomacy and of facilitating multinational collaboration. Space is also a thriving area for 'Citizen Science' collaborations.[116] The UK has a thriving partnership with the ESA, investing a record £1.84 billion between 2023 – 28 including delivering the TRUTHS space climate laboratory which will set the standards for satellite climate measurements, and the Microcarb joint mission with France, which will be the first European satellite dedicated to measuring atmospheric CO_2 from all around the world.[117] The science of space (including astronomy) has also had valuable spin-off benefits for on-Earth technologies, products, and services. However, the competing interests of science (such as astronomers wishing to retain dark skies for their telescopes) and commercial interests may increasingly collide.[118] We need to preserve opportunities for future science and innovation, such as clean zones for future scientific experimentation.

Scientists can help foster public discourse and provide a counterbalancing narrative to defence and commercial interests in space. In the future, the establishment of permanent space laboratories will help to develop novel technologies for the benefit of humans on Earth and in space and help us to find novel solutions to challenges such as climate change and overpopulation. However, we also need to ensure that scientific experimentation does not lead to risk-taking which could have unintended or accidental

[116] https://science.nasa.gov/citizen-science/

[117] UK Government National Space Strategy In Action, 2023.

[118] Nikita Amir, 'Light Pollution Threatens Millennia-old Indigenous Navigation Methods', Discover Magazine, 2021

negative consequences. Ensuring equity of access to the benefits of science is also important, particularly if there are trade-offs where some people may lose out.

Traffic Management and Awareness

As more use is made of the space environment for all kinds of purposes, it will become increasingly important to manage traffic flows, allocate slots for the use of LEO, attribute and track the movement of objects in orbit to prevent collisions occurring (and thus reduce potentially expensive damage to spacecraft and the likelihood of space debris). This relies on optical tracking using telescope networks, sensing, and radar: some objects reflect light better and are easily visible. 'Space situational awareness' (SSA) and 'space domain awareness' (SDA) are important for enabling a future space 'traffic management' system: SSA is defined by the MOD as the provision of sufficient understanding of the risks and hazards associated with domain congestion and complexity to enable safe and effective space operations, and SDA 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.[119]

Developing space traffic management could be seen as analogous to aviation, where the UK played a key role in the expansion of international air services from the 1920s and in the development of the civil aviation framework after the Second World War. However, there are key practical differences in space, such as sparse sensing, astrodynamics, and uncertainty representation. Effective space traffic management relies on sensors and data science to monitor position, as well as a strong internationally agreed framework for safety measures, priority, access, control. and assurance – for example, agreed contingency measures, near miss reporting and accident investigation. For example, there needs to be agreement on how to access and use strategic locations (such as Lagrange Points – a small number of positions in space where objects tend to stay put in equilibrium between two opposing gravitational forces, but which can also be difficult environments as they are also areas where debris collects), and who can access key resources to avoid the chaos of a 'gold rush'. A standard method for verifying position will be required to allow this traffic management, strategic locations in space and resources in space.

In defence, the UK Space Operations Centre (UK SpOC) collates, analyses, and assesses space information in order to support the UK and allied forces, and coordinate operational space activities for Defence: at present, this is not a wider civil capability although work is underway to develop a combined military and civilian National Space Operations Centre (NSpOC) to collate, analyse, and assess space object monitoring data in order to coordinate operational space activities for Defence, support UK and Allied Forces and

[119] UK Government, Joint Doctrine Publication 0-40 UK Space Power, 2022

provide conjunction alerts and monitoring services for UK-licenced satellite operators. Services from the NSpOC could be made available to commercial operators through the ‘Monitor My Satellite Service’ and to research institutions - but there are many issues still to iron out.

The UK should develop a framework and functions for a future ‘Space Traffic Control’ system and civil tracking capability which would enable safe, reliable, and managed access and use of outer space, including monitoring space debris and space weather, and which the UK could offer as a service to the international community. This could be achieved by establishing a multinational specialist capability (‘International Space Safety Organisation’) to inspect and enforce internationally agreed regulations and share information and best practices on similar lines to the International Maritime Organisation (IMO) or the International Civil Aviation Organisation (ICAO) – possibly through a hub-and-spoke model of central expertise with small teams embedded in key spacefaring nations. International law could include powers for the organisation to temporarily step in and take over the control and operation of remote-operated spacecraft and associated services, if necessary, until they can be brought under control and made safe. The UN 2024 Summit of the Future could provide an opportunity for the UK Government to call for a new Convention to agree on the elements of a new International Space Safety Organisation, like the 1944 Chicago Convention that established ICAO and the 1948 Geneva Convention that established the IMO.

5. Exploring Future Scenarios

This section summarises our work to develop potential future scenarios and understand where the UK could best leverage strategic advantage.

SWOT analysis

We undertook a SWOT analysis to understand from the UK's perspective where the strengths, weaknesses, opportunities, and threats lie.

Table 3: SWOT assessment of UK position

STRENGTHS	WEAKNESSES
• Space inspires people/ public interest • Driver for scientific discovery • Spin-out benefits for products/ services • Low gravity benefits for manufacture • Potential new energy sources • UK's diplomatic, financial services and legal strengths • UK seen as a trusted honest broker (not a big player ourselves, fewer vested interests) • UK has strong technical and data science capabilities	• Scepticism over billionaires/ tourism • Skills scarcity • Over-reliance on space services/ resilience/ potential for costly disruption • Overcrowding/ space junk and debris • Potential for future conflicts in space • High capital costs and infrastructure • Unclear regulatory environment/ lack of international agreement in key areas • Lack of clarity over terminology, determining position, attribution • Fragmented ecosystem, roles and responsibilities unclear
OPPORTUNITIES	**THREATS**
• Global digital services/ broadband • Equity and fairness as a key purpose, sustaining/ managing space resources • Addressing (maybe solving) energy and climate change challenges • Future overpopulation – colonisation of space could help our species survive • UK could lead on space law, develop a space traffic management system and lead on debris removal services	• 'Arms race' militarisation of space • Cyber criminals/ organised crime/ state-sponsored threats including espionage • Competition and profit motives lead to unrestrained 'gold rush' (first mover advantage/ soft power) • Potential pollution and destruction of space heritage/ scientific discovery • Accidents lead to loss of life and debris • Potential for Kessler Syndrome event

Trends Analysis

We undertook a STEEPLE analysis to understand the various trends over the next 30 years out to 2050. There are several key drivers operating in the space sector: most notably, increasing commercialisation and competition for space resources, increasing dependence on space services for our daily lives, and increasing opportunities to utilise space for multiple purposes.

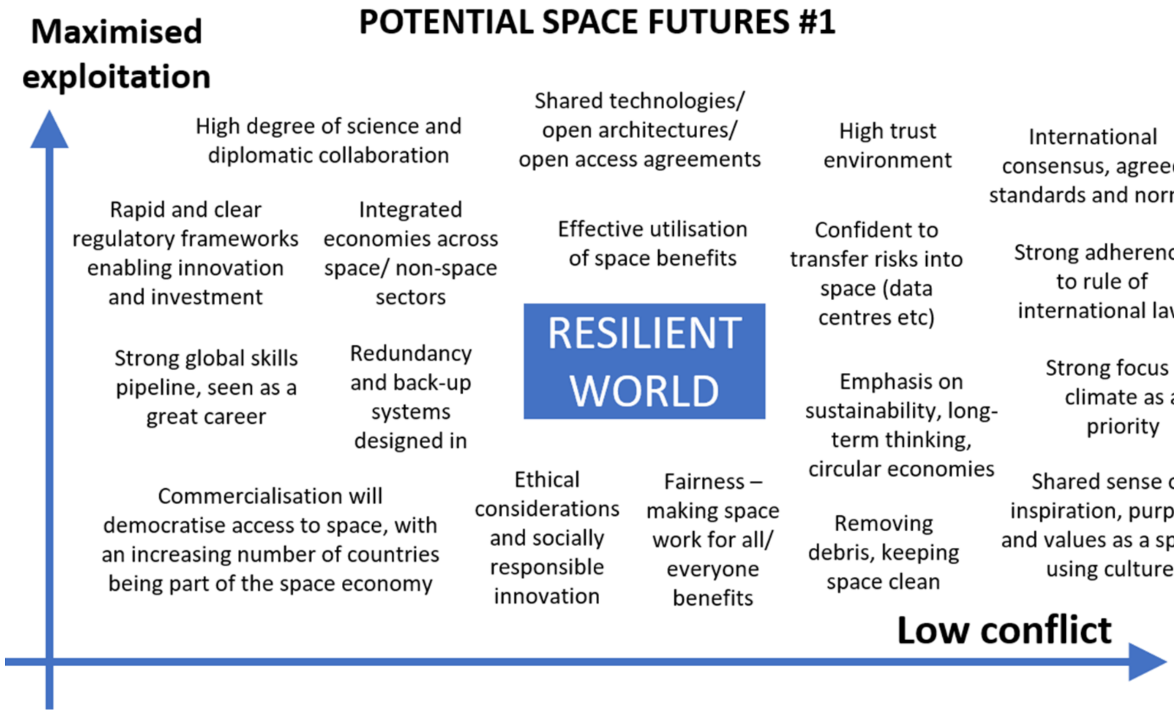
Table 4: Trends out to 2050

	Trends to 2050
Social	• Increasing public dependence on space services and products • Competing interests – potential for pressure groups • Potential for space tourism/ private individuals funding space travel • Democratisation of space – increasingly accessible • Uneven distribution of benefits disadvantaging some countries • Increasing concern over dark and quiet skies/ cultural heritage
Technological	• Ongoing trend towards safe and reliable shuttle (launch and return) • Increasing data storage and analysis challenges • Ongoing development of underpinning technologies (AI, robots) • Reducing costs and weight, improving performance
Economic	• Ongoing trend for cheaper launch/ assets and infrastructure • But capital costs remain very high for investors • Space as a service – reduces the need to invest in own assets • Profit as a key motive for space exploitation • Increasing private/ venture investment in space companies • More diversity of insurance products and services
Environmental	• Increasing overcrowding of LEO, more space debris • Increasing focus on sustainability and the environment • Legal means to prevent polluting/ burden-sharing responsibilities
Political	• International geopolitics playing out in space • Increasing militarisation of space/ need to defend space assets • Need to develop space ‘statecraft’ • Ability to respond quickly/ take action as needed • Need to verify information
Legal	• Potential for non-compliance/ more irresponsible behaviours • Creation of regulatory frameworks enables better use of space • Lack of legal recourse/ redress, increasing case law
Ethical	• Potential for unfair (dis)advantage for some people/ countries • Potential human colonisation – new societies and cultures

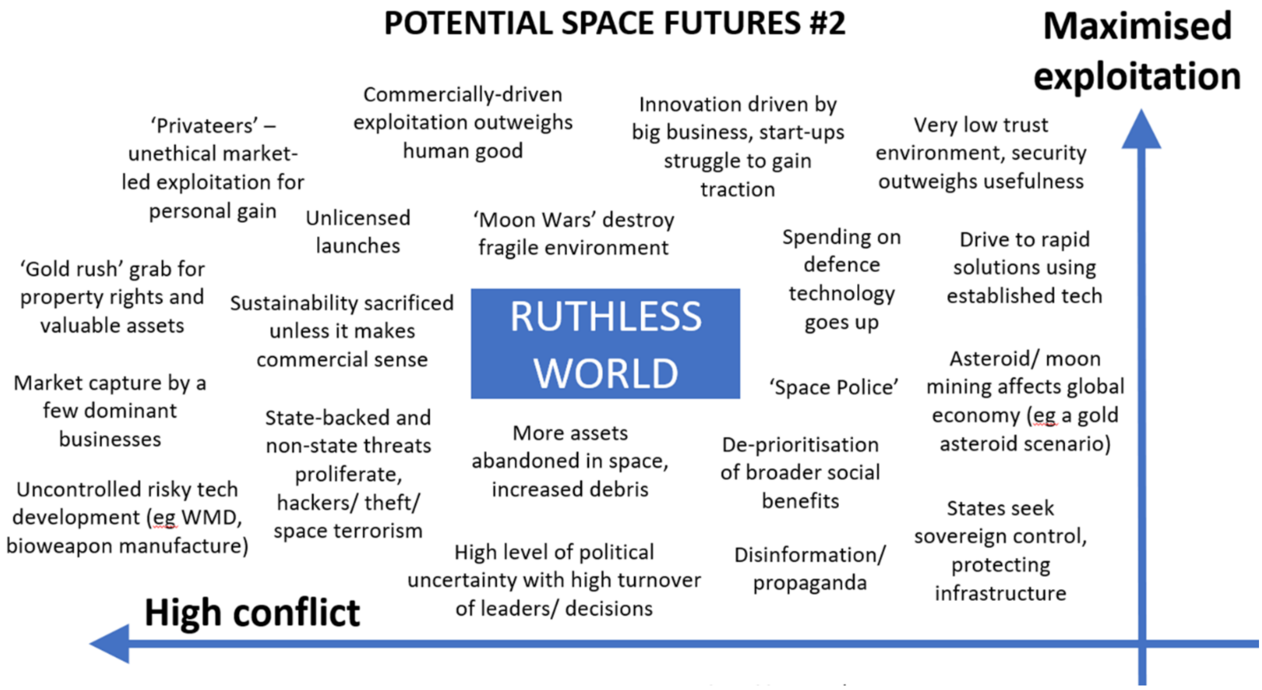
Future Scenarios

Working with a diverse group of stakeholders through a workshop and open collaborative 'collective intelligence' drafting, we explored four potential future 'worlds'. Given the key trends set out above, we decided to explore two key axes: low-to-high *conflict* (to what extent we are facing a world of cooperation or competition) and minimal-to-maximal *exploitation* (to what extent are we making use of and dependent on space in our daily lives). We developed four 'worlds' to explore: a 'Resilient World' of low conflict and maximised exploitation; a 'Ruthless World' of high conflict and maximised exploitation; an 'Adaptable World' of low conflict and minimal exploitation; and a world in which we fail to benefit from space with high conflict and minimal exploitation. The reality is likely to be that we will end up with elements of all these; however, they provide a useful thought exercise to map out and bring to life alternative potential futures.

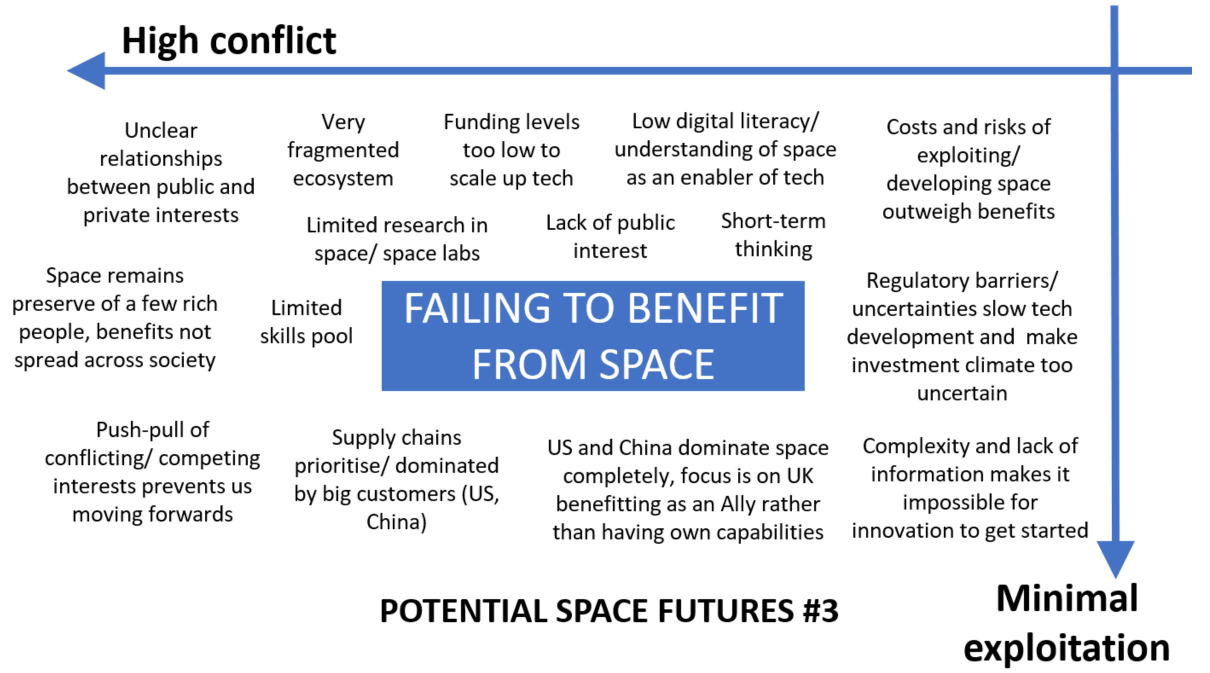
Resilient World - This is probably the most desirable future, in which we are able to reap the benefits of space in a low-conflict environment with internationally agreed regulations, standards and behaviours. In this world, we can work together with international partners to ensure that peace and harmony is maintained, that the space environment is protected, and new capabilities can be developed with confidence in our ability to operate them safely. This is a future in which the benefits of space are harnessed to address key global challenges (as set out in the UN's Sustainable Development Goals) This is a future where access to space and space-based resources is shared with less technologically advanced nations.



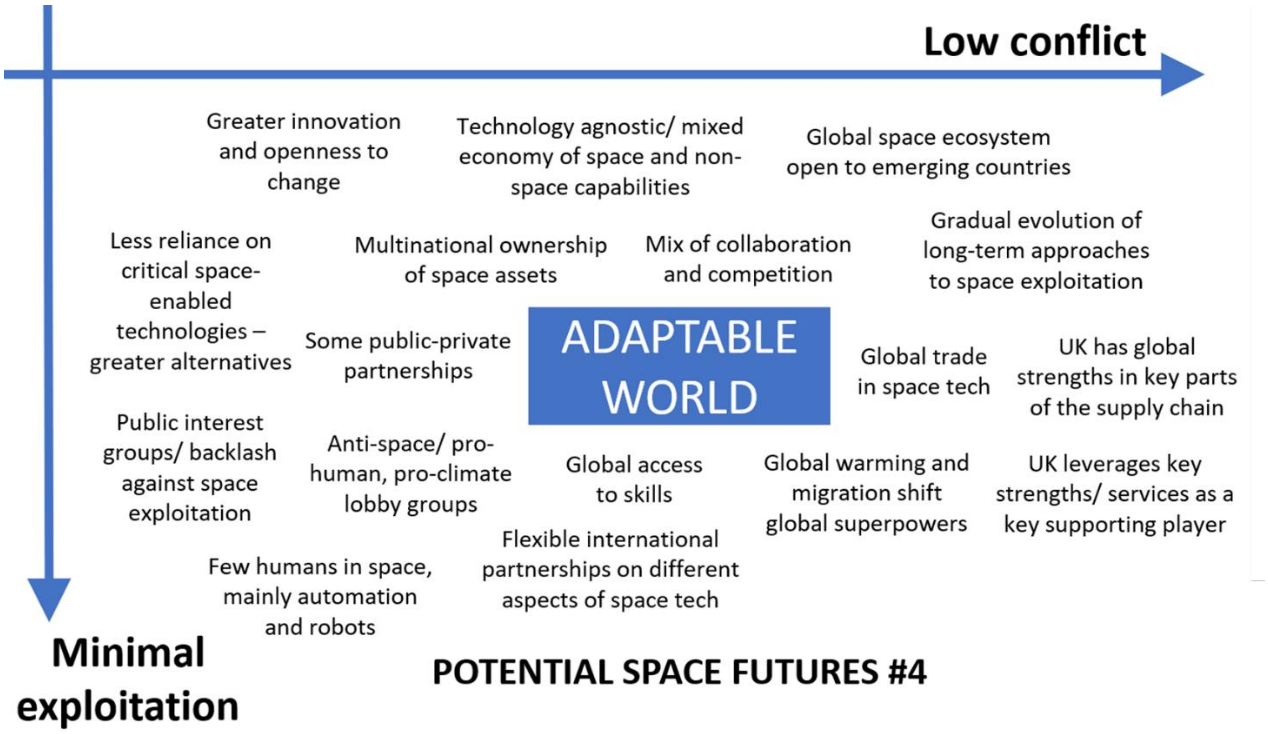
Ruthless World - In a high-conflict environment, we could see a drive to commercialise space leading to unethical and short-term behaviours which focus on gaining strategic and tactical advantage over long-term harmony, pushing towards more risky technologies.



Failing to Benefit from Space - The flip side of a ruthless world could be a high-conflict environment where risk aversion, lack of funding and lack of buy-in leads to a decades-long lag in exploiting technology to benefit humanity and drive scientific advances.



Adaptable World - We might see less focus on exploitation but a move towards a mixed economy if different partners, multiple ownership, and service models, with a more open ecosystem emerging.



The discussions were wide-ranging, and many participants found it hard to engage imaginatively with specific examples, given the degree of uncertainty over how any such events may be handled, risk appetite and lack of ability to prosecute or enforce any breach of agreements. The future worlds were explored further through four hypothetical 'speculative fiction' examples (Table 5), exploring different levels of risk (likelihood versus impact) to understand how an incident might play out differently in these different kinds of future worlds. Please note <u>these are not real</u> and were created to facilitate debate.

The discussion had a strong technology-driven approach, with many interested in the potential applications of technologies and the opportunities afforded by space. The risk of space war came out strongly from discussions over the 'Ruthless World', including some private companies potentially wishing to remove competitors and assert control over strategically important locations/ orbit/ spectrum. There were concerns that the UK could find itself locked out of the economic benefits by being too slow to regulate. The need for good data was a clear theme throughout. For example, in the event of an accident there needs to be a single source of the truth, trusted by all parties and an ability to collect evidence. The lack of ability to seek legal redress and likely long protracted legal processes would deter future investors and entrepreneurs from the space sector, delaying innovation. Regulation was seen as both a key barrier and an enabler of success if we get it right.

Table 5: 'Speculative fiction' – exploring potential future scenarios

SCENARIO 1 **High Likelihood, Low Impact**	**SCENARIO 2** **High Likelihood, High Impact**
An AI algorithm designed to track space traffic and steer away from potential collisions, created by an Indian start-up company which specialises in space software, based on automatic car software and installed on a UK research satellite, miscalculates trajectory and sends the spacecraft off-course and out into outer space. The business is sued by the satellite owner for losses and declares bankruptcy. The police investigate whether a crime has been committed, and by whom. The CPS decide to prosecute the satellite owner for failing to conduct due diligence. The case goes to the High Court on appeal.	*A technologically advanced serious organised crime group based in China hacks into a UK satellite and steals petabytes of personal data, comms messages and sensitive security information. Wikileaks breaks the news of the huge data breach. It turns out that chips inserted early in the supply chain in legacy technology had a vulnerability which allowed back-door access to data. The police are unable to prosecute due to jurisdiction and lack of evidence. The UK Government asked the NCSC and Information Commissioner to conduct a thorough inquiry and make recommendations to prevent recurrence.*
SCENARIO 3 **Low Likelihood, High Impact**	**SCENARIO 4** **Low Likelihood, Low Impact**
A collision between two satellites – one owned by the UK and one by a private multinational corporation based in the US – leads to the UK satellite crashing into a city in the Philippines, killing over 20,000 people and injuring many more. Debris is scattered over thousands of miles, causing millions of pounds of damage and interruption to aircraft. Angry relatives sue the UK. Anti-space lobby groups march in London causing social unrest. The global insurance industry nearly collapses and is bailed out by multiple states. An international inquiry is convened at The Hague.	*A private sector-owned, and UK-based vertical space launch takes place from the Outer Hebrides. The launch system carries 2 space tourists (citizens of the UK/USA, UK/France), the first such activity by the UK. The intended trajectory is a N-S polar orbit at 500 km. Unfortunately, during ascent, the vehicle is hit by man-made micro-meteorite debris (provenance disputed, suspected to be US) which causes it to malfunction and ultimately leads to a sub-orbital catastrophic failure. Launcher debris then rains down on Iceland and Greenland, causing damage to wildlife and infrastructure plus low-level (but cancer-causing) pollution.*

6. UK Space Regulation Strategy

This section sets out the main elements which we believe a UK Space Regulation Strategy should include and considers some of the key gaps and opportunities for the UK.

Regulation is how activities and processes are controlled through a range of measures from mandatory rules (law) to guidance, self-regulation, regulatory bodies and inspectorates, creating the conditions for effective and safe practices. While regulation is often cited as a barrier that impedes development and prevents timely exploitation of innovation (in a way which permits 'first-mover' market advantage), regulation can enable innovation by providing the framework to experiment safely and give investors' confidence. Current and future spacefaring nations need to develop together a proportionate and flexible regulatory approach to space alongside, and not after, the technologies which may create future capabilities in space such as debris removal, solar energy generation, mining, and manufacturing. Regulation can be a great enabler for space capabilities and can position the UK at the forefront of global regulation.

It is vital that the UK create a space regulatory system that allows innovation to flourish. Experimentation initiatives such as sandboxes, test beds and digital simulation to test out regulations for new products and services within a controlled environment would be helpful for space technologies. The UK has a long heritage of developing space technologies to build on, and our space sector is now a vital part of our economy, worth over £16.4 billion per year with an average long term growth rate of 6.4% and employing over 45,000 people across the UK. This is a great success story for the UK, with the UK Government committing to invest over £10 billion in space over the coming decade: supporting all this with the right regulation will be critical to ensuring continuing growth and prosperity.

The RHC's key finding is that space regulation is mostly 'missing in action', whilst technologies are racing ahead. Without clear rules and guidelines setting out who can do what in space and how, humanity will fail to benefit from the opportunities of space. Space is still a new domain for humanity, but we can learn from the development of regulation in parallel sectors such as maritime and aviation law to accelerate progress where possible, but we must also acknowledge that space has some distinctive challenges: "The novelty of human ingenuity need not scare us into thinking that the development of space law is an impossible task. Space will require unique solutions to peculiar problems".[120] Regulatory regimes need to be developed through international agreement and cooperation, and the UK can play a key role.

[120] Lauren Peterson, 'The future of governance in Space, 2021

Current state of Space Regulation

The main international space regulation was developed in the 1960s and 1970s, primarily the Outer Space Treaty 1967, the Rescue Agreement 1968, the Liability Convention 1972, the Registration Convention 1975, and the Moon Agreement 1979, overseen by the UNCOPUOS. The OST is a mix of broad principles which provide for some flexibility for state practice to develop over time. There are also specific rules, which are important, such as banning nuclear weapons in space. Article 3 of the OST makes clear that international law applies in space, which means the UN Charter applies and international humanitarian law, which are critical for international peace and security. This provides an important foundation which serves a useful purpose and can be built upon. Treaties are not binding, and there is no international court or means for dispute arbitration, but many of these have been translated into domestic law by the major spacefaring nations, including in the UK the Outer Space Act 1986, Space Industry Act 2018, and Space Industry Regulations 2021 and multiple bilateral and multilateral agreements such as the Artemis Accords.[121] Relevant international legislation also includes legislation governing the use of technologies which depend on space, such as data sharing and the regulation of the electromagnetic spectrum, which is already highly contested and subject to its own regulatory system, Satellite telecommunications are managed by the UN's ITU based on the Constitution, Convention, and the Radio Regulations 1992. As more and more technologies are deployed into space or become reliant on space, more and more relevant and emerging legislation may need to be navigated, creating an increasingly complex picture.

However, work needs to be done to develop the governance arrangements for the variety of activities envisaged in future. The future trends explored in Section 5 illustrate the potential for increasing conflict and exploitation in space. At the time the OST was created in 1967, spacefaring activities were entirely undertaken by State entities (due to the high costs and resources needed): nobody imagined the enormous potential for private sector operations in space. The commercialisation of space is a key and accelerating future trend with huge potential benefits for medicine, science and more. In space, as in many sectors, technological possibility runs ahead of regulatory frameworks. Over the past decade, we have seen the emergence and flourishing of a thriving global space industry ('NewSpace') with ventures such as private launch companies, small satellite constellations, and even sub-orbital tourism,[122] as costs and barriers to entry have reduced. Since 2019, SpaceX has launched more than 5,800 satellites into space, making the internet available to 70 countries. On 8 January 2024, a US space company launched the first commercial Moon lander, whose cargo controversially included the cremated remains of at least 70 people, including Star Trek creator Gene Roddenberry, and one dog, thanks to companies which sell people the opportunity to be interred on the Moon (a propellant leak caused the

[121] https://www.nasa.gov/artemis-accords/

[122] European Space Policy Institute, The Rise of Private Actors in the Space Sector, 2017

spacecraft to turn around and return to Earth).[123] We can envisage a future – not very far away - where complex international and private partnerships co-create spacecraft and other space objects and collaborate on creating installations on the moon.

While these advances are leading to many benefits, there are also concerns over space as a new Wild West'[124] [125] free-for-all where some entrepreneurs ('astropreneurs') feel they can do anything if they can get a licence, with some states vying for their business.[126] Some states or regions within them may seek to introduce more lenient licensing regimes to attract business, leading to space shuttles or other technologies being used unsafely. Unfettered profit-driven models for future space exploitation could degrade the space environment, while the increasing number of space objects potentially increases the likelihood of costly and damaging accidents where multiple parties could be affected. There could also be unintended consequences, such as the *de facto* occupation/ ownership of strategically important space territories and orbital areas, with creeping annexation pitching competing State and private interests against one another. It is also possible that, as costs come down and technology becomes more widely available, at some point in the future, objects will be launched into space illegally without licence or registration, and it may not be possible to prove who the perpetrator is.

Another key trend is the increasing military use of and reliance on space. Military organisations have always been part of space exploration and are ramping up investment in space technologies, with the major powers of the US, China, and Russia all having military units specialising in space operations: the requested budget for the US Space Force in 2024 was over $30 billion. Defence organisations rely on satellites for secure communications and ISR and PNT services for ground-based operations. Ukraine, despite not being a spacefaring nation, has made effective battlefield use of space-based communications and ISR to defend itself against the Russian invasion. Over the next decade defence activities in space are likely to increase. In recent years, China has tested hit-to-kill interceptor missiles, and Russia has conducted successful flight trials of anti-satellite missile systems.[127] In February 2024 there were concerns over the possibility that Russia could put a nuclear weapon into space.[128] Future uses of space for military purposes – including the need to defend commercial and State interests and assets – may also lead to reckless behaviours by some actors in an 'arms race', reflecting global geopolitical trends. There is the potential for irresponsible behaviours, non-compliance with guidance, and the exercise of 'soft power', influence and use of proxies by states and

[123] Nature World View, Stop sending human remains to the Moon, 16 January 2024

[124] A.C. Grayling 2024 *Who Owns the Moon?: In Defence of Humanity's Common Interests in Space*. Oneworld Publications

[125] Greg Wyler. "Earth To Regulators: Space Needs You.' Forbes, 9 Nov. 2022

[126] Steve Simon, A cause for concern: Developing regulatory competitions in NewSpace. Acta Astronautica, 187, 212-224, 2021

[127] Ministry of Defence, Defence Space Strategy: Operationalising the Space Domain, February 2022.

[128] New York Times US Fears Russia Might Put a Nuclear Weapon into Space, 18 February 2024.

by private actors, which could unfairly disadvantage others in future uses of space. Making space an even more hostile environment is not only dangerous but will deter commercial actors and investors, delaying the benefits of space for humanity.

As a result of this expanding use of the space environment, the existing international treaties and corresponding domestic legislation do not cover many of the activities which are now – or soon will be – possible in space, such as the kinds of new capabilities set out in Section 4, hence the RHC's key finding that space regulation is largely 'missing in action'. The principles envisaged in the OST and subsequent international treaties (including the Liability Convention 1972 and the, much less supported, Moon Agreement 1979)[129] may come under considerable stress-testing, including in international courts, and could potentially lead to space exploration and exploitation being halted or operating outside of international law while issues such as liabilities are resolved (if ever). The principles of equality of access may be tested as some states or private companies seek to assert dominance or claim ownership over natural assets and resources, and to protect their own investments. There is also debate about the use of non-geostationary orbits because they are a scarce resource and need to be shared equitably among all states large and small, regardless of their current space capabilities. Many of the key issues have been under discussion for decades with no prospect of consensus over how to create and maintain the conditions for safe, peaceful, and profitable use of space. Sadly, current geopolitics do not suggest easy solutions will be found. Broadly two competing groupings are emerging: alliances between various Western and other states such as the US, UK, France, Japan, and UAE, and Russia/China-led coalitions with other aligned nations.[130] This leaves smaller future spacefaring nations, and those who wish to benefit from and use space capabilities, having to 'choose sides'.

Even the treaties which exist are not enforceable: and any dispute resolution must be bilateral between states, with no international 'Space Court'. For example, the use or presence of nuclear weapons in space is banned by Article 4 of the Outer Space Treaty, while the New START nuclear arms treaty between Russia and the US (which expired in 2021) aimed to reduce the number of deployable nuclear arms[131] and the Partial Nuclear Test Ban treaty (1963) bans nuclear explosions in space: however, there are no means to monitor or enforce these rules. Negotiations have been underway since 1985 through the Committee on Prevention of an Arms Race in Outer Space (PAROS) under the UN Conference on Disarmament:[132] in 2008 Russia and China proposed a Draft Treaty (updated in 2014), but this has been continuously rejected by the US and its allies as

[129] The Moon Agreement has been signed by less than twenty nations and is not considered legally significant

[130] Center for Strategic International Studies, Repositioning the US-Japan Alliance for Space', June 2023

[131] https://www.nti.org/education-center/treaties-and-regimes/treaty-between-the-united-states-of-america-and-the-russian-federation-on-measures-for-the-further-reduction-and-limitation-of-strategic-offensive-arms/

[132] Proposed Prevention of an Arms Race in Space (PAROS) Treaty

being unverifiable and too limited. There is no immediate prospect of the accord, with none of the main spacefaring nations seeming willing to 'give ground' and lose potential future strategic advantage or bind themselves to conditions they believe the other will not keep.

The lack of international consensus on what the rules should be, weak international governance, and lack of clarity over liabilities risk slowing progress in deploying key future capabilities such as debris removal. The UN has been clear that the governance of space needs addressing: "The human presence in outer space has fundamentally changed in the past 10 years, and this change is likely to accelerate in the coming decades. We need to develop further the existing governance so that we can sustainably accelerate innovation and discovery."[133] A lot of good work is already underway, including through UNCOPUOUS[134] and the Inter-Agency Debris Coordination Committee (IADC),[135] which are focused on voluntary measures for managing orbital activities. The UK plays a key role in UN and international space policy development, including the Working Group on Reducing Space Threats Through Norms, Rules and Principles of Responsible Behaviours,[136] such as sponsoring the UN General Assembly initiative on space behaviours adopted in 2020.[137] The UK Space Command (part of the RAF) was the first formal partner in the US-led Operation Olympic Defender, a multinational coalition formed to strengthen deterrence against hostile actors in space and reduce the spread of debris in orbit.[138] Placing sustainability at the core of space activity is the purpose of King Charles' Astra Carta initiative, which aims to convene the private sector in creating and accelerating sustainable practices across the global space industry, recognising the unique role that space can play in creating a more sustainable future on Earth and the need for the space industry to consider environmental and sustainability impacts beyond our planet.[139]

While there is a lot of excellent work going on across Government, in UK Space Agency, Satellite Applications Catapult, Civil Aviation Authority Space Team and others, there is a huge amount of work needed to plug the future regulatory gaps in space. Good licensing regimes, compliance and dispute arbitration mechanisms will be critical to the future development of safe space. The international community will need to develop regimes to govern how increasing numbers of launch-and-return spaceflights will be managed across international airspace and outer space, the allocation of space 'traffic management' responsibilities and 'rules of the space road', what is considered suitably trained and

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[133] United Nations, Our Common Agenda Policy Brief 7, For All Humanity – the Future of Outer Space Governance. May 2023

[134] United Nations Committee on the Peaceful Uses of Outer Space (COPUOS)

[135] Inter-Agency Space Debris Coordination Committee (IADC)

[136] Aidan Liddle, 'Responsible behaviours in outer space: towards UNGA 76,' Foreign, Commonwealth and Development Office Blogs, 8 June 2021

[137] United Kingdom, National Submission on Space Threats, 30 April 2021

[138] Penny Mordaunt, 'Defence Secretary outlines future space programme,' Royal Air Force RAF News, 18 July 2019

[139] His Majesty The King. 'The King unveils the Astra Carta seal at a Space Sustainability Reception at Buckingham Palace.' The Royal Family, 28 June 2023

qualified personnel, how to prevent and investigate future crimes in space, and more. Focusing on areas of mutual benefit (traffic control, debris removal) could be a good start.

A lot can be learned both from the development of maritime and aviation technologies and laws and applied to space. Because space technologies have much in common with other sectors such as aviation, maritime, the Antarctic, and submarine (for example, in the use of robotics and creating survivable habitats in hostile environments), it would be beneficial to create a coordinated approach to common problem-solving and learning, to shorten time to market and develop parallel regulatory regimes. There are relevant discussions on the development of regulatory regimes and standards for AI safety, quantum technologies, engineering biology, and more – of which their use in space is just one aspect.

Maritime and aviation regulations provide a potential blueprint for some aspects of how to govern the future uses of space. Maritime law sets out the principle that the laws governing a vessel change depending on the relative position of the vessel: in international waters, it is governed by the laws of the State in which the vessel is registered; in the contiguous zone of a coastal State, they are subject to that State's limited rights; and once in territorial waters the laws switch to those of the coastal State. Maritime law includes the concept of 'innocent passage', where a vessel may cut across a State's territorial seas continuously and expeditiously without causing disruption and should be allowed to traverse territorial waters without interruption. The same principle can be applied to permit spacecraft to traverse national airspace to launch and return (in practice, launches require intense planning and coordination to close airspace and enable safe passage). With increasing numbers of international spaceports and launch sites, this is likely to become more complicated. Another key principle from maritime law is the way that nations can fish from international waters without this conferring ownership, which some have seen as a principle that could be applied to mining space assets.

Aviation law sets out some important principles about traversing airspace, and governing crimes committed on aircraft in flight. The original principle of property law *cuius est soleum, eius est usque as coelum et ad inferos* ("whoever owns the soil it is theirs up to the heaven and down to hell") became untenable as aircraft passed through airspace: in 1946 the US Supreme Court decided that Government possessed air space above lower altitudes. The principle that nation-states hold exclusive air rights over their domestic airspace (above low altitude and extending up to space) applies globally. The vertical limit of state sovereignty (the delineation between airspace and outer space) is generally understood to be somewhere between nineteen miles above Earth (the altitude of the highest aeroplanes and balloons) and ninety-nine miles above Earth (the altitude of the currently lowest-orbiting satellites). The International Standard Atmosphere sets 47km as the stratopause (the upper limit of the stratosphere) for the purposes of determining whether an activity is 'sub-orbital; however, in future, this may require a clearer definition if liabilities are to change at specific altitudes to avoid a loophole on whether space law or aviation law will apply. In 2018, the UNCOPUOS called on the UN to pursue a multinational legal solution on the delineation of the boundary between airspace and outer space. Understanding and clarifying uncertainty in these areas will become very important as more states and private companies are involved, the complexity of interoperating and cooperation agreements increases, and more objects are launched, manufactured, and operated in space with increasingly complex and 'dual use' technologies.

Analysis of current international law suggests there are many current and future regulatory gaps to address, including but not limited to those highlighted in Table 6.

Table 6: Current and future regulatory gaps

Current Gaps	Likely Future Gaps
• 'Outer space' is not clearly defined, even though liabilities differ in space • 'Launching State' is not clear as this could mean any or (or all of) 1. The State which launched, 2. The State which procures the launch, 3. the State whose territory was used for the launch, and 4. the State from whose facility a space object is launched, or 4. in the case of privately owned satellites, the State of incorporation of the company could be considered a launching state: multiple states could therefore be considered jointly and severally liable • Permitted 'scientific research' may vary in interpretation and could be deliberately (mis)interpreted to justify missions with concealed or dual purposes or potentially dangerous research and development activities • 'Environmental damage' is not clearly included in the Liability Convention and could affect the ability to insure space activities • The legality of conflicts in space, including creating military bases on	• Managing and governing space traffic from states which are signatories to international space law and those which are not, and partnerships between such states, including proximity rules • Definitions, rights, and responsibilities of 'astronauts' and other kinds of space users (tourists, other spaceflight participants – perhaps in future humans born in space), including future AI robots • Intellectual property rights for novel R&D conducted in space may become more complex and difficult to attribute as multinational public/private partnerships become more common • Regulation of mining and exploitation of space natural resources and manmade resources such as recycling parts of defunct satellites • Managing access, reciprocity and rendering assistance between states, and between privately operated space activities, such as where two or more states are operating on the Moon or in the same area of space – for example,

spacecraft in LEO, GEO or outer space and the use of the Moon and outer space for military/ dual purposes • Weaponisation of space and how ‘dual use’ technologies can be developed, traded, and used without undue risk of intentional or unintentional harm • Launching authorities need to be fully aware of the sensitivities and potential risks of any technologies on spacecraft launched from their territories, even if supplied by other states/ companies • Criminal responsibility and jurisdiction on spacecraft launched and operated by multiple partner states and potentially by private operators • Exemptions to the Liability Convention on the grounds of sabotage are likely to be very difficult to prove, and do not explicitly include activities such as espionage, and terrorism	seeking to use the same part of the Moon for landing or development • Responsibility, accountability, and liability burdens between public and private partners collaborating on increasingly integrated joint ventures, including responsibility for return/ rescue • Being able to hold private companies liable rather than only the State; and allowing private parties to pursue legal action • Real-time information and registry will be needed on what objects are in space and who is the responsible party/ parties for each, including default responsibility in the event of the object being unregistered or unascertainable • Applying regimes for criminality to space including jurisdictions, obtaining evidence, prosecution, and penalties

Regulatory Aim

The RHC asks that the UK Government continue to **aim towards a future for outer space that protects the space and Earth’s environment and maintains peaceful and equitable uses of space, through developing a proportionate and flexible regulatory regime which supports innovation**. While it is key for the international community to work together to develop regulatory approaches, the UK can play a key role through our international influence (formal and informal, including ‘science diplomacy’ and co-operation), our legal and financial services sector in key enabling areas such as data science and analytics, and cutting-edge science and technology. We would like to see alternative routes for civil society to shape the future of space, ensuring that a more diverse range of voices are heard, and that the future of space is co-created with all interested parties.

Key areas for the UK Government should be:

1. In line with the Space Industrial Plan, build on existing work to address the challenges of space sustainability especially preventing overcrowding, and in-orbit servicing including removing debris removal, both through technology development and creating enabling regulations and guidance governing when and how these technologies can be deployed, ensuring both government and commercial actors operate responsibly;

2. Establish the UK as the global centre for space law, arbitration, insurance and financial products and services, and data science/modelling, which will help establish international norms of responsible behaviour and enable effective and safe space operations;

3. Create new mechanisms for public engagement and collective responsible investment in ethical space technologies and capabilities with shared global benefits.

A key problem with the development of international space regulation has been a seemingly unending cycle of expert groups (such as this one) drafting important recommendations in the hope that they will be incorporated into enforceable regulations, only to be met with diplomatic and legal impossibility. We hope that, given the strategic importance of space to the UK, the UK Government will take action to implement the recommendations set out here and hold action owners accountable for delivery.

We propose that a UK Space Regulation Strategy should set out three Strategic Objectives for the next ten years:

1. Use the UK's international platforms to advocate for and prioritise environmental protection, peace, and equitable use of outer space;

2. Make the UK the go-to place for space regulation, arbitration and enabling services;

3. Ensure that the UK is at the forefront of a few key enabling technologies and capability development.

These are discussed in more detail below with specific recommendations for each area.

Strategic Objective 1: Use the UK's international platforms to advocate for and prioritise environmental protection, peace, and equitable use of outer space

The UK has a strong international standing and reputation which we can use to advocate for key principles for how outer space should be used in future. This means acting internationally – through the UN, EU, multilateral discussions, and bilateral discussions – to ensure that the law, definitions, governance, and structures exist to agree on these priorities and ensure that all countries and private entities comply. Internationally acceptable legislation is needed to cover all the potential future capabilities in space and to provide clarity on what can be done where and who is responsible.

It is important to be clear about which competing priorities take precedence in developing legal and regulatory frameworks, and we suggest the order of priority is 1. Environmental Protection, 2. Peace, and 3. Equitable Use. Any activities which could result in a major – even existential – level of threat to Earth, the lives of future generations and present-day humanity should be the highest priority and made illegal, or at least be very heavily and carefully regulated, including those with the potential for deliberate or accidental harms. However, it would be disproportionate to apply heavy-handed regulation to areas where the risks are much lower, or can be managed, or are acceptable risks considering the potential benefits, so we envision a tiered and iterative approach to regulation in which the degree of regulation varies according to risk and experience. As we become more adept at utilising space, regulations can adapt.

1a. Protect the Space Environment

Sustaining the space environment for future generations is critically important: this environment is already under threat, putting at risk the key capabilities that we already rely on space to provide (telecommunications, internet, navigation) and compromising future scientific discovery. In space, unlike the air, land or ocean, debris remains circulating for very long periods of time until it might burn up in the atmosphere. We need to be very careful with activities we carry out in space which could contaminate the environment: any hope of finding evidence of life on other planets, for example, requires pristine conditions, and any prior contamination of abiotic organics or indigenous biota would undermine such research. Debris and contaminants from man-made objects in outer space (including chemical and biological material) can contaminate the Earth's surface, the orbit and surface of the Moon, and other celestial objects. The Committee on Space Research (COSPAR) Planetary Protection Policy[140] recommendations are nonbinding and are

[140] COSPAR Planetary Protection Policy, 2020

limited to biological contamination and scientific protection; other potential contamination and non-scientific use cases are not included (such as protecting the Moon's surface).

Currently, land, sea and air environments are subject to legal protection to prevent pollution: we could enshrine in law similar protections for space (including for space launches) and apply a precautionary approach, given that we have no idea what the ramifications of introducing such foreign material – either from forward contamination or backward contamination - may be.[141] The consequences of introducing extra-terrestrial microbes, for example, to our planet could be devastating. The UK Government should work with the international community through the UN to establish strong legal protections for the space environment to limit pollution (including debris) and mitigate future environmental risks and preserve 'clean zones' to act as open corridors for future use (such as for scientific experimentation, transport, and communications), with a clear regime to manage the environment including exemptions and licenced use.

It is a real possibility that deliberate or accidental collisions in space result in debris which would destroy the Earth's orbital environment: the Kessler Syndrome hypothesis[142] posits that collisions between objects in space could cause a cascade effect that increases the likelihood of future collisions, destroying more and more satellites and increasing the debris cloud further. As even tiny fragments travelling at orbital speeds can cause huge damage to spacecraft, this would eventually make it difficult or impossible to operate in space for generations to come. Collision with an object greater than a centimetre could penetrate the shields of a crew module and anything larger than ten centimetres could shatter a spacecraft, causing potential loss of life. Every satellite destroyed could result in more than 100,000 new pieces of such high-speed shrapnel, which could take as long as 1,000 years to burn up in the Earth's atmosphere. Currently, there are at least half a million deadly space fragments in the Earth's orbit and hundreds of millions of objects under one centimetre; preventing any more should be a key priority. The UK Government should work with the international community through the UN and IADC to restrict the number of objects put into space to a sustainable level, with agreed quotas for spacefaring nations, potentially managed by a new international body such as an 'International Space Safety Organisation', similar to the ITU's role in managing and coordinating the global use of spectrum. As set out in Section 4, the UK Government should signal the intention to put into future domestic legislation in 10 years the requirement for space objects and components to be made from materials which meet specified standards for non-pollution and minimise impact on the space environment, and fund research and development of the materials as well as development of the standards for satellite design and development to facilitate ready disposal.

[141] Georgie Hughes,' Space needs environmental protection too, says study', Environment journal
[142] Wikipedia, 'Kessler Syndrome'

As set out in Section 4, space debris removal is one of the major challenges and could be a key focus for the UK to develop services and, crucially, regulations to enable these services to operate. The UK could also create a future civil ‘Space Traffic Control’ system and tracking capability as a service to the international community.

1b. Maintain Peace in Space

So far, space exploration and use have been primarily in a spirit of shared scientific endeavour and benefit to all humanity, often with a strong defence presence. However, the coming decades may see more conflict in space, as shown in the future world scenarios in Section 5. The RHC believe the first order of priority should be to ensure peace in space so that the Earth and all its inhabitants and future generations can benefit from space, as previous generations have. While the threat of alien invasion is quite unlikely, one of the greatest risks we face in space is the potential (likelihood) of future human conflict. Any violent conflict in space could make space unusable for decades:[143] “Space will be a key future battlefield with the most dangerous threat being an exo-atmospheric nuclear attack’.[144] We should be most concerned about anything which could harm the Earth, Moon, or our atmosphere. Conflict can also make commercial activities in space impossible or too risky and uncertain for private sector operators and investors, and thus slow the pace of innovation. Ideally, all nations and private actors in space would agree never to wage war in space and refrain from using spacecraft as weapons, with control regimes based on those developed for nuclear, biological, and chemical weapons. Dual-use technologies are also a key concern. Action needs to be taken now and continuously to de-escalate potentially harmful rhetoric and promote a vision of space as a shared global resource which can be used in peace and harmony to benefit all of humanity, now and in the future. It is possible that this could lead to bold strategic choices for the UK in choosing to support US foreign policy or brokering support from like-minded nations and corporations for whom peace in space is critical to continuing to be able to use outer space safely.

How peaceful use of space can be assured in future is an area for open debate. Some feel that banning weapons in space is not feasible because it is difficult to define a space 'weapon', and it is virtually impossible to verify whether satellites possess weapons. Given the nature of space capabilities, capabilities not developed as weapons (for example, for debris removal) could be used as such, making enforcement very difficult. The UK approach is to advocate for the regulation of behaviours in space rather than capabilities, which is more easily verified. Responsible behaviours could be composed of legally

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[143] Anelí Bongers and José L. Torres, ’Star Wars: Anti-Satellite Weapons and Orbital Debris’, Defence and Peace Economics, 1-20, 2023

[144] Ministry of Defence, ‘Defence Space Strategy: Operationalising the Space Domain’, 2022

binding measures as well as political commitments, guidelines, and non-legally binding measures, which can be effective and may lead to legally binding measures in future.

The RHC recognise that seeking international agreement is slow and subject to current geopolitics, so we do not rule out other parallel approaches, but on balance we feel that seeking international agreement is the right thing to do. We accept that a pragmatic approach is to work with like-minded nations on areas of agreement to build momentum, but we would like to see efforts to listen to and respond to other perspectives and to seek global consensus wherever possible. We recognise that monitoring and verification will be key to assurance. The UK Government should continue to work with the international community led by the UN, and including other nations, to prevent and deter conflicts in and using space, through an international non-proliferation space weapons treaty banning the development and use of weapons in space by states and by private actors, clarifying the application of international humanitarian law and the Law of Armed Conflict to space, and identifying pathways to move from voluntary pledges, guidelines and standards to legally-binding agreements and measures to monitor, assure and manage prohibited technologies and activities in space, given the increased future likelihood of conflicts in and using space and the risks this would pose to humanity.

There are some existing protections we can build on. Article IV of the Outer Space Treaty (1967) prohibits signatory states from placing in orbit around the Earth any objects carrying nuclear weapons or any other kind of weapons of mass destruction, installing such weapons on celestial bodies, or stationing such weapons in outer space in any other manner. It goes on to state that the moon and other celestial bodies must be used for "peaceful purposes" and prohibits "the establishment of military bases, installations and fortifications, the testing of any type of weapon, and the conduct of military manoeuvres on celestial bodies": however these prohibitions do not apply to spacecraft or objects in orbit around the Earth or other celestial bodies, or to the assertion of 'soft power' – for example, developing and protecting a State-owned mining operation on the Moon which then becomes a *de facto* outpost. These gaps should be addressed and closed by the international community. As elsewhere, the UK could take a lead in English Law.

The UK Government should continue to work with the international community led by the UN through the Open-Ended Working Group on Reducing Space Threats (through Norms, Rules and Principles of Responsible Behaviours) and UN Resolution 77/41 (which calls on States to commit not to conduct destructive Direct Ascent Anti-Satellite missile tests), to create an international space arms regulatory regime based on existing non-proliferation treaties for chemical and biological weapons, to monitor, assure and manage the potential development of prohibited technologies such as nuclear, bioweapons, anti-satellite (ASAT) weapons, explosives, jamming, spoofing and electromagnetic interference with satellite operation, with powers to order research, development and deployment operations to be stopped and for those responsible for being prosecuted. We recognise that compliance and enforcement are likely to be key issues.

The UK Government should work with international partners to add a space peacekeeping strand to the work of the UN Peacekeeping[145] and establish a multinational specialist capability ('International Space Safety Organisation') to inspect and enforce internationally agreed regulations and share information and best practices on similar lines to the International Maritime Organisation (IMO) or the International Civil Aviation Organisation (ICAO) – possibly through a hub-and-spoke model of central expertise with small teams embedded in key spacefaring nations. International law could include powers for the organisation to temporarily step in and take over the control and operation of rogue spacecraft and associated services until they can be brought under control and made safe. The UN 2024 Summit of the Future could allow the UK Government to call for a new Convention to agree on the elements of a new International Space Safety Organisation, like the 1944 Chicago Convention that established ICAO and the 1948 Geneva Convention that established the IMO.

As launch costs reduce, there is an increased potential for a reckless unlicensed launch, which should be treated as potentially extremely dangerous both as a risk to life and could be perceived by global adversaries as escalating conflict. Current legislation holds States fully responsible for any object or spacecraft launched from their territory, so the UK could be fully liable for the consequences of any such illegal activity. To deter, detect and prevent such activities from occurring, the UK Government should apply a similar approach to that used to prevent terrorist attacks, and amend domestic terrorism legislation to give law enforcement and intelligence agencies remit and powers to address and prevent planning or intending to carry out unlicensed launches or illegal interference with satellites or satellite communications, and ensure that the intelligence agencies and police service have the funding, skills and resources to address these threats in future.

In future, resilience in space is likely to become even more crucial. The UK Government, via the Civil Contingencies Secretariat, should work with its international partners, such as the UN's International Telecommunication Union (ITU), to develop plans to prepare for and recover from any major future conflict or accident that may occur in space through 'wargaming' and future scenario development and incorporate the lessons from this into international and national regulations to reduce the likelihood of such incidents occurring.

Cybersecurity, including supply chains, is an increasingly important issue for protecting space capabilities. The UK Government, through GCHQ and the National Cyber Security Centre, should create a cybersecurity programme with industry and academia, including developing and publishing domestic guidance and standards and feeding into the development of international standards, ensuring secure-by-design and deterrence principles are adhered to and possibly mandated for some key products and services.

Organisations and businesses in the UK's space sector and supply chain should be aware of the potential threat of hacking, espionage and spying, including human vulnerabilities (recruiting people knowingly or unknowingly to provide intelligence to hostile foreign

[145] United Nations Peacekeeping

intelligence agencies). Existing guidance is not very helpful for businesses seeking to understand and respond to threats.[146] Given that space is defined as part of the UK's critical national infrastructure, the UK Governments through the National Protective Security Authority, should develop and publish helpful, up-to-date advice to the space sector on how to manage and respond to supply chain threats, share appropriate information on threats, and expand the membership of its space sector protection group to relevant businesses.

1c. Ensure Equitable Use of Space

Space has already yielded great benefits to our daily lives through a mixed economy of public and private interests and we hope will continue to do so in future. We cannot stop using space, so we must find ways to grow the space economy as an asset for humanity, ensuring equity of access and spreading the benefits for all people. This starts with seeing outer space as a shared global asset for all humanity and future generations. However, realising equitable benefits from Space will need concerted global efforts including by civil society, because the incentives and drivers towards inequitable use are so strong, as we saw in Section 5. There are real risks that commercial interests and profit motives, while accelerating space technology and exploitation, lead to cumulative adverse effects (the 'Tragedy of the Commons' refers to this situation where individuals with access to a public resource (a 'common') act in their own interests making small scale decisions for short-term benefits even with the best of intentions but often with incomplete knowledge of the whole, and unintentionally deplete the resource or make unavailable for others). The immediate risk is the increasing commercialisation of space assets in ways which inhibit others' access and use. This trend will likely accelerate as more commercial uses are made of the space environment, especially if left unchecked. Space mining/ manufacture/ maintenance are the most economically promising areas for commercial interests but could lead to degradation of the space environment and *de facto* occupation/ ownership of parts of space/ celestial bodies, and by needing defending, drive up the potential for future conflict.

So, we will need a concerted strategic effort to ensure equitable access to benefits arising from space technologies and capabilities. Firstly, the UK can leverage its international role to mitigate the potential damage from future space activities. The UK Government should work with the international community through the UN to develop an international regime to govern, authorise, and manage future space mining and manufacturing activities with a holistic and impartial perspective that prioritises environmental protection, peace, and equitable use. Such a regime could, for example, broker partnerships between developed and developing countries when developing space capabilities, as well as when carrying

[146] UK Space Agency Guidance on security matters for applicants and licensees, 2021.

out space-related R&D, so that people from developing countries can contribute; the capability will be more inclusive in terms of the needs of different countries, and so that other countries can be made aware of the potential and how it might affect them.

The UK Government should aim to ensure that everyone can benefit equitably from space and can a say in how space is developed and used in the future. Getting the balance right between commercialisation and public benefit is key. Still, there are many good examples where commercial businesses, such as telecommunications and the internet, can generate a public benefit at a reasonably low cost, or even free. The incentives for businesses need to lie towards growing new markets (including in developing countries) but doing so sustainably and ethically. The UK Government should continue to work with the UN to define and promote responsible space behaviours, drawing on multidisciplinary expertise including behavioural scientists, social scientists, technologists, and ethicists.[147] Space ethics is an emerging field that will need many more practitioners.

Equitable use should reflect the interests of future generations, who may be able to develop technologies and capabilities we can't even imagine yet, if the environment is preserved sufficiently to enable future scientific research. The UK Government should work with the international community through the UN to protect and preserve sites in space of historical and cultural significance, such as the Apollo landing sites, non-terrestrial areas of outstanding natural beauty, and sites of great scientific research significance as well as preserving areas for future scientific research. Human colonisation presents even more social and cultural challenges, and we should ensure this is approached in a diverse way that includes inclusive of different interests and concerns. These initiatives should seek to include inputs from developing countries and different cultures, including traditional cultures.

Giving the public a greater say in what happens with space is one way to counterbalance the push towards militarisation and commercialisation. Because space is supra-national, State-based democracy does not easily translate into voting on what happens with space; however, the UK could lead the way in public engagement to ensure that regulations consider the interests and perspectives of minority groups, global interests, especially non-spacefaring and developing nations and cross-generational perspectives. The UK Government could provide a voice for alternative views through a diverse Citizens' Space Assembly based on the 'Citizens Assembly' in Ireland[148] and the 2017 Citizens' Assembly on Brexit:[149] a panel of 100 randomly selected citizens who are presented with evidence on a particular topic from experts, and who then make recommendations for possible policy or constitutional changes that are then passed for debate in the Parliament. This could provide a means to arbitrate between conflicting interest groups, such as the need

[147] 'Space Ethics Research Group'
[148] Citizens Information, 'Citizens Assembly', 2023
[149] Citizens Information, 'Citizens Assembly on Brexit'

for Dark and Quiet Skies compared with the commercial interests of satellite providers and their customers. Such a Panel could also explore the complex interests in making space data open access (so that all countries could benefit freely from it) compared to commercial interests in owning and analysing data.

To provide an alternative to venture capital investment models for the development of space technologies, and develop future space capabilities for the common good, such as debris removal and space traffic management, the UK Government should explore the potential for public 'Space Bonds' or community shares for ethical investment in space technologies so the public can be stakeholders and have a say in investment decisions, possibly offset through tax credits. The UK Government can also mitigate against the risks of short-term economic incentives through means to incentivise long-term thinking and future risk mitigation, calculating investments from a social, fairness, environmental and ethical perspective as well as economic, and over a longer period.

Strategic Objective 2: Make the UK the go-to place for space regulation, arbitration and enabling services

While many of the areas set out above will need international agreement to be effective, we believe there is the potential for using UK law to create the foundations which become, by default, international as a parallel approach to pursuing lengthy and intractable international negotiations. The law of England and Wales ('English Law') is already the preferred governing law for business transactions worldwide, thanks to our well-respected reputation for jurisprudence and the strengths and flexibilities of the common law approach, in which the interpretation and development of laws are influenced by the input of the courts through precedent, as compared to code-based civil law. This is a key opportunity for the UK.

The UK National Space Strategy 2021 sets out five goals to grow and level up our space economy, promote the values of Global Britain, lead pioneering scientific discovery, and inspire the nation, protect and defend our national interests in and through space, and use space to deliver for UK citizens and the world.[150] It sets out the aim of leading the world in modern space regulation, building new space trading partnerships with the world, building on the success of the UK-Australia 'space bridge', and continuing international collaborations with the European Space Agency plus new and enhanced bilateral relationships with countries such as the United States. The RHC believe the recommendations we set out below fully support these aims.

150 UK Government, National Space Strategy 2021

2a. Dispute Resolution

Given that space is open to all, the regulatory frameworks which govern it need to be inclusive and internationally agreed upon by as many nations as possible – ideally, all nations. In addition to agreeing to the regulations, the international community must agree on how future space law will be arbitrated and enforced. However, some nations are increasingly extending their geopolitics into space and are reluctant to agree to any international treaties which could constrain their own future freedom of operation in space, while often being keen to curtail the activities and aspirations of others. Support for arms control in space, for example, is perceived as contradicting the actions and rhetoric of the states with leading space capabilities, such as the US, China, and Russia.[151]

The Liability Treaty (1972) established a dispute resolution procedure through direct diplomatic negotiations between the parties (claimant State, injured nation, and launching State) rather than by applying to the International Court of Justice, although disputes may be facilitated by the UN if necessary. If no settlement is reached within one year, either party may require the establishment of a Claims Commission appointed by the parties, which would determine its own procedure and evaluate the claim. So far, no Claims Commission has ever been formed. This mechanism for direct negotiation is not likely to operate effectively given the geopolitical climate and does not provide the stability and certainty needed for investors and States to operate with confidence. It also limits parties to States rather than private companies, who must be represented by a nation State. So far, liability agreements are non-binding.

There needs to be a suitable international court, or agreement to use the courts of a particular country by default, to resolve disputes about rights to exploit the orbit, spectrum and possibly enforce future potential regulatory responsibilities (such as removing space debris, and end-of-life deorbiting), based on perceived impartiality, technical and legal expertise, and authority to enforce any penalty. The UK has a strong heritage in commercial law and is widely respected globally – for example, the Dubai International Financial Centre (DIFC) and Abu Dhabi Global Market have both adopted English law as their jurisdiction. The UK could strongly position itself as the preferred law of choice. However, short-term, geopolitical considerations make it unlikely that the main spacefaring nations (Russia, China, the US) would submit to the jurisdiction of a UK court, or permit private companies based in their states to do so. In February 2021, the UAE announced the establishment of a 'Court of Space' for outer space dispute resolution:[152] the DIFC and the Dubai Future Foundation (DFF) then announced the formation of an international

[151] Patrick Butchard and Claire Mills, 'International Regulation of Space', Research Briefing
[152] Space Court Foundation, 'Towards Space Arbitration and Beyond'

working group. The UK should put in place arrangements for exchanging of information between the UK Courts and the UAE Space Court.

Alongside this, the UK Government need to consider the application of its civil and criminal law to space including penalties. Other than fines, penalties could include removing access to that State's support ecosystem, registration and licensing regimes, making the offender unable to operate in that (and possibly Allied) geographies, and possibly removing any multilateral agreements for research collaboration and funding. Enforcement is a key issue and one which could hold up development if not addressed in the next decade.

Dispute resolution is likely to be through arbitration rather than national courts, and the UK has some of the best arbitration lawyers and capabilities in the world.[153] The UK could, therefore, be a popular choice for space arbitration: arbitration under UK law and with UK support does not have to be based in the UK. Still, it could sit and determine disputes anywhere in the world (or, eventually, in space). A good starting point would be establishing a Space Arbitration Faculty - a panel of specialist arbitrators who can sit and determine disputes anywhere in the world, with a dedicated secretariat and other administrative support in London. This would be open to both States and private parties, and would develop a binding dispute settlement procedure, including between private parties with no State involvement. The existing Space Arbitration Association could be a useful international convener.[154] The UK could help play a role in this: the SAA's objective is to create room for exchange between the international arbitration and space communities by creating a registry of articles and public documents on space-related arbitration proceedings, organising events on topics related to space arbitration, and addressing current issues on its blog. If the Space Arbitration Faculty were to become widely used, this would provide legal stability, a source of expertise that can form the foundation for future space operation. While the future model may well be commercial (with clients paying for arbitration services), initial funding to create, sustain and preserve the expertise will be needed as well as to develop the requisite processes, guidance and frameworks. As a strategically important capability for the UK, guaranteeing a level of funding will help ensure that key skills and knowledge are preserved. Many emerging technologies and capabilities will need to draw in deep experts and case law from parallel sectors – communications, data protection, intellectual property rights and commercial law, criminal law and more. There is likely to be a need for a specialised profession for space law, with its own training and qualifications, given the highly technical and complex nature of the operations and likely disputes. The UK Government needs to consult representatives of the law profession about how best to develop a sustained pipeline of specialised space lawyers with relevant expertise.

[153] The Bar Council, 'International Arbitration Brochure', 2022
[154] Space Arbitration Foundation

2b. Financial Services

It is well known that the UK has world-leading strengths in financial services, insurance, and other business services. The UK is a global financial hub with a highly skilled workforce, strong market access and coherence with international standards: the City of London is a centre for foreign banking and investment and holds a nearly 40% share of global foreign exchange investment turnover. In 2021, the financial services sector contributed £173.6 billion to the UK economy, 8.3% of total economic output. In 2021, exports of UK financial services were worth £61.3 billion in 2021 with a surplus trade of £44.7 billion. These strengths can be leveraged in the global space sector.

The UK has been successfully attracted foreign investment in space technology: since 2015, over $47bn of private capital has been invested across the global space sector, with 17% inward investment to the UK, second only to the US.[155] The UK's space sector is generating an annual income of £14.8 billion. Several venture firms have also invested in space technologies, including the UK Government through the National Security Strategic Investment Fund (NSSIF). However, investment in scaling up and buying UK-produced space technologies has been lagging, due to a lack of awareness of the opportunity, lack of specialist sector and technical knowledge, risk-aversion and unclear return on investment. Financial investors balance their portfolio risk profile carefully, and it is easier at present to make profits elsewhere than in space capabilities, which might be seen as difficult, dangerous, or too close to defence and national security.

The UK Government could do more to encourage UK investors to invest in UK space capabilities and accelerate the scale up of technologies into deployment, including through co-investment mechanisms and risk-sharing. However, this should be alongside the development of alternative public funding routes to prevent profit-driven reckless exploitation of space (see above)

Apart from direct investment, the UK should do everything it can to deploy its financial services strengths into growing our space economy and position the UK as a the 'go to' place for enabling financial services that will underpin the global space economy. Creating a diverse market of insurance products, services, and expertise combined with strong data science, modelling and technical expertise is a huge opportunity for the UK. London is already a global leader in space insurance underwriting and broking with over 25% of global space insurance capacity located there.[156] While primarily the private sector, the UK Government can create a more stable environment by creating a Space Reinsurance Pool,

[155] UK Space Agency, 'UK leads Europe in race for space investment, new report finds', 2023
[156] Satellite Application Catapult, 'Creating A Global Centre for Space Finance in the UK', November 2023

along similar lines to PoolRe[157] and FloodRe,[158] to underwrite major insurance losses and enable a wider range of insurance products. Space is exactly the kind of environment where rare, but very expensive accidents might occur, and mitigating the financial impacts will help investors and entrepreneurs develop new capabilities.

2c. Commercialisation and Scale-Up

Supported by a world-leading R&D ecosystem, the UK has a thriving start-up ecosystem in the space sector with considerable business support services, including the Satellite Applications Catapult,[159] the UK Space Agency Accelerator[160] and the Innovate UK Knowledge Transfer Network Space Sector Landscape Map.[161] The UK Space Agency announced in October 2023 that it is investing £65M ($79M) into early-stage space tech projects through the newly established National Space Innovation Programme (NSIP), on top of £25M since the program launched in 2020. The UK's space industry income grew +5.1% in real terms to £17.5 billion in 2020/21 – the second fastest annual growth in the last seven years. In 2022, the industry numbers 1,590 organisations[162] with an estimated 48,800 jobs in 2020/21 and £5.9 billion in exports in 2020/21, accounting for 34% of total income. The UK space industry has a strong commercial focus – 80% of income is commercial, comprised of consumer sales. However, just 14 organisations account for 81% of total space income in the UK and only 162 organisations generate space income of more than £5m. There are several UK-based investors in space, such as Seraphim Venture Capital Group,[163] which has its own Space Accelerator programme. Still, the evidence suggests that not enough space companies are making it across the 'valley of death' to scale into large profitable businesses. Too often, growing businesses offshore to find investment elsewhere, to attract and retain global talent, or to unblock barriers – for example, access to licenses for launch and operations – and the UK needs to maintain a positive investment climate for scale ups. Given the importance of the space sector in the UK, the UK Government could seek to address the gaps in scale-up equity and non-equity funding to help businesses bring products to market quickly, including Government direct procurement (for example in defence) as a first customer or co-procurer.

Regulation, whilst only part of the issue, will play a large role in determining the future success of UK start-ups and scaleups, and we believe it has been an overlooked part of the policy ecosystem. The Government Chief Scientific Adviser's (GCSA) *Pro-innovation*

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157 Pool Reinsurance, 'Building Resilience Against Terrorism Risk'

158 Flood Re

159 Satellite Application Catapult, The UK Space Ecosystem Cluster Directory

160 UK Space Agency Accelerator

161 Innovate UK, 'UK Space Sector Landscape Map'

162 UK Space Agency, 'Size & Health of the UK Space Industry 2022 Summary Report', 2022

163 Seraphim

Regulation Review crosscutting paper[164] noted that regulators are facing a number of pressures and challenges in regulating emerging technologies and innovations, including: fragmentation across cross-sectoral and territorial boundaries; technological developments often outpace the speed at which regulatory systems can respond, while introducing regulations too early can hinder the development of emergent tech; attracting relevant skills and talent, such as digital, data and technology profession experts; limited reward for taking risks in support of innovative products; and lack of capacity for pro-innovation programmes like sandboxes and innovation hubs. All these issues can be observed in the space sector.

In 2023/24, the RHC explored how regulation can better support and enable the UK's innovation ecosystem to scale their businesses so that the UK can benefit in terms of prosperity, and also so that innovative solutions can be brought to market more quickly to benefit consumers.[165] Several of the recommendations in this report, if implemented, would be beneficial to scaling space capabilities, including: establishing a flexible fund that would enable regulators to bid for additional capacity for work on technology areas with high potential return on investment for the UK, including international benchmarking; reviewing mechanisms to facilitate agile legal changes to support regulatory experimentation and agile governance of rapidly developing technologies; and expanding government and regulator awareness of innovative regulatory science approaches such as digital twins; encouraging regulators to evaluate the effectiveness of pro-innovation measures, such as sandboxes, on early-stage businesses, and share learnings; and establishing more consistent and comprehensive monitoring of regulatory impacts on innovation, for example through an annual innovation review, which could bring together metrics on regulatory approvals, waiting times, and small business participation in regulatory experimentation initiatives.

2d. Intellectual Property

Intellectual property (IP) rights play a key role in developing new technologies into novel capabilities, giving people the ability to copyright creative work, trademark goods and services, or patent inventions so they can benefit financially from their IP for a certain period. None of the main body of international space law contains any provisions expressly dealing with IP. The Paris Convention for the Protection of Industrial Property is the basic international treaty for managing industrial property, and the Berne Convention for the Protection of Literary and Artistic Works is the basic treaty in the field of copyright and related rights: neither expressly consider the question of intellectual property rights in outer space. However, several relevant principles apply since space capabilities are often

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[164] HM Treasury, 'Pro-innovation Regulation of Technologies Review ', 2023

[165] Department for Science, Innovation and Technology, 'RHC report about the role of regulation in supporting scaling-up', 2024

industrial property, rely on applying sophisticated technologies which are expensive to invest in, create and deploy, and are hard to replicate. The 1996 Declaration by the United Nations Committee on the Peaceful Uses of Outer Space on International Cooperation in the Exploration and Use of the Outer Space for the Benefit and the Interest of All States, Taking into Particular Account the Needs of Developing Countries states: “States are free to determine all aspects of their participation in international cooperation in the exploration and use of outer space on an equitable and mutually acceptable basis. Contractual terms in such cooperative ventures should be fair and reasonable, and they should be in full compliance with the legitimate rights and interests of the parties concerned as, for example, with intellectual property rights.”

IP is a strong driver and enabler for commercial activities in space. The UK has a generally well-respected IP regulatory regime in the Patents Act 1977 which sets out provisions for direct infringement and contributory infringement, but in both cases the Act applies within the UK and for the purposes for putting the invention into effect within the UK. However, as national law applies only to the territory (including air space) of a State and not to outer space, the question arises as to whether the IP law of launching State extends to the objects the respective country has registered and launched into outer space. When a satellite is launched from the UK, it will (in most cases) be under the jurisdiction of the UK: while UK laws apply, this does not necessarily mean that it is within the UK. The Interpretation Act 1978 defines the United Kingdom as being ‘Great Britain and Northern Ireland’ - rather than as being where the UK has jurisdiction - as such, once a satellite has been launched, it is likely outside of the UK. Indeed, the very existence of the Outer Space Treaty implies, and requires, that space is not within the borders of any country. Also, to ensure equitable access to the benefits of space, there are some areas where open source or public/ communal IP may be beneficial, to help to manage competition that may lead to adverse outcomes for peace in space and the space environment.

It will be important for the future to clarify what rules apply for technologies and capabilities created for, or arising in, space, with regards to IP, especially when the object is the joint creation of multiple states and private entities. The United States of America is the only country that has enacted an explicit provision establishing a link between the three key elements (inventions, jurisdiction, and territory): other countries have no explicit statutory provision except that, by virtue of the ratification of the 1988 Intergovernmental Agreement, German intellectual property law applies to the ESA-registered elements. Similar legal uncertainties exist for trademarks and industrial designs. For copyright protection, what matters is the author’s nationality, making this potentially less problematic: however, there is a potential conflict between the requirement to make remote sensing data available to all users on a non-discriminatory basis and copyright law application to analyse data, potentially covered by the EU Database Directive 1996/9. Any new treaty would also have to address multiple issues such as how to extend current national/regional rights to outer space, whether there would be common law trademark use rights in outer space or only registration rights, and how other laws, such as unfair competition, would apply. Other issues to hammer out would include deadlines, length of agreements, and other IP-related time concerns.

The World Intellectual Property Organization (WIPO), a UN organisation, is responsible for the promotion of the protection of intellectual property throughout the world and has explored the issue of space IP: “The importance of establishing a legal regime that effectively protects intellectual property in space cannot be overemphasised”.[166] This is a developing area, partly because it is only in recent years that space activities have shifted towards private sector commercial activities and private investors who are more protective of their property and assets (as that is how they generate revenue/ return on investment). Primary concerns have been for patent protection of inventions created or used in outer space, and the copyright protection of databases using data acquired through space activities: “Because of the large investments involved in space activities, a legal framework that assures a fair and competitive environment is necessary to encourage the private sector’s participation in this field. Limited exclusive rights conferred by intellectual property protection would bring competitive benefits to right holders either by concluding a licensing agreement or by excluding competitors from using a given technology.” Space activities have also become more global, and international cooperation more common (such as on the ISS), requiring ways for each State to protect their own technologies (especially if sensitive), in the absence of a reliable international regime through bilateral and multilateral agreements on issues such as ownership, rights of use, rights of distribution and licensing of data, information capable of legal protection and confidentiality. This is not binding on third parties.

As Sections 3, 4 and 5 set out the development of new technologies, capabilities and potential alternative futures suggests that IP regimes will be increasingly important in the coming decades to enable space activities to operate. If it became commonplace, space tourism, might lead to a need to protect trademarks and industrial designs in outer space. Lack of legal certainty will hinder the development of space capabilities and could prevent international cooperation. The UK could take the opportunity to develop and mature a comprehensive IP regime for space in UK law, which could form the basis for international agreements and provide certainty for UK industry to enable rapid progress. The UK already has a strong regulatory IP regime which includes tax exemptions for certain R&D activities: leveraging this could help to ensure we are retaining the benefits of UK R&D and could encourage entrepreneurs to come to the UK in order to benefit from our IP regime.

Because IP is often a difficult issue in creating contracts – for example, getting the balance right between government investment in defence and national security capabilities (which may need sovereign ownership) and commercial interests in owning their own IP – the UK Government could reduce friction by creating a menu of standard space contracts setting out options for IP arrangements and terms and conditions (similar to the Joint Contracts

[166] World Intellectual Property Organisation, ’Intellectual Property and Space Activities’, Issue Paper, 2004

Tribunal which produces standard construction agreements), which would enable quick and easy contracting under one of a small number of standard framework agreements.

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2e. Trade and Exports

The protection of sensitive information is necessary but complex and can have a suppressing effect on effective international collaborations and free enterprise. International export control regimes, often designed to stem the proliferation of nuclear weapons and related technologies, prohibit the sharing or sale of a huge range of 'dual use' technologies – that is, technologies which can also be used for military purposes. Virtually every aspect of space technology, including the satellites themselves, could be potentially considered 'dual purpose' and come under export control regimes such as the 1996 Wassenaar Arrangement between 42 countries and International Traffic in Arms Regulations (ITAR) administered by the US State Department through a very lengthy process. ITAR has made it more difficult for U.S. companies to sell satellites and satellite components to customers outside the United States, even at present to friendly nations such as Canada and Britain, somewhat to the advantage of non-U.S. companies who can provide ITAR-free alternatives. Since most insurers are based outside the US, they are prevented by ITAR from obtaining the technical information they need to make decisions on insurance policy terms and premiums. University researchers have also been subject to ITAR to control the sharing of technical details of scientific spacecraft.

UK export controls similarly place some form of restriction on nearly all space-related exports.[167] The UK's Strategic Export Control List[168] includes defence spacecraft and a range of 'dual use' civil and defence items which are used in space, including nuclear and radioactive materials, facilities and equipment, electronics, computers, telecommunications and information security, sensors and lasers, navigation and avionics, aerospace and propulsion technologies, launch vehicles, payloads and critical subsystems such as command telemetry, payload data handling and altitude control, as well as weapons of mass destruction (WMD) end-use controls and the provision of technical assistance with a WMD end-use. As emerging technologies evolve, they may be added to the list.

There is a conflict between the need to regulate defence products (to promote peace, prevent proliferation, and avoid harm caused by sensitive technologies falling into the hands of adversaries) and the need for open sharing to promote scientific and technological advancement and support innovation. Where space capabilities have the potential to cause great harm (see above), they should be highly regulated; however, in other areas with less risk, lighter-touch regimes could be developed to enable rapid

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[167] Andrew Horton, 'Space, the International Export Control Regimes and the UK Strategic Export Controls', 2018

[168] Department for Business and Trade, 'UK Strategic Export Control List', 2023

innovation. It would be helpful to define and agree on clear definitions for military, non-military, quasi-military and dual-use capabilities and create a proportionate classifications scheme to manage them appropriately at the lowest classification needed, with refreshed rules on exports and trade aimed at encouraging collaboration and innovation while managing risk, aligned with a counter-proliferation arms control regime (see above).

The UK has been very successful in attracting inward investment and trade in its space sector. Some countries, such as India, have liberalised their FDI regime to permit increasing levels of FDI into their space sector up to 100% FDI limits, to attract capital investors. FDI can facilitate technology transfer between states – for example, disseminating technology from developed to developing countries – and provide access to innovative technologies. However, FDI can also lead to losing control over strategically important industries and conflicts between the interests of the investing company and the host country. There have been concerns over a 'brain drain' of FDI into key technology start-ups, leading to the UK Government's National Security and Investment Act 2021 to screen investors and manage risks to national security, with powers to scrutinise and intervene in certain acquisitions that could harm the UK's national security. All 17 of the sensitive areas which are 'notifiable acquisitions' – including Satellite and Space Technologies as a separate category – are or will be relevant to space, including Advanced Materials, Advanced Robotics, AI, Civil Nuclear, Communications, Computing Hardware, Critical Suppliers to Government, Cryptographic Authentication, Data Infrastructure, Defence, Energy, Military and Dual Use, Quantum Technologies, Suppliers to the Emergency Services, Synthetic Biology, and Transport. It is too early to determine the Act's effectiveness in identifying upstream businesses and intervening effectively at the right stage of the investment cycle. Still, it will affect space businesses in the UK. In future, the UK Government should consider extending the remit of the National Security and Investment Act to cover in-orbit trade of assets, goods and services (for example, selling a satellite in orbit) and how bankruptcy would be handled for in-space assets.

2f. Regulatory Regime

This RHC believe that current space law will become even more inadequate as future capabilities are developed and deployed over the coming decades. The slow pace of regulation is a key concern: "The increase in the number of spacefaring nations, the contributions of private space companies, and the functionality of space objects has pushed space law to its very limit".[169] The UK must create a space regulatory system that allows innovation to flourish. It needs to be proportionate, scalable, and as-light-touch-as-possible, which gives people confidence in the UK and manages 'real' risks while not being heavy-handed where the risks are less severe. In June 2022, the RHC published its

[169] Lauren Peterson, 'The future of governance in Space, page 38, 2021

first cross-cutting report, *Closing the Gap Between Regulatory Principles and Practices*, outlining a number of practical solutions that regulators, policymakers and industry can use to put widely recognised pro-innovation regulatory principles into practice. It recognises that rushing to put new regulations in place too early risks ‘locking in’ regulations that are not proportionate to the risks posed by the innovation and discouraging innovation. Conversely, early regulation can provide protection and certainty, which helps investors and entrepreneurs understand what they can or cannot do.

We know that space exploration carries great risks of failure, and regulation must strike the right balance between rapid innovation and growth while ensuring space technologies’ safety, reliability, security and resilience, working with our global Allies. “Space exploration requires large, high stakes projects, usually at the forefront of technology, that carry a risk of spectacular failure at literally all stages of development and execution…it’s a slow, expensive and painstakingly detailed process, demanding no less than excellence”.[170] We should be humble enough to acknowledge that much space technology is in the early stages of development and use (for example, we do not yet even have a fully mature system to launch and return routinely, although the costs of launching into space are reducing).[171]

Because the technology is developing rapidly, we must take the opportunity now to iteratively put in place the guidance, standards and regulations which will enable responsible and safe use of current and future technologies, developing the regulatory regime in parallel with the evolution of the capabilities. We have seen from multiple other areas of technology development that leaving it too late to develop regulations and standards can open up opportunities for the abuse and misuse of technologies and make it difficult to apply *post hoc* regulation: we should learn from these and act now to develop regulatory systems alongside, and not after, the technologies and capabilities we are creating.

The RHC’s *Closing the Gap* report proposes a range of solutions to iterative co-creation of the regulatory frameworks, through experimentation initiatives such as sandboxes, test beds and digital simulation to test out regulations for new products and services within a controlled environment and to learn more about the potential risks. These approaches would be helpful for space technologies, where the risks of getting something wrong in space can be difficult to easily recover. For this reason, safety regulation in space will be of key importance. Space technologies have much in common with other sectors – such as aviation, maritime, Antarctic, and submarine (for example in the use of robotics and creating survivable habitats in hostile environments) – and would benefit from a coordinated approach to common problem-solving and learning, to shorten time to market and develop parallel regulatory regimes.

[170] Lauren Peterson, ‘The future of governance in Space, pages 95-96, 2021
[171] Harry W. Jones, ’ The Recent Large Reduction in Space Launch Cost‘, 2018

Effective regulation is founded on clarity over what is being regulated and why, with a set of key principles that set out an overarching intent within which detailed regulation can be interpreted. Usually, clarity is achieved both drafting the regulation and accompanying guidance and through a body of case law developed over time in specific circumstances. In the case of space law, despite key international laws such as the Outer Space Treaty having existed since the 1960s, there is little case law to provide a guide to how the regulations have been interpreted. In future, there may be much more case law, as space becomes more crowded and different interests – and possibly objects - collide.

The UK will need to iteratively develop and evolve a comprehensive regulatory regime for future space activities, building on existing laws, covering all the current and future capabilities discussed in Section 4 and above in Section 6 with appropriate law and associated guidance, authorities, accountability and enforcement regimes. As with any emerging technology area, space regulation should be under review, and a learning, iterative approach should be adopted to adapt against an overarching, clear roadmap and direction, providing clarity and, where possible, certainty for investors and developers. It would be useful to create a rapid regulatory challenge, feedback loop, and advisory group to explore how regulations work and adjust as needed through secondary legislation and guidance, and to explore how UK regulation can be streamlined for space products and services, to consolidate application and review processes for space systems[172].

The UK has a proven track record in regulating certain aspects of space activities, such as safe satellite operations, and this could be built upon to make the push for responsible use and regulation of future space capabilities. Safety is an area where the UK wields considerable influence at the international level. The UN frequently references our domestic implementation of the international requirements (binding and non-binding) as a role model for the international community, and the UK is proactively engaged in making recommendations for further measures at the UN and exchanging best practices with existing spacefaring nations and new entrants.

A key issue is that currently, under international space law, only launching states can be responsible for spacecraft and man-made space objects and carry all the liability and risk through their licencing regime unless otherwise agreed at international level through bilateral/multilateral agreements. The UK's Outer Space Act 1986 and Space Industry Act 2018 already extend UK Government liability stemming from international space law to UK space companies (this liability is capped in UK licences so that companies do not carry unlimited liability). The legislation also requires UK operators to carry third-party liability insurance for their space activities. Increasingly, as private companies and potential blends of public/ private entities are operating in space, regulatory frameworks will need to directly address the activities, responsibilities, and liabilities of private businesses as parties in their own right, in the same way as aviation and maritime businesses and

[172] https://www.techuk.org/resource/techuk-s-first-emerging-space-technologies-report-is-now-live.html

consortia. This will allow private businesses to be a party to seek legal recourse, as well as sharing responsibility with the host State for their own assets, products, and services which should drive responsible behaviours. This will lead to a more complex but more comprehensive regulatory regime and enable the development of good space law, anticipating the potential for an incident to occur in which a State is held liable for damage caused by a private, possibly multinational, entity. The UK Government should consider extending current and future domestic law and pushing for the extension of international law, to the activities of private actors and consortia operating in space.

The UK already has many groups and councils forming a complex picture of current space governance and regulation. The Government lead is the Minister for Science, Research and Innovation in the Department for Science, Innovation and Technology, which sets overall policy. In July 2023, the Prime Minister established the National Space Council as a new Inter-Ministerial Group, to set the cross-government ministerial direction for space policy and strategy. The National Space Board includes senior officials across all relevant departments and agencies and reports to the National Space Council. The Space Leadership Council acts as a knowledge exchange forum and offers clear and strategic advice to Ministers.[173] The Spaceflight Safety and Regulatory Council (SSRC) is a partnership between industry and government bringing together ministers and senior-level stakeholders to ensure the UK's commercial spaceflight regulations effectively support the growing UK spaceflight market and contribute to the UK's ambition to become a global leader in space.[174] The CAA's space team lead on licensing and regulation for launch and operations,[175] and Ofcom's space and satellite team regulate satellite and space science use of radio spectrum and telecommunications, including broadcast TV, broadband connectivity, global positioning, satellite imagery and climate information.[176] Several joint sector/HMG advisory groups exist for space, such as the Regulatory Advisory Group (UK Space Agency and sector co-chaired), the Spaceflight Safety & Regulatory Council (DfT and sector co-chaired) and the CAA's Space Launch and Orbit Group.

To many stakeholders, the UK space sector appears to have a slow, unclear, undefined, and fragmented ecosystem, which can be hard to engage with. The Innovate UK KTN Space Sector Landscape Map[177] is very helpful, but because the UK space sector is growing rapidly, different organisations, networks and collaborations are being created or are evolving, leading to considerable uncertainty and assumptions about who is, or will, do what and where responsibility for different aspects lie. There is the potential for overlapping remits and accountabilities, gaps, and a lack of good, up-to-date information,

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173 Space Leadership Council
174 Spaceflight Safety and Regulatory Council
175 Civil Aviation Authority, Space
176 Ofcom, Satellite and space science
177 Innovate UK KTN, UK Space Sector Landscape Map

exacerbated by the cross-cutting nature of space activities, which erode traditional boundaries between defence, commercial and civil sectors.

The UK needs to create the right ecosystem to manage regulation with clearly allocated roles, remits, and responsibilities fit for the future development of mature space capabilities. The RHC suggest that, given the breadth and complexity of the issues, consideration should be given to whether the range and complexity of future space activities may require in the next 10 years the creation of a separate specialist space regulator to shape and enact future regulatory policy and be responsible for pursuing the UK's interests in space in an ethical, proportionate and values-led way, taking over from the current CAA Space Regulator and relevant parts of OFCOM, the UK Space Agency, and Health and Safety Executive, and potentially parts of the Information Commissioners Office as the relevance of space data grows. As this would require significant primary legislation and upheaval, the benefits and costs of this need careful consideration, including clarifying how a new space regulator's remit interacts with other regulators' terrestrial remits. Given the range and responsibilities set out in implementing these recommendations, we suggest that the UK Government establish clear leadership and accountabilities across the Government potentially including in future a dedicated Space Minister to provide a single focus point bringing together all the multiple interests, strengthening the role of the National Space Board holding government officials to account for delivery and unblocking policy challenges, reporting to the National Space Council, and that space security is a routine item on the agenda of the National Security Council with appropriate attendance from leads on space policy.

In support of a clear, comprehensive regulatory framework for space activities, the UK Government needs to agree with international partners on a legal definition for outer space (in particular the height at which it begins) and definitions and terminologies for different kinds of space areas, environments and objects, as the basis for applying different legal systems to outer space and to avoid future dispute. The Space Industry Act 2018 has a definition for where the Act applies, which meshes with the scope of the Air Navigation Order and links to wider aviation/airspace considerations.[178] This could become an international standard, if adopted more widely.

It would be similarly helpful to clearly define the 'space sector' and space technologies and what is included/ excluded, to provide the baseline for future monitoring. Currently, international standards of industrial classification do not recognise space as a category, resulting in differences in the definition, coverage, and methodology of national space statistics worldwide. This lack of international comparability hinders accurate comparisons between countries.[179]

[178] CAA, Large Rocket Permission,

[179] ESA, 'Measuring the Space Economy', 2019

Strategic Objective 3: Ensure that the UK is at the forefront of a few key enabling technologies and capability development

The UK can't do everything in space, and nor should we, but we have a few key strengths we can leverage to ensure that we can play a key role in the future development of space capabilities and services and benefit from them. By moving upstream, the UK can establish a key role in providing enabling services and technologies. This section highlights the UK's strengths in science, technology, and data, as well as opportunities for focused and targeted investment of funding, skills, and effort, as well as securing the global supply chain and building the skills pipeline needed to support the space sector. The UK's investment in space launch capabilities provides a potential future sovereign capability and testbed, which can drive investment and attract expertise into the UK. The UK's Space Industrial Plan sets out five specific capability goals where the UK seeks leadership across Space Domain Awareness (SDA): in-orbit servicing; assembly and manufacturing; space data for earth applications; PNT; and satellite communication technology[180]. The RHC have focused on a small number of relatively low-cost investment areas which could have significant dividends.

3a. Scientific Research and Applied Technology Priorities

The UK has great scientific strengths in key areas for future space capabilities but is competing against global talent. Having a world-leading reputation in these areas secures a seat at the table and the credibility to broker international cooperation, using our strong track record of global 'science diplomacy'. Sections 3 and 4 set out many of the key technologies and capabilities where the UK has strengths, including AI and Machine Learning, Data Science, Energy, Engineering Biology, Telecoms, Human Sciences, Novel Materials and Nanotechnology, Quantum Technologies, Robotics, Semiconductors, Sensors and the Internet of Things. Core investment in these areas will help benefit space, as well as other sectors. in addition to the wider efforts to develop technologies such as AI and quantum safely and effectively, with appropriate regulatory regimes, there are two areas specific to the space sector where the UK could invest in science and technology to give us a strategic advantage: The UK Government should invest in semiconductor novel materials and fundamental design for space, drawing on the Harwell test site, as the UK is very well placed to develop this element of a globally significant supply chain; and also seek to establish an assured onshore integration capability in atomic clocks and timing with a clear assurance approach, and create a terrestrial PNT distribution network. The UKRI should also fund multidisciplinary research and development projects on space

[180] https://www.gov.uk/government/publications/space-industrial-plan

capabilities which include human behavioural and social sciences and psychology, as these enable other capabilities such as future human colonisation.

There are three other key capability areas highted in this report where the UK could have a strategic advantage and which will contribute to security, stability, and prosperity: the UK Government should seek to develop a deployable debris tracking and removal service, a global civil ‘space traffic management’ system, and continue to develop ‘data as a service’ capabilities. Underpinning work on this is already being done across UK Space Agency, UKRI and Met Office, and the programmes are well aligned with National Space Strategy. Together, these capabilities will enable any space user to operate safely; however, they will require substantial upfront investment, which will need strong government support, including investment in underpinning technology areas, including bioengineering, robots and autonomy, and rendezvous and proximity operations. A key enabler will be to develop and refine standard classifications of position in outer space (the space equivalent of latitude and longitude) to classify and map space to create future navigation, positioning, travel corridors and ‘traffic control’ rules – currently there are different coordinate systems for spacecraft navigation such as the Celestial Coordinate System. The UK is also in a particularly strong position to contribute to understanding and forecasting space weather and its impact on the population of objects (human-made or natural) in orbit.

3b. Data and Economic Modelling

Many of the areas set out here for future development – insurance, regulation and legal arbitration processes, investment, information-sharing, and the operation of key capabilities such as space traffic management – rely on good data and economic modelling of risk and benefits. Statistical modelling helps government, insurers, regulators, and investors understand the risks and benefits of acting (and the opportunity costs of not acting promptly). Better data could help us set out the economic case for investment in space (including public investment), help insurers develop better products and services for customers, and develop ways to de-risk space technologies and capabilities. Having better metrics for success also us to measure success and stop failing projects earlier on, saves money and time.

The UK Government should commission a programme of work overseen by HM Treasury to develop and publish economic and data modelling frameworks and standards for the space sector and subsectors, including related capability areas, which can underpin these considerations. This programme can also explore approaches to broaden the metrics for future space investment to encompass social, environmental, and other long-term benefits in addition to purely economic factors, factoring in the cost of future protection of a limited and fragile space environment. There are examples in other sectors of how to combine multiple variables in economic modelling to underpin proportionate regulatory approaches.

For example, aviation regulation combines fundamental safety requirements with more price-based approaches on the availability of space in the air and on the ground; while environmental regulation increasingly seeks to price-in negative impacts (such as light pollution) to clearly signal the costs imposed by some actions. Combining such explicit forms of regulation with more subtle 'nudges' (such as more systematic linking of government financial and nonfinancial support to outcomes such as returns from first-move advantages) could help blend private sector innovation with improved use of space. This programme could include frameworks for risk analysis (considering options for characterising risk based on issues like exposure, value at risk and vulnerability to the realisation of risks), what data sets to draw upon (data sets tracking debris, property in space, launch plans etc., the approach to risk analysis (for example, the potential to use machine learning to track activity and predict risks versus more established techniques such as probability analysis) and dissemination of the analysis and links to activities in other countries. This work could position the UK as a trusted, honest broker for global risk modelling and support the UK's role in insurance services for space activities. The work should also develop standardised metrics jointly between the UK Government and the space industry for UK space sector programmes to monitor progress and impact, ensure objectives are being achieved, and enable good management and decisions.

Another key capability area where the UK could have global influence would be establishing metrics to monitor the 'health' of the space environment – much like the Essential Climate Variables used by the Global Climate Observing System to understand and predict the evolution of the Earth's climate. The UK should fund international research – working with the UN Office for Outer Space Affairs, NASA, ESA and other relevant institutions - to establish key datasets providing empirical evidence to understand and predict the evolution of the space environment, assess risks, guide mitigation measures and enable attribution of changes to underlying causes. This would be a critical enabler to inform policy and international regulation.

3c. Securing the Supply Chain

The UK Space Sector should not underestimate the security challenges the private and public sectors face in the cyber and physical aspects of its supply chain. The issue of supply chain security is particularly vital to the space sector due to the significant threat of nation-state attacks on spacecraft to harm rival countries or for cyber espionage. A solely sovereign supply chain is very difficult to achieve, but there need to be aspects which are independently owned and operated by the state. It is important to understand what is sovereign, what is assured capability and what is independent capability, and where the cumulative risks lie. For example, the availability of electronic and other components is a key issue, with the potential for shortages if states or companies hoard them for strategic or commercial advantage. The space industry is facing a growing threat from nation-state cyberattacks and complex supplier networks, making it critical for organisations to know who has built every component that makes up a spacecraft. Hardware Systems are highly reliant on genuine, high-tolerance components and critical rare earth metals. Operational Technologies are reliant on secure software operating systems, patching, and resilient communication links. A single supplier being compromised could result in a disastrous incident. There are areas of global good practice and standards that could be applied such as NASA, the NIST commercial satellite reference document on cybersecurity, and integrated logistics practices like resilient hardware and software Bills of Material.

The threat to the global supply chain for space is taken so seriously that in the US an entire organisation, the Office of Safety and Mission Assurance (OSMA), has been created. OSMA has a Supply Chain Risk Management (SCRM) programme that focuses on strategies, tools, techniques, and guidance to generate knowledge about supplier risk and create approaches for maximising successful quality outcomes throughout NASA's supply chain for mission hardware. The Satellite Applications Catapult's UK Space Sector Supply Chain report[181] highlights several structural issues and potential threats to the UK space sector supply chain. It sets out a taxonomy which has been developed by the Satellite Applications Catapult and created a Supply Chain Dashboard which has been incorporated into the UK Space Capabilities Catalogue.[182] In addition to tackling cybersecurity threats, the UK Government need to create a programme of work with the private and public sectors to ensure that the UK Space sector supply chain is secure.

3d. Investing in Skills and People

Skills gaps have been repeatedly highlighted across the space sector as a barrier to growth,[183] and this is likely to grow more acute in future unless action is taken quickly – echoing wider concerns about the national shortage of STEM skills. The space sector also needs business expertise, communications, legal expertise, and other specialists. The UK has a strong R&D base, with many universities offering courses in space science and relevant science and technology disciplines at undergraduate and graduate levels. Most require STEM A-levels, which may limit the diversity of students participating. The UK Government could fund Universities to create 'space bursaries' encouraging a wider range of students to take space science and engineering and introduce new modules on space applications in relevant degrees such as human sciences and ethics. It may be possible to include in relevant A-levels topics in space science, introducing younger people to the potential for careers in the space sector. Outreach is also very important, through STEM ambassadors and the work of high-profile inspirational role models such as Tim Peake. In addition, the UK Government could create a Young Peoples' Panel on Space Futures for

[181] Red Kite Management Consulting, 'The UK Space supply chain', 2022
[182] Catapult Satellite Applications, 'Space Capabilities Catalogue'
[183] UK Government, 'UK Space Skills Survey', 2023

under-25s to sit alongside and shadow the Government's National Space Board. As the UK space sector grows, the UK Government may wish to explore further professionalising key career streams to ensure career pathways are clear and standards are maintained. Equality, diversity, and inclusion are key to ensuring everyone who wants to can pursue successful careers in the space sector: more needs to be done to encourage and retain under-represented groups.

Attracting and retaining top global talent in the UK is key for the UK space sector to thrive. Space sector jobs tends to require relatively high-level qualifications and are competing with multiple other technology industries, many of which may pay more. If the UK wants to place itself at the forefront of space technologies and capability development, we need to offer competitive salaries and conditions. The UK also needs to bring in talented people from overseas, including entrepreneurs and scientists, to support the development of the UK space industry. Given the strategic importance of space for the UK, we propose the UK Government explore the potential for 'Space Visa' exemptions for specialist space technology expertise, easing the requirements for salary thresholds, sponsors and spousal restrictions and making it easier to take up jobs here with fewer barriers to entry, in particular where the roles are critical for businesses meeting the terms of their licenses requiring them to have suitably qualified personnel: an issue supported by the recent techUK report on emerging space technologies.[184]

Regulators themselves will need the right skills to regulate space, now and in future, and plan a pipeline of future skills and training[185] – for example engaging with students and young people about the social impact of careers in regulation and opportunities to get involved at junior levels. It might be useful to create a 'technical expert' track parallel to the generalist management career pathway to retain technically skilled staff into mid and late-career roles, consider appropriate pay scales benchmarked against market rates for technical expertise, and continue to draw on external expertise. Recognising that space regulation is an international ecosystem; it might be useful to explore partnerships and exchanges/ secondments with other international regulators to broaden the talent pool.

Raising public awareness of the importance and reliance on space is also important to help engage the public in co-creating future space capabilities. The UK Government could commission the UK Space Agency to create an educational scheme to raise awareness and excite people about career opportunities in the space sector through multimedia approaches, possibly in partnership with the BBC. To address the skills gap in the space sector, the Government should partner with universities and relevant industries to co-create authentic learning opportunities that are integrated into academic programmes, giving students and graduates opportunities to explore and potentially solve mission-led space challenges. Such partnerships help to align university curricula with the needs of

[184] https://www.techuk.org/resource/techuk-s-first-emerging-space-technologies-report-is-now-live.html
[185] Angela McLean, Pro-innovation Regulation of Technologies Review 2023

the space sector, emphasising experiential and problem-based learning approaches. Furthermore, these collaborations raise awareness of the sector and career opportunities whilst equipping students with sector-specific knowledge and 'job ready' skills. Examples of these partnerships can be found in Defence which have resulted in a higher number of university students pursuing careers in the sector and are actively helping to shape a diverse and sustainable talent pipeline.

Conclusions

Our review explored how critical technologies (including the five set out in the Government's Science and Technology Framework) can be effectively and safely leveraged to enhance the capabilities of the UK space sector, while addressing regulatory gaps and ensuring their optimal utilisation. We explored these technologies and how they create current and potential future capabilities. Our review worked with a broad range of stakeholders to explore future trends and identify gaps and opportunities for the UK.

The RHC's key finding is that space regulation is mostly 'missing in action', whilst technologies are racing ahead. Current and future spacefaring nations need to develop together a proportionate and flexible regulatory approach to space alongside, and not after, the technologies which may create future capabilities in space such as debris removal, solar energy generation, mining, and manufacturing. The RHC is concerned that trends towards the increasing militarisation and commercialisation of space could increase the potential for future conflict, and lead to the degradation and misuse of the space environment. Without clear rules and guidelines setting out *who* can do *what* in space and *how*, humanity will fail to benefit from the opportunities of space. All spacefaring nations need to manage the space environment carefully to prevent over-exploitation and pollution, ensure that peace is maintained, and enable everyone to benefit equitably.

The UK can play a key role in shaping the future direction of space and 'do the right thing' by making the case for prioritising environmental protection, peace, and equitable use. We can also build on our position as a globally trusted, honest broker, leveraging our international strengths in science diplomacy, technology, financial services, law, data science, and assurance. The RHC proposes three key areas to focus on:

1. Build on existing work to address the challenges of space sustainability especially preventing overcrowding, and in-orbit servicing including removing debris removal, both through technology development and creating enabling regulations and guidance governing when and how these technologies can be deployed, ensuring both government and commercial actors operate responsibly;

2. Establish the UK as the global centre for space law, arbitration, insurance and financial products and services, and data science/modelling, which will help establish international norms of responsible behaviour and enable effective and safe space operations;

3. Create new mechanisms for public engagement and collective responsible investment in ethical space technologies and capabilities with shared global benefits.

Acknowledgements

The report was created by RHC Members Lucy Mason and Andy Greenfield, Kieran Saggar and Zoe Wright from DSIT, and Cyrielle Opitom, University of Edinburgh, with thanks to all members of the RHC and RHC team for their insights and comments.

The RHC thank James Black, Theodora Ogden and Mélusine Lebret, RAND Europe, and Mark Chang, Capgemini Invent, and Jo Petrolati and Stefan Krstevski, Cambridge Consultants, for their help in creating this report. We would also like to thank Wilton Park for the Future Space Threats event.

The RHC would like to extend our thanks to all who contributed to this report, including participants in our workshops and interviews and those who reviewed the document and kindly made comments on our draft, including Matthew Bell, Emma Barrett, Katherine Courtney, Murray Gardner, Geoff McBride, Lauren Payne, Elizabeth Pasatembou, Barney Reynolds, Nic Ross, Nick Shave, Ollie Whitehouse, Mike Short, Mark Wheatley, Tim Watson and multiple Government officials who kindly offered their insights and advice.

We thank the following organisations for their input and support: Civil Aviation Authority, the UK Space Agency, Satellite Applications Catapult, Ofcom, The Royal Society, and others.