REGIONAL GROWTH TEAM

The UK Space Supply Chain

Prepared for the Satellite Applications Catapult and the UK Space Agency by Red Kite Management Consulting.

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March 2022

This report reviews the UK space supply chain and makes recommendations on how to develop it to support the National Space Strategy.

It assesses current UK capabilities, including a review of 17 regional reports commissioned by the UK Space Agency, Satellite Applications Catapult, and regional bodies. It examines the economic impact of the sector, in and beyond the space supply chain. It considers trends in the industry, potential emerging markets, strategic issues, and makes recommendations that will shape the successful space supply chain of the future.

The Red Kite Team

Red Kite Management Consulting

- Lead: Robin Tucker
- Strategy, marketing, public policy
- Knowledge of space application markets: telecoms, transport, agri/environment

Connected Economics

- Lead: Dominic Walley
- Economics, data and public policy
- Experience with space, related markets and regional development

Commercial Space Technologies

- Lead: Alan Webb
- Launch and satellite industry experts for over 35 years
- Contacts through space & supplier industry

Contents

The UK Space Supply Chain

1. Executive Summary

The UK Space Supply Chain has a great range of capabilities and opportunities, but also structural issues and threats. These can be tackled by using existing needs intelligently to build space capabilities and markets, and linking in other UK capability areas, as shown in this report and the recommendations. made in Chapter 8

In reviewing the breadth of its capabilities, we found no major gaps except launch and emerging sectors. The UK space sector can bring together components and construct large or small satellites, operate complex satellite systems in space and on Earth, and develop applications in all major domains.

Currently, it appears dominated in income terms by downstream or applications businesses, which the Size & Health study puts at 71% of sector income. However, the true picture is more nuanced. This is partly because Sky UK is shifting its services to terrestrial broadband and only spends a minority of its income in the space supply chain. It is also because applications have more potential for 'cascade' effects down the supply chain, this is diluted by the availability of free data (e.g. from Galileo and Copernicus satellites), and by much of their supply chain being from the general IT sector rather than the space sector. We estimate satellite manufacture to have about 45% greater cascade expenditure within the UK space industry per pound of income than non-DTH satellite applications.

The UK upstream sector has structural weaknesses, balanced with strengths.

- It is highly dependent on imports, for about 60% of its inputs – from tiny electronic components to large subsystems. The sector exports strongly as well, and the two are in approximate balance.
- There is only one UK 'large satellite' integrator, Airbus Defence and Space. This limits competition for UK contracts, but helps the UK gain a role in ESA and large commercial contracts.
- It is underrepresented in 'Medium to Very Large companies' with 100+ employees. It has large numbers of smaller SMEs. It also has several 'outposts' of large foreign-owned groups that have expressed intention to expand (e.g. Lockheed Martin, Thales Alenia Space).
- Linked to this, there is limited ability in 'sub-system integration' – the key step between components and complete satellites – outside the major prime contractor.

Markets are shifting in a way that threatens some existing UK strengths, and opens new opportunities.

The UK's strong GEO satcoms industry, and wider supply chain, is under threat from LEO constellations such as Starlink and Kuiper. This supply chain includes upstream (Airbus, Teledyne, Thales Alenia and other suppliers), service operators (Inmarsat, Intelsat, OneWeb, etc.), and ancillary services

(finance, insurance, IT, legal, consulting). The threat comes from constellations with vertically integrated business models, manufacturing their own satellites and largely raising their own funds and self-insuring. There is some insulation due to UK-based OneWeb, but its supply chain is very international.

The major needs expressed by the supply chain across regions are for basic inputs. Skills were the most common concern, with some specific gaps, but basic STEM skills over long-term being the biggest concern. Funding was an issue outside areas with strong funding networks. Where there was no existing space cluster, space companies wanted better awareness and coordination of the sector.

The 'cluster' approach works well, and the regional evidence shows different types of clusters helping firms to find opportunities, learn from each other, and share resources. As well as local contact, clusters also provide a focus for inter-regional contact, and they may to help offset some of the difficulties of the UK having a predominance of small businesses. Clusters are a vital part of the UK space ecosystem, but they need critical mass to be effective and should be developed strategically where there is sufficient space activity or potential, rather than everywhere.

New space markets with large public benefit could be opened by public sector 'market creation'. In upstream, Space Environment Management can be kick-started by UK public procurement, but international regulation should be the objective. In downstream, there are many applications with a public benefit, for example Environment Act Biodiversity Net Gain monitoring, Road pricing, Health monitoring. For these, public procurement or regulation can play a key role. Because of the benefits, these markets can save public money and can even raise funds if the 'polluter pays'.

There are several emerging markets in the in-orbit sub-sector, including: satellite constellations (in all three main application areas[1]), in-orbit servicing and manufacturing (IOSM), space-based solar power (SBSP), and launch vehicles, yielding an increasing level of space activity. These markets will require businesses with significant resource to exploit them, and the UK has some advantages and some disadvantages.

UK advantages:

- Airbus DS – part of a world-leading international space business
- Research, engineering, and creative 'problem-solving' skills
- Financial and professional services – London's expertise here has proved valuable before
- International partnerships and foreign investment – UK proven open for business

UK disadvantages

- Foreign partnerships/operations often mean invisible imports/outsourcing
- Lack of large suppliers beyond Airbus limits the opportunity to tackle large challenges

[1] Satellite Communications (Satcoms), Earth Observation (EO), and Position, Navigation and Timing (PNT).

Investing in these markets should bring good returns for the industry and the nation, but they will only grow to full maturity in the 2040s or beyond. By 2032, the ten-year timeline for this report, the UK's share of potential In-Orbit Servicing and Manufacturing markets is estimated to be £200-300m. To that we can add knock-on benefits to the supply chain of £100m, and a total impact of circa £180m for UK launch. In total, new markets will generate about £500-700m to add to the industry's income in 2032 – transformative for individual companies, but not for the overall size of the industry.

If the sector continues its long-term 7% growth rate (outside a DTH segment expected to shrink), it will reach £28bn income by 2032[2], and a more even mix between upstream and downstream. Achieving £40bn would require significant stimulus to develop large UK upstream and downstream space businesses, with actions along the lines described in recommendations 4, 5 and 6.

Overall, we see the 2020s as a time for strengthening the UK's capability base in preparation for a larger space economy. The 2030s will start to see a scale-up depending on technology readiness and investment. The 2040s should see a larger industry supporting more orbital activity.

Delivering this vision, in line with the National Space Strategy, requires an ecosystem of technology, regulation, services, and customers. The UK should not attempt to do everything, but to focus on the areas where it has most advantage. National effort should focus in three categories:

Ecosystem development	Technology development	Major programmes
Developing the capabilities and the 'environment' (skills access, regulation, etc.) of the supply chain. These are the focus of most of our recommendations. (Recommendations 1,3,4,5,6)	Enabling technologies for new and advancing space markets e.g., Optical communications, Mission simulation for IOSM, Robotic assembly for SBSP. Recommendation 2 covers technology development, and Recommendation 4 shows how it can be extended to develop capabilities as well.	Very large programmes requiring major investment & coordination, e.g. Space-based solar power, Launcher using SABRE engine. Major programmes are essentially a larger form of technology development and capability development, requiring greater investment over a longer period.

[2] Expressed in 2019 prices

We make six recommendations for the UK space supply chain to support the National Space Strategy as shown in figure 1.1.

- One is a **Capability Enabler**, which addresses the basic requirements of a growing sector for skills and finance.
- Two are **Capability Developers** – Existing activities to build capability in the space supply chain.
- Three are **Capability Multipliers** – New activities that could significantly increase the capabilities of the UK space sector, often with limited cost.

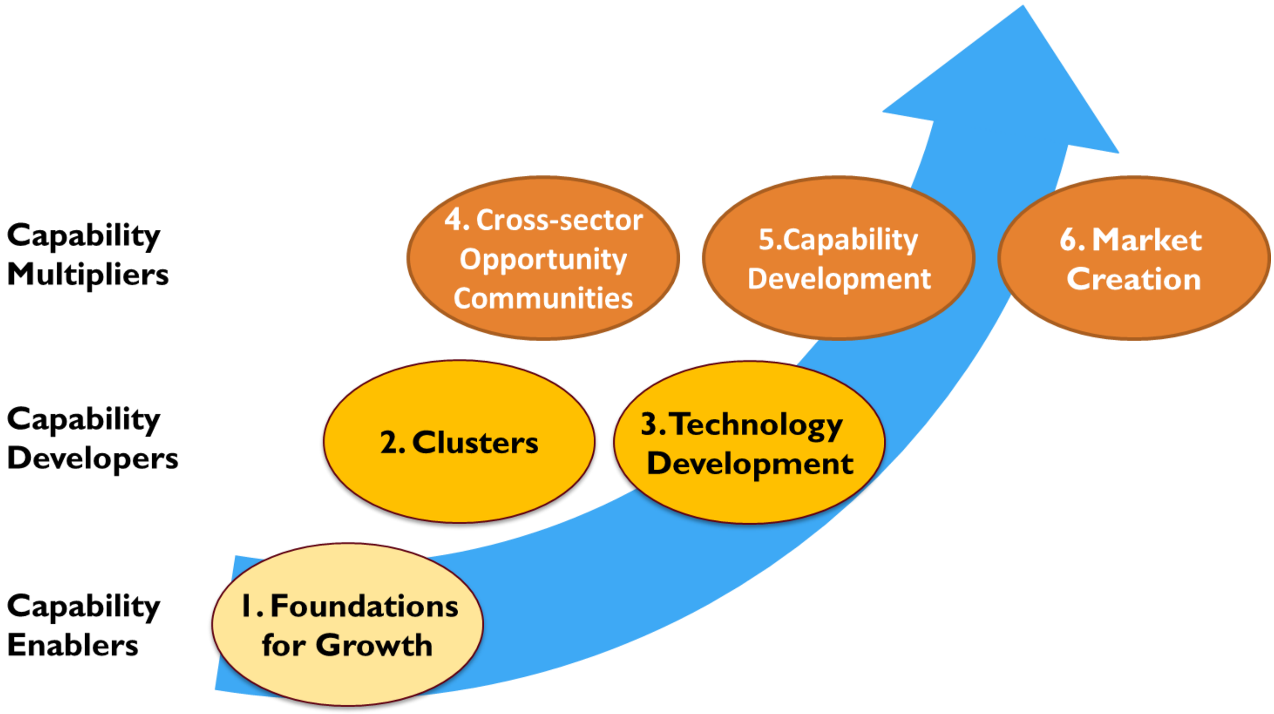

Figure 1.1: Six recommendations for the UK space supply chain

These recommendations are described in the table below and detailed, with Action Plans in Chapter 8.

Recommendations for the UK Space Supply Chain

1: Foundations for Growth	Improve access to skills and finance, with a plan that meets the growing needs of the sector.	The space sector is not alone in needing more people with STEM skills, but it can also help to inspire and train them. Finance is an important enabler too.
2: Space Clusters	Continue space cluster development and creation.	Space clusters have been positive, but need critical mass. A strategic view should be developed of the areas with sufficient space activity or potential, and cluster creation and development continued on that basis, in addition reinforcing links between clusters.
3: Technology Development	Invest in technology development to accelerate progress, but aware of the dangers.	Investment in Research and Development for space has paid good return, and helping as many across the 'space proven' hurdle as possible should be a goal. However, it is important to know there is a realistic potential market and financial plan.
4: Cross-sector Opportunity Communities	Reach out to related sectors that can unlock big space opportunities.	The big opportunities in space will be best realised by supplementing the capabilities of the space sector with those of other sectors in which the UK has world-class skills, such as advanced manufacturing, communications (including optical and quantum), IT, robotics, and professional services.
5: Capability Development	Use programmes to improve UK industry capability, not just technology.	The programmes required for science missions and technology development can also address the UK's industry structure deficit. RFPs can include requests for UK and SME content and how these will be enhanced by the programme, developing a more capable UK industry.
6: Market Creation	Be proactive in market creation, using regulation and public procurement as tools.	Several opportunities for space are held back because the markets do not exist, but they could be created or catalysed by the public sector. This can save public money where space services save expense elsewhere, or even raise money e.g., through environmental regulations.

2. Objectives for the UK Space Supply Chain

The UK space sector is successful, growing, highly productive, and underpins a large amount of the UK economy. As such, it is important that there is a strong UK supply chain that can support its continued growth, or other nations will gain the benefit from this expanding and strategic sector. The National Space Strategy (NSS), published in September 2021, sets out the goals and overall plan for the UK in the sector. It identifies 14 strengths and opportunities, with eight key capability priorities for the UK to develop.

2.1 National Space Strategy: UK Strengths and Opportunities

The NSS identifies four **Existing Strengths for the UK** space sector. These provide insight into the breadth of the space sector and the complexity of many of its aspects:

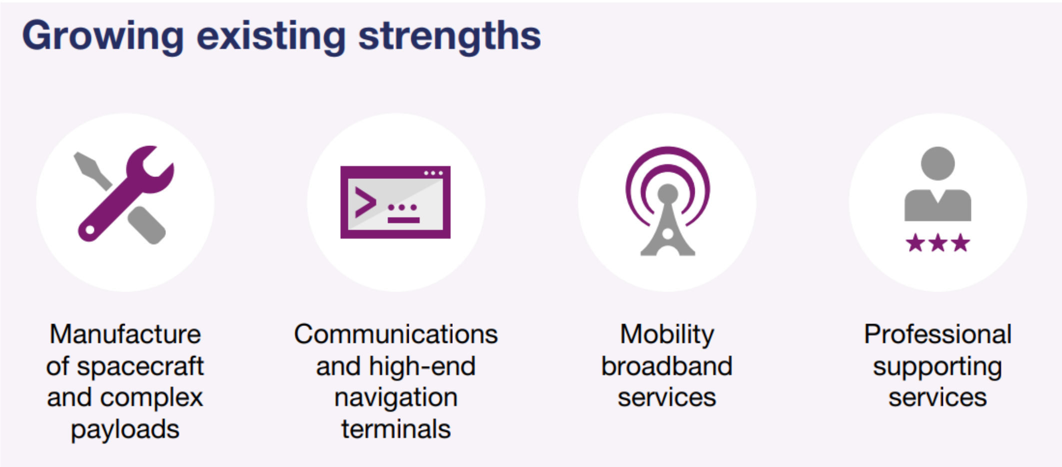

Figure 2.1: UK Existing strengths – National Space Strategy, 2021

- Manufacture of spacecraft and payloads has a complex and specialised supply chain, which will be discussed at length in this report due to its strategic nature.
- Communication and navigation terminals has a simpler supply chain, but is still very specialised electronic and radio-frequency (RF) equipment.
- Mobility broadband services, exemplified to date by Inmarsat but undergoing a revolution with the development of Low Earth Orbit (LEO) constellations, relies on both of those in its own supply chain.
- Professional support services include IT, insurance, legal, finance and management consultancy.

These are diverse, but their inputs are in skills, funding and IT resources – things that are much more generally available, although the firms or people involved are often specialised in space.

Four areas are identified as **High Growth Areas** where the UK has potential to establish leadership in global markets:

Figure 2.2: High-growth areas – National Space Strategy, 2021

- With planetary environmental crises and current transport systems needing to transform there is no doubt that Earth Observation and Navigation applications have a large potential to contribute to the global economy. Many of what will become large 'environmental markets' have not been established yet and need to be created by public sector action. Even so, UK industry has already shown positive signs in these areas, with small and medium firms, and divisions of larger corporations developing satellite applications, such as Frontier Agriculture's SOYL precision farming division. These application businesses rely on the space sector supply chains that deliver Earth Observation data and images, Navigation signals, and (non-space) IT supply chains to process the data and manage customers.
- The more objects there are in space, the more important it becomes to know where they are, which is known as Space Domain Awareness (SDA), or Space Situational Awareness (SSA). It can be ground or space-based, which have different supply chains, but always require sensors – usually optical cameras or telescopes – and computing to process the trajectories of space objects.
- Satellite broadband is going through a revolution alongside mobile broadband services. It is still currently mostly provided by large High Throughput Satellites in Geostationary Earth Orbit (GEO). But the advent of OneWeb and Starlink means a switch is coming to LEO constellations, although GEO satellites will (probably) still have a role. In either case, the satellite manufacture and launch supply chains are essential, but for constellations the need for volume increases, outweighing pure focus on reliability. In addition, the operations challenge increases many-fold.

Finally, six Emerging Sectors are predicted by the NSS, which will generate new markets and have new supply chains:

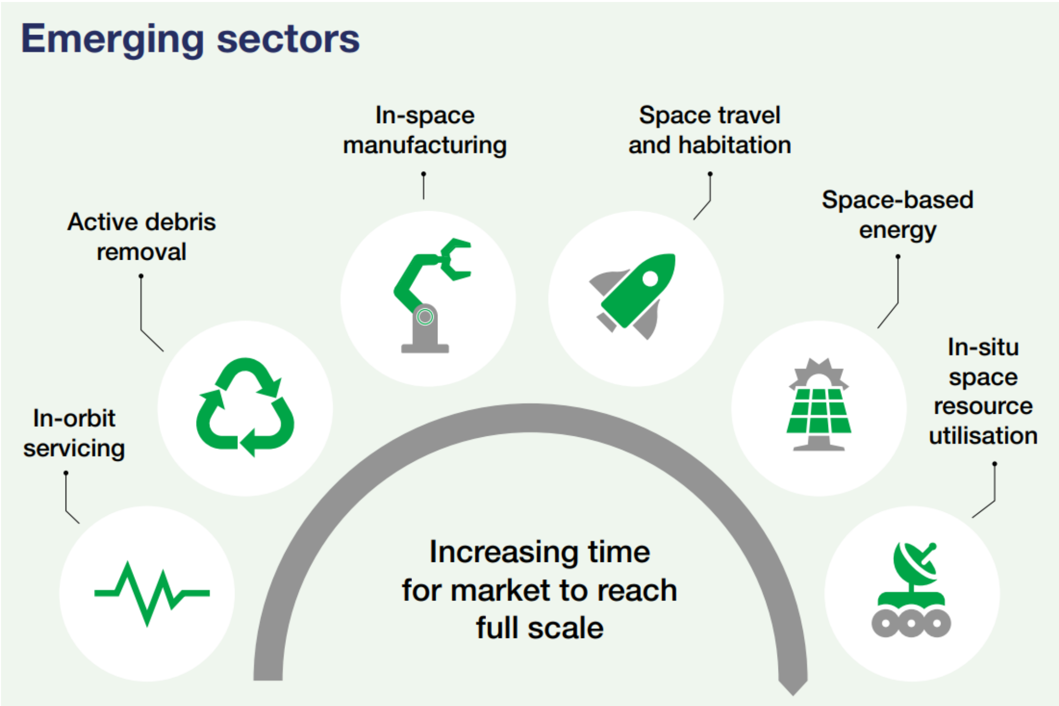

Figure 2.3: Emerging sectors – National Space Strategy, 2021

It is notable that all six emerging sectors are related to in-orbit operations, which points to several common needs in their supply chains. Launch will be essential – large-volume equatorial launch. Large structures are required by many, so spacecraft modules will be built on Earth and assembled in space. This will require complex space operations, robotics, and advanced automation.

National Space Strategy: Key Capability Priorities

The NSS also identifies eight 'key capability priorities' for the UK. These are rooted in the 14 strengths and opportunities, and are the capabilities needed to achieve the UK's ambitions in space, covering both civil and defence:

Key civil and defence capability priorities for the UK
• Satellite Communications: Global, secure, and resilient • Earth Observation (EO) and Intelligence, Surveillance and Reconnaissance (ISR) • Command-and-Control, and Space Capability Management • Space Control • Position, Navigation and Timing (PNT). • Orbital Launch Capability • In Orbit Servicing and Manufacturing (IOSM) • Space Domain Awareness (SDA)

Figure 2.4: Key space capability priorities – National Space Strategy, 2021

The NSS describes how the UK will adopt an 'own-collaborate-access' framework on how to procure technologies, as described in the Integrated Review[3]. But, "We will seek to establish a leading role in space-related technologies where there is a realistic prospect of delivering strategic advantage for the UK."

This puts a high priority on these eight areas for the supply chain, at minimum to ensure the UK has access to these crucial areas, and ideally to take on a world-leading position, or be part of a world-leading partnership. We assess the UK's status and current programmes in these areas in Section 3.4.

The UK Government has a Ten Point Plan for the highest impact opportunities and cross-cutting enablers for the UK's future in space. Various aspects of the supply chain support each area of the Ten Point Plan. We have reviewed the analysis and recommendations of the report to ensure that supply chain capabilities to deliver each area of the plan are included.

Ten Point Plan: Initial Focus Areas
1. Capture the European market in commercial small satellite launch
2. Fight climate change with space technology
3. Unleash innovation across the space sector
4. Expand our horizons with space science and exploration
5. Develop our world class space clusters
6. Lead the global effort to make space more sustainable
7. Improve public services with space technology
8. Deliver the UK Defence Space Portfolio
9. Upskill and inspire our future space workforce
10. Use space to modernise and transform our transport system

Figure 2.5: Ten Point Plan – National Space Strategy, 2021

2.2 Delivering on the Opportunities

The opportunities that space creates and enables will require an extensive and globally competitive supply chain to deliver, especially if the UK is to be a leading player. This section outlines the key opportunities, trends, and challenges that the supply chain will face over the next ten years.

The space supply chain is wide and complex and has proven itself to be flexible and cooperative, inside and out of the sector, to tackle many challenges and to create opportunities, some that were not foreseen until people started to make them happen, such as reusable launchers and low-cost IoT services. In the next section, we describe the UK space supply chain and how it measures up to the objectives and direction of the National Space Strategy.

[3] https://www.gov.uk/government/publications/global-britain-in-a-competitive-age-the-integrated-review-of-security-defence-development-and-foreign-policy

3. The UK Space Supply Chain Today

3.1 Overview

The space sector supply chain includes manufacture of components, assembly, integration of both hardware and software and testing, plus launch, operations, communications or downlinking data, processing it, and developing and running end-user applications. Government also plays many roles in shaping the industry: being a key customer, providing licences, developing skills, places, industry agencies, and more.

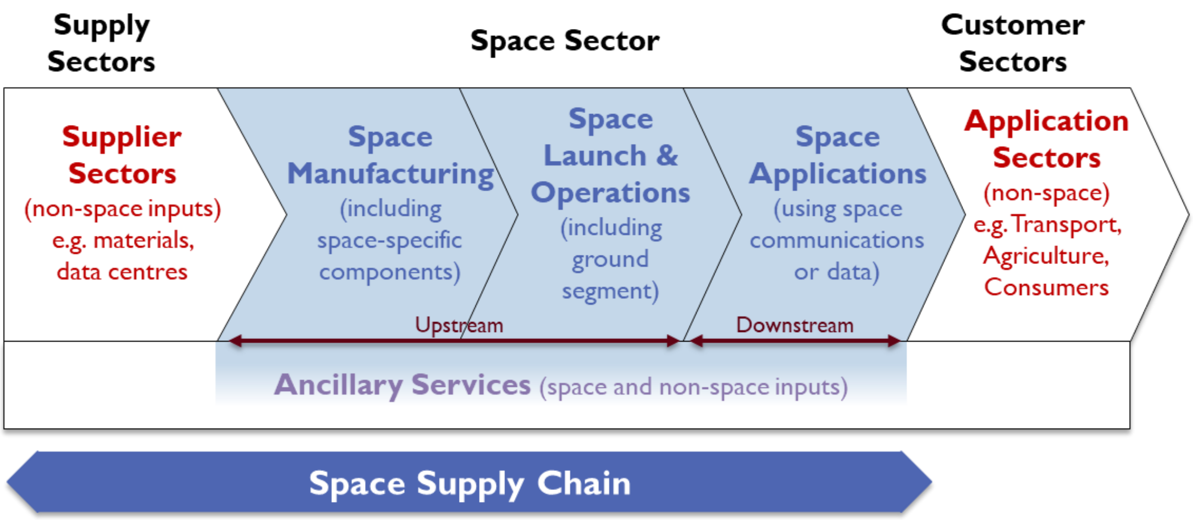

Figure 3.1: Space Sector Value Chain showing the Space Sector (blue shading) and the Space Supply Chain. (Based on 'Size & Health' segments)

The UK space sector has an income of £16.4 billion[4] and comprises over 1200 organisations. Direct employment is 45,100, up from only 16,000 15 years ago, and it supports a total of 126,300 jobs across the supply chain. These employees are highly productive and well paid. The sector's productivity is 2.6 times the national average at £145,500 per employee giving a total of £6.6 billion Gross Value Added (GVA). The average wage in the space sector is £49,000 compared to an average across all sectors of £38,552

At £16.4bn, the space sector is about the same size as Manufacture of basic chemicals and plastics (£16.0bn) or Manufacturing of pharmaceuticals (£20.7bn). It is smaller than Manufacture of motor vehicles (£60.9bn) or Manufacture of aircraft, spacecraft & related machinery (£27.8bn of which only ~£1.5bn would be spacecraft). It is larger than Ship and boat building (£5.2bn) or Iron and steel manufacturing (£7.1bn).

[4] Figures in this section paragraph from Size & Health of the UK Space Industry 2020, know.space, May 2021

Commercial income dominates the space industry, but civil and military demand are significant. Commercial income is 81% of space industry income (56% of which is DTH Broadcasting), 10% is Civil, and 9% is Defence.

The space sector is present across the whole UK, but it is not evenly spread. London and the South East are the clear leaders for income, employment, and number of organisations. But each region has space businesses and connects to the national and international space supply chain. We cover geographic considerations more fully in chapter 4.

Describing the boundaries of the space sector is not a simple task as space becomes a 'general purpose technology' and permeates more of our lives. The 'Size & Health' study approaches this by focusing on 'space-related activities' and organisations that are engaged in them. So it includes the sale of an application based on satellite data to a farmer, but it would not include the farmer's revenue from their crops. The economics of the supply chain are analysed further in chapter 5.

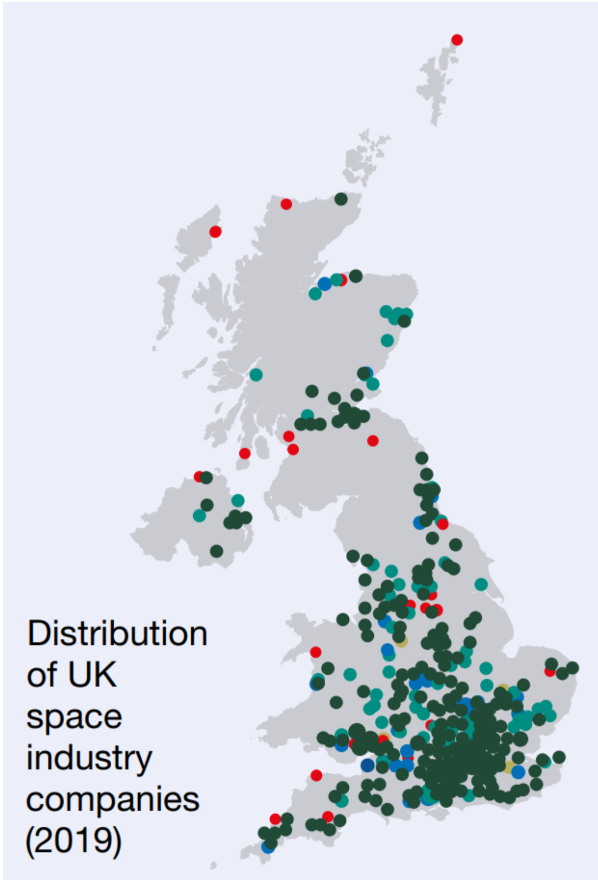

Figure 3.2 Distribution of UK space companies
Source: KTN, National Space Strategy

Space also supports vital aspects of the wider UK economy, underpinning at least £360bn (17%) of UK economic output.

The UK supply chain has capabilities across the space value chain, it can deliver complete satellites and applications, and the gap in launch will soon be filled. Many of the opportunities and capability priorities set out in the National Space Strategy are already covered, but some need developing for the future, some need more scale, and some are dominated by a few large companies – which has advantages and disadvantages. We look into the future in chapter 6 and explore these strategic issues in chapter 7.

3.2 Along the Chain

We describe the space supply chain in terms of 'Upstream' (broadly space and ground equipment) and 'Downstream' (broadly the services it provides). However, the two are often difficult to separate, with companies like OneWeb or Spire integrated between the two, and an increasing amount of data processing being performed on satellites.

The complexity of the Upstream Supply Chain

The complexity of the space supply chain is indicated by the diagram below. A satellite or a launch vehicle starts with a design and thousands of raw materials and components ranging from metals and composite panels to electronic components, some of which will be complex Application Specific Integrated Circuits (ASICs). Some of these are assembled into more complex units such as sensors or actuators.

Components are often combined into subsystems that perform key functions, for example the payload of a satellite (perhaps communication or imaging and relaying data to Earth), or attitude control. Subsystems are important because they can be subcontracted, potentially simplifying the task of the satellite integrator and allowing a subsystem manufacturer to add more value than if they were making components alone.

Satellites and launchers come together at a spaceport, which has its own supply chain, first to be constructed and then a set of supplies and services around each launch.

Following launch, the satellite must be operated to deliver its application, and this also requires a ground station or a network of ground stations – both to control the satellite and to receive the application data. A satellite operations centre and a ground station also have a supply chain for construction and for ongoing operation.

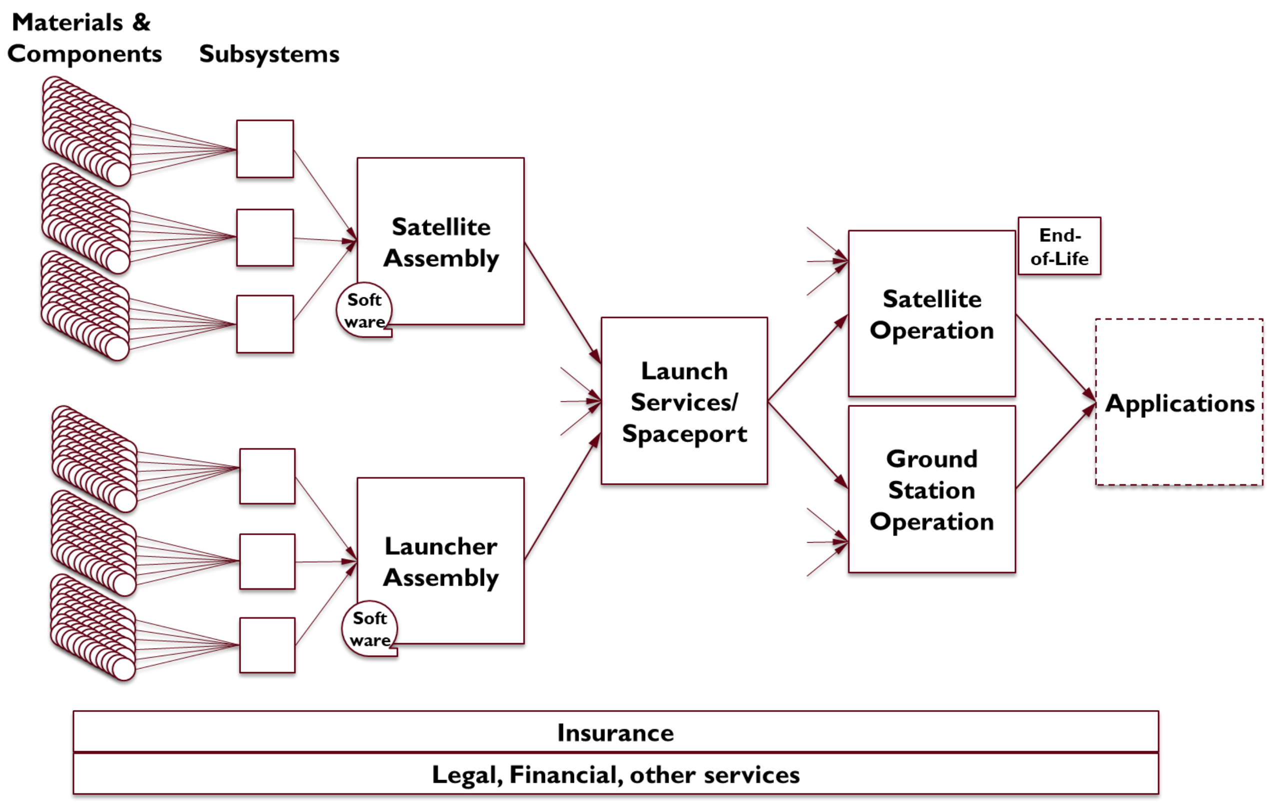

Figure 3.3: Simplified view of the Upstream Space Supply Chain. Unanchored arrows indicate the many inputs not shown at each stage.

Underpinning every aspect of the chain are several ancillary services. Software is found in most pieces of space hardware, and is essential to launch, satellite and ground station operations. Cyber security is a priority as satellites are too valuable to fall prey to cyber-attacks. Insurance, legal, financial and other services are also essential in enabling the complex industry to operate and manage risk.

Because of the low volumes, high costs and high reliability expected in the space industry, and the potential dangers in rocket launches, almost all of the upstream supply chain has until recently been highly specialised industries. Components and materials bought in have undergone rigorous checks for ability to withstand the physical and radiation stresses of launch and the space environment, with wide safety margins. The emergence of much smaller satellite formats, in particular 'CubeSats', and the use of commercial-off-the-shelf (COTS) instead of space-specific parts, has changed this, as discussed in section 6.2.

Downstream (Applications) Supply Chain

For applications, the supply chain is quite different, and differs between satellite communications, Earth Observation (EO), and Position/Navigation/Timing (PNT) applications.

For EO and PNT, the key space-related input is the satellite data. After this, the supply chain is very much like any Earth-bound IT business and we see in the Economic view in Chapter 5 that this makes the space supply chain impact much smaller. Once on the ground, the data needs storage and processing, which may be company-owned, privately hosted, or 'in the cloud' (e.g. Amazon Web Services, Google Cloud Platform or Microsoft Azure). Services are delivered through IT platforms or consulting services, requiring software development and customer relationship management that is like any other business, except for the need to handle and display geospatial data.

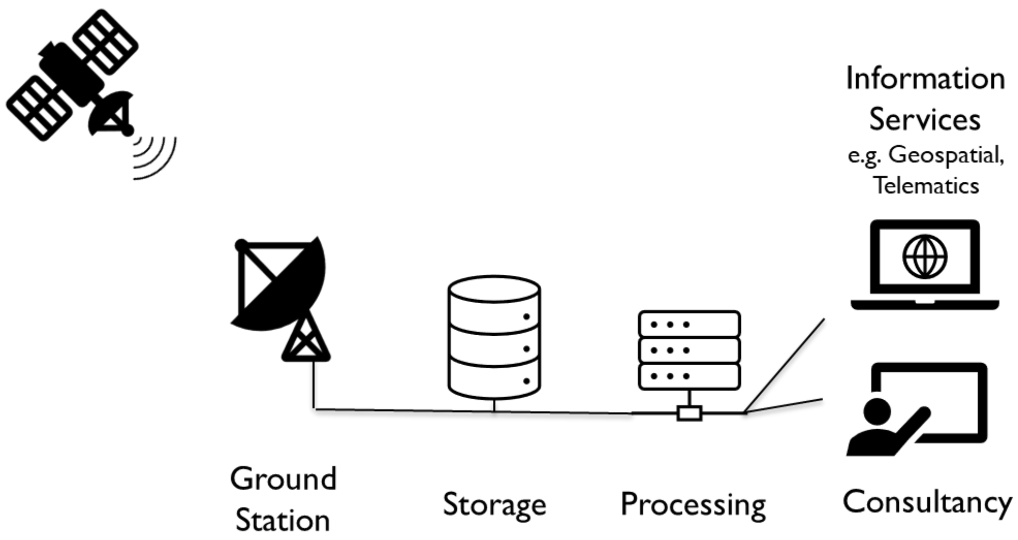

Figure 3.4: Simplified view of the Supply Chain for Downstream applications based on satellite data

Satellite communications businesses, including satellite broadcasting, are different in that the data flows in two directions (or outward for broadcasting) rather than inward, and there may be less need for storage and processing, so a higher percentage of the value remains in the space sector.

Considered overall, these are technology and skills-based businesses with supply chains very similar to their terrestrial analogues, with the addition of the (usually large) costs for the satellite links that make them unique.

3.3 Describing the Supply Chain

The space supply chain contains a diverse range of activities and there are diverse ways to describe it. As background to the detailed descriptions, we describe three of them here.

Upstream/Downstream

The simplest classification has only two elements. Upstream usually refers to the manufacture and operation of space-related assets, including ground-based launch sites and ground stations. Downstream refers to space applications, so the communication, PNT[5], or Earth Observation based services connected to space only by signals.

Size & Health Segments

The Size & Health study defines 4 Segments and 33 Activities. The Segments are:

- Space Manufacturing: Including satellites, launch vehicles, ground systems, their components, research, development, and testing.
- Space Operations: Including launch, satellite, and ground station operation.
- Space Applications: Communications, location-based and other applications.
- Ancillary Services: Including insurance, software, and professional services.

Satellite Applications Catapult Taxonomy

The Catapult has developed a taxonomy to categorise space business for the UK Space Capabilities Catalogue (UKSCC). This is high level, but its real strength is in 243 (and growing) detailed 'system' categories that enable identification of organisations with specific capabilities.

- Build: Design and manufacture of space hardware and software, and the organisations in the 'space ecosystem'
- Launch: Building and operating launch vehicles and infrastructure
- Operate: Operating satellites or high-altitude platforms, including ground stations

[5] Position, Navigation, Timing

- Downlink: Providing technologies or operating inter-satellite or satellite-to-ground communication
- Analyse: Providing technology or processing data from satellites
- Product: Products making use of satellite data, signals, or communication links
- Explore: Infrastructure and operations beyond the Earth, including space stations, manufacturing, resource utilisation and tourism.

We apply this taxonomy in a quantified analysis of the UK space sector below (Section 3.5).

3.4 UK Supply Chain Capabilities: Delivering the National Space Strategy

The NSS identifies eight key capability priorities (both civil and defence) that are vital to delivering the strategy and the UK's ambitions. For each of these, we have identified the key supply chain areas that support them, reviewed current UK capability, and sought to identify near-term developments.

These are vital capabilities. There is no simple answer as to whether UK capability is 'good enough' – there is continuing development, and the UK needs to continue development and work with international partners; to stay as the leaders in each field. We would, however, extend the definition of 'Space Domain Awareness' to the more holistic 'Space Environment Management'.

Key Capability Priority	Key Supply Chain Areas	Current UK capability and near-term developments
Satellite Communications: Global, secure, and resilient	• Satellite integration • RF payloads and antennas • Ground segment equipment • Ground station operations • Fixed and mobile communication services • Finance, Insurance and Legal services	• The UK is strong in all areas for GEO satellites, but with one dominant upstream supplier. • Recent emergence of LEO mega-constellations are a disruptor and significant risk. • The UK is HQ for OneWeb, and supplies some parts, though integration is in USA. Has technical and financial capabilities for ~648 satellites OneWeb, but ~12,000 satellites Starlink would be a stretch. • Investing in Skynet 6. • Developing optical communications, quantum and quantum-proof encryption, which are UK strengths. • Other innovative capabilities such as small IoT constellations.
Earth Observation (EO) and Intelligence, Surveillance and Reconnaissance (ISR)	• Sensors • Attitude Determination and Control System for accurate pointing • SSO launch (preferred orbit for many EO missions) • EO Satellite operators	• Strong on optical sensor components (e.g. CCDs), some SAR capability (e.g. SSTL/Airbus payload for NovaSAR launched 2018). Need more businesses able to deliver whole subsystems not just components. • Several SSO launch vehicles and spaceports in development

	• EO and geospatial data and processing platforms, specialised (e.g. Geocento), or general (e.g. AWS) • EO and geospatial service providers (many types)	• Developing small ISR constellation (Horizon). • Intending to continue as part of EU Copernicus EO programme. • A global leader in EO applications.
Command-and-Control, and Space Capability Management	• Satellite Operation • Ground station networks	• Strong experience of civil and military satellite operation and ground stations. (DMC, Inmarsat, Skynet, National In-Orbit Servicing Control Centre) • No overall view of ground station needs, capacity and responsiveness. With rapidly expanding needs this is important to understand. • Now establishing National Space Operations Centre and UK Space Command.
Space Control	• Satellite Operation • Ground station networks • Resilience to disruption	• Establishing Space Control systems and resilience as part of the Defence Space Strategy.
Position, Navigation and Timing (PNT).	• Timing equipment (atomic clocks) • PNT signals from satellites • User equipment • Applications	• Good through foreign-owned UK-based suppliers (TAS, Teledyne) though impacted with loss of Galileo contracts • OneWeb may offer route to unique capability & resilience (not yet developed) • Capability in high-end terminals and some consumer devices, but not mass market • Strong in applications, e.g. Telematics
Orbital Launch Capability	• Launch operations • Ground segment • Spaceports • Launch vehicle manufacture	• Several orbital launch operators developing, with 3 aiming for launch in 2022: Skyrora, Lockheed Martin (with ABL), and Virgin Orbit • Seven proposed UK spaceports and two companies exploring sea launch • Of the proposed vehicles, Orbex, Skyrora and the Moog OMV for LM have significant manufacture in the UK. • In addition, Reaction Engines has a unique technology for rocket engines that are air-breathing in early flight that may be transformational for launch vehicles.
In Orbit Servicing and Manufacturing (IOSM)	• Orbital manoeuvring/docking • Robotic manipulation • Propulsion • Simulation • Ground segment • Space Domain Awareness (see below) • Satellite manufacture	• The UK has some capability in all of these areas, including some pilot debris missions (RemoveDEBRIS, ELSA-d target) • It needs to develop as the state-of-the-art develops. A 2021 report[6] for UKSA identified 3 areas to be addressed and proposed an Active Debris Removal and a testbed 'Space Bench' mission to improve capabilities.

[6] https://sa.catapult.org.uk/news/in-orbit-servicing-capability/ by Astroscale, Fair-Space and Satellite Applications Catapult

		• Close proximity operations – where the UK has an advantage based on ELSA-d and ESA missions, but needs more development. • Robotic manipulation – where the UK lags in space robotics, but could transfer robotics skills from other sectors. • Mission end-to-end simulation – where the UK has not invested, but has good digital and simulation skills in other sectors.
Space Domain Awareness (SDA) *(Could expand to Space Environment Management / Space Sustainability)*	• Sensor systems (ground and space) • Data Processing	• UK capability is limited (e.g. NORSS) and a long way behind government-sponsored systems in USA, China, Russia. • UKSA and UK satellite operators pay for foreign data or manoeuvre satellites more frequently to reduce risks, depleting fuel. So UK data would be valuable. • Growing communities of interest in DSTL, GNOSIS[7] and Stardust-R[8]. • NSS includes intention to expand sensor and data networks on dual use basis, working through NSOC. • Early signs of the UK taking a lead in building international partnerships and working towards regulation on Space Sustainability. (e.g. UKSA co-hosting global Summit for Space Sustainability, June 2022). • The UK has a global presence through UK Overseas Territories and international development.
	• Space weather alerting	• The UK plays a leading role in space weather science and programmes, including key instruments and satellite integration of SOHO and Solar Orbiter and RAL Space leading the instrument package for the planned Vigil mission (formerly Lagrange).

Figure 3.5: Current UK capability in the eight National Space Strategy Key Capability areas

3.5 UK Supply Chain Capabilities: A Quantified View

We have used the UK Space Capabilities Catalogue (UKSCC), developed by the Satellite Applications Catapult, to gain a quantified view of the UK space supply chain. At the time of this work the Catalogue contained 777 companies and other organisations, with organisation, location and revenue

[7] https://gnosisnetwork.org/
[8] http://www.stardust-network.eu/

data where available. The Catapult has also developed a hierarchical taxonomy for codifying the capabilities of space organisations. (Figure 3.6)

UKSCC Hierarchy level	Number of categories (March 2022)
Activity	7
Category	25
System-1	84
System-2	243

Figure 3.6: Levels of the Satellite Applications Catapult's taxonomy

The Catalogue is in 'Beta' version, and the dataset and coding will build over time. 354 of the 777 companies had been coded with this taxonomy, with 604 individual capabilities identified (i.e. a mean of 1.7 capabilities per company). Even in its current form we can draw some useful insights.

From the company data, Figure 3.7 shows most of the companies are small, but most of the employment in space-related businesses is in the non-space activities of very large businesses. This shows the current importance of understanding the difference between space activity and total activity.

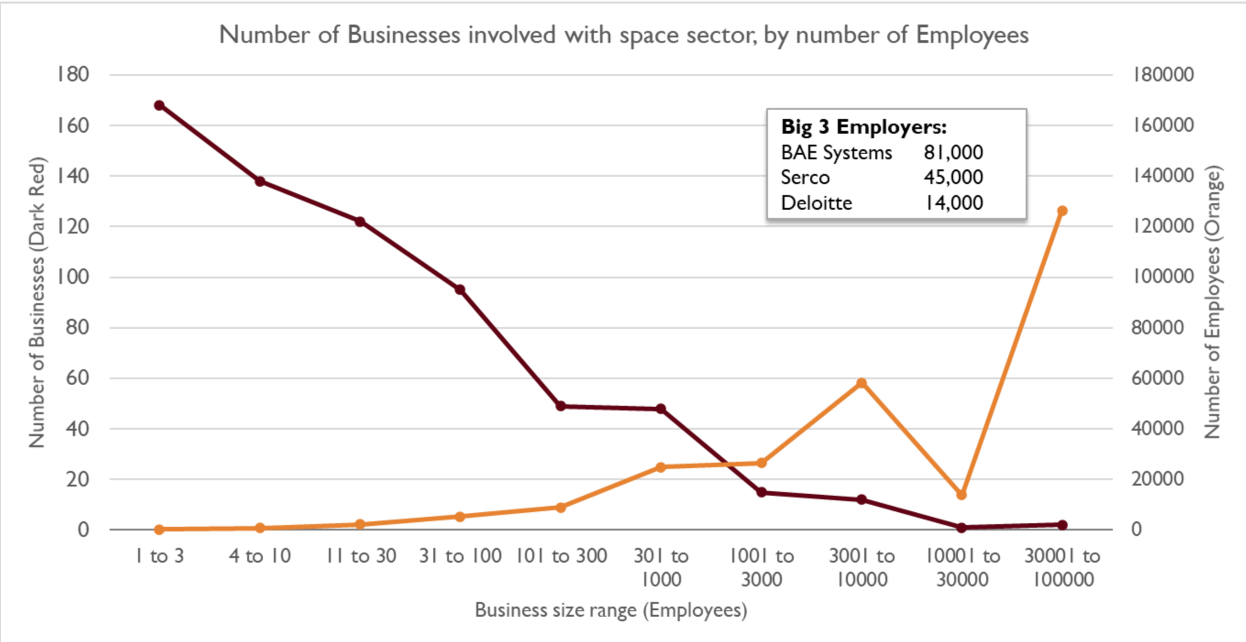

Figure 3.7: Number of Businesses and Employees involved in space sector, by number of employees

The data shows a wide range of employment growth rates from 2017 to 2020, both positive and negative, but overall, far more are positive. (Figure 3.8)

Figure 3.8: Growth rate of businesses (2017-2020 CAGR by employees)

The taxonomy data, while limited to 46% of the companies so far, shows the breadth of the UK's space capabilities. There is some capability in at least 155 of the 243 'System-2' areas.

Number of Companies	Number of S2 areas
0	88
1	67
2	35
3+	53
Total	**243**

Figure 3.9: Number of UK companies in each of the 243 'System-2' level capability areas

Looking closer (figure 3.10), we see that the greatest depth of capability is in 'space ecosystem', the other 'build' capabilities (apart from materials), and capabilities in Operate, Downlink, Analysis, and Product that were linked to satellite communications and geospatial applications. Areas where capabilities are missing, in some categories like 'Spinoff technologies' and 'Space exploration', are to be expected due to the novelty of those areas. In other categories such as 'Space hardware', 'Communications' and 'Mapping and Imaging', there are either sub-categories that are novel capabilities, such as 'Future propulsion' or 'Optical relay systems'. In many cases, coding has captured one capability, but may have missed a similar one, e.g., 'thermal control', but not 'thermal electronics', or 'solar energy management', but not 'wind energy management' product, and there is an existing UK capability.

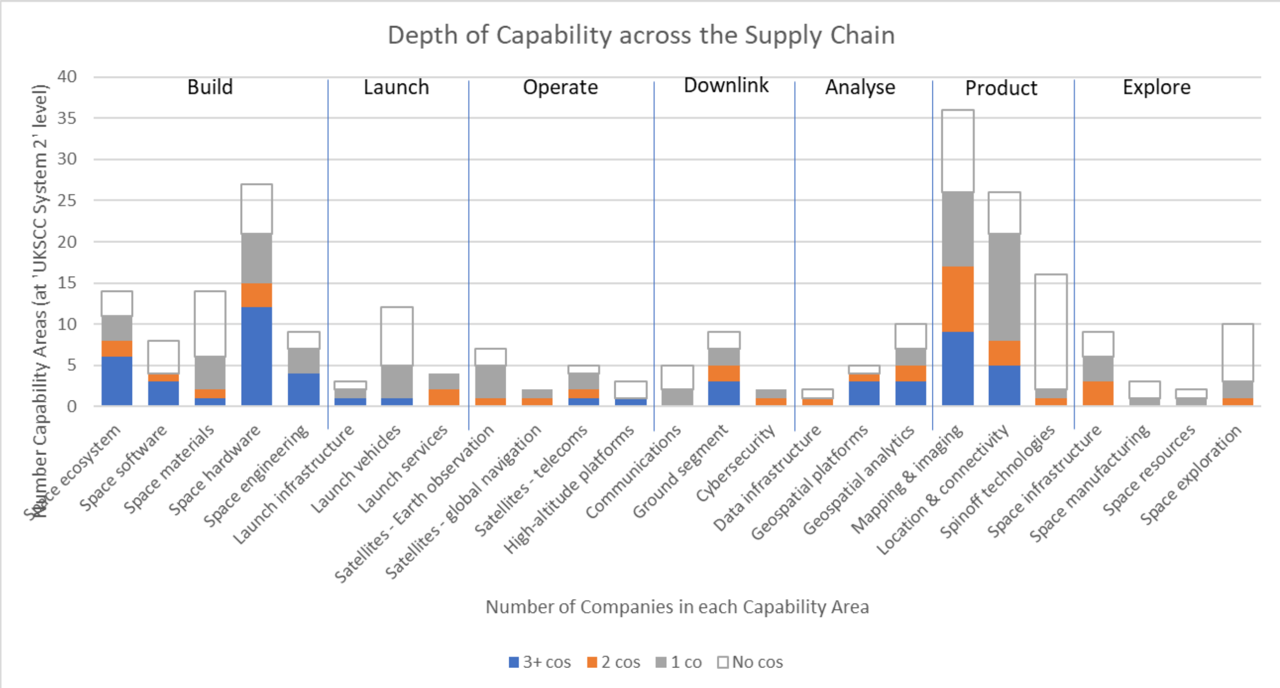

Figure 3.10: Number of UK companies in each of the 243 'System-2' level capability areas, by 25 Categories

Looking at these capabilities geographically, the Catalogue data echoes the Size and Health study in that the largest concentration of the industry is in London and the South East. London is a focus for 'Space Ecosystem', where other regions in the southern half of the UK, and Scotland, have most capabilities in hardware and software aspects of 'Build'. Product and other Downstream capabilities are more evenly spread across the UK. (We don't show the data on this as the sample is geographically uneven at this stage and would give a misleading impression. Data is being added in early 2022 to balance this up.)

Additional insights may be gained by:

- Considering, and coding which of the capabilities are 'current' in the industry and which are 'emerging', and you would not expect significant capability yet.
- Considering the 'depth' of each capability further. This is very difficult without detailed investigation, and our proxy is simply the number of companies identified with the capability. A further step would be the size of the company (e.g. Micro, Small, Medium, Large) on the basis that larger companies would tend to have greater capability. This is clearly not always true with specialist small businesses.
- Tracking development of capability over time, perhaps repeating this analysis once a year.

4. Regional View

The UK space sector spans across the breadth and length of the country, but it is unevenly distributed.

The Satellite Applications Catapult and the UKSA have commissioned 17 studies to understand the space sector in regions of the UK. In this section, we summarise those reports to identify the strengths, weaknesses and recommendations for the regional space sector supply chains. In addition, with a view across multiple reports, we can find opportunities to join supply chains between regions, and overall strengths and weaknesses for the UK.

4.1 Regions and Clusters

There are many ways of dividing the UK regionally. However, it is not wise to draw rigid boundaries on the space sector. Much activity takes place in 'clusters', but many cross regional boundaries, operating nationally and internationally.

The seventeen regional space sector studies examined in this chapter started in areas where interest was high or funding was available, working between UKSA, the Catapult, and the LEPs or other bodies. From 2018 to early 2022, the studies have extended, sometimes with slightly varying remits, to cover the whole UK, except Leicestershire which was covered in a 2018 Science and Innovation Audit. In this section we review the findings of these regional reports[9]. These may not correspond to defined clusters or cluster boundaries – although space clusters are an important feature of the space sector in the regions that have them.

The upstream space sector has been easier to identify and categorise by region because it is more reliant on geography (e.g. transport links for materials) and specific regional attributes (e.g. advanced manufacturing activities, skills and test facilities). By contrast, downstream

[9] We present these in 18 tables/pages, splitting the London and Berkshire as the sector differs greatly between the two.

sector businesses, such as satellite data applications, are less dependent on location and can mostly utilise standard IT infrastructure. As a result, downstream capabilities are far more evenly distributed nationwide, making supply chain gaps and needs harder to identify.

The reporting for each region is generally good at showcasing strengths and capabilities, and making recommendations for investment and development of the local space industry, but comments less on needs or gaps (potentially because this could be perceived negatively by investors or local stakeholders). This has made it challenging to find inter-regional links between needs and strengths, so most of the links focus on connecting strengths where existing capabilities could be enhanced. The Catapult can generally support these links by facilitating targeted events, coordinating dialogue between regional authorities (such as LEPs and devolved governments) and arranging direct connections between individuals or entities.

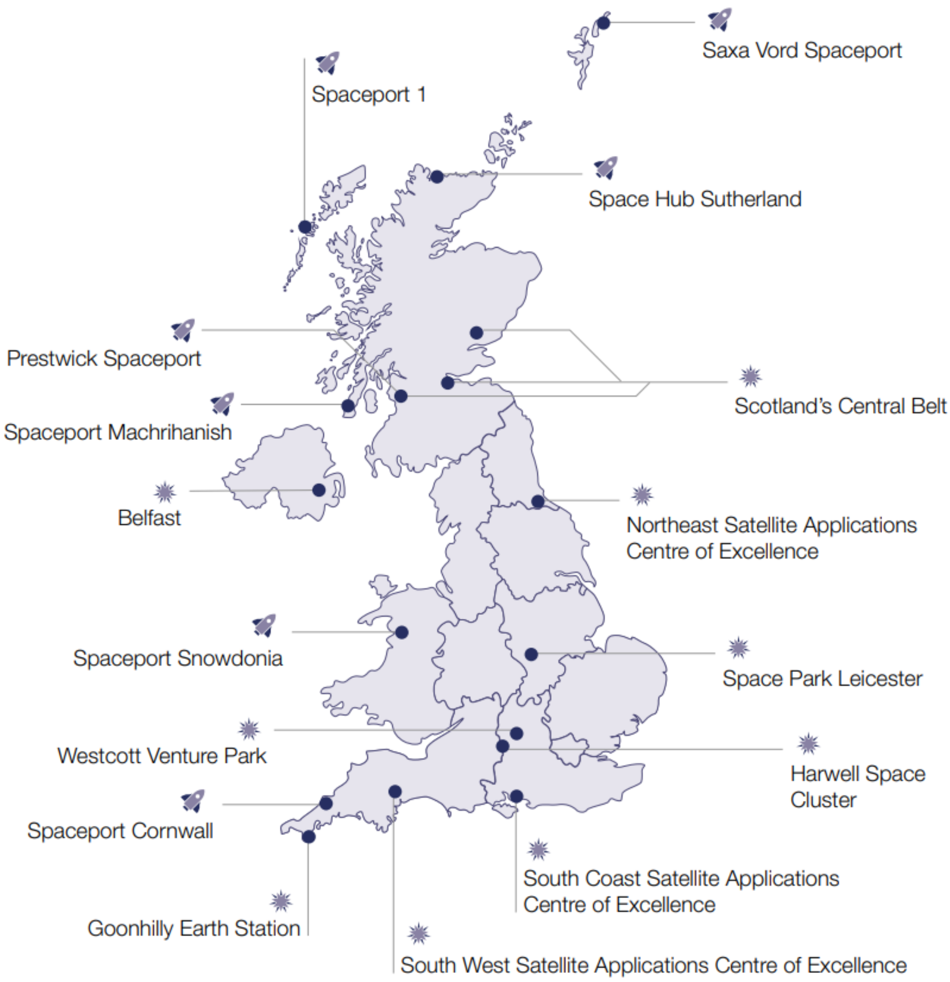

Figure 4.2: Space clusters, Spaceports (potential) and other centres of space activity (Source: National Space Strategy)

Clusters are concentrations or hubs of space activity. There are a growing number of space clusters in the UK, and each attracts a local concentration of space businesses and activity, and brings it benefits. There is no clear definition for when rising space activity in an area becomes a 'cluster'. The influence and benefits of clusters are further discussed in 'Strategic issues' (Section 7.11)

4.2 The Regions of Study

4.2.1 Scotland[10,11]

<table>
<tr><td colspan="3">Scotland - Regional Focus overall
Scotland is a global hub for satellite manufacturing, when combined with data processing and upcoming launch developments and operations the region has the potential to offer full turnkey space solutions.</td></tr>
<tr><th>Market Opportunities</th><th>Supplier Strengths</th><th>Supply chain needs</th></tr>
<tr><td>Upstream
• Orbital small satellite launch
• Planetary exploration and in-orbit assembly
Downstream
• Space data acquisition and processing</td><td>• Small satellite manufacture
• Components and subsystems
• Strong electronics industry
• Space sensors, opto-electronic systems
• Earth observation
• Space data, analytics, AI/machine learning, data science</td><td>• Prime contractors, or satellite operators
• More representation of space applications providers
• Large national or regional rocket engine testing facilities
• Skills (graduate level outreach)</td></tr>
<tr><th colspan="3">Regional recommendations</th></tr>
<tr><td colspan="3">• Small satellite manufacture expanded with the electronics industry
• Recommended future areas of space growth:
    o Robotics and tele-operation of in-space assets;
    o Planetary and asteroid prospecting (links to geoscience, AI, and Big Data);
    o Landing technologies.
• Connect upstream and downstream to create full turnkey solutions
• Grow ground segment opportunities to support launch providers and satellite operations</td></tr>
</table>

Potential inter-regional links:

There are several complementing upstream strengths between Scotland, Northern Ireland, the North West, and North East England, possibly including North Wales and Yorkshire as well:

- Between these northerly regions of the UK there are strengths in satellite manufacture (whole spacecraft, subsystems and payloads), testing, and the adjacent sectors of advanced manufacturing and aerospace.
- There is an opportunity for the regions to combine their resources and skills, attracting investment and IP, to increase capabilities, output and exports, becoming a powerhouse in satellite technology.
- The proposition of developing full turnkey satellite solutions in Scotland, combining upstream satellite manufacture and launch with downstream capabilities in end-user applications is powerful (some of the largest space companies, such as SpaceX and Blue Origin follow a similar model). Although Scotland has most of the necessary capabilities, the process could be supported further by coordinating efforts with the IT activities (AI, data science, machine learning and space data) in Northern Ireland and the North East.

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[10] (2021) A plan for space in Scotland, Astro Agency

[11] (2021) SSLC Scottish Space Cluster, Astro Agency

4.2.2 Northern Ireland[12]

Northern Ireland - Regional Focus overall

Strong **aerospace** and other engineering capabilities with growing attention to space, especially in **electric propulsion**. Existing facilities can support much of the **spacecraft testing** cycle. **Astronomy** and **astrophysics** research inputs into **space exploration** technologies, along with advanced **materials** and **sensors** applicable to **life sciences**. **Data science** and analytics is also strong.

Market Opportunities	Supplier Strengths	Supply chain needs
Upstream • Growing small satellite market with need for short turnaround times (<2 years) • Supporting the satellite testing cycle (clustering testing reduces transport) • Potential involvement in spacecraft design, manufacture, and test to support UK launch Downstream • Potential to integrate space data/satellite information into insurance and FinTech • Public sector underusing space, unaware of satellite applications/data benefits	• Analytics for Satellite applications • Engineering capabilities including Aerospace • Space Electric Propulsion Centre • Antenna, microwave and RF circuit design • Vibration testing facility • Growing collaboration with other UK space companies • Advanced health and life sciences research (human spaceflight applications) • Data science and AI • University R&D on new space technologies e.g. data analytics • Astrophysics and Solar Weather prediction • Satellite data supporting/informing marine insurance	• Better knowledge of space sector that exists • Better outreach • Better engagement with the rest of the UK • Identify businesses that can benefit from space • Formal support and coordination structure

Regional recommendations

- Work to improve industry cohesion and representation
- Lack of local understanding on how space data can support existing or new commercial solutions
- Stakeholder/leadership group to promote NI space sector within UK and abroad
- Help NI companies to register to ESA tendering portal
- Deepen coordination between local government, industry and research
- NI-based accelerator program to promote & support new space SMEs

Potential inter-regional links:

- Northern Ireland and the North West of England both emphasise a lack of coordination and outreach for their space sectors as major needs. Along with Wales they share strengths in Aerospace, a high-profile adjacent sector that could be a good target for collaboration and could also support outreach.

[12] Hill, R (2020) Invest Northern Ireland Space Sector market insight report, Northern Ireland Space Office

4.2.3 North West[13]

North West - Regional Focus overall

The North West has the largest **aerospace** sector in the UK and a sizeable **digital** sector, with strengths in **engineering**, **nuclear energy**, **advanced manufacturing**, shipping, biotech, pharmaceuticals and **telecoms.** Despite this, its space activity is small with potential for **growth**. A concentration of **universities** provides a supply of skilled graduates and expertise.

Market Opportunities	Supplier Strengths	Supply chain needs
• Upstream • Space exploration: leveraging materials and manufacturing expertise • Space nuclear power (e.g. RTGs.) • Downstream • Connectivity (satellite communications): as testbed for new infrastructure • Potential in cyber, AI, quantum, advanced manufacturing, clean technology • Cybersecurity to secure satellite signals • Opportunities for big data to support growth in satellite data • End user markets: energy, shipping, ICT, biotech, pharmaceuticals, telecoms	• Strong engineering base • Large aerospace industry • Advanced manufacturing • Established space industry players • Strong nuclear industry • Strong and growing innovation ecosystem • University and research institutes • Astrophysics (Jodrell Bank; HQ of Square kilometre Array)	• Regional space industry 'significantly underexploited' • Better coordination between sub-regions • Factor for region's large area when planning networking events • Economic recovery is a key priority – needs better outreach on how space can support • Better local and national visibility of regional space research • Better interaction between academia and industry • Better outreach to local aerospace companies on opportunities in space

Regional recommendations

- Develop plan for space in support of economic recovery
- Growing, re-skilling and retraining local expertise
- Establish a dedicated North West Space Cluster, establishing a Space Leadership Group, and developing regional programmes / activities aligned to local priorities and themes, e.g. space nuclear energy
- Identify and foster synergies between upstream and downstream and links between subregions
- Workshops, activities and funding to pair up local strengths with space sector needs and opportunities
- Showcase local space research on a dedicated platform
- Provide engagement opportunities to close gaps between industry and academia

Potential inter-regional links:

- The North West shares capabilities with Space Hub Yorkshire in Advanced Manufacturing.
- Already shares ESA Ambassador with North Wales, and possible links to aerospace sector in North Wales.
- See Scotland and Northern Ireland for further linkages

[13] (2020) The North West Space Cluster, UKRI-STFC, and Support to the development and consolidation of the North West Space Cluster, PricewaterhouseCoopers

4.2.4 North East[14]

North East - Regional Focus overall		
Expertise in **satellite communications**, **photonics** and **quantum** clocks for PNT offer support to UK defence and civil objectives both nationally and overseas. **Academia** and other **R&D** organizations also conduct space research (e.g. sustainable development, space weather monitoring, and computational cosmology). Cluster development is desired to grow the region's international impact.		
Market Opportunities	**Supplier Strengths**	**Supply chain needs**
Upstream • Next generation communications • Photonics R&D supporting next generation technologies • Ground segment components and parts Downstream • Space domain awareness services • Satellite derived data applications and analysis	• Test facilities (including clean rooms) • Robotics and autonomous systems (e.g. manufacturing and inspection) • Small satellite components & subsystems • Telecommunications R&D (e.g. RF, optical comms, phased array antennas) • Photonics R&D (e.g. RF and optical payloads, sensors, and integrated circuits) • IT (AI, machine learning, quantum)	• Primes as an anchor tenant • Governance: Region has capabilities, but they need more focus towards space applications (both upstream and downstream).
Regional recommendations		
• Increase capacity for bespoke, innovative component & assembly level design and manufacture • Increase supply to UK sovereign projects for resilient UK communications infrastructure • Build upon success of Kratos UK to develop next generation ground segment capability • Engage local RAFX in addressing RAF operational & community-level problems with innovative solutions • 5G testbed for next gen comms for marine, autonomy, rural connectivity, remote healthcare, and rail • Integration with LEP strategies focused on regional prosperity, innovation and wider societal benefits • Leveraging CfAI to provide critical support role in emerging LEO and GEO satcom systems markets • Deeper engagement with the UK smallsat industry as scaled manufacturing capabilities build • Servicing space and non-space markets e.g. Northumbrian Water 5G enabled AR engineer support • Cross-sector transfer of advanced space computing capabilities		

Potential inter-regional links:

- See Scotland for description of how the northern UK regions could reinforce each others' strengths in space sector manufacturing.

[14] (2021) North East regional space study, BryceTech

4.2.5 Yorkshire[15,16]

Space Hub Yorkshire - Regional Focus overall		
Regional capabilities include: **satellite data**, **IT**; **quantum** technologies; **telecommunications**; surveillance and **cyber security**; and **advanced manufacturing**. Priority commercial focus linked to these capabilities include space data services (particularly EO), space surveillance, space data security and the manufacture of **spacecraft systems** and **payloads**.		
Market Opportunities	**Supplier Strengths**	**Supply chain needs**
Upstream • RF and microwave solutions • Software • Further potential in satellite systems & payloads Downstream • Geospatial artificial intelligence • Telematics using satellite data and services	• Spacecraft systems, payloads and ground infrastructure • Advanced manufacturing • Electronics • Precision engineering • Space data processing • Connectivity, future communications infrastructure and secure communications • Clusters around Leeds, Sheffield, Huddersfield, Bradford, Hull and York.	• Prime contractors • Skills (lack of resource in small businesses to supply internal training and lack of external conversion courses)
Regional recommendations		
• Developing technology for future communications infrastructure, particularly in RF tech and electronics • End-to-end testing and demonstration of quantum technologies for secure satellite communications		

Potential inter-regional links:

- The North West and North East share complementary capabilities with Space Hub Yorkshire in Advanced Manufacturing.
- Yorkshire may have more to offer other regions in its IT, software and communications strengths.

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[15] (2021) Space Hub Yorkshire strategy & action plan – landscape review, Perspective Economics
[16] (2021) Space Hub Yorkshire space innovation report, Perspective Economics

4.2.6 Wales[17,18,19]

<table>
<tr><td colspan="3">Wales - Regional Focus overall
Existing advanced manufacturing and technology clusters in: aerospace, automotive, electronics & software, medical, semiconductors, photonics/optoelectronics/optics, life sciences, cyber security, and EO including sensors, analysis and data consolidation. Test and evaluation eco-system based on existing facilities and ranges, and strong public sector support from UK and Welsh government.</td></tr>
<tr><th>Market Opportunities</th><th>Supplier Strengths</th><th>Supply chain needs</th></tr>
<tr><td>Upstream
• Tracking of launch operations (sea- and air-launched)
• In-space manufacturing
• Launch: Spaceport Snowdonia/Sea Launch
• Possible new electronics research centre
Downstream
• Comms: broadband/5G in rural coverage
• Proposal for a sustainable space accelerator
• General space data applications (e.g. transport, planning, administration)</td><td>• Aerospace (e.g. UAV's)
• Plasma Wind Tunnel (accurate re-entry modelling)
• Sensors, Optics inc. OpTIC technology centre
• Analysis and data consolidation
• Test & evaluation
• Advanced Manufacturing
• Earth Observation
• Research & Teaching</td><td>• Prime contractors
• Research and development focus on applications that deliver to the sustainability agenda</td></tr>
<tr><td colspan="3">Regional recommendations
• Research and application of sustainability and alternative energy technologies
• Review sea-based launch solution, to be based in Port Talbot
• Further R&D into UAVs using hybrid inputs (from space and ground assets alike) for traffic and logistics management</td></tr>
</table>

Potential inter-regional links:

- The Aerospace industries of Wales and the North West offer complementary skills and technologies, the former focused on UAVs and the latter on aviation. As with West Midlands, there are further strengths in adjacent sectors, such as advanced manufacturing and precision engineering. These adjacent sectors are not yet well connected to each other, or to space. Space could become a shared theme between the regions to encourage collaboration and innovation between these adjacent sectors.
- Industry strengths in optics and Earth Observation (EO) could be combined with the satellite manufacturing capabilities in the Glos/Worcs/Wilts and West Midlands regions and with the satellite component and software strengths of WECA (West of England Combined Authority) to support EO satellite production and services. By utilising the manufacturing skills of the West Midlands, these neighbouring regions could become a converging point for manufacture of EO satellite constellations, thus addressing global demands for EO data.

[17] (2021) Wales a sustainable space nation – brochure, directory and capability matrix, Space Wales
[18] (2021) A sustainable space nation – leading to a greener space, Space Wales
[19] (2021) A sustainable space nation – the report, Space Wales

4.2.7 WECA (West of England Combined Authority)[20,21,22]

WECA (West of England Combined Authority) - Regional Focus overall
(Bristol and parts of Gloucestershire, Somerset)

Regional strengths in **IT**, **quantum**, **manufacturing**, **satellite applications**, engineering consultancy, **research**, and **ancillary services,** with strong support to military space requirements. Recently established a local Space Hub and developed a local Space Strategy and Action Plan with industry, academia and local government backing.

Market Opportunities	Supplier Strengths	Supply chain needs
Upstream • Space launch • IOS&M and assembly • Growth in existing markets: space exploration, space and climate science, defence space comms, EO, smallsat manufacture • Small satellites and constellations (component manufacture, operations and management) • Space Environment Management • Spaceflight/space tourism Downstream • EO/PNT satellite data and image processing, new products, services	• Satellite components and software • Satellite communications (especially military) • Next generation propulsion (rockets and satellites) • Space weather • Space exploration • Space science and instrumentation • Quantum technology • Downstream applications (especially climate change, defence and disaster response)	• Need for space investment • Need for legal and regulatory services • Skills: lack of suitably qualified people due to the speed of industry growth in the UK in the past 10 years

Regional recommendations

- Grow small satellite and launch capabilities (R&D, structures and components manufacture, through-life support and services, payloads, financial and professional services)
- Develop upstream and downstream satellite services (satellite constellation operations, SSA, space debris, space weather, applications to new end-user communities, particularly the public/para-public sectors.
- Preparing for new markets (R&D activity, market analysis) – e.g. IOS&M, space-based solar power
- Legal and regulatory services mostly served from London but could be expanded in the West of England
- Engage key regional stakeholders (e.g. MoD and Primes) on space and cyber security (links to quantum)
- Collaboration with close-by regions, such as Cornwall & Isles of Scilly LEP (Spaceport Cornwall), South West LEP (Met Office) and Gloucestershire (MoD Corsham, defence space and cyber security).

Potential inter-regional links:

- Innovation gains could be achieved by combining the satellite software strengths in WECA with the cyber security skills and activities in the 'Glos/Worcs/Wilts' region. As our reliance on space data and services increases, so will the importance of security. A pipeline for investment and sales could be established through the defence ties of both regions (e.g. CGI in WECA and QinetiQ in Gloucestershire).

[20] (2020) West of England Space Hub – landscape mapping (WP1), West of England Combined Authority
[21] (2021) West of England Space Hub – future opportunities (WP2), West of England Combined Authority
[22] (2021) Innovate accelerate collaborate – a West of England space strategy, West of England Combined Authority

4.2.8 West Midlands[23,24,25,26]

<table>
<tr><td colspan="3">West Midlands - Regional Focus overall
A unique regional strength is in manufacturing, leading to potential in upstream for manufacturing (materials, components, and assemblies), leveraging local aerospace supply-chains. Downstream space application sectors, leveraging specialisms in IT and data, end-user sectors (e.g. automotive, rail and agriculture) and ancillary services (e.g. business and professional). Space manufacture in West Midlands is dominated by a handful of companies.</td></tr>
<tr><th>Market Opportunities</th><th>Supplier Strengths</th><th>Supply chain needs</th></tr>
<tr><td>Upstream
• Advanced additive manufacturing
• Precision machining
Downstream
• Satellite telecommunications
• End user markets (5G testbed, future mobility zone, autonomous vehicles, medical and emergency services, construction, industry 4.0)</td><td>• A small network of supply chain companies who provide materials and components to space
• Strong academic research
• Strong manufacturing base
• Large digital sector
• Regional strengths in key end-user sectors (Automotive, Rail, Modern Services (Smart City), Health and Life Sciences and Agriculture)</td><td>• Primes
• Regional space assets
• Shift from low volume, bespoke and strict QA to standardised high - volume production
• Shift from low to high value part of the manufacturing value chain
• Skilled labour for space manufacture
• Better access to finance
• Better outreach on opportunities in space</td></tr>
<tr><td colspan="3">Regional recommendations
• Run workshops and events to connect regional suppliers to opportunities in space
• Support transition towards low-cost volumetric production of launch vehicles and satellites utilising advanced manufacturing and standardisation processes
• Adoption of Industry 4.0 technologies for enhanced efficiencies, productivity, and quality management
• Global recognition and leadership - rapid growth of both domestic and international space manufacturing markets through leveraging/pivoting existing strengths/capacity
• More training programmes that address skills gap for space manufacture</td></tr>
</table>

Potential inter-regional links:

- The central position of the West Midlands means its manufacturing skills of the could be linked to satellite expertise in the East Midlands, the Ox-Cam Arc, Wales, or a northern cluster.
- West Midlands should look for partners to establish its space credentials, where it could rapidly become an attractive base for space manufacture.

[23] Billing, C. and Bevan, R. *et al.* (2021) The West Midlands Space Cluster Development: business case, University of Birmingham

[24] Billing, C. and Brittain, B. *et al.* (2021) The West Midlands Space Cluster Development Programme: Regional LEP and Policy Overview, University of Birmingham

[25] Billing, C. *et al.* (2021) The West Midlands space sector strengths, underpinning assets, and market opportunities, University of Birmingham

[26] Billing, C. and Pugh, A. *et al.* (2021) The West Midlands Space Cluster Development Programme: University Asset Mapping, University of Birmingham

4.2.9 East Midlands[27]

East Midlands - Regional Focus overall *(Staffordshire, Derbyshire, Nottinghamshire, Lincolnshire)*

Diverse range of relevant **industrial capabilities** that could support highly capable **space missions**. Range of adjacent industries and **academic institutions** with space heritage, and clear evidence of collaboration. Large **Defence** presence creates potential for MOD to be an influential customer and testbed. Presence of defence, aerospace and space **primes** and their suppliers underpins existing supply chain and creates opportunities for further growth.

Market Opportunities	Supplier Strengths	Supply chain needs
Upstream • Advanced manufacturing and ceramics • Commercialisation of space-related academic excellence Downstream • Future logistics and smart ports • Support to offshore wind energy	• Strong space heritage in industry & academia • Small satellite manufacturing (components, subsystems, systems, payloads, and platforms) • Test facilities, including clean rooms • Range of space & defence companies (>5 primes) • Next-gen telecoms R&D • Resilient software for space systems • Hardware and software for robotics and autonomous systems • Downstream applications and satellite-data enabled services • Advanced computing (AI, machine learning, quantum computing) • Maritime port (confirmed as freeport), airports, well connected rail network	• Large aerospace/ defence/space primes in region not primarily engaged in space • Dialogue and collaboration between academia and industry could be greater • Better recognition and support for space from G.Lincs LEP • Skills

Regional recommendations

- Aerospace primes, though not active in space, present opportunities for SMEs, startups and academia to build relationships
- Harness advanced manufacturing capability to address demand in space and aerospace industries
- Harness primes' existing supply chains as customer and enabler of wider industry
- Leverage regional universities' capabilities to support sovereign GNSS capability, PNT-enabled systems and data, hardware and systems for space missions and operations
- Leverage regional infrastructure as testbed for space-enabled smart logistics

Potential inter-regional links:

- Significant overlap with Oxford-Cambridge Arc (space academia, satellite manufacture, test facilities, etc.), albeit on a lesser scale. This offers opportunities for companies from the Arc to extend operations to the East Midlands for lower operating costs.
- Aerospace and defence primes in this region can engage more directly with space. Space activities are already pursued by aerospace/defence primes in the Arc, setting an example to follow.

[27] (2022) Regional Space Study, BryceTech

4.2.10 Oxford Cambridge Arc[28]

The Oxford Cambridge Arc - Regional Focus overall

Strong **academic** and skills base enhanced by the technology **clusters** (Harwell, Westcott and Culham) that form a critical mass of activity and **innovation** in rocket and satellite **propulsion**, **satellite technology** and **testing**, **downstream** services and fundamental space research.

Market Opportunities	Supplier Strengths	Supply chain needs
Upstream • Capacity for large complex projects • Linking with aerospace • In-orbit inspection and servicing • Space debris removal Downstream • Satellite broadband • Health and life sciences applications • Space data for environment, mobility and spatial planning • Spin-out technologies to other industries	• Satellites, components and subsystems • Satellite assembly, integration and test • Test facilities (spacecraft and engines) • Launch vehicle propulsion and spacecraft R&D • Payload manufacture • Deployable structures and antennas • Aerospace manufacture and R&D • Advanced manufacturing and materials • Ground systems support • Skills • Space research and academia • R&D de-risking technologies (to TRL4), but volume limited • Finance and business support	• Excellent research often not commercialised • Satellite antennas, control facilities for transmitting and receiving • Continued expansion of Harwell campus, inc. clean rooms • Needs to retain a younger workforce (high cost of living) • Improve public transport connections to clusters

Regional Recommendations

- Links between space and adjacent sectors not fully exploited
- Work with other sectors on national & global problems (e.g. problem-focused challenge fund)
- Develop the benefits of collaboration across the Arc and across Sectors, with small to large-scale initiatives, such as workshops and collaborative research projects with adjacent sectors
- Build on existing Harwell and Westcott clusters, and the nearby supply base.
- Further develop a healthy space ecosystem: Finance, facilities and business support.
- STEM skills developed with targeted courses and apprenticeships.

Potential inter-regional links:

- Space activity in Southwest Arc already forms a 'growth engine' that may be tapped by other regions, e.g. as 'spin-outs' due to high costs in the Arc., or by being the starting point for problem-solving collaborations.
- The Eastern Arc, including Cambridgeshire, is rich in adjacent sectors and end-user markets, but with a modest space sector. It could benefit from working with space expertise in Oxfordshire or East Midlands.
- South East and East Midlands feature satellite manufacturing capabilities, the former also developing suborbital launch technology. These activities and other would likely benefit from the skills and resources of the North-eastern part of the Arc.

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[28] Tucker, R. Walley, D. Webb, A. (2021) Developing the Space Sector in the Oxford-Cambridge Arc: Rising to the Challenge, Red Kite Management Consulting

4.2.11 London[29]

<table>
<tr><td colspan="3">London - Regional Focus overall
Centre of financial and professional services for the space sector, and location for many HQs, especially satcoms.. Several universities and accelerators help promote a strong skills, innovation and start-up culture.</td></tr>
<tr><th>Market Opportunities</th><th>Supplier Strengths</th><th>Supply chain needs</th></tr>
<tr><td>Downstream
• London as a base for global space business
• Transition from GEO satcoms to NewSpace, constellations and emerging markets
• Space sustainability linked to insurance capabilities
• Finance, insurance and consultancies as early adopters of space innovation
• Work with GLA to develop smart city
• Innovation through university/ research base</td><td>• Satellite operations
• Good skills
• Strong financial, insurance, business, legal and consultancy services
• Strong start-up culture and support
• Seat of UK government; drives policy, regulation
• Several universities with space activities
• Learned societies, institutions, professional groups
• Convergence point for events</td><td>• Subsidised or dedicated real estate for small scale manufacturing, and admin/support, etc.</td></tr>
<tr><th colspan="3">Regional recommendations</th></tr>
<tr><td colspan="3">• Crowded, expensive real estate and high living costs potentially stifling new growth could be counteracted with subsidised work areas (e.g. dedicated space incubators)
• Good skills, research and finance, allowing London to adapt to market forces and fill gaps
• Maintain London's position as a natural base for a global space business – ensured through alignment with policy makers and encouraging cross-sector communication and networking through events
• Arrange 'Sustainable Space' event and encourage solutions through targeted grants, regulation
• Finance, insurance and consultancies as early adopters of space innovation – encouraged through market research and outreach programmes demonstrating benefits
• Work with GLA to develop 'Smart City' enabled by satellites –with market-based challenges for SMEs
• Support opportunity in the University/research base – space targeted grants and coordination close university incubators</td></tr>
</table>

Potential inter-regional links:

- Its international status as a financial and services hub means that London already connects to the space sector across the UK.

[29] Tucker, R. Walley, D. Webb, A. (2022) The Space Sector in Berkshire and London, Red Kite Management Consulting

4.2.12 South East[30]

<table>
<tr><td colspan="3">South East - Regional Focus overall (Hertfordshire, Essex, Norfolk, Suffolk, East Sussex, Kent)
Advanced engineering and manufacturing heritage, underpinned by space and defence primes and by several academic institutions, enabling collaboration. A range of adjacent industries creates opportunities for technology transfers downstream applications.</td></tr>
<tr><th>Market Opportunities</th><th>Supplier Strengths</th><th>Supply chain needs</th></tr>
<tr>
<td>Upstream
• Satellite manufacturing, supply chain, & mission management
• Next-gen satcom and 5G services
Downstream
• Maritime assets and multi-modal logistics
• Support to offshore wind and other renewable energy
• Port applications Felixstowe (freeport), airports and Eurostar terminal</td>
<td>• Satellite manufacturing (components, subsystems, systems, payloads, and platforms)
• Capabilities for launch vehicles, ground support and operations
• High number of space companies in region; >5 space and defence primes
• Academia with renowned space capability
• Range of innovation centres and networks including 5 space-aligned
• Next-generation telecom R&D
• Resilient and secure space software
• Hardware and software for robotics and autonomous systems
• Adjacent industries include advanced computing, defence, life sciences, terrestrial telecommunications
• Some focus on AI and 'data revolution'
• Full range of downstream applications and satellite-data enabled service capability
• Innovation and test bed assets include marine, digital, agricultural, life science, 5G</td>
<td>• Skills in some LEP areas
• LEPs and defence industry could be better connected
• Dedicated space strategy by local LEPs (none currently despite regional capabilities).
• More interaction between regional industry and adjacent University of Cambridge.</td>
</tr>
<tr><th colspan="3">Regional recommendations</th></tr>
<tr><td colspan="3">• Regional space and adjacent assets can be testbeds for downstream applications and tech transfers
• Encourage Primes and their supply chains to create opportunities for cross-sector and regional collaboration
• Encourage Primes to facilitate collaboration between industry and academia driven by excellence rather than proximity
• Regional capabilities closely aligned to NSS Priority Capabilities in Satellite Communications and PNT; aligned capabilities also in EO and ISR, SSA, IOSM and launch – create strategy to recognise and exploit</td></tr>
</table>

Potential inter-regional links:

- There is value in both directions in linking space capabilities in the South East (satellite manufacture, sub-orbital launch and applications) to the skills and adjacent sector capabilities of the Cambridge and Cranfield Universities located in the neighbouring Oxford-Cambridge Arc.
- The South East has a large upstream sector, so linking it to the nearby Leicester (and East Midlands) cluster would help fuel that cluster's growth.

[30] (2022) Regional Space Study, BryceTech

4.2.13 Berkshire[31]

<table>
<tr><td colspan="3">Berkshire - Regional Focus overall
A small region, which is the base for some foreign space company HQs and a strong IT, communications and electronics sector. Its potential is supported by its location between Harwell, the M3 cluster and London.</td></tr>
<tr><th>Market Opportunities</th><th>Supplier Strengths</th><th>Supply chain needs</th></tr>
<tr><td>Downstream
• Engage digital cluster: link IT and communications to space industry's data processing needs
• Space applications for environment and mobility
• Public sector: climate change, transport, public health
• Leverage space to stimulate innovation ecosystem</td><td>• Space components: electronics, power and communications
• Satellite communication and broadcast
• Extensive non-space tech sector including IT and electronics
• Several large datacentres
• System and technology consultancy (mission planning, constellation management, design optimisation)
• Strong health and life sciences sector
• EO Agri/Environmental data & applications
• Composite structures, substrates and sandwich panels
• Strategic location between Harwell, Guildford/Farnborough and London</td><td>• Small space sector, no cluster
• Limited 'innovation ecosystem'</td></tr>
<tr><th colspan="3">Regional Recommendations</th></tr>
<tr><td colspan="3">• Focus on growing and linking sectors over 'gap filling'
• Engage the digital cluster in space
• Develop space opportunities around local sector strengths</td></tr>
</table>

Potential inter-regional links:

- Berkshire has key strengths in large IT firms, both hardware and software, that would be valuable to encourage into supporting space applications.
- With a position between the strong space regions of Oxfordshire (in the Ox-Cam Arc) and EM3, Berkshire, and good access to London and international links, Berkshire may be an ideal location for corporate HQs.

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[31] Tucker, R. Walley, D. Webb, A. (2022) The Space Sector in Berkshire and London, Red Kite Management Consulting

4.2.14 Enterprise M3[32]

<table>
<tr><td colspan="3">EM3 - Regional Focus overall
A highly skilled region supported by local and neighbouring universities that feeds and draws from neighbouring space/advanced technology regions (London, Oxford-Cambridge Arc, South Coast). Satellite manufacturing, of whole spacecraft and of components and subsystems, is strong as is space research and R&D.</td></tr>
<tr><td>Market Opportunities
Upstream
• Further spacecraft manufacturing
• Mission control
Downstream
• Space data acquisition for Exploration, Mining, Communications, Forestry, Agriculture and Maritime</td><td>Supplier Strengths
• Small satellite manufacture
• Components and subsystems
• Earth observation
• Skilled labour force</td><td>Supply chain needs
• Primes (not counting regional 'prime affiliates' like SSTL and In Space Missions)
• Satellite operators
• Ground segment suppliers
• Governance</td></tr>
<tr><td colspan="3">Regional recommendations
• Develop a more granular understanding of local companies i.e. size, role in the pipeline, gaps etc.
• Space networking events in partnership with local and national space support networks
• More Trade & Investment activity (e.g. trade missions and UKSA/DIT promotion activities)
• Skills & Education - collaboration with educators (e.g. FE Colleges, schools) to promote STEM through Careers Enterprise Company and by collaboration with STEM Now and Esero UK (i.e. projects, competitions, career fairs)
• Targeted cross-sector workshops/initiatives reflecting local industrial / economic strategy i.e. clean growth
• Clustering - DISC Innovation Centre at Fawley Waterside, Tech Forest Innovation Centre at Whitehill & Bordon, Application towards and ESA BIC</td></tr>
</table>

Potential inter-regional links:

- The Enterprise M3 region is already experiencing a flow of skills and services with its neighbours (London, Oxford-Cambridge Arc, and South Coast), but this could be further improved by better regular contacts. For example joint events between clusters or in London (e.g. regular invitations to events and workshops at Harwell, or through the Satellite Finance Network or UKSA).
- As two smaller and nearby clusters, EM3 and South Coast, may benefit in coordinating events.

[32] (2021) EM3 Space hub – Introducing its growing space ecosystem – UK Space Agency local space cluster development project – An evidence and intelligence-based skills action plan for the enterprise M3 area introducing its growing space ecosystem, University of Southampton, University of Surrey, Hampshire County Council, Oxford Innovation, enterprise M3, South Coast Centre of Excellence in Satellite Applications, UK Space Agency

4.2.15 South Coast[33]

South Coast - Regional Focus overall		
Strong capabilities in **satellite manufacture** (Airbus DS Portsmouth). Local targets are to broaden the impact of this through connecting space and non-space businesses, R&D, and startups to maximise societal benefits.		
Market Opportunities	**Supplier Strengths**	**Supply chain needs**
Upstream • Manufacture of satellites (multi-tiered industrial base) • Satellite operations Downstream • End user applications - (geospatial data, asset monitoring, position, navigation and timing) • Next gen sat comms • Next gen ground segment	• Turnkey satellite manufacture (components, subsystems, assembly and testing) • Presence of space prime contractors (OneWeb, Airbus) • Access to early-stage equity investment • Strong IT and applications sector	• Measures to improve competitiveness to international satcom service providers • Software engineers (limited national supply of wider software skills to exploit next-generation satellite capability)
Regional recommendations		
• Leverage existing and developing capability inside and outside the space industry to provide critical encryption and cyber resilience to uplink, downlink, and onboard spacecraft data traffic • Integration with LEP strategies focused on regional prosperity, innovation, and wider societal benefits • R&D of technology for un-crewed missions and operations, building towards LEO commercialisation, and future lunar and Mars missions. Potential for high value cross-sector technology spin outs • Cross-sector technology transfer of advanced computing capabilities (data science, machine learning and machine intelligence) to wider industry and use cases • Development and operation of satellite data and communications services, both terrestrial and in space • Developing next gen ground infrastructure and low-cost phased array antennas for commercial, civil, and defence applications		

Potential inter-regional links:

- A need for software engineers could be supported by the strong academic capabilities of London. The awareness of software job opportunities in the South Cost among London universities could be supported by targeting careers fairs, as well as coordinating internships and industry placements with specific university computer science courses.
- As two smaller and nearby clusters, EM3 and South Coast, may benefit in coordinating events.

33 (2021) South Coast Regional Space Study, BryceTech

4.2.16 'Glos/Worcs/Wilts'[34]

<table>
<tr><td colspan="3">'Glos/Worcs/Wilts' - Regional Focus overall (Gloucestershire, Worcestershire, Wiltshire and Swindon)
A prominent range of Cyber capabilities constitutes this region's primary strength, backed up by a range of advanced computing and manufacturing capabilities with potential for both upstream and downstream applications, particularly in agriculture.</td></tr>
<tr><th>Market Opportunities</th><th>Supplier Strengths</th><th>Supply chain needs</th></tr>
<tr><td>Upstream
• Cyber and quantum technologies for space
• Advanced manufacturing
Downstream
• Next-generation agriculture and environmental intelligence</td><td>• Range of capabilities for satellite manufacturing
• Additive manufacturing and precision engineering
• Advanced manufacturing, aerospace, defence suppliers e.g. QinetiQ
• Computer, electronic and optical products, pharmaceutical, electrical equipment
• Cyber capabilities, including cyber resilience: home to 'Cyber Valley'
• High-performance computing and data science
• Academic and industrial agriculture expertise with demand for agri-tech solutions
• Policy and regulations expertise (home of UK Space Agency, Innovate UK, GCHQ)</td><td>• Need more space-focussed companies, academia, or innovation assets
• Primes
• Need for high quality office space in Worcestershire</td></tr>
<tr><th colspan="3">Regional recommendations</th></tr>
<tr><td colspan="3">• Encourage space to link to regional strength in all aspects of cyber (a clear opportunity for the region)
• Link encryption, cyber resilience, advanced computing and AI, quantum technologies to space
• Potential to harness advanced manufacturing capabilities into space and aerospace industries
• Potential to develop satellite-enabled capabilities for agricultural sector e.g. environmental intelligence, precision navigation, robotics for sensitive food handling</td></tr>
</table>

Potential inter-regional links:

- A need for more space assets could be met by formalising arrangements between the local satellite industry and the test facilities in the Oxford-Cambridge Arc
- 'Glos/Worcs/Wilts' could use its position as the home of space policy makers like UKSA, to encourage Primes from the South Coat and Oxford-Cambridge Arc to establish a regional presence.

[34] (2022) Regional Space Study, BryceTech

4.2.17 Heart of the South West[35]

<table>
<tr><td colspan="3">South West – Regional Focus overall (Heart of the South West: Devon, Somerset)
The South West has a small space sector, but strengths in several related engineering and electronics areas. Growth in Cornwall is likely to catalyse growth for the space sector in this region.</td></tr>
<tr><td>Market Opportunities</td><td>Supplier Strengths</td><td>Supply chain needs</td></tr>
<tr><td>Upstream
• Supply to Cornwall spaceport
Downstream
• Environmental Intelligence
• Satellite Data Analysis
• PNT for autonomous systems</td><td>• Robotics and autonomy
• Extreme environments/nuclear
• RF & satellite communications
• Precision engineering/ advanced manufacturing
• PNT and satellite communications
• IoT
• Advanced computing and data science
• Photonics cluster in Torbay</td><td>• Primes
• CAD, software agencies</td></tr>
<tr><td colspan="3">Regional recommendations
• Work with future launch and AIT facilities at Spaceport Cornwall, attract existing and emerging remote sensing operators and smallsat manufacturers to the region (HotSW)
• Commercialise SDA capabilities based in and around universities to meet increasing demand
• Potential addressable demand for precision engineering, advanced manufacturing and satellite data analysis</td></tr>
</table>

Potential inter-regional links:

- Heart of the South West has limited space activity and should be 'plugged in' to nearby regions such as Cornwall, 'Glos/Worcs/Wilts' and EM3. Work with future launch and AIT facilities at Spaceport Cornwall could attract existing and emerging remote sensing operators and small satellite manufacturers to the region – satellite manufacturing capabilities in WECA, 'Glos/Worcs/Wilts' and the South Coast could support this.
- Photonics expertise of great value to next generation satellite communications (and possibly on-board systems). This capability needs to be better communicated to the space sector, including to businesses in the Arc and South East.
- The need for software agencies could be supported by outreach to the satellite software capabilities in WECA (namely CGI).

[35] (2021) South West Regional Space Study, BryceTech

4.2.18 Cornwall[36]

Cornwall - Regional Focus overall		
Orbital launch (Spaceport Cornwall) from a Newquay airport , existing **ground station** (Goonhilly Earth Station) and other **data assets** (fibre links) offer national and international commercial opportunities, the stimulation of space/technology clusters and regional **upskilling**.		
Market Opportunities	Supplier Strengths	Supply chain needs
Upstream • Orbital small satellite launch • Mission control • Microgravity research Downstream • Near-to-deep space teleport • Exploration, Mining, Communications, Tourism, Agriculture and Maritime	• Goonhilly ground station • Cornwall spaceport and connected infrastructure • Data assets (storage, fibre etc.) • 2 Enterprise Zones linked to cluster	• Critical mass • Primes/OEMs • Investment and incubation • Upstream space manufacture • Dedicated test facilities • HEI/RI presence in upstream R&D • Skills • Supply chain for spaceport • Governance
Regional recommendations		
• Ground network research linked to SKA, MeerKat and e-Merlin (radio telescopes and networks) - aligning to advanced manufacture R&D. • Software innovation in artificial intelligence and machine automation. • Improved testing platforms - "test bed Cornwall" particularly in future flight technology (including clean energy), AI/automation in both launch and ground station infrastructure and space resource mining. • Develop a stronger research and innovation platform in specialist areas of excellence in Cornwall, e.g. specialist University Departments and Institutes, to identify areas requiring stronger industry alignment. • Local business would create their own R&D Departments if supported (Engage UKRI / STFC and UKSA). • Develop a dedicated space skills education programme • Develop Ion propulsion technologies		

Potential inter-regional links:

- With a major ground station and a developing spaceport, space businesses in Cornwall should look first to the Heart of the South West and the WECA region where they will find a number of complementary businesses in electronics, photonics and advanced engineering.

[36] Rothwell, S. (2019) Cornwall's upstream space supply chain and cluster: mapping and review, Rothwell

4.3 National Needs and Opportunities

Looking across all the regions, some common themes emerge:

Common Strengths

- Satellite applications are seen as a strength and an opportunity almost everywhere, particularly Earth observation or geospatial applications. This is perhaps not surprising given the UK's IT skill and technology base, and range of solutions addressing environmental problems.
- Linked to this, IT and data sciences are widespread strengths and, in many regions, identified as opportunities.
- Many regions note precision engineering as a skill, and this could be applied to the space sector. However, space companies do not express a gap in this area.
- Not 'common' between regions, but the UK has some world-class strengths that can be applied to space: manufacturing (e.g. MTC, NMIS, TWI), aerospace (Cranfield, GKN, Meggitt, in additional to well-known space players Airbus, BAE Systems, QinetiQ, Rolls-Royce), robotics (RACE, RU Robots, Shadow Robot), construction (major consultancies and research institutes) and others. The UK is very strong in research institutes that cross-over into delivery, for example MTC and TWI have both made low volume components for SpaceX, but would also act as consultants to help firms to set up a larger volume production facility. Some people in the space industry are aware of some of these capabilities, but not all, and there is an opportunity to make more of them, for example thinking ahead to the challenges of large structures in space.

In these areas, we have noted significant opportunities for clustering, but not every opportunity for inter-regional links, because there is potential for a link between almost any pair of regions.

Common Needs

- Fewer supply chain needs emerged than expected. That is partly because the industry has developed over many years to meet the needs of its markets, and sources what it needs, from abroad where necessary, and so does not consider it has gaps in the supply chain. Secondly, the regional reports focused more on the strengths and opportunities for their region rather than any gaps or problems.
- Skills: Skills were mentioned in 11 of the 17 regional reports. Sometimes specific skills are mentioned, but mostly it is a concern about the overall level of STEM skills, and the of 'converting' these into the space environment.
- Prime contractors: Other than the South of England, almost all the regions of the UK have a desire for large space (or aerospace/defence) contractors ('Primes') to help catalyse finance, a 'critical mass' of activity, and government interest to the area. However, Primes cannot be everywhere, and most local clusters must develop strategies to build critical mass in other ways.
- Funding: Mentioned for several places that are not in the well-funded 'hubs' of London, Edinburgh, Oxford & Cambridge.
- Awareness of the space sector and its opportunities: In firms that might work with the space sector, for example engineering or IT firms

- Governance: Mentioned in places which don't have a 'local guiding body' for space, e.g., a Catapult, Centre of Excellence, or local 'Space Council'. However, we do not think all locations or regions have the 'critical mass' or 'shape' for a space cluster. We recommend a strategic view is taken (Recommendation 2.1) and a small number of businesses will, unfortunately, have to connect to a more distant cluster.

Common Opportunities

- Several regional reports mention precision manufacturing or satellite manufacturing as an opportunity. Caution is urged on investment as there appears to be more potential demand than supply and it would make sense to cluster capabilities rather than spread them. However, there are good prospects for potential satellite or subsystem manufacturers, who would have several locations to consider, and capabilities to draw on.
- SSA/Space environment management: Frequently mentioned as an opportunity.
- Green tech and environmental intelligence: Many downstream opportunities waiting for markets to be fully established, and a passion of many entrepreneurs, waiting for an economic basis to tackle problems that they know need to be solved.
- Opportunity for related sectors to get involved as suppliers/partners (especially IT, but also engineering).
- Launch collaboration: Spaceports in Cornwall, Wales, and Scotland compete in some ways but complement in others (pros and cons of horizontal vs. vertical launch, different weather conditions, etc.) and could offer a more robust and exportable service by working together.
- Testbeds: Several regions offer capabilities and interests in end-user services that make them a potential testbed for future space applications (5G, autonomous vehicles, etc.)
- The opportunity to link LEP objectives and activities to the National Space Strategy and the enabling benefits that space can deliver in applications and inspiration.
- Financial outreach: There is entrepreneurialism in all regions, but finance does not yet seem to be equally accessible. Both the space sector and investors can benefit from opening the full geographic range of opportunities.

These findings inform the recommendations made in Chapter 8; in particular, Recommendation 2 for developing regional space activity and clusters.

5. Economic View

Investment in space sector programmes – public and private – creates jobs and wages with the prime contractor, but the ripple of economic benefits goes well beyond this. Primes assemble launch vehicles and satellites from systems and subsystems made by themselves or suppliers, who in turn buy components and support a wave of activity through the supply chain. The same applies to downstream space companies who buy upstream space products and services. This cascade effect goes beyond the space sector, supporting non-space suppliers such as IT, insurance, professional services and many others. In an integrated and mutually reinforcing domestic space sector, these ripples will be large as high quality domestic suppliers step up to take a major role in the supply chain.

Investment in space has a wide range of impacts that cascade through the economy. Pure and applied science, and technology development can spread to other companies and business models, spurring innovation. Space achievements can inspire people to learn new skills or become entrepreneurs. Agile, creative, and responsive supply chains provide a healthy ecosystem for entrepreneurialism and innovation to thrive.

In this section, the economic aspects of the space supply chain are analysed to understand how their strengths and weaknesses affect wider development of the sector and the economy as a whole.

5.1 Economic Value of the Sector

Cash returns flow from the space sector into people's pockets through wages and through profits made by space sector companies that are paid out as dividends. This direct and quantifiable economic benefit, known as Gross Value Added (GVA), was valued by the 2020 Space Sector Size and Health Survey at £6.6bn in 2018/19. The analysis in this section uses definitions consistent with the Size and Health Survey to draw the boundaries of the space sector[37].

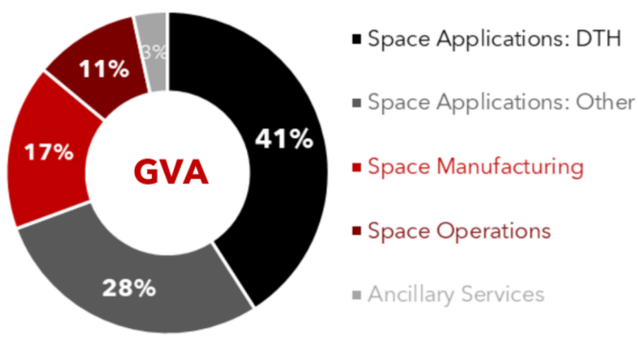

Figure 5.1 Gross Value Added in the Space Sector
Source: Size & Health Study 2020

The largest contributor to this was Direct-to-Home Broadcasting (primarily Sky UK) which accounted for 41% (see chart). However Sky UK revenue includes many services that are delivered only partly by satellites (Sky Q – now over 70% of their customer base) or not by satellite at all (Sky Mobile, and the

[37] This is the best source we know of in the UK that identifies space related economic activity and provides a comprehensive and quantified view of it.

new Sky Glass TV via broadband service). Looking forward, Sky might switch to fully terrestrial delivery, like its competitors, leaving space income and GVA about equal between upstream and downstream.

The Size and Health Survey suggests that the imports and exports of the space sector are quite finely balanced with exports of around £5.8bn in 2018/19 (mostly to the rest of Europe) and imports of around £5.7bn. Trade surpluses tend to create jobs as foreign demand drives domestic firms to expand. The UK Space Innovation and Growth Strategy target – to increase the UK share of the global space economy from 6% to 10% by 2030, anticipating a £400 billion global space market and a £40 billion domestic one – is a reflection of this desire for a world leading export focussed industry contributing to job creation and a positive space trade balance.

The economic value of the sector also encompasses productivity impacts and spill-overs that enable the economy to grow, impacts on innovation, and activities enabled by the space sector. The following sections examine the supply chain linkages between different parts of the space sector and then these other relationships between the supply chains and economic value.

5.2 Direct Economic Impacts of Space Market Segments

The largest segment in the Size and Health survey is the Direct-to-Home Broadcasting segment, with income of £7.5bn per year in 2018/19, and value added (GVA) of nearly £2.7bn. The high level of GVA for DTH is due to the size of the segment, not its GVA intensity. Some segments are in their infancy and currently generate low levels of GVA, including SSA and space environment management, IOSM, energy, and space tourism, and nascent domestic launch capabilities[38]. Upstream segments tend to boast higher wages[39] while some activities (notably satellite operations and satcoms) generate a large share of profits compared to their turnover[40] (largely because of high levels of capital, i.e. satellites).

The share of turnover that provides value added (GVA) depends on the balance of wages and profits compared to purchases of other intermediate inputs. A higher GVA share, therefore, reflects companies that are either more labour intensive or can generate high levels of profit per unit of turnover. Profitability within the segments depends on the degree of competition that companies face and the level of market power they can exert to set prices. These positions of market power are gained either through publicly imposed barriers to entry (such as costly or specialised licensing requirements), or through difficult-to-replicate technical excellence – often underpinned by patents, research and employee talent. However, the open international nature of much space activity means

[38] The 2020 Size and Health survey records only £3m of turnover for SSA and space environment management, £5m for IOSM, energy and space tourism, and £7m for launch services and spaceports.
[39] 2021 Space Census
[40] Inferred from turnover and employment data from the Size and Health Survey and salary data from the Space Census – and corroborated against company accounts for the largest satellite operators. Inmarsat, for example, is highly capital intensive with depreciation and amortization equivalent to more than a third of revenues in 2020. GEO satellites can cost £1 billion and the risks of technology change and obsolescence demand high profitability to reward risk taking associated with large and risky capital investments.

that markets are often globally competitive (e.g. satellite manufacturing), constraining the market power of individual UK firms.

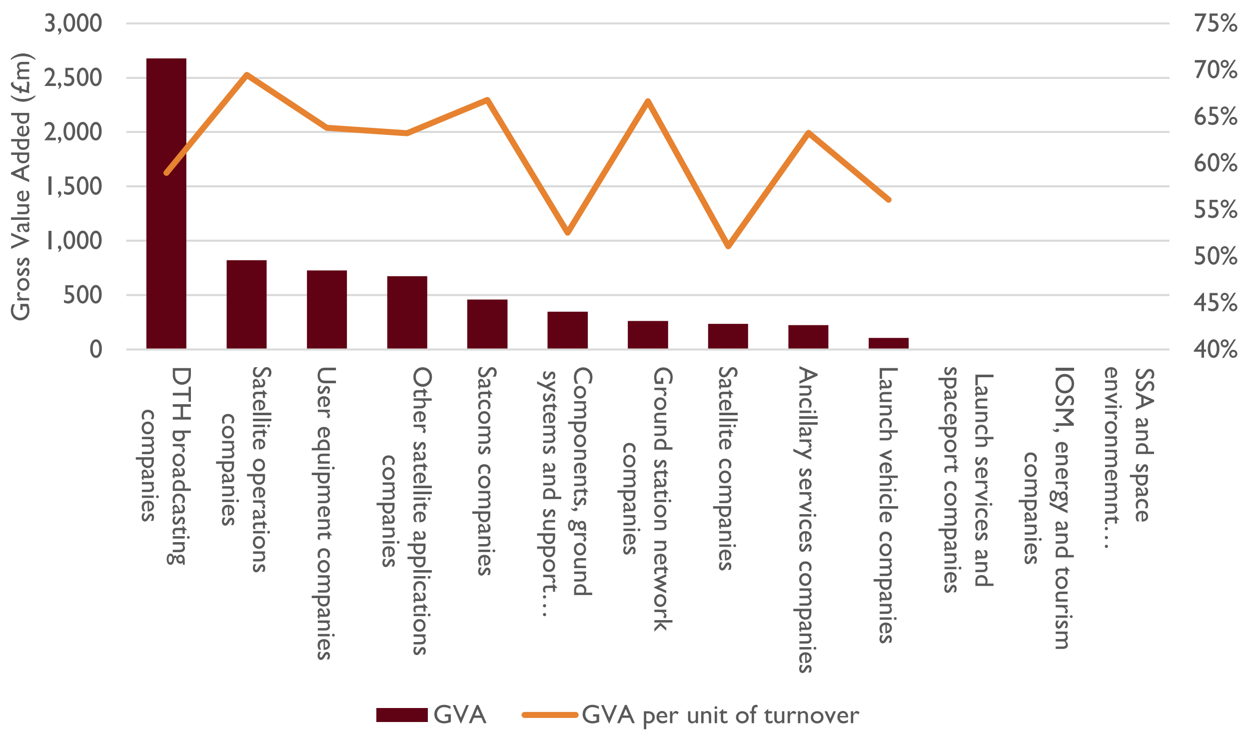

Figure 5.2: Estimated direct impacts on GVA of expenditure in different segments of the space sector (2018/19)

The Direct-to-Home Broadcasting segment competes with other entertainment delivery channels (e.g. BT Broadband, Virgin Media, etc which are provided via fibre/cable connections) limiting Sky UK's ability to charge higher prices and earn higher profits. Competition amongst component suppliers could be expected to give them relatively low levels of market power, particularly when supplying to primes.

We estimate that the segments that support the most direct employment are: Direct-to-Home Broadcasting (nearly 20,000), Components, ground systems and engineering support (4,500), Satellite manufacturing (3,000), and Ancillary services (2,800)

5.3 Indirect Impacts: Multipliers and an Integrated National Supply Chain

The impact of a space company grows as it passes through the economy. The overall impact on GVA of investment in space – the multiplier – depends on how much of the project is delivered by suppliers in the UK. A deep, capable, and integrated domestic space supply chain will enable the UK space sector to find more of its suppliers domestically and increase the national economic benefits of space investments as investment benefits cascade through the supply chain. This section examines the shape of the existing domestic supply chain and quantifies it as far as the data allows.

Drawing on a wide range of sources[41], for different segments of the UK space sector, the Red Kite team have estimated the major supply chain linkages between the different market segments and their import and export behaviour. Some of the inputs are sourced from data, but many are the team's estimates taking a view across partial or subjective data sources. However, a lot of the value of the industry is concentrated in a few businesses (e.g. Airbus, Sky, Inmarsat, Intelsat), many of which we have interviewed and analysed the accounts of. This analysis echoes recent work by the Bureau of Economic Affairs in the USA which recently used the same input-output framework of analysis for the first time to measure the size of the US space sector[42], adding to confidence that the overall conclusions are correct.

Sources, assumptions and methods in the economic analysis

Our model of supply chain relationship draws information on cost structures from:

- Market reports
- Conference presentations
- Trade body data
- Company accounts
- Interviews with industry experts and company representatives

From these, we have used judgement to develop a matrix of the expenditure pattern of different space market segments, reviewing our judgements across the team. For example, we estimate that 20% of the UK satcoms segment's input costs are satellite operations. Using information about supplier relationships, limited public data and judgement, we then estimate the share of these segments which are supplied by domestic suppliers and the share that is imported.

The implications are then traced through an input-output modelling framework to establish overall industry expenditure patters, imports and exports. Assumptions are then moderated to ensure that the modelled outputs conform to information from the size and health survey and other sources, including

- Total inputs to the UK space sector from other UK space sector firms (from S&H survey)
- Total inputs to the UK space sector from UK firms not in the space sector (from S&H survey)
- Total space sector imports (from S&H survey)
- Total space sector exports (from S&H survey)
- Total use of space products & services by non-space companies (inferred from S&H survey and other data)
- Government expenditure on space products and services from UK space companies (from bottom-up analysis of departmental expenditure)

After this balancing process, we develop scenarios for future growth and supply chain relationships and use these to examine how supply chain relationships could evolve as the industry grows.

[41] Including market reports, company accounts, published economic data and evidence from surveys. We have examined the annual reports and accounts of firms that make up around 75% of the revenues of space sector.

[42] Highfill, T. and MacDonald, A, Space Policy, January 2022, *Estimating the United States Space Economy Using Input-Output Frameworks*

Figure 5.3 shows our estimates of the share of expenditure in each segment that is spent on domestic space suppliers, generating the second-round industry effect – the first ripple in the space supply chain. It shows that satellite manufacturing appears to have the largest second round impact on the domestic supply chain. Airbus (including SSTL) is the largest satellite manufacturer and supports a domestic supply chain of subsystem and component manufacturers.

This is a larger share than many other segments. For example, satellite communications is dominated by Inmarsat, which appears to have a very international supply chain, sourcing a higher share of inputs from overseas. Another example, the ancillary services sector buys more from the UK, but relatively less from the space sector. Its main inputs are wages, the Ancillary Services sector itself (through sub-contracting), and non-space sector (e.g. IT, office space and other general business suppliers).

Spend on UK space Sector Suppliers per £ of Turnover	Market Segment
Very High Impact (Greater than 30%)	Satellite Manufacturing
High Impacts (20% to 30%)	Launch Services and Spaceports Other Satellite Applications Ground Station Networks Launch Vehicle Manufacturing
Medium Impact (10% to 20%)	IOSM, Energy and Space Tourism Companies SSA and Space Environment Management Other Space Manufacturing (Components, Ground Systems, etc.) Satellite Operations Satellite Communications User Equipment Suppliers
Low Impact (Less than 10%)	Direct-to-Home Broadcasting Ancillary Services

Figure 5.3: Estimated fraction of segment spend that is within the UK space sector

Drawing on this analysis, it is possible to examine the likely effect on the overall space supply chain once this and subsequent ripples through the supply chains have taken place. For each segment, the analysis allows us to deconstruct how this supply chain cascade affects other segments within the space sector – shown in Figure 5.4.

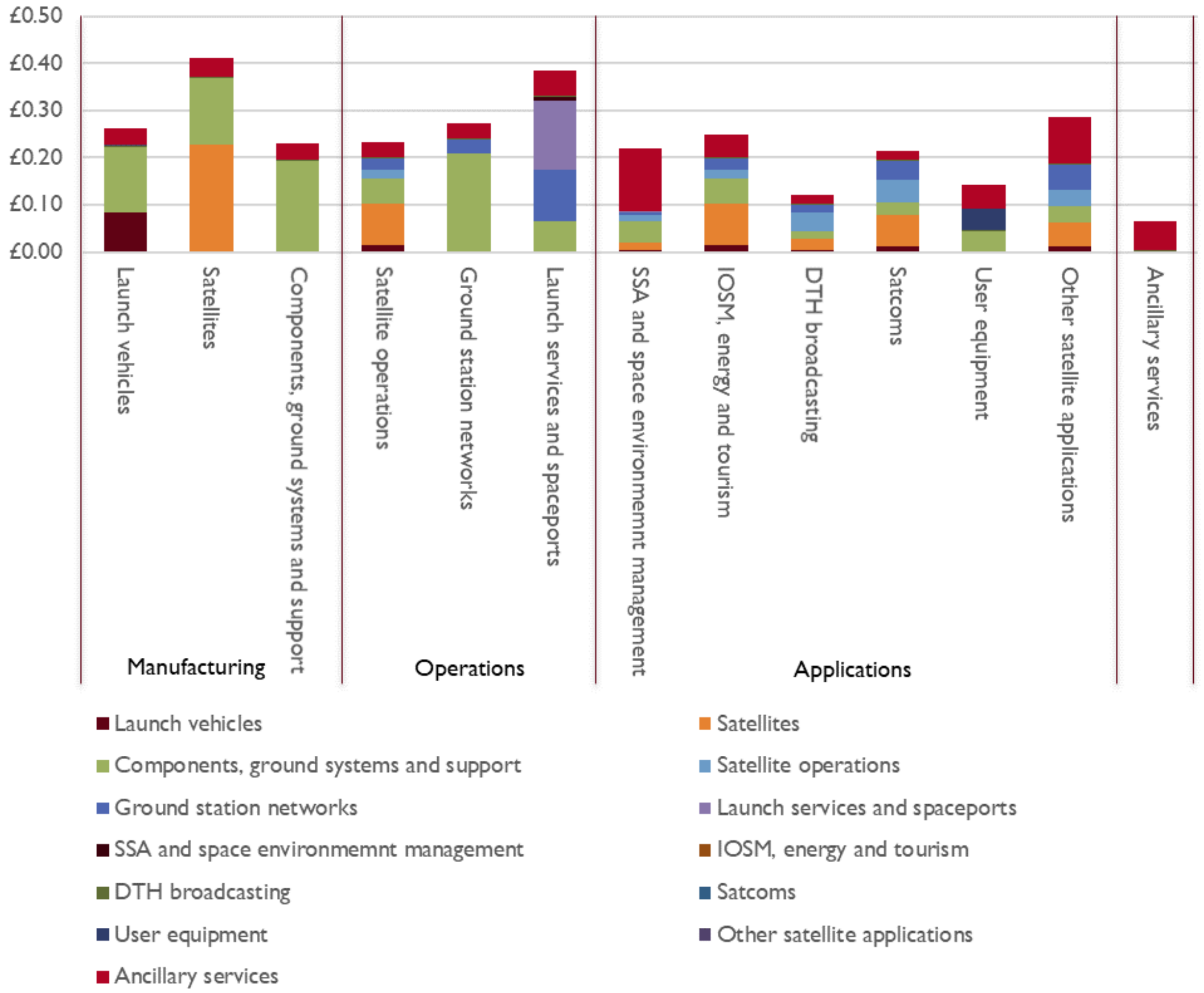

Figure 5.4: Estimated knock-on UK supply chain expenditure per £ of segment income

Figure 5.4 shows that for every £ of expenditure on Satellite manufacturing, we estimate that approximately 40 pence will cascade through to other suppliers. The composition of this supply chain impact is shown by the stacked colours. The largest impact of a growing satellite manufacturing is on other satellite manufacturers and subsystem suppliers (shown as the orange segment of the second column of the chart), followed by components and other manufacturing suppliers, and with a much smaller impact on ancillary services support (such as software an IT). The smallest knock-on space sector supply chain impacts come from ancillary services which may subcontract some work to other space companies, but generate the smallest overall cascade effect.

Large impacts through the space supply chain are also likely to come from launch services and spaceports – although domestic supply in this segment is currently tiny (see Figure 5.2) as no UK spaceports are operational yet – and from other satellite applications which tend to buy significant quantities of domestically produced support services (e.g. software.) as well as having important supply chain linkages to ground station networks, satellite operations, and ultimately to upstream manufacturing.

We estimate each pound (£) of activity in space sector segments supports a further 6 to 41 pence in the wider space supply chain, depending on the segment. (This means a multiplier of between 1.06 and 1.41 because multipliers are expressed to include the initial output as well as its subsequent supply chain impacts). Impacts of investment in the applications segments are not necessarily larger, but are certainly more diverse as they cascade upwards through the operations and manufacturing segments.

Multipliers capturing the impact on the whole economy through upstream supply chains are a little higher, ranging from 1.30 to 1.53 because they also capture indirect demand generated in non-space suppliers. For comparison, National Statistics data shows a comparable median multiplier of 1.66 multipliers across 105 business sectors, ranging from accounting activities at the low end (1.24) and up to electricity transmission at the top end (2.72). Upstream space output multipliers are somewhat lower than other sectors due to the space sector's relatively high import content.

From the Size and Health Survey, we know that space imports and exports are quite finely balanced – strong export performance is matched by a high intensity of imports in the production process (58% of all intermediate inputs to space companies come from abroad[43]). Some of these imports happen at the system level within large international groups such as Airbus, Lockheed Martin and Thales Alenia, where units worth millions of pounds may be imported to include in a larger 'UK built' system or satellite. Some of them are at the component level, where a semiconductor component, a sensor, or some other component may be sourced from Asia, Europe or North America for inclusion. Discussions with people in supply chain confirm this picture.

5.4 Induced Impacts: Benefits of Employees Spending Wages and Generating Demand

Upstream impacts through the supply chain are one part of economic impact. Another is the boost in demand that comes as space sector workers spend their income in the local economy (usually outside the space sector). These effects give rise to different types of economic multiplier (Figure 5.5).

Multipliers – how economic activity propagates through the supply chain
Type 1 multipliers: Capture links 'backwards' through a company's supply chain Type 2 multipliers: Capture 'backward' links as well as 'forward' links through the expenditure of company employees' wages in the local economy. Different multipliers can also describe how different economic variables change. For example **employment multipliers** will describe how an increase in employment in one sector supports jobs across the wider economy, while **output multipliers** will describe how a change in economic output in one sector affects output in the economy as a whole.

[43] Based on responses to the Size and Health Survey from 118 respondents

Finally, multipliers can capture how supply chain effects propagate from one sector to another or from one sector to the whole economy (for example, in our analysis of multiplier impacts that affect the space sector, and those that affect the whole economy).

Figure 5.5: Types of economic multiplier in supply chains and economies

The different multipliers we have calculated for the different market segments are shown in Figure 5.6. We calculate that Type 2 output multipliers (including induced effects – i.e. spending of wages) range between 1.7 and 3.2. This is comparable to the overall Type 2 multiplier in the Size and Health Survey of 2.4 and implies that £1 of space company income will drive between 70p and £2.20 of further income for other firms across the economy. The different multipliers we have calculated reflect different ways that the space supply chain, wider supply chain and downstream expenditure of wages affect the economy.

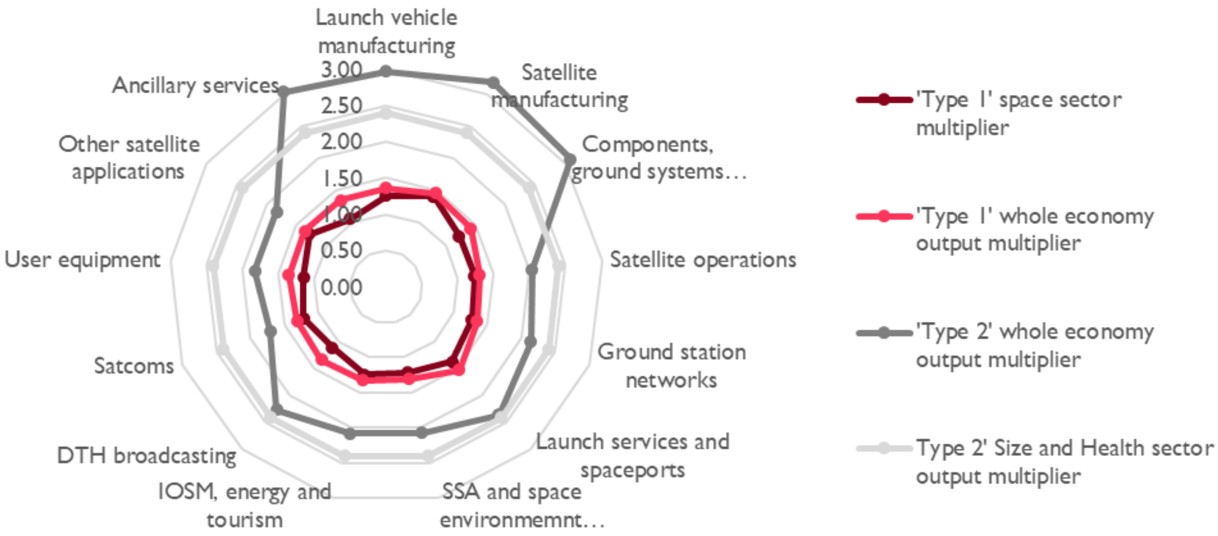

Figure 5.6: Estimated multipliers for different space segments

The Type 1 space sector multiplier (shown in dark red) and discussed in the previous section is an indication of how expenditure in that segment cascades to suppliers in the rest of the UK space sector. The Type 1 whole economy multiplier shows how expenditure in that segment cascades to all suppliers in the rest of the domestic economy – including non-space suppliers. The largest differences between these two effects are in the ancillary services segment and in the DTH broadcasting segment.

Both of these segments have significant non-space inputs so domestic supply chain effects in the space sector tend to be relatively small while effects in the wider national supply chain are somewhat larger. These multipliers are ultimately driven by the share of the whole supply chain for that segment that is imported rather than being produced domestically. Boosting Type 1 space multipliers means sourcing more space inputs from UK suppliers while boosting Type 1 whole economy multipliers also means spending a higher share with domestic non-space companies rather than foreign non-space suppliers. This may mean, for example, growing the capabilities of the domestic IT sector to provide specialised service to space companies. However, the opportunity to boost non-space multipliers is somewhat limited because all companies also need more general supplies that other countries may produce more efficiently (e.g. IT hardware, support services, etc.).

Type 2 whole economy output multipliers describe the overall impact of a segment on the whole economy including through supplier relationships and through induced demand as their employees spend their wages. These are largest for the space manufacturing sector (launch vehicle manufacturing, satellite manufacturing and components and other manufacturing). This is largely due to their multi-tier supply chains (although much of this is imported) as well as the higher wages that tend to be paid in the upstream space sector. This is closely followed by ancillary services. For this segment, the space supply chain impacts are small, but a high share of income is spent on wages which support the wider domestic economy. The ancillary services segment also has a more domestically focussed supply chain, boosting its multiplier effect from supplier relationships.

The assessment of supply chain connections has several weaknesses and so is intended to be indicative – conveying the main inter-industry connections. In particular, data on the purchasing patterns of segments has been inferred from industry reports, interviews and company accounts and data quality is poor. This relates particularly to imports where there is limited survey data and we have had to rely in many cases on industry knowledge of major supply relationships and control to high level industry import totals. The analysis also assumes that once something is bought from abroad the domestic economic impacts ceases. However, imported systems or subsystems may contain components originally sourced in the UK.

A critical factor driving multipliers is the use of imports as intermediate products in the supply chain. Where imports make up a high share of company inputs, the supply chain benefits go abroad and ripples through the UK supply chain die away quickly. In the USA, for example, where a larger domestic market provides more of the inputs, each dollar spent in the space sector returns around $5 of impacts on the overall economy – roughly twice what we see in the UK.

5.5 Catalytic Effects: Technology, Innovation and Best Practice

Space activities catalyse wider impacts across the economy through:

- Developing new technologies and high-quality standards.
- Spreading industry best practice through highly developed and complex supply chain relationships (such as partnership approaches, inspection plans, recording and auditability);
- Productivity gains in other fields (e.g. new business models enabled by PNT, accurate weather forecasting, faster comms (e.g. for banking), etc); and
- Driving innovation, entrepreneurialism and inspiration.

While these different effects can be difficult to disentangle, there is solid evidence that when these wider impacts are accounted for, government supported investments – particularly R&D – can lead to sizeable economic returns. Work by UCL's Institute for Innovation and Public Purpose[44] examined the multiplier effect of different types of government spending. The results of their empirical work (based on quarterly US data from 1947-2017) is shown in Figure 5.7.

Type of government spending	GDP multiplier
Consumption	1.12
Investment (including R&D, but mostly other types of public investment)	2.12
Non-military R&D	7.76
Military R&D	8.82

Figure 5.7: The powerful economic impact of research

UCL's work was based on statistically modelling the effects of changes in different types of US government expenditure on national GDP over a long time period. The model shows that for each dollar spent on public consumption expenditure, in the long term, GDP increased by $1.12 (the dollar spent and an additional 12 cents), while every dollar spent on investment expenditure created $2.12 of GDP, almost twice as effective. R&D expenditure is considerably more effective again and 'crowds in' significant private sector research and development activity. What UCL describe as 'task oriented public R&D expenditure' (here proxied by military R&D aimed at a particular research objective and tangible output) is found to be the most effective form of government expenditure at driving subsequent GDP growth. This implies that public investments in space technology development will tend to yield very substantial economic payoffs over time.

5.6 Enabling Effects

The space sector is now ubiquitous, playing an enabling role in almost all aspects of industry and commerce. This is a different lens to observe space sector supply chains through - not reflecting the value of services purchased from the space sector, but the value of the economic activity that it enables.

This highlights a critical difference between supply chains and value chains. The value that derives to the ultimate users of space derived services depends on what those space services enable them to do. However, if markets are competitive, the price they pay may be only a tiny fraction of this. A consumer GPS device (for example the GPS receiver in a smartphone) may cost only a few pounds, but the apps it enables could create hundreds or even thousands of pounds of value for the users. This is a key reason why the value of 'space enabled' goods and services is many times the turnover of the

[44] Deledi, M. et al (2019) The macroeconomic impact of government innovation policies: A quantitative assessment, UCL [https://www.ucl.ac.uk/bartlett/public-purpose/sites/public-purpose/files/macroeconomic_impact_innovateuk_iipp_report_final_web.pdf]

space sector. Critically, the price of space products and services could fall sharply as technology improves, production costs fall and competition increases. This represents an important shift in value to consumers, but is likely to pile pressure on industry growth targets measured in industry turnover or GVA. Good data is now available from the US Bureau of Economic Affairs showing that this is already happening in the US space sector. A boom in building rockets and satellites between 2012 and 2019 actually saw nominal spending on space-related manufacturing fall. This is because a million dollars bought a lot more capability in 2019 than it did in 2012.

The OECD has a framework for the wider impact of space activities (Figure 5.8).

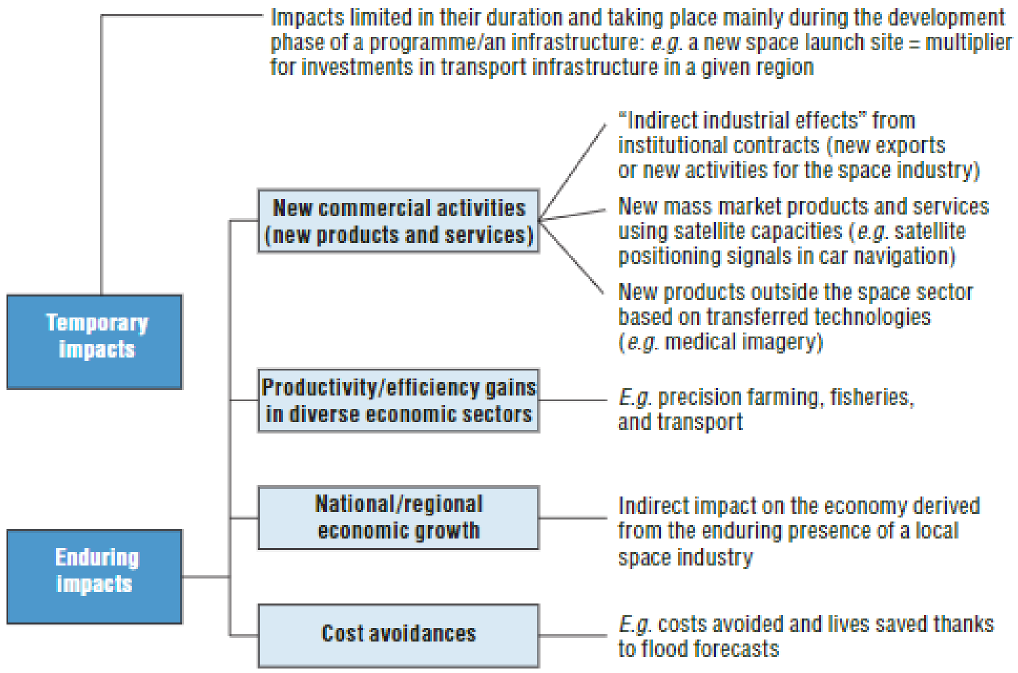

Figure 5.8: Possible impacts from space activities[45]

This framework captures the supply chain impacts and multipliers described above as well as looking forwards through the supply chain to the users of space technologies. It has been estimated that space underpins £360bn of UK economic activity[46] (Figure 5.9).

[45] OECD Handbook on Measuring the Space Economy [https://read.oecd-ilibrary.org/economics/oecd-handbook-on-measuring-the-space-economy/measuring-socio-economic-impacts-from-space-activities_9789264169166-8-en#page3]
[46] Size and Health Survey, 2020

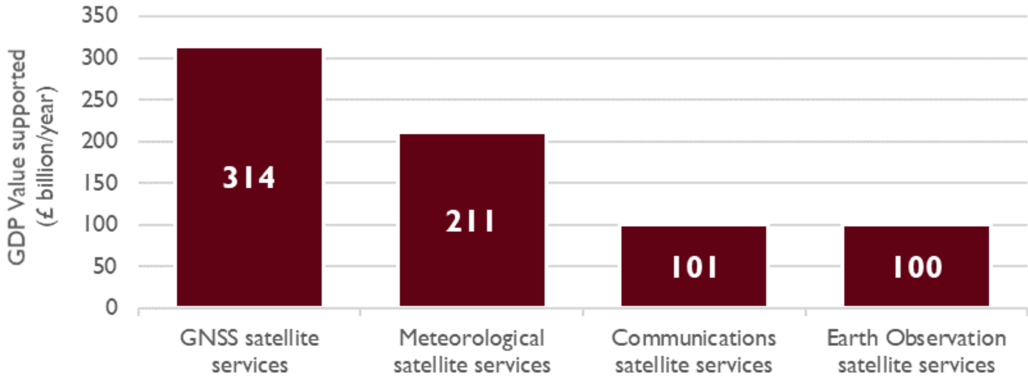

Figure 5.9: Satellite services that support the wider economy (There is overlap, but total is at least £360bn)

Methodology[47] developed to understand the value of Copernicus data shows how the benefits of space to the wider economy can become highly diffuse once data enters the business processes of customers/users. A farmer may benefit from EO data to improve crop yields, but their customers only care about the quality and price of their produce not whether or how satellite data was used to produce it. Copernicus data is available for free. With no market for it, the value cannot easily be tracked through sales of the data.

5.7 Conclusions from the Economic Analysis

- The single largest supply chain linkages identified are:
  - Satellite operations inputs to DTH broadcasting
  - Trades between companies within the 'other manufacturing' segment which includes ground systems, scientific instruments, materials and components suppliers, fundamental research, and test facilities
  - DTH broadcasting's expenditure on satellite manufacturing
  - Trade between different parts of the satellite manufacturing segment (e.g., supplies of subsystems to primes).
- Satellite manufacture spends the most on domestic intermediate inputs per pound of output
- Multi-tier supply chains of upstream space can lead to large multipliers
- Import intensity is high - weakening domestic supply chain relationships and driving down multipliers from investment
- There is significant, though not huge, sourcing from the UK non-space industry – particularly software and IT. Downstream businesses buy much more in terms of 'general data processing'
- The wider economic impacts of research through catalytic effects can be very large, but the transmission mechanisms are diverse and difficult to disentangle.

[47] https://earsc.org/sebs/wp-content/uploads/2020/12/SeBS-Methodology-2020.pdf

Case Study: OneWeb Supply Chain

The OneWeb supply chain illustrates the range of supply chain activities and their international nature behind a UK-headquartered business.

OneWeb employs 229 people at the company headquartered in White City in London, as well as many more manufacturing satellites and user terminals, launching and operating satellites. When operational, OneWeb will also support jobs at telcos that resell OneWeb bandwidth and services. The supply chain impact of OneWeb in the UK will depend on how much of this supply chain is delivered domestically. Gen 1 satellites are currently being built by Airbus in Florida while South Korean company Intellian is the main partner for user terminals and a global network of ground stations is being built out. Key elements of the Gen 1 OneWeb supply chain comprise:

- Airbus which currently integrated the elements of the OneWeb satellites at its purpose-built facility in Florida, USA (although production may be moved to the UK)
- RUAG Space who make the satellite backbone in Florida, the satellite dispensers in Sweden, and the satellite insulation in Austria
- Teledyne who provide signal converters and filters from their facility in Shipley, Yorkshire
- MDA make the antenna systems in Montreal, Quebec
- Syrlinks who make transceiver in Rennes, France
- Sol Aero in Albuquerque, New Mexico (now owned by RocketLab) who make the solar panels
- SpaceTech, who make the solar array deployment mechanism in Immenstaad, Germany
- Star trackers are made by Sodern, a subsidiary of Ariane Group based in Paris
- NewSpace Systems in South Africa make the magnetic torquers
- Korean firm Intellian make the user terminals while Satixfy are developing terminals for aircraft and other mobile locations at their facility in Cheadle, Manchester
- Hughes Networks is developing much of the ground system hardware in Maryland, USA,

All 11 launches so far (except the first one from Kourou) have been from either Baikonur or Vostochny using Soyuz-2.1b rockets with Fregat upper stages. The Russian invasion of Ukraine has jeopardised the Russian elements of the supply chain – particularly the use of Soyuz as a launch vehicle – highlighting the benefits of domestic capability and of either well-managed vertical integration, or competitive and diversified supply chain providing multiple choices of supply partners.

6. Forward-Looking View

6.1 PESTLE Analysis

We aim to consider supply chain developments over the next ten years, to 2032. To help us think ahead and consider the supply chain of the future, we have conducted a PESTLE analysis.

PESTLE Factor	Potential changes	Potential impact on space sector and supply chain
Political	• Increasing recognition of role of space in defence and security (see Integrated Review)	• Increased space capabilities and role for both sovereign capabilities and international partnership (own-collaborate-access model in Integrated Review)
	• UK exit from EU	• Investment in UK may increase or decrease; Possible EU reaction; New trade relationships; IP/Supply Chain risks; Potential change in ESA/UK balance of activity
	• Continued transfer of space from public sector to private sector. Markets sometimes driven by companies or billionaires, not governments	• Not predictable; Need to develop own initiatives or be ready to respond quickly; May be more vertically integrated with fewer supply chain opportunities; May open other opportunities (e.g. smallsat launches)
	• A new 'space race' – new wave of space exploration	• Opportunities in exploration supply chain (e.g. Lunar Pathfinder, ESA Lunar Village, future space stations); Inspiration for the next generation
Economic	• Economic fall-out from Covid	• Shortage of investment; Efficiency drive may benefit space applications, or harm it with budget cuts
	• Economic development in low-income nations, alongside environmental issues is a major opportunity for satellite services	• More a market opportunity than supply chain, but there may be linked opportunities e.g., partnerships
Social	• Ever increasing consumer desire for data e.g. streaming video	• Ubiquitous connectivity, fast data requirements
	• Rise of 'peer-to-peer' and PNT enabled business (Uber, Airbnb, Deliveroo, e-scooter rental)	• Need for ubiquitous, accurate civil PNT e.g. distinguishing footpath from road.
	• Greater focus on environment including legal obligations on Government on GHG emissions, biodiversity, air pollution, etc.	• Opportunities for EO supply chain, and space applications that support more efficient energy, mobility, agriculture, etc.
	• Public health issues (esp. connected to inequalities, lifestyle, pollution)	• Opportunities for health applications markets
Technological	• Launch vehicle cost reductions inc. reusability; Electronics capability increase; Propulsion advances; Scale; standardisation and cost reduction	• Satellites and constellations increasingly viable for more applications
	• Global satellite broadband constellations	• GEO satellites and their supply chains may become uneconomic or niche

	• Additive manufacture/3D printing/ advanced materials • In-orbit service & manufacturing • AI, quantum, other advanced computing, • Ever growing need for data processing	• Drivers of capability and more rapid development • A potential new industry with new supply chain requirements and revenues. • Enables in-orbit autonomous operations, larger constellations, cryptography, processing large data sets (e.g. EO); Possible in-orbit processing (e.g. IoT).
Legal	• UK Launch regulations clarified or eased • Incipient regulations on space debris mitigation, in-space resource utilisation • Spectrum regulation under increasing pressure to balance between GEO, LEO, terrestrial and hybrid systems • Skills mobility changed by immigration rules	• UK Launch takes off, establishes supply chain • Opportunities to supply debris mitigation technologies, ISRU in pilot only in ten-year timeframe • Spectrum efficiency and avoiding interference will only increase in value • May be more difficult to get skilled people from EU, but easier from elsewhere.
Environmental	• Increasing climate change impacts and biodiversity/ecosystem problems	• Rising need for EO satellites/data/apps for science, mitigation & resilience – drives upstream & downstream supply chains • Rising need for Navigation & other apps that enable emission reduction • Emergence of off-planet resource acquisition and manufacturing projects, initially as concepts in conference or journal papers, but sometimes becoming funded projects.

Figure 6.1: PESTLE analysis

6.2 Key Industry Trends

Innovations in satellite manufacture and commercial launch are revolutionising the space sector, enabling vast satellite constellations, and setting the scene for the in-orbit and wider space economy of the future. This change, going far beyond the 'NewSpace' of today has profound implications for the supply chain.

Smaller, Faster, Cheaper

Miniaturisation and standardisation of satellites has played a great role in opening the space segment. We've moved from space being for government bodies and international telecommunications agencies to being affordable by small businesses. Orbital Astronautics at Harwell now offers a 3U CubeSat for £60,000 and estimates a further £95,000 for launch costs.

The UK has played a key role in this development. The University of Surrey pioneered the move to smaller satellites using commercial off-the-shelf (COTS) components with the 54kg UoSAT-1, launched 'piggyback' on a US Delta rocket in 1981. Its main computer was a then standard 8-bit RCA microprocessor. This approach to satellite design, and piggyback launch, continued to develop in parallel to the 'conventional' space industry. After a series of satellites, the operation was spun out of the University as a company: Surrey Satellite Technology Limited (SSTL) in 1985. A majority stake was acquired by Airbus in 2009 and it has now produced over 70 satellites and employs 360 people.

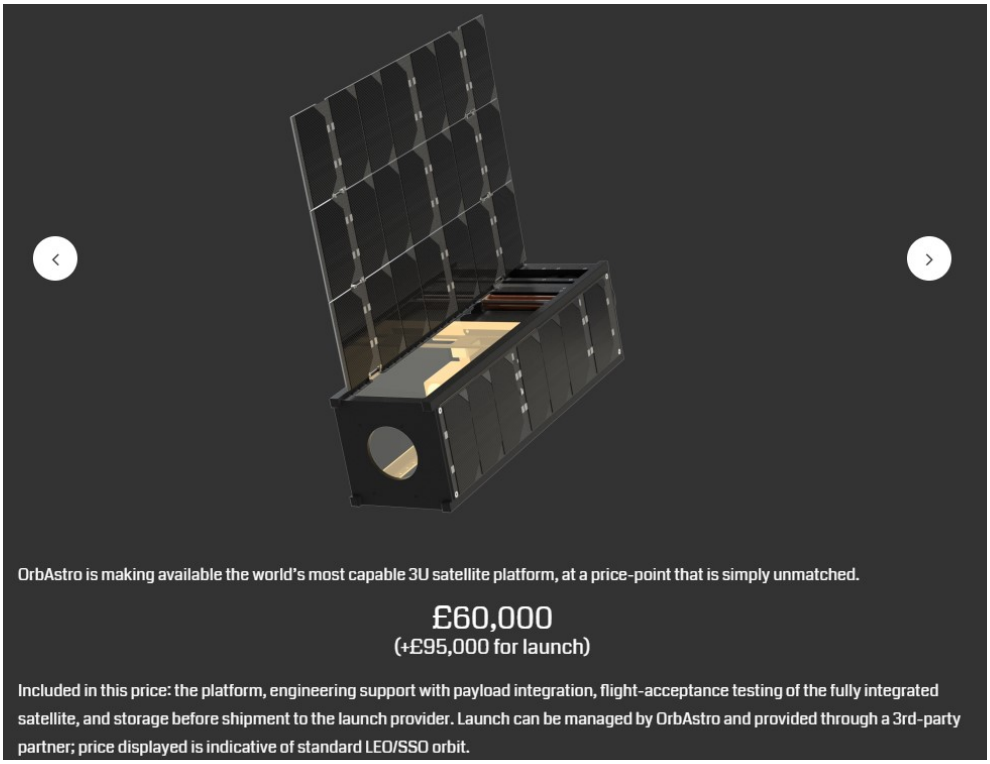

Figure 6.2: Orbital Astronautics indicates how low satellite prices can be

CubeSats were the next major stage in the low cost satellite revolution. These were first proposed as a graduate student design project at Stanford University in 1999, and the first ones were flown in 2003. CubeSats both shrunk and standardised the form-factor. This has enabled satellite manufacturers to create standard platforms containing power and avionics and launch businesses to create standard deployment systems for the standard CubeSat sizes (1U, 2U, 3U, 6U, 12U).

Now, several businesses offer Minisat platforms at 100-150kg maximum mass. (We set out which UK companies integrate satellites at each size in section 7.2). This appears to be a sweet spot where satellite capabilities can be significantly higher than a CubeSat, and volumes still high enough to keep costs down. They also fit an emerging generation of commercial small launchers in addition to existing piggyback options discussed in the next section.

With these standard platforms has come volume, and with volume, lower unit costs and timescales. Reducing the costs reduces the risks, because a lost mission can be replaced for £100k-£1m in perhaps 1 year rather than many tens or even hundreds of £ millions for previous generations. This has two effects:

- First, within the supply chain itself there is not the ultimate focus on reliability that there is in previous satellite generations. That is not to say that CubeSats are not assembled with care. But, they do not need as many layers of testing and redundancy as a £200m GEO satellite on a £100m launcher. This magnifies the cost difference. However, data shows CubeSats suffer from high early failure rate[48].
- Second, the lower costs have enabled new missions and new businesses. Ideas for new space applications can now be tested at low cost. An example is Lacuna Space, a novel IoT venture, who launched their first space sector relay as one of two payloads on a 6U NanoAvionics CubeSat in April 2019. This type of proof-of-concept is essential for many small businesses needing to raise capital for further development.

The twist is that because costs are low, these satellites, and the services based on them, may have low economic impact on the space supply chain, even while creating a large benefit elsewhere. They may even replace more expensive space services, reducing the size of the space sector.

Halfway to Anywhere[49]

The commercialisation of launch services has brought down the cost of launch services and increased the access to space. This is exemplified by SpaceX and the Falcon 9 reducing launch costs to $3000/kg compared to $10,000/kg (for large satellites) to $30,000/kg for the previous generation[50], but this is not the only example. SpaceX also has its Microsat rideshare programme – from $1m for a 200kg satellite to SSO[51]. There are other commercial launches available with Ariane, Northrop Grumman, RocketLab, ULA, Virgin Orbit, ISRO and JAXA, and piggyback launch opportunities for microsats and nanosats with most of these.

This increased access and competition makes it easier for a satellite operator to get into orbit and reduces launch costs. Arguably it is the vast increase in launch capacity that the high launch cadence of the reusable Falcon 9 that has been the big opener of satellite markets – enabling a large number of satellite operator to take advantage of the low prices.

This was all enabled by the original development of the Falcon 9, unlocked by a commercial approach to public procurement for cargo delivery to the International Space Station.

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[48] https://www.sciencedirect.com/science/article/pii/S0951832021007584

[49] From a Robert Heinlein quote "Once you get to Earth orbit, you're halfway to anywhere in the solar system.", referring the to energy required to reach Earth orbit.

[50] 'The Recent Large Reduction in Space Launch Cost', HW Jones, NASA Ames at 48th International Conference on Environmental Systems. https://ttu-ir.tdl.org/bitstream/handle/2346/74082/ICES_2018_81.pdf, confirmed with launch brokers Commercial Space Technology.

[51] https://rideshare.spacex.com/ - although this is very much a basic price not including logistics, deployment system, etc.

Case Study: NASA COTS and CRS

COTS (Commercial Orbital Transportation Services) and CRS (Commercial Resupply Services) were NASA initiated programmes to develop and procure respectively commercial freight delivery services to the International Space Station (ISS). As NASA Administrator Dr Griffin stated, "With the advent of the ISS, there will exist for the first time a strong, identifiable market for "routine" transportation service to and from LEO." COTS and CRS used this market-building opportunity.

Under COTS, NASA initially signed development contracts with SpaceX and Rocketplane Kistler in 2006, however Rocketplane Kistler pulled out soon afterwards and NASA re-awarded the contract to Orbital Sciences in 2008. The programme resulted in the development and demonstration flights of SpaceX's Falcon 9 launcher and Dragon capsule, and Orbital Sciences' Antares launcher and Cygnus capsule. Two new launchers and two capsules for a public investment of $821m with commercial partners adding $1044m[52]. The remainder of the investment was made by the private companies, knowing that these assets would have commercial opportunities under CSR and in the open market.

SpaceX Dragon Capsule

The first CRS contracts were awarded in 2008, $1.6bn to SpaceX for 12 Dragon cargo missions and $1.9bn to Orbital Sciences for eight Cygnus missions to ISS. In 2016 CRS phase 2 contracts were awarded to SpaceX, Orbital ATK, joined by Sierra Nevada with their Dream Chaser lifting-body spaceplane. Similar approaches are now being used for the Commercial Crew programme and some aspects of the Artemis lunar programme.

NASA's Aerospace Safety Advisory Panel considers the COTS programme "extremely successful" and says "we would encourage NASA (and other Government agencies) to consider adopting similar approaches where possible."

This approach using public procurement as an anchor customer for 'market creation' is one that can be effective for upstream and downstream services, and forms part of the basis of our Recommendation 6.

Constellations

The combination of reduced satellite and launch costs enable space agencies or businesses to operate not just one satellite, but a constellation of several, or even thousands. At the lower end, Earth Observation operator ICEYE currently has 14 SAR satellites in orbit. At the upper, SpaceX has over 2000 satellites in orbit (March 2022) – a number that could grow as high as 42,000 if the company's regulatory filings are fully utilised.

Constellations change satellite manufacture from an individually crafted item to a (still high precision and high cost) production, almost mass production item. Multiple copies enable economies of scale, satellite manufacture often involves procuring a spare of everything so even going from 1 to 4 has enormous savings. OneWeb's factory can produce 2 satellites per day at far lower costs than 'traditional' satellite manufacture[53].

Constellations, particularly LEO constellations, also have planned lifecycles to replace each satellite every 3-7 years. This creates the need for ongoing production, but makes it possible to build iterations and improvements into satellite design.

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[52] https://www.nasa.gov/content/cots-final-report 2014

[53] https://oneweb.net/factory

This has other implications for how the supply chain is managed. With a regular flow, not just a one-off purchase, inventory and timing become an issue – there is not enough space for all the parts to arrive at once. Satellite production becomes more like other forms of mass production than individual high-precision objects.

Future Communications

Communications is a vital satellite application area. We discuss in section 7.4 the implications of the emergence of LEO constellations for the UK's GEO focused satcoms sector, and the ground segment in section 7.10. Here we cover trends application-driven trends. The Satellite Applications Catapult ran a supply chain workshop on Future Communications, including members of the UKSpace Satellite Telecommunications Committee. This reviewed potential opportunities and chose three for further discussion: land mobility, security & defence, and 'the other four billion' people in low-income areas.

These areas shared four common themes: that satellite communication had a lot to offer; that it would require public sector (usually regulatory) action as well as technology action, and that satellite technology needed to be working in connection with terrestrial mobile phone technologies, and (in the first and third) that affordability is important. There is a big market, so encouraging UK businesses with promising technologies, even in early stages, should be considered.

For land mobility, opportunities were seen everywhere in enabling Connected and Autonomous Vehicles and in taxing them through Road Pricing, and also in providing the greener alternative through Mobility-as-a-Service apps. UAVs or drones were also discussed as an alternative to road freight. These applications all require enabling regulation both for the services and the communications. To make the services viable they will require a combination of 4G/5G mobile (for capacity) and satellite (for coverage and resilience). And bringing the costs down will require innovation for low costs in flat-panel antennas, integrated circuits and business models.

In security and defence, where governments are the main customers, satellites provide secure communications as well as resilience, in combination with mobile networks. Development of encryption and secure technologies was seen as key, this included encryption that was secure to quantum computing attacks, and quantum encryption (e.g. for key distribution). Optical links were noted as valuable to improving security. Satellites would also become more 'software defined', both in terms of their beam patterns and their on-board networking features.

Satellites were seen as a way to reach the 'other four billion' people on the planet, not living in medium or high-income areas. Technology starts with cellular network backhaul (already happening today) and may develop to direct satellite to mobile communication, to be viable for this group it must be affordable. Regulation is important to ensure that low income countries get access to scarce spectrum resources, but constellations could be an advantage as they will have spare capacity available when they fly over these countries.

Several other markets noted, but not discussed in detail, have strong market potential for satellite communication services and user equipment: Satellite-to-aircraft links, UAVs, maritime, health, and enterprise, consumer and public sector connectivity applications. There are key emerging technologies including flat panel antennas – which enable tracking of multiple satellites without physical movements, optical communications – which enable very high data rates, and inter-satellite links - important for some satellite constellations and in-orbit operations (optical communication is effective here). The UK has proven expertise in all these areas and businesses that could grow to be global leaders.

Geospatial Applications

There is growing use of applications based on Earth Observation (EO) and Position, Navigation and Timing (PNT) in many sectors and these comprise over 80% of the 'enabling benefits' of satellite services on the wider economy (see Section 5.6).

New applications are being developed all the time in many sectors[54], often enabled by free data from Copernicus and Landsat EO, and Galileo and GPS PNT satellites. The UK is home to many of those businesses. This trend will continue as more businesses and entrepreneurs spot the potential of satellite data.

Beyond the taxpayer-funded services, customers have seen value in premium services. For Earth Observation, these offer higher resolution (down to 30cm today), higher cadence (several passes a day) and different frequency options (multi-spectral around the optical bands and radar). For PNT the concerns are accuracy and resilience, particularly for defence, security, aviation and maritime applications. We see these trends continuing as more customers, public and private, see how satellite services can improve their services or profits.

Value chains are diversifying. Most large satellite manufacturers offer some form of geospatial application or consulting service (e.g. Airbus, Maxar, the exceptions are new small satellite manufacturers) and some have designed a specifically integrated business model (e.g. Planet, Spire). However, there are many more businesses in the 'downstream only' part of the value chain just using the data to provide solutions to multiple sectors (e.g. Earth-i, Rezatec) or specific sectors (e.g. SatSense, SOYL). There are also platforms and analysis tool providers offering a variety of services (e.g. Google Earth Engine, AWS, Cleos, Astraea, Picterra). This diversity is likely to continue. We expect the wider IT industry to get more involved as adoption widens and they may create their own tools, or acquire existing ones.

This area is very application driven and to develop the supply chain our recommendations focus developing 'pull' from customers by creating markets. In the private sector, this is by demonstrating the potential for value creation to businesses that can be early adopters and drive applications forward,

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[54] Several examples in the Catapult's podcast: https://sa.catapult.org.uk/podcasts/ep-2-earth-observation-artifical-intelligence/

such as IT and engineering consultants (part of Recommendation 4). In the public sector, it is in creating markets though public procurement or regulation (Recommendation 6).

In-Orbit Activity

For many years there have been forecasts of an expansion in in-orbit activity. A key tipping point is a switch from political drivers, funded through national and international space programmes to commercial drivers, funded through markets and customers – even if these customers include the public sector. We appear to be approaching this point for many areas of orbital activity due to an increasing value of space-delivered activity and a reducing cost of delivering it.

The in-orbit activities considered include assembly and servicing of in-orbit structures that make use of the space environment with its solar power, microgravity and position above Earth: orbital data centres, large antennas for satellite-to-mobile telecoms, in-orbit power production, manufacturing, or space tourism.

These structures bring a host of related needs. Even if they are single satellite structures, they will need deployment and servicing, requiring in-orbit operations like those seen at the International Space Station, but at commercially acceptable cost levels.

Some will involve larger structures, and these will require docking and assembly, automated or under remote supervision because human presence is still too expensive.

With large structures in orbit for a long duration, there will need to be an investment in 'Space Environment Management', applied both to themselves and other objects that share their orbits. In Space Environment Management we include:

- Space Situational Awareness (or Space Domain Awareness): To understand what is where, when avoidance manoeuvres are required, and for locating debris to remove.
- End of Life Management: What to do with a satellite at the end of its life
- Active Debris Removal: What to do with inactive objects that may cause a hazard
- Space Weather Readiness: Forecasting and being prepared for appropriate action in adverse solar weather conditions

Two recent studies examined In-Orbit Servicing and Manufacturing (IOSM) and Space-Based Solar Power (SBSP) in more detail, including their capability requirements and current UK capabilities.

In-Orbit Servicing and Manufacturing

A report on In-Orbit Servicing Capability[55] was developed by Astroscale, Fair-space and Satellite Applications Catapult for the UK Space Agency. It 'conservatively predicted' a global IOSM market of

[55] https://sa.catapult.org.uk/news/in-orbit-servicing-capability/

$4.4bn cumulative revenue by 2030, of which about half was 'life extension', of which the UK was capable of capturing about $1bn. Given the market will be phased late in this period, we think this implies perhaps £200-300m UK IOSM service revenue in 2032, with knock-on revenues through the supply chain.

It identified 15 'Key IOSM capabilities', and that "The UK has existing or developing offerings for all key services and capabilities for both IOS and IOSM." The number of capabilities required for a full offer is important to note here:.

Capabilities required for IOSM
• Uncooperative Search & Approach • Client Diagnosis • Advanced Client Examination • Close Proximity Operations (CPO) • Unprepared Servicing • Cooperative Docking • Uncooperative Docking • De-orbiting • Robotic Manipulation • Fine Propulsion • Propulsion for Orbital Transfers • Mission End-to-End Simulation • Ground Segment • SSA (Space Situational Awareness) • Satellite Manufacturing

Figure 6.3: Key IOSM Capabilities, Source: UK In-Orbit Servicing Capability

The IOSM report identified three capabilities that the UK needed to address: Close Proximity Operations, Robotic Manipulation, and Mission End-to-End Simulation. Even so, it considered that "There are at least four UK based companies that could deliver a complex, commercial, IOSM mission, and a supply chain covering both low and high levels of assurance". And while other nations were ahead of the UK on space robotics, no-one yet had a 'usable product' for IOSM and the UK had a supply chain that could develop to deliver this.

It also noted that:

- The UK's strengths in robotics and simulation in other sectors could be used to assist IOSM development.
- Regulation is a key lever, and the UK has been a regulatory leader in some space and telecommunications sectors to significant advantage.
- Financial services will also be important, and the UK, particularly London is a leader here. (It focuses on investment, but insurance will also be crucial.)

- The industry will progress through international partnerships, and with under half the investment in space of the 6 highest spending nations, IOSM provides an excellent platform for the UK to leverage its capabilities to get engaged in advanced programmes.

It recommends two sets of actions to develop the UK's capabilities:

1. A portfolio of missions, starting with two:
   - A multi-target Active Debris Removal mission
   - Development of a 'Space Bench' in-space IOSM testbed platform
2. Parallel enabling actions:
   - A long-run plan for IOSM and the in-orbit economy
   - Regulatory leadership
   - Demand-side innovation – developing the demand and commercial opportunities
   - Unlocking UK finance and investment
   - International partnerships
   - Engage adjacent sectors, including robotics, energy, manufacturing, motorsport

The Satellite Applications Catapult ran a supply chain workshop on In-Orbit Service and Manufacturing, which included many members of the UKSpace IOSM Committee. The group noted the importance of regulation and international partnerships in establishing IOSM markets and capability. Initial missions are expected to be government-funded demonstrators, perhaps debris removal followed by servicing missions. Beyond this, operations will be more diverse including satellite repositioning, and in-orbit structure assembly and manufacture. Key technologies are initially manoeuvring and manipulation: control systems, robotics and simulation. Later, for larger structures, new materials, assembly methods and propulsion, become important.

Space Based Solar Power

Frazer-Nash Consultancy undertook a study in 2021[56,57] for the Department for Business, Energy and Industrial Strategy (BEIS) exploring the technical and economic feasibility of Space Based Solar Power (SBSP), which could help the UK achieve Net Zero emissions by 2050.

This report concluded that space solar power is technically feasible, affordable, and could both bring substantial economic benefits for the UK, and support Net Zero pathways. To be effective the scale must be massive, with an operational 2GW system being 5km by 1.7km and 2000 tonnes in Geosynchronous Earth Orbit, an order of magnitude larger than the ISS.

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56 https://www.gov.uk/government/publications/space-based-solar-power-de-risking-the-pathway-to-net-zero
57 https://www.fnc.co.uk/discover-frazer-nash/news/frazer-nash-report-for-uk-government-shows-feasibility-of-space-solar-power/

The report sets out a four phase development plan to reach an operational system of several stations over 20 years, estimating a £17bn investment requirement, largely borne by the public sector, but with some shared by the private sector in later phases (Figure 6.4).

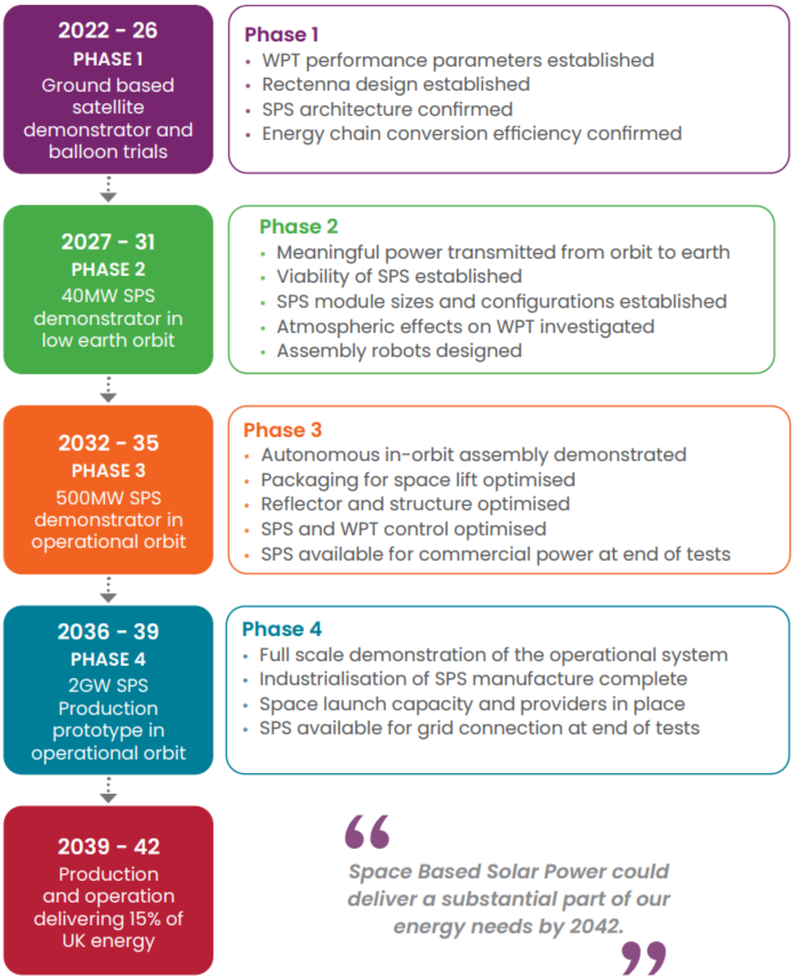

Figure 6.4: Space Based Solar Power development plan (Source: Frazer-Nash Consultancy study)

The report identified the subsystems required and their current Technology Readiness Level (TRL), both in the UK and internationally (Figure 6.5).

Not surprisingly, key parts of the power systems are not current technology: Collect, Convert, Transmit, Receive, Rectenna. Also, the technology to assemble and manage such a large structure in space is lacking, both in the UK and internationally: Structure, Thermal Management, Control System, In-Orbit Assembly, Maintenance and Decommission. Control systems, station-keeping and communication are well understood for GEO communications satellites, but not for giant structures in high Earth orbit transmitting 2-3GW in the GHz radio bands. Spacelift is rated high TRL of 8 internationally (presumably because the technical problem is solved), but 3 for the UK. The report notes that affordable (and hence reusable) launch systems are essential.

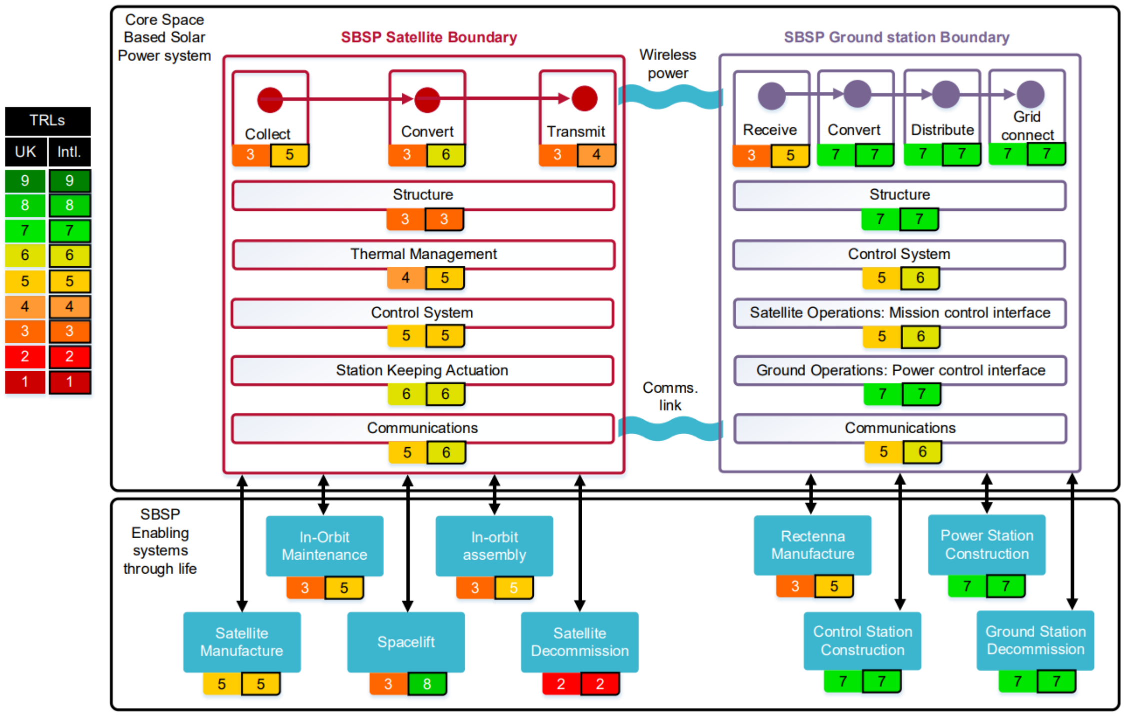

Figure 6.5: Space Based Solar Power current TRLs (Source: Frazer-Nash Consultancy study)

Key technologies mentioned as risks are: in-orbit robotic assembly, lightweight panels, wireless power transmission, accurate beam pointing, and the size, scale and operational life of the satellite. Risks in several other categories are also identified.

There are recommendations in five areas, which broadly align to the IOSM report.

- **Policy and Strategy:** Integrating Space Based Solar Power in UK energy strategy, policy and models, and in space and innovation strategy.
- **UK Research and Development**: Begin design studies, technology development and examine the wider considerations.
- **Energy Market Engagement:** Engage with energy generators and distributors, and maintain a watch on other options.
- **Space Transportation:** Conduct regular analysis of space lift options, establish a strategy for heavy lift capability and explore the business case for the UK's SABRE technology as part of the solution.
- **International Collaboration:** Profile SBSP at COP26 and initiate international discussions about collaborative development.

A workshop organised in March 2022 by the Satellite Applications Catapult, including members of the Space Energy Initiative[58], agreed with many of the findings of this report. It considered the space-side challenges to materials, assembly and resilience to be the largest – it is highly linked to IOSM. On the ground, the largest challenges were thought to be non-technical: establishing sufficient credibility to

[58] https://spaceenergyinitiative.org.uk/

raise investment for the production units (which would be facilitated by orbital demonstrators) and siting for the ground receivers – reflecting on issues with land and sea based windfarms.

The ten-year timeframe of this report, to 2032, might see a technology demonstrator in LEO, which would open possibilities, but not in itself be a great driver for the supply chain. The true potential for SBSP comes if this is successful and there is an industrial scale up in the 2040s and beyond.

Commercial Destinations in Space

As a guide to future development and opportunities in the supply chain, in the USA, NASA is planning for 'Commercially owned and operated LEO Destinations' (CLDs), or commercial space stations, to be the next stage for human operations in Earth orbit following on from the International Space Station.

NASA intends to be an 'anchor customer' for these space stations, buying access for astronauts and experiments alongside commercial customers. Just like the transition from directly specified launch vehicles to the Commercial Orbital Transportation Services (COTS) and Commercial Resupply Services (CRS) missions that delivered the SpaceX Falcon 9, and Northop Grumman (formerly Orbital Sciences) Antares, they expect a great cost saving, enabling NASA to focus funding and concentration on Artemis and future exploration missions. Like COTS and CRS, they are using the approach of specifying their functional and volume requirements to give confidence to suppliers that the market exists for their high-investment products. (Although at the current stage development costs are also being paid by NASA).

Table 1: Key Quantifications Used in NASA's LEO Forecast for Intended Purchase of Future Services

Category	Quantification
Crew Accommodation and Training	Minimum two NASA crew for six month stays
Human Research	Ongoing LEO research focused on exploration mission analogs; private crew available as additional test subjects; ability to conduct long-duration (> one year) missions
Physical and Biological Research	At current NASA research level of ~20 investigations/year
Technology Demonstration	Ongoing testbeds for NASA's life support, exercise equipment, medical equipment, plant growth facilities, quantum communications, in-space manufacturing, robotics, and autonomous systems
Science	External sites occupied by NASA instruments
National Laboratory	~110 projects/year

Figure 6.6: NASA's quantification of future demand for LEO services (more detail in document)[59]

To date, they have awarded three design contracts[60], to teams led by:

- Blue Origin and Sierra Space for $130m: Their 'Orbital Reef' is human-centred and designed as a "mixed-use space business park" for US and international visitors.
- Nanoracks LLC for $160m: "Starlab" would be launched on a single flight as a continuously crewed research station.

[59] https://www.nasa.gov/sites/default/files/atoms/files/forecasting_future_nasa_demand_in_low-earth_orbit_revision_two_-_quantifying_demand.pdf
[60] https://www.nasa.gov/press-release/nasa-selects-companies-to-develop-commercial-destinations-in-space

- Northrop Grumman for $125.6m: A modular design building on Cygnus and expanding to support science, tourism, and industrial research.

In addition, Axiom Space has a contract for modules to be attached to the ISS, and later detached to form a separate station, and Bigelow Aerospace already has an inflatable module attached to the ISS under a $18m NASA contract[61].

Figure 6.7: NASA's plan for Economic Development in LEO[62]

These facilities are targeted to be operating by 'the late 2020s', in advance of ISS decommissioning in 2030, so that there will be a continuation of human activity in space. This is a significantly earlier timeline for large scale orbital operations than space-based solar power.

Supply Chain Implications

The low-cost approaches of CubeSats, Minisats and commercial launch have proven themselves and we can expect them to embed themselves further in the industry, gradually pushing out more expensive approaches.

The emerging sectors will require capabilities in the space sector that are different in scope and scale. In-orbit servicing or debris removal requires the supply chain to deliver more complex operations and coordination, both on the ground and in space. Assembly of large structures for manufacturing or tourism would be possible today, but needs innovation to make the costs viable. Solar power requires a completely different order of magnitude, with very large structures and the ability to manage them -

[61] https://newspaceglobal.com/nasa-confirms-178m-contract-bigelow-aerospace/
[62] https://www.nasa.gov/leo-economy/vision-for-low-earth-orbit-economy

perhaps new materials and construction techniques will be involved. Businesses with large financial resources and management capability as well as technical skill will be necessary to deliver these, and it is here that the size of the space economy will really start to multiply.

Structures will be assembled in space and companies will want this to be quick, automated and risk-free rather than a complex astronaut tended process (International Space Station) or a tense multi-dependency deployment (James Webb Space Telescope multiplied by ten or a hundred). This is an opportunity where the UK does have a lot to offer in clever design or mechanisms (e.g. Oxford Space Systems) and robotics and automation in extreme environments (e.g. RACE at Culham).

These structures will need lifting into space, requiring larger launch vehicles (not currently a UK capability) or frequent affordable launches. The UK already has opportunities for components and for small launches that will be viable when customers want rapid response or specific orbits. The large structures required by space-based solar power provide the size of opportunity that may make a launcher based on Reaction Engines' SABRE technology, such as their Skylon concept, viable.

The number and size of structures in space will require management of the space environment, and development of a sustainable approach to space. The markets to enable this are not yet established, and will require international regulation. The upside will be the creation of new opportunities and industries. The downside of inaction will be another 'tragedy of the commons' as businesses and states essentially take their chances on loading more assets into space until it becomes too many.

The supply chain that delivers these technologies will be a descendant of today's launch and spacecraft segments, but we should expect some disruptions of the magnitude of the CubeSat, Falcon 9 and 'mega-constellation' disruptions. Some of today's businesses will prosper and grow, others will not, and new ones will arise.

Predicting the Future

We considered whether it was possible to develop a timeline for space developments over the next 2 to 10 years, and decided against it. The space sector is littered with shattered timelines, and there is a reason for this. A new space application typically needs many parts of an ecosystem to develop before it can emerge as a success: satellite technology, communications, ground station infrastructure, end-user equipment, the actual end-user market ready to buy, and investors confident enough to invest at seed, scale-up and mass market stages. If any of this is delayed, the whole timeline is delayed or may fail completely.

Satellite broadband provides an excellent example. Teledesic started in 1994 and gained funding from Bill Gates and cellular entrepreneur Craig McCaw for a constellation of 840 LEO satellites. Only one demonstrator was launched before the project folded into bankruptcy. But now, 28 years later, Now, OneWeb and Starlink are on the cusp of delivering the broadband from LEO that was promised.

Sub-orbital space tourism provides another example. With the successful flight of SpaceShipOne, Virgin Galactic was founded in 2004. In 2008, Richard Branson predicted the first space flight would be within 18 months. In practice, it was 2018, and then a series of further problems delayed the first passenger flight until 2021; 13 years after Branson's forecast.

However, it is possible to say that 'large-scale' applications can take ten years or more to mature, and so such technologies that are ideas or early stage today will not be in commercial use in ten years' time. It is conceivable that a major effort could accelerate this, but we think this applies to technologies like Skylon, space-based solar power (Fraser-Nash suggest 2036 for a production prototype), nuclear power for space (which Rolls-Royce are developing both for on-board energy and propulsion), and a Thales proposal for beamed energy launch.

The small satellite revolution means that this timescale no longer applies to applications that can be delivered on a 10kg or 100kg satellite. There, things can move much faster, with missions possible to deliver in under a year.

6.3 The Future Supply Chain

The UK Space Sector has been targeting around £40bn of revenue by 2030 – based on an ambitious vision of capturing 10% of the global space economy. Drawing on our examination of the market trends and drivers, we have constructed some future scenarios to help understand the likely shape of future supply chains and investigate how industry growth could become self-reinforcing.

The Outlook for Sector Growth

Our core scenario is based on industry reports which individually forecast growth in different market segments. For segments where such forecast reports are not available, growth is assumed to maintain the impressive 7.0% CAGR that the industry has witnessed over the last 20 years. The one exception is Direct-to-Home broadcasting (currently the largest segment by far) where delivery of digital content is increasingly coming under pressure from terrestrial broadband and where turnover is anticipated to decline. Together, these assumptions drive an overall industry with a turnover of nearly £28bn in 2032 compared to £16.4bn today[63]. The evidence we have reviewed suggests that emerging segments (e.g. IOSM, space tourism, space solar power) will remain small relative to the large existing segments (e.g. satellite operations and satcoms) by the early 2030s. In our core scenario, satellite operations, user equipment sales and satellite applications all grow into £3.5-4.5bn market segments and overtake a declining DTH broadcasting segment. Overall space revenue growth is 3.8% per annum (or 7.5% if DTH broadcasting is excluded).

[63] All expressed in 2019 prices

Achieving a £40bn domestic market requires sustained high growth across all fronts, with the UK greatly surpassing a 10% global market share in rapidly expanding new markets in order to compensate for areas where a 10% global share is not plausible (e.g. heavy lift launch) or where the market is unlikely to achieve high growth (e.g. DTH broadcasting). This 'target matching' scenario by 2032 is compatible with the emergence of a new, large UK prime, a shift of OneWeb satellite production to the UK, deepening UK supply chain linkages (i.e. reduced dependence on imports), and rapid development of downstream SMEs into global champions. To achieve this, the sector needs to achieve compound growth of 6.6% until 2032 (and 9.7% outside the DTH broadcasting segment, which is assumed as static). This level of growth will not be achieved on the current trajectory and it is likely that significant stimulus will be required.

Which Segments are Driving Demand in the Space Supply Chain?

In the core scenario, as overall industry revenues swell from £16.4bn to £27.7bn by 2032, the £8.2bn of industry growth will provide market opportunities for domestic suppliers. Figure 6.8 shows anticipated industry growth.

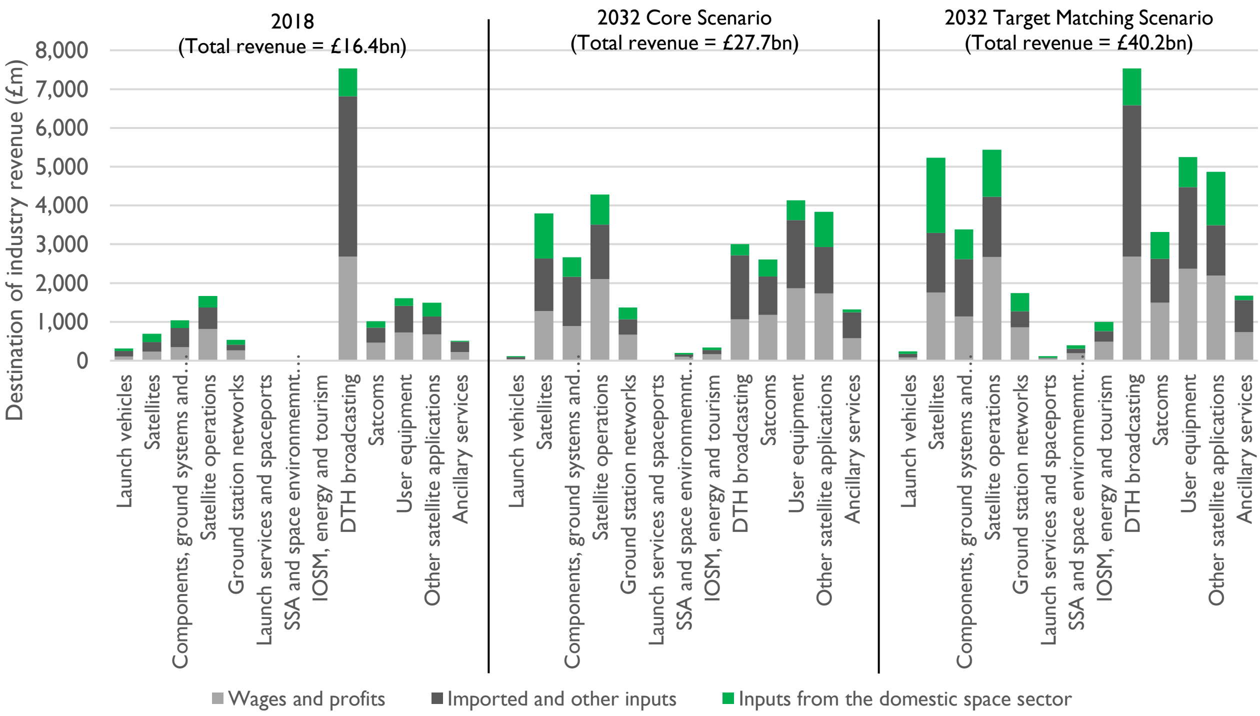

Figure 6.8: Market growth and opportunities for the domestic space supply chain

Overall, the space sector grows rapidly in both scenarios, and a change in its structure is clearly apparent as DTH broadcasting makes up a smaller part of the market as other segments expand, resulting in a far more even balance between upstream and downstream. The largest drivers of sector growth by revenue in the core scenario are satellite manufacture, satellite operations, user equipment and other satellite applications which all grow by well over £2bn by 2032. These are followed by a second tier of activities including components, ground systems and support and satcoms which grow by around £1.5bn. Growth in other segments is anticipated to be relatively small – especially emerging segments such as space environment management, IOSM, energy and tourism which, while expected to grow rapidly, are still likely to make up a small part of the overall sector by the early 2030s.

Despite different underlying assumptions, the 'target matching' scenario shows a similar structure of supply chain growth drivers and opportunities – with the excep tion that DTH broadcasting holds steady and so does not act as a brake on demand. In revenue terms, emerging sectors such as IOSM, energy, and space tourism are likely to remain fringe drivers of demand in the sector even if they hit optimistic forecasts for their growth.

Other sectors on the fringes of the space sector are also likely to see substantial growth opportunities – although not included in this analysis. Downstream activities (particularly other satellite applications) will make increasing demands of sectors such as computing and IT as they build their businesses. Critically, this analysis only captures the cost flows through supply chains and does not also capture enabling impacts in other sectors that use space services such as transport (e.g. through connected and autonomous vehicles), agriculture, health, etc.

An Interdependent Supply Chain

While the height of the stacks in Figure 6.8 shows projected overall revenues of the different segments, the green parts show the share of sector revenue that is spent with UK space suppliers – highlighting the interdependencies between different market segments.

The chart below (Figure 6.9) focuses on these effects showing the induced impacts from direct growth in each segment in our core scenario. The largest is from a rapidly growing 'Other satellite applications' segment (£1.5bn in 2018 to £3.8bn in 2032), which is anticipated drive over £600m of additional business with suppliers in diversified activity across the sector. This includes a significant ramp up in ancillary services demand of £230m (shown as the red part of the penultimate stack). The 'other satellite applications' segment also drives growth in demand for ground stations, operations and upstream manufacturing amongst others.

Likewise, growth in satellite manufacturing drives supply chain demand in the components sector while satellite operations growth drives demand from the upstream satellite manufacturing sector and to a lesser extent from the components sector. The anticipated decline in DTH broadcasting has an effect across the supply chain as it reduces expenditure on operations and GEO satellites with potential knock-on impacts on other segments such as components. The large and growing satcoms sector is anticipated to boost supply chain demand, but to a smaller extent than satellite manufacture or operations. While Ancillary services grows, it has very little induced impacts because most of its inputs come from outside the space industry.

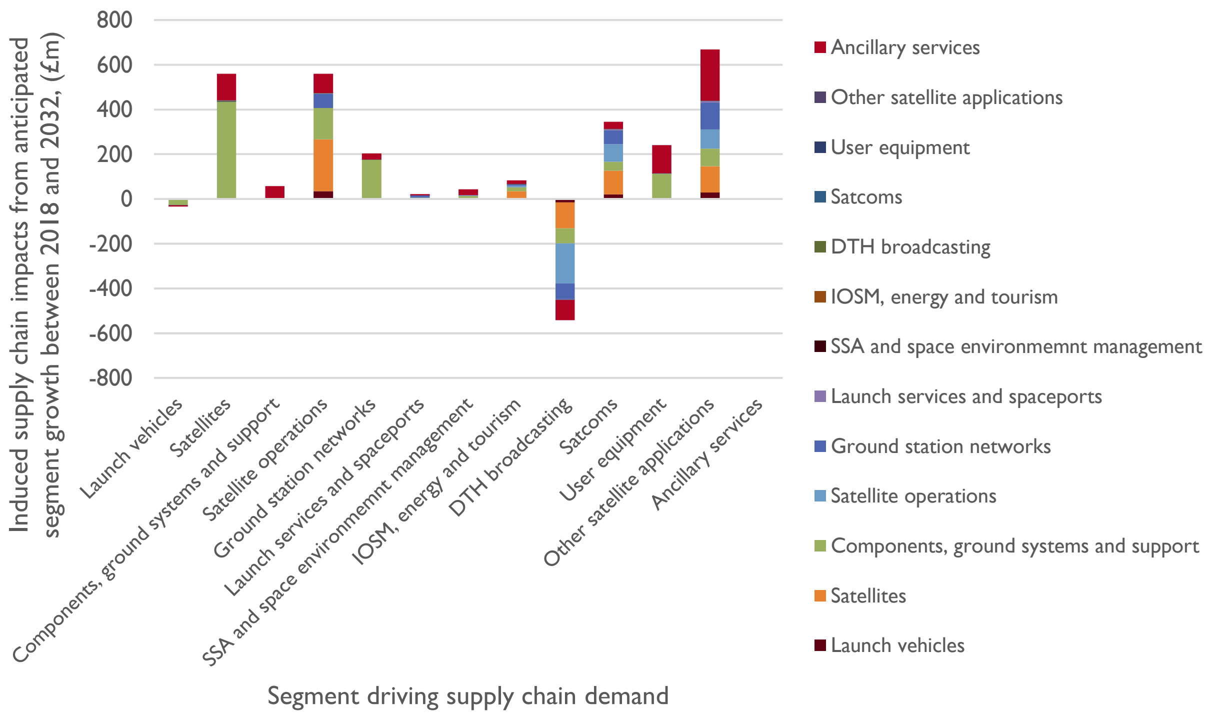

Figure 6.9: Supply chain demand driven by growth of satellite manufacturing and other applications, but held back by decline in DTH broadcasting

The total induced supply chain impact in the chart is £2.2bn, about 20% of anticipated growth in the core scenario. This means that external demand growth accounts for most of growth in demand for UK space businesses, rather than being driven internally by other growing parts of the domestic space sector, assuming supply relationships in the future look similar to today[64]. The opportunity to 'piggy-back' as suppliers off growth of UK space companies is much larger if UK firms can win a larger slice of the supply chain pie from foreign rivals – an additional 10% of space goods & services bought from UK suppliers by 2032 would add a further £1.1bn income to the UK industry.

Key Implications of Industry Growth for the Supply Chain

The forward-looking quantitative analysis points to some key conclusions about future supply chains:

- There is uncertainty about how the industry will develop, particularly regarding timelines. These are reflected in concrete terms through major upcoming commercial decisions (such as the wider supply chain for Skynet 6 and OneWeb), future competition between GEO and LEO satcoms, and the development of unicorn satellite application companies.
- In the long term (over 10 years) emerging segments could become established as significant revenue earners, but they will not make large demands on the supply chain in the medium term.
- Meeting a target of 10% of the global space market will take a huge effort and sustained growth across many fronts.

[64] The £2.2 billion of induced or interdependent demand is somewhat conservative because it excludes the impact of growing market segments driving revenue growth of suppliers within that same segment (such as satellite operations companies subcontracting other companies in the satellite operations segment).

7. Strategic Issues

In this section we consider number of strategic issues that affect the UK Space Supply Chain.

7.1 UK Ownership and Control of Space Capabilities

Space is exploited by firms, organisations, and countries around the world to achieve a wide range of goals – primarily economic and security related. In this section we explore the strengths and weaknesses of developing capabilities in the UK and the implications for achieving the National Space Strategy.

Economic Goals

Growing the domestic space sector will provide jobs in the UK, stimulate growth in skills, develop national industrial capability, and contribute to wider industrial policy (including levelling up), R&D, innovation and domestic tax income. UK jobs come from UK domestic operations of firms, regardless of their ultimate national ownership or registration.

The exceptional skill intensity of the space sector means that almost all space sector activities will support growth in UK skills and high value jobs, although their specific location within the UK will be important for meeting regional development goals. Some skills are also provided from abroad through high-skilled migration. While this means that wages flow to foreign born workers, it can also accelerate industry growth and the catalytic and supply chain benefits that flow from this. Following Brexit, the UK needs to be careful not to curtail these benefits by threatening skilled migration. The 2021 Space Census showed that foreign nationals in the space sector are three times more likely to be changing jobs because of immigration issues, such as Brexit, and the Space Skills Survey found that "Brexit has made it more difficult to recruit from Europe and has encouraged some European staff to return to their original countries."

Leveraging international best practice is a tried and tested way to bolster domestic industrial capabilities and boost productivity. A wide literature supports this but recent findings for the Office for National Statistics (ONS)[65] are worth particular consideration. ONS allocate a 'trader status' according to whether firms are intensive importers, intensive exporters, or both, and find "a strong, consistent, positive link between labour productivity and … trader status", and that "businesses which export are around 21% more productive than businesses which do not, while businesses which import are around 20% more productive, after controlling for an array of their characteristics".

The profits of companies flow to their owners, some of which may be in the UK and contribute an economic benefit to the UK. For large companies the owners are almost always shareholders (mostly

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[65] UK trade in goods and productivity: new findings, ONS, 2018 https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/articles/uktradeingoodsandproductivitynewfindings/2018-07-06

pension funds and other large institutional shareholders) which are widely distributed around the world, although some of the large European primes are part owned by national governments (e.g. Thales is 26% owned by the French government, Leonardo is 30% owned by the Italian government). To some extent ITAR and other rules controlling trade in technology limit who can be a shareholder of space companies, but in general, profits quickly get distributed around the world.

Impacts on R&D, innovation, and domestic tax income are more complex and may be influenced by whether companies are nationally owned and registered or not. While companies own IP rather than countries, there are often fears that foreign acquisition of firms with specific IP or capabilities may lead to that capability being appropriated by a foreign owner. To a large degree this depends on how foreign companies manage their UK acquisitions. Some are undoubtedly asset strippers or may declare profits in different jurisdictions in ways that reduce UK tax income. They may also change how they distribute their functions around the world – for example by shifting R&D or manufacturing activity out of the UK. Softbank's takeover of ARM in 2016 did not result in asset stripping or a shift in functions. Indeed, it is a good example of a company driven by excellence in research-led advanced technology, based in Cambridge where the economic value proposition would be difficult to relocate. ARM makes its money from licencing its technology, so manufacturing of chips themselves was never a part of their UK operations. However, once a UK registered company has been sold, the UK government loses much of its future influence on the company – for example through public interest tests for future acquisitions.

Many, but not all, of the incentives for foreign owners are the same as for UK owners of companies – they seek profits and manage companies and subsidiaries to achieve this. The UK excels in, for example, basic research, engineering design and professional services, so foreign and domestic owners alike will find benefits of locating these activities within the UK where they benefit from rich supply chains, innovation networks and an entrepreneurial environment. The economic literature is beginning to show the economic benefits of specialisation in different functions[66] – with relatively richer countries specialising strongly in R&D (and less strongly in marketing and management), and poorer countries specialising in fabrication/assembly.

Another critical issue is the security of an industrial capability and its supply chain. Best practice is to know where all the elements of your supply chain are and have processes for reviewing the impact of supply chain shocks such as national policy changes or disruption events (weather, war, natural disaster, etc.). The invasion of Ukraine has recently spotlighted this with disruption of supplies from Russian companies (e.g. supplying Soyuz to OneWeb) and Ukrainian ones (e.g. Skyrora which has elements of production in Ukraine). The physical location of production activities affects the security of supply chain connections. Suppliers that are closer, in more stable jurisdictions and subject to more well respected legal systems are more secure and less likely to be disrupted. Ownership and registration can also be

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[66] Marcel P Timmer, Sébastien Miroudot, Gaaitzen J de Vries, Functional specialisation in trade, Journal of Economic Geography, Volume 19, Issue 1, January 2019, Pages 1–30 https://doi.org/10.1093/jeg/lby056

important features affecting trade restrictions and applicable law. Companies follow the laws of the country in which they are registered, and are also subject to certain laws in countries where their shares are listed – although these primarily relate to financial reporting and disclosure. For example, Airbus SE is listed in the Netherlands as a European company with shares traded on stock exchanges of France, Germany and Spain. It, therefore, primarily follows Netherlands law, but has some other commitments under French, German and Spanish law. The shareholding is widely distributed around the world with many shares held by US institutional investors. The UK subsidiary, Airbus DS UK is registered in England and follows English law.

National Security and Critical National Infrastructure

Space is one of 13 national infrastructure sectors. The Centre for the Protection of National Infrastructure define Critical National Infrastructure as:

"Those critical elements of infrastructure (namely assets, facilities, systems, networks, or processes and the essential workers that operate and facilitate them), the loss or compromise of which could result in:

a) Major detrimental impact on the availability, integrity, or delivery of essential services – including those services whose integrity, if compromised, could result in significant loss of life or casualties – taking into account significant economic or social impacts; and/or

b) Significant impact on national security, national defence, or the functioning of the state."

The list is naturally confidential and includes a description of critical capabilities and the connections between them. Defence assets (such as Skynet satellites and ground stations) are likely among the capabilities designated. As space derived services – such as satcoms and PNT services – become essential components of modern military and security systems, sovereign capabilities in these areas become more important. However, this also is a complex area where sovereignty is measured on a sliding scale. Satcoms services, for example may be procured jointly with allies, with sharing agreements whereby different national capabilities can be combined into more capable shared capabilities. For example, the UK borrows much of its space surveillance capability from the US 'Space Fence' system. It is conceivable that, at least in some circumstances, this capability could be withdrawn – and the UK is not at liberty to share the information from this collaboration more widely.

A domestic space situational awareness capability, for example, would enable the UK to monitor compliance of satellite operators with their obligations, provide surety for UK based launches (a collision on launch assessment is required for launches), etc.[67].

Security concerns are paramount in defence technology and are mediated by trade restrictions. In the UK, for example, the Export Control Act controls trade in 'dual-use items' (which can have military or civilian uses). In some cases, there may be risk of 'strategic control'. Huawei, for example, are deemed

[67] Towards a UK Space Surveillance Policy https://www.kcl.ac.uk/dsd/assets/towards-a-uk-space-surveillance-policy-final.pdf

as high risk with new equipment banned and existing equipment to be removed from UK 5G telecommunication networks by 2027.

Overall view of UK Ownership

In summary, jobs and wage income will be boosted by any domestic space activity regardless of foreign or domestic ownership or registration. However, foreign ownership may mean that company taxes are paid abroad. The actual shift of functions and skills is more complex, and the best way to keep these in the UK is a strong skills base and attractive business environment.

Security of supply is important and multidimensional. It is influenced by the physical location of corporate activity, the nation of registration and the structure of ownership. Strategic concerns over sovereign capabilities in space are growing as space derived services play a larger role in military capabilities.

7.2 Upstream: Satellite Integration

The ability to integrate or finalise the assembly of satellites and their key systems is a key role in the space supply chain, as the companies who can do this often act as prime contractors or otherwise set the standards for the rest of the supply chain. The UK has important strengths and weaknesses here.

The UK is the only large European country that has only one large satellite and space systems integrator (Figure 7.1), based on procurement data for ESA programmes.

UK	France	Germany	Italy	Spain
• Airbus DS	• Thales Alenia Space • Ariane Group • Ariane Space[68] • Airbus DS • CNES*	• Airbus DS • Ariane Group • OHB • DLR*	• Thales Alenia Space • Avio • Leonardo	• Airbus DS • GMV

Figure 7.1: Large satellite or space system integrators for the five largest nations in ESA programmes.
** National space agency with significant delivery role.*

[68] A 74% owned subsidiary of Ariane Group, but listed separately as Ariane Group (formerly Airbus Safran) has space activities outside Ariane Space

For this study, CST reviewed which UK-located companies could integrate satellites and 8 key systems for each size class of satellite:

Satellite Size	Large 500-10,000 kg	Minisat 100-500kg	Microsat 10-100kg	Nanosat / CubeSat 1-10kg
UK Satellite Integrators	• Airbus DS	• SSTL (Airbus) • Thales Alenia Space (not yet demonstrated)	• In-Space (BAE) • NanoAvionics (AST) • Orbital Astronautics	• AAC Clyde Space • Open.Cosmos • Spire (own use) • Orbital Astronautics
Propulsion	• NAMMO • Thales Alenia Space	• NAMMO • Thales Alenia Space • D-Orbit	• NAMMO • D-Orbit	• AAC Clyde Space • Orbital Astronautics
Attitude Determination & Control System	• SSTL	• SSTL • D-Orbit	• AAC Clyde Space • D-Orbit • SSTL • Orbital Astronautics	• AAC Clyde Space • Orbital Astronautics
Comms & Antennas	• Printech • Airbus DS • Teledyne DS	• Printech • Oxford Space Systems (OSS) • AAC Clyde Space • Teledyne • SSTL • SatixFy	• Printech • OSS • AAC Clyde Space • SSTL • Orbital Astronautics • SatixFy	• Printech • OSS • AAC Clyde Space • SSTL • Orbital Astronautics • SatixFy
Payload / Instrumentation	• Airbus DS • Teledyne e2V • Thales Alenia Space • SSTL	• Teledyne e2V • SSTL • Thales Alenia Space	• AAC Clyde Space • SSTL • Orbital Astronautics	• Lacuna • AAC Clyde Space • Craft Prospect • Orbital Astronautics
On-Board Computer	• Airbus (own use only)	• D-Orbit	• D-Orbit • AAC Clyde Space • Orbital Astronautics	• AAC Clyde Space • Orbital Astronautics
Structures	• Airbus (own use only)	• Oxford Space Systems • Magna Parva	• Oxford Space Systems • AAC Clyde Space • Magna Parva • Orbital Astronautics	• Oxford Space Systems • AAC Clyde Space • Magna Parva • Orbital Astronautics
Software	• CGI	• CGI	• CGI	• Bright Ascension
Power	• ABSL/ Enersys	• ABSL/ Enersys • AAC Clyde Space	• ABSL/ Enersys • AAC Clyde Space • Orbital Astronautics	• ABSL/ Enersys • AAC Clyde Space • Orbital Astronautics
Companies in the table above have either demonstrated hardware in-orbit or are fully funded or credibly close to flight qualification. Suppliers below 'sub-system' level, academic and non-commercial organisations are not included.				

Figure 7.2: UK Satellite and system capability (Source: Commercial Space Technologies)

The UK has companies with capability to integrate all common sizes of satellite, and which can provide all the crucial systems. However, Airbus is the only UK supplier with current capability to manufacture and integrate satellites above 115kg[69,70] and supply many of their key subsystems. This has advantages and disadvantages.

Having such a capable player, developed with a single focus, has been successful in getting the UK involved in large commercial and ESA space projects, for example beating Boeing to win the SES 12 contract from the Luxembourg based satellite operator[71], Inmarsat 6, or the Rosalind Franklin Mars Rover.

However, it means that there is a limited competitive field for the procurement of large national space systems, such as the Skynet military communications system.

Airbus DS serves as an access point for smaller suppliers. In 2014, Airbus DS had 400 UK suppliers, and half were SMEs. It is difficult for us to take a full view of Airbus from a suppliers' perspective without a thorough survey, but we can identify some themes from industry sources. There are concerns about the administrative burden, but it is difficult to split out what is Airbus procurement from the necessary requirements of a complex satellite project, or of a client such as ESA. There are concerns about suppliers being contracted for specific services and not having room to innovate, but Airbus has shown that it can bring in innovation through suppliers such as Sylatech with an innovative waveguide combiner/divider network developed under the Artes programme and first flown on Eutelsat 172B, and Oxford Space Systems with their novel deployable antennas.

There are several reasons to wish to improve the UK's satellite integration capability. In the short-term, there is the opportunity to increase the UK content of satellites, and the Minisat market opportunity discussed below. In the long-term, there is the opportunity of the orbital economy. Larger satellites will be needed for data centres, solar power, manufacturing and tourism. These will be much larger than existing satellites, more like a space station, and it will make sense to make the biggest structure that is economic to launch, and then assemble them on orbit.

The Minisat boom provides both a market opportunity and a proving ground for small satellite integrators to develop their capabilities for larger satellites. All categories of small satellites how been growing, but the rise in Minisats has been such that we have had to remove the 1273 satellites launched by Starlink and OneWeb in 2021 from the green 'Minisat' column in Figure 7.3 below to get a sensible scale. Even without this, the Minisat category is still growing.

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[69] NanoAvionics MP42 microsatellite goes up to 115kg (as this is only just over 100kg, we still class it as a Microsat).

[70] This has been the case since Airbus (then EADS) acquired SSTL in 2009. In 2004, SpaceX acquired 10% of SSTL, which could have led to a different industry structure.

[71] Upstream Space, Science and Innovation Audit Report 2018 p71

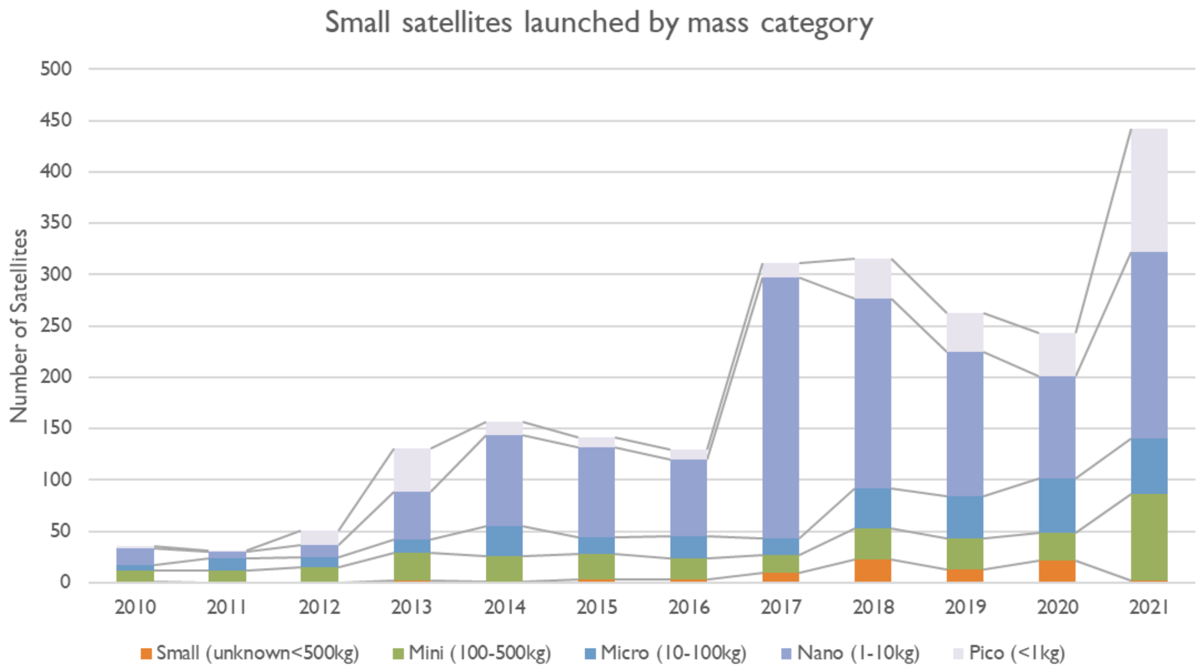

Figure 7.3: The popularity of small satellites, with Starlink and OneWeb removed

Beyond current market success, the future seems positive for Minisats, as a lot of capability can be put in a 200-500kg payload. They are capable of LEO communication, EO and PNT[72] missions. They are a size compatible with planned UK-based small launchers, the SpaceX Smallsat Rideshare programme, and a proliferation of small launchers worldwide, so their continued success seems well supported.

At present, the UK only has Airbus's SSTL integrating satellites in this size range. There would appear an opportunity to encourage growth.

NanoAvionics, a US firm with a UK integration, assembly and test facility in Basingstoke, started with CubeSats and has recently added a Microsat platform of up to 115kg to its portfolio. In 2018, it also received investment from AST SpaceMobile, who took a majority interest. Nearby mission integrator In-Space, also started with a 6U CubeSat and have developed a 100kg platform. In-Space has recently been acquired by BAE Systems, giving it strong financial, distribution and skills backing for extending its range of offers and missions.

Thales Alenia Space have capabilities in several satellite subsystems in their three UK sites and beyond. Although they have not integrated a satellite in the UK to our knowledge, we believe they have the capability to integrate a Micro or Minisat. Lockheed Martin recently also announced their intention to set up satellite manufacture in the North East of England[73] as a complement to their involvement with Launch UK from Scotland.

[72] next-generation Galileo satellites are 640kg
[73] https://investnortheastengland.co.uk/news/lockheed-martin-space-skills-supplier-summit/

With increasing capabilities in the supply chain, it may be possible for Airbus DS to acquire more subsystems from UK-based suppliers. With further development, we can see the valuable addition of a second, maybe a third UK integrator in the Minisat class in the 2020s, ready to step up further as the orbital economy develops.

7.3 Upstream: Scale of Space Companies

The UK space industry is structured differently to its continental equivalents, with more smaller companies (under about 100 employees) and fewer larger businesses with a significant UK space operation. We believe this structure may hold back the UK's growth potential significantly.

This has been discussed anecdotally in many forums, including the UKSpace SME Committee, where it has been noted that the UK's SME Membership is generally smaller SMEs (under 50 or 100 employees), while the continental membership of the pan-European SME4SPACE organisation is generally larger SMEs (50-250 employees). We have been able to confirm these anecdotes with data from three sources.

- Our analysis of UKSCC data, which shows a drop off in the population of businesses above 100 employees or £20m turnover.

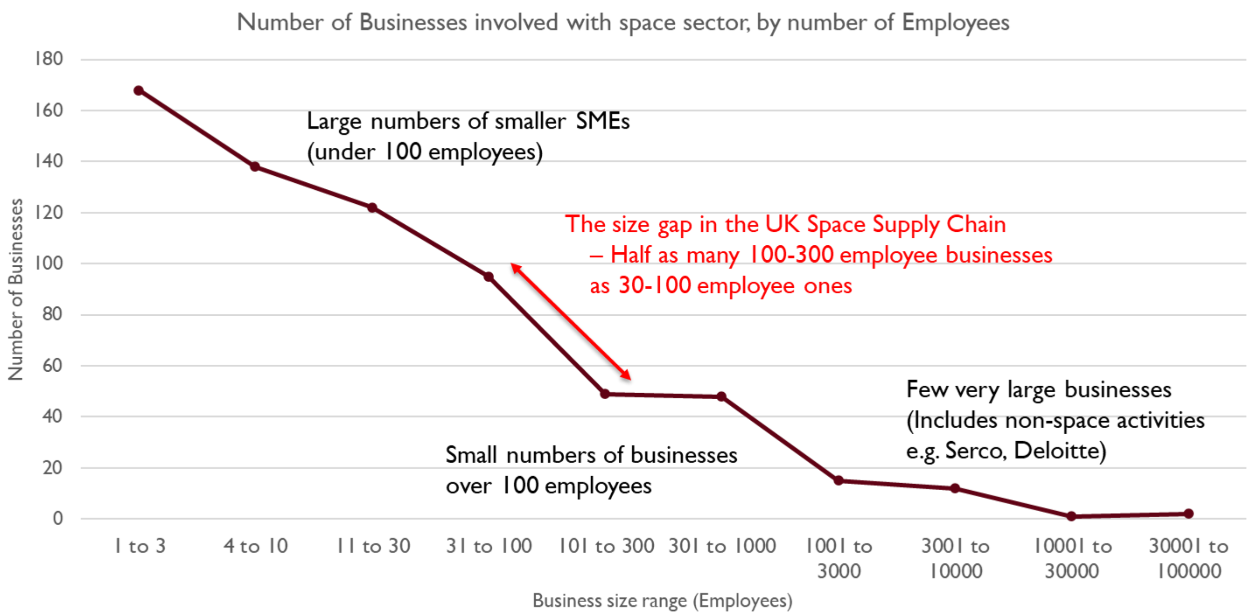

Figure 7.4: The number of UK space businesses drops rapidly above 100 employees, and again above 1000 employees (data from UK Space Capabilities Catalogue)

- Data on ESA programme spending shows that the UK has a unique concentration on a single company within its top ten UK suppliers, with its biggest suppler supplying almost ten times as much as the next company. The UK also has a uniquely high number of SME suppliers to ESA programmes, and double the amount spent with SMEs than the ESA average (15% vs. 7.5%). ESA has noted that the UK's industrial structure might contribute to the UK's low geo-return in ESA programmes compared to nations with a larger number of large suppliers.

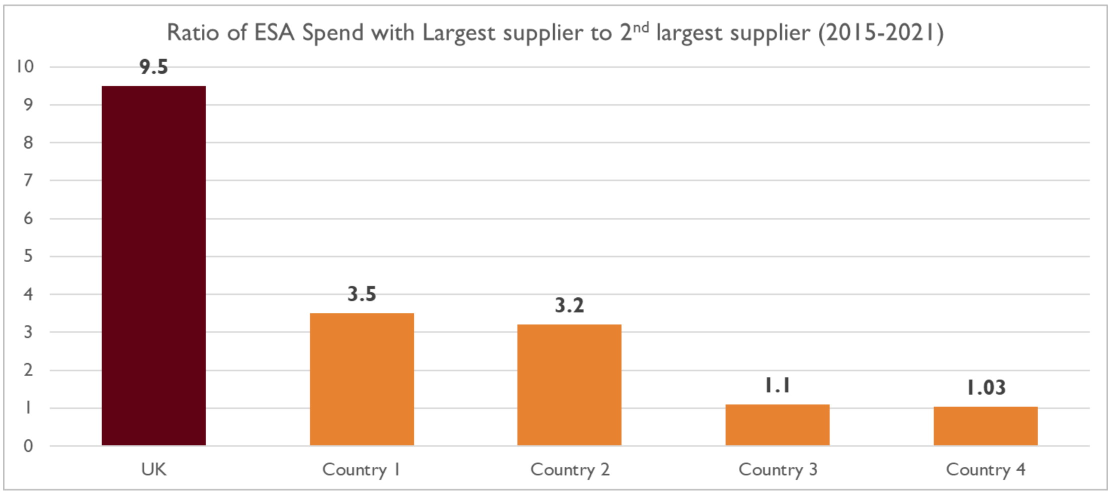

Figure 7.5: Concentration of ESA spending on largest supplier is much higher in the UK than 4 other large ESA countries (data source ESA under limited permission)

- The structure shown in analysis of data from an ASD Eurospace industry survey[74], Figure 7.6 and 7.7, showing that the UK has the highest percentage of SME employees (16%) and far lower percentage in Large companies (11% with 251-10,000 employees) than all but France where Very Large Groups dominate. Almost all of the UK's 'Very Large Group' employment will be at Airbus DS, which employs about 3000 people. Other large groups such as Thales Alenia and Lockheed Martin currently employ small numbers on space in the UK.

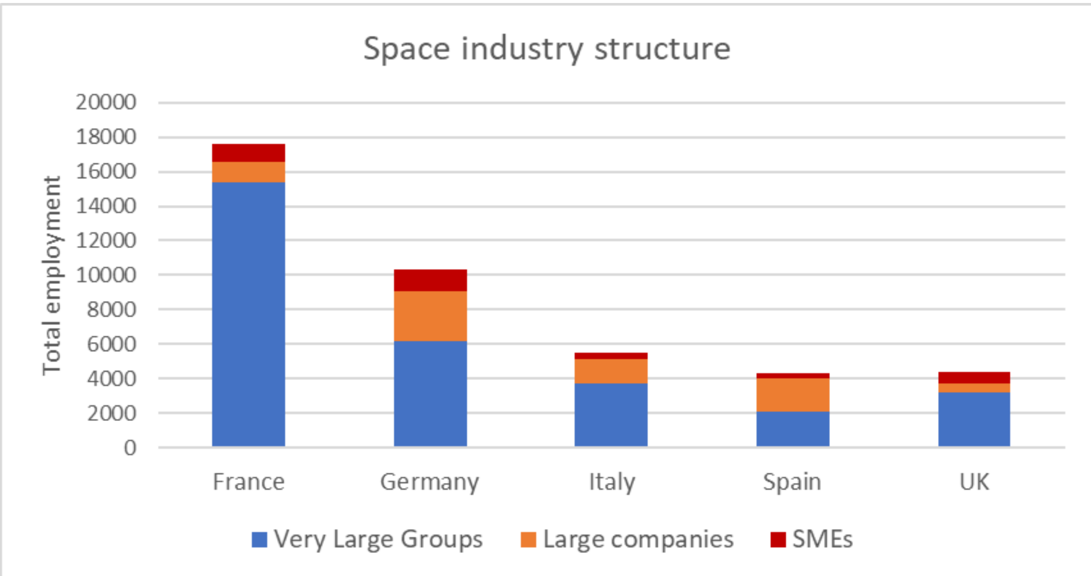

Figure 7.6: Space industry employment in five countries, based on ASD-Eurospace Web Release 2021

As the UK sector grows, the ideal target would be a structure more like Germany's, which has 3 large primes and a strong cohort of domestic suppliers supporting them, large, medium and small, providing a diverse field and resources for innovation.

[74] https://eurospace.org/publication/eurospace-facts-figures/

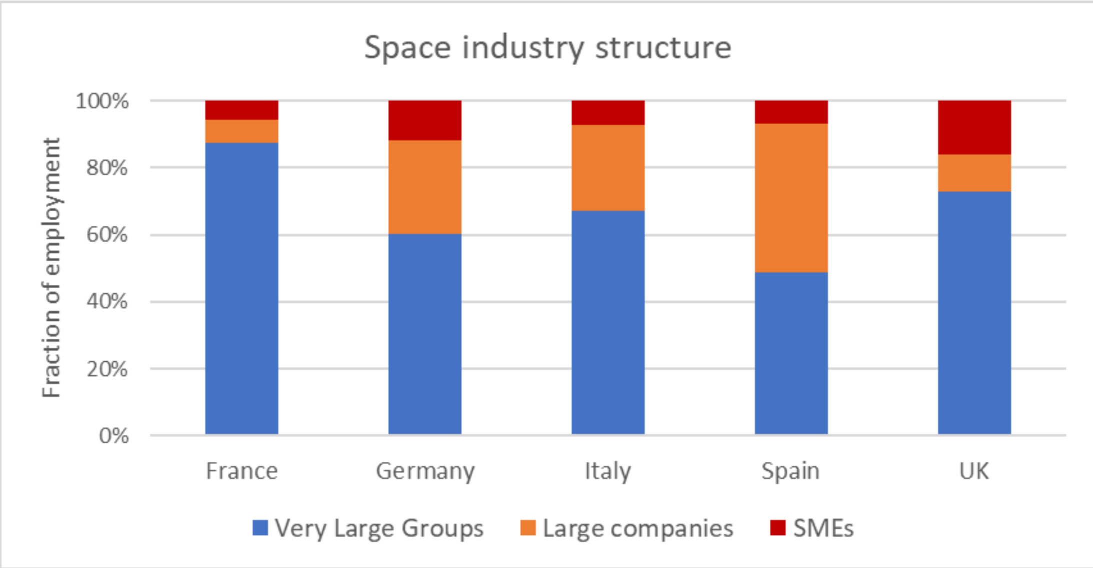

Figure 7.7: Space industry employment structure, based on ASD-Eurospace Web Release 2021

This UK structure makes it difficult for a large 'prime contractor' to assemble a satellite or similar complex programme based on UK subsystems. In practice, the UK's largest upstream satellite integrator, Airbus DS, often develops subsystems for large satellites in-house, either in its UK facilities at Portsmouth, Stevenage, or SSTL Guildford, or in its European facilities at Toulouse or Friedrichshafen.

The structure also makes it difficult for the large number of innovative SMEs to contribute fully to the growth of the UK space sector. An OECD study[75] found that SMEs were key in driving innovation and sustainable growth. In a world of diversifying markets and changing technologies, an SMEs nimbleness can outweigh the disadvantages of smaller size.

The UK Government recognises the value of this innovation and has had a strategy to utilise this innovation for defence and security[76] which noted an aspiration that 25% by value of Government contracts should benefit small businesses, including in supply chains, across the Spending Review. In the year to March 2011, 13.2% by value of MoD contracts were placed directly with SMEs, with more in the supply chain. It would be valuable to track this more fully in the space sector where industry classification data is poor.

However, space projects are often large and complex by nature, and SMEs often do not have the resources to take on such projects. The issues are in complexity and relationships rather than pure 'volume' as in almost all cases production volumes for space are low, and where they are not, manufacturing can be outsourced. Complex projects have high technical requirements and risk, and in a risk averse industry, customers are likely to choose a proven supplier, which tends to favour the status quo. Such complex projects also rely on relationship management, which is resource intensive, and it is the large companies that have the resources to be in constant contact with key customers.

[75] Enhancing the Contributions of SMEs in a Global and Digitalised Economy, OECD 2017
[76] National Security Through Technology, Secretary of State for Defence, February 2012 (para 192-198)

Finally, there can be a great imbalance in size, perhaps a 100 times size differential, between a 'prime contractor' and a SME subcontractor that gives significant market power to the prime.

Figure 7.8: AAC Clyde Space are a great example of what a UK SME can offer, but they are a small-scale business with 73 UK employees in 2020

In many cases, the prime-subcontractor relationship works well. At best, the prime aids the subcontractor through the relationship and makes them feel a trusted and respected part of the team. However, in the worst cases the smaller party can feel like a commodity supplier to be negotiated to the lowest price by a bureaucratic procurement department, or to have their innovation plundered.

There are ways to overcome the structural issue. Over time, SMEs can grow their capabilities, as we have seen NanoAvionics and In-Space extending from 10kg CubeSats to 100kg Microsats. SSTL extended its capabilities from Microsats to the 660kg GIOVE-A launched in 2005 before it was acquired by EADS, now Airbus. Their growth strategy included early adoption of innovative technology (e.g. GPS positioning onboard satellites, N2O and water-based propulsion), international partnerships (co-developing satellites with lower income nations), and leveraging public programmes to develop their capabilities (DMC, GIOVE).

Larger businesses also seed smaller ones. The founders of Clyde Space, In-Space, and KISPE were all ex-SSTL, and there are also supporting links from SSTL to Astroscale, Lacuna Space and others.

Investment can develop UK based capability. BAE Systems has acquired In-Space, regaining a range of space capabilities and with the resources to expand and develop them. In-Space recently added a second UK Defence contract, for Prometheus 2, to its existing Titania contract, and BAE Systems have recruited a senior space strategist from Airbus DS to expand their business. Lockheed Martin[77] and Thales Alenia Space have both expressed their intention to expand their UK space businesses, both aiming to be capable of satellite integration in the near future.

Teledyne UK provides evidence for the value of shifting the scale of business interactions. While Teledyne is a large US-owned group, its UK businesses, such as Teledyne e2v (imaging sensors) and Teledyne Reynolds (connectors) have tended to act independently. They have recently moved to act more as 'one Teledyne', bringing their portfolio of space solutions together and offering to integrate sub-systems across their business units. They can do this because they are a larger group with sufficient financial and people resources to take on the greater project risks. At least one major prime contractor has already responded well to this, as it simplifies procurement and manufacturing. Teledyne are hopeful of doing business with other prime contractors as well, as it offers them more value-added and reward potential.

The procurement of the Orbital Manoeuvring Vehicle for the Lockheed Martin UK launch vehicle demonstrates both a prime that has preferred to select a proven large subsystem supplier in Moog, and that this can also be used to develop UK capability to some extent. Moog is US based, with a small UK outpost near Reading. Moog UK is expanding to include assembly, integration, and test facilities for the SL-OMV, and the programme also involves AAC Clyde Space, ABSL, KISPE and Nammo UK's test facility at Westcott[78].

Business capability can also be accelerated by well-designed technology development projects, which benefit several partners, bringing their technologies to the important 'space proven' level and delivering valuable end-results. An example due for launch in 2022 is 'Joey-Sat', a beam-hopping technology demonstration satellite funded by the UK Space Agency and involving Astroscale, Celestia UK, SatixFy Space Systems and OneWeb.

SatixFy also provides an innovative example of getting around the 'cost of low scale' barrier in the space business. Many things in space are low volume compared to other sectors. Some space manufacturers are now getting around this by using COTS parts, then adapting them or their housing for the environment of space. SatixFy gets volume from ground segment antennas, but supplies the same ASIC designs for satellites, having benefitted from scale.

Large scale investments, such as that possible from BAE Systems, Lockheed Martin and Thales Alenia, innovative approaches that enable suppliers to scale up, and a host of potential growth candidates (e.g. Astroscale, Honeywell, Moog, NanoAvionics, Open Cosmos, Raytheon, Skyrora) have the potential of transforming the structure of the upstream UK space industry to one that is larger and more balanced.

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[77] https://spacenews.com/lockheed-martin-plots-u-k-satellite-manufacturing-base/

[78] Small Launch Orbital Maneuvering Vehicle https://www.moog.com/content/dam/moog/literature/Space_Defense/spaceliterature/white-papers/Moog-Path-to-First-Flight-of-SLOMV.pdf

7.4 Impact of Launch Cost Reductions and Mega-Constellations

We are seeing a dramatic expansion in satellite telecommunications constellations and a dramatic rise in launch capacity, coupled to a fall in launch costs. The two are strongly linked – only the telecoms market is big enough to justify the thousands of satellites and tens of launches per year to sustain a constellation the size of Starlink. This has been enough to bring the price of a Falcon 9 launch under $3000/kg and the costs under half that[79]. SpaceX's Starship offers an order-of-magnitude reduction beyond that.

These shifting costs have important implications for the UK supply chain, tied to the fate of major markets.

1. What is the Impact of OneWeb on UK Supply Chains?

The OneWeb supply chain is highly international (see case study in section 5.7). The main UK impacts that we are currently aware of are the HQ, mobile terminal development (Satixfy), and signal converters/filters (Teledyne). The HQ is driving financial and professional services income in London.

There are a few significant questions about OneWeb's economic footprint on the UK in the future. As it begins to have service revenues, it will likely have significant accumulated losses (including depreciation and interest) so the location of profits for taxation will not be a question for some time.

The possibility of re-basing satellite manufacture from Florida to the UK, has been raised. We do not see any fundamental technical or skills reason that this should not happen. However, the Chair of their largest shareholder has warned that should not be an assumption[80].

Finally, there is the question of OneWeb's business prospects and approach. OneWeb will compete with SpaceX's Starlink, and later Amazon's Kuiper, but with a different proposition. The OneWeb constellation is much smaller and operates at higher orbits, so satellites will last longer, and it will have much lower operating costs. The UK's investment and desire for a sovereign PNT system open the question of how far it would support OneWeb for strategic reasons.

For the supply chain, despite being smaller than Starlink, it is still very large and sources systems more openly from 'space companies' rather than being tightly integrated. Its international nature means that any risk or reward is spread widely between nations, but very valuable for individual companies.

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[79] https://www.cnbc.com/2020/04/16/elon-musk-spacex-falcon-9-rocket-over-a-million-dollars-less-to-insure.html (Falcon 9 will lift 22,800kg to LEO)
[80] Sunil Bharti Mittal quoted in Financial Times, 1 March 2022, https://on.ft.com/36FtajU

2. Do Starlink, OneWeb, and Others Threaten the UK's GEO Strengths?

The UK's space industry has been very successful with GEO telecom satellites. It manufactures some of the most advanced (Airbus DS) and efficient compact versions (Airbus subsidiary SSTL), London is the base for many of the world's operators (Inmarsat, Intelsat, Eutelsat, Avanti), and it provides finance, insurance, and other professional services.

Some of that will transition to the new world of mega-constellations. OneWeb is a global firm, based in London, and Airbus DS is part of their manufacturing consortium. But SpaceX and Amazon break the mould with high levels of vertical integration, producing most of their own hardware, operating their own satellites, and, to a large extent, self-insuring by using large numbers of satellites to act as redundancy.

GEO businesses have long timescales and the advantages of known reliability and coverage, and their costs have also been falling. It is likely that they will retain a place particularly for broadcast services, but broadcast is increasingly switching to terrestrial fibre – over 70% of Sky UK's customers are now on Sky Q, which is part-satellite/part-broadband, and it has recently launched Sky Glass, a non-satellite integrated TV product.

Overall, it is highly likely that the UK GEO ecosystem revenue will come under pressure from the shift to LEO constellations. For those that make the transition there are opportunities in increased volumes and new markets (e.g. in space environment management), but slow movers risk losing out.

3. Will Low-Cost Launch Eliminate the Opportunity for UK Launch?

With SpaceX delivering, and Blue Origin, RocketLab and others planning reusable high cadence launchers, it is likely we will see launch prices drop further from their current levels. Will there be a space for UK launch?

This is important to the UK supply chain because it draws on UK suppliers for the launch vehicle and launch operations, and gives an advantage to UK satellite manufacturers. In addition it gives the 'soft', but very important, benefit of a very visible space activity that will help to inspire more people into STEM and space-related skills and careers.

Based on CST's extensive, long-standing, and regular research into launch markets, we believe there is a place for UK launch, although it will be of limited volume (discussed further in the next section). UK spaceports and launch providers are building their offer around a flexible and responsive service, where customers can choose their orbits and launch schedule. Launch masses will be from up to 180kg (Orbex) to 1350kg (Lockheed Martin/ABL) to LEO, with a target price of $12m[81] for ABL giving $8,900/kg. This is not the cheapest, but will lower than prices of circa $7m for 200kg to SSO on

[81] https://ablspacesystems.com/rocket/ - also chart showing 900-1000kg to common SSO orbits.

RocketLab's Electron and affordable in the context of many business cases. Prices can be expected to fall over time as the benefits of scale, experience and partial reusability accumulate.

However, the UK is not alone and, while it may gain an early advantage, it must be ready to compete internationally with a growing field of small launchers and spaceports in Australia, Brazil, Scandinavia, the USA, and more.

7.5 How will UK Launch and Space Tourism Affect the UK Supply Chain?

UK launch can establish itself as a viable industry in the next few years and continue despite price pressures from high-volume launch providers elsewhere. This benefits the UK launch vehicle sector, and hence the makers of components that go into them, and it benefits launch services and spaceports, and the various suppliers that support them.

In some cases, particularly the horizontal spaceports, UK launch will help enable the space tourism business: for sub-orbital tourism by sharing costs of the spaceport infrastructure, and for ground-based space tourism by adding value to the attraction. (Orbital tourism is not envisaged from the UK for current technologies and would require something like Reaction Engines' Skylon concept.)

In the ten-year timeframe we don't expect space tourism to have a major impact on launch rates or the space supply chain, although it will probably feature. The Ansari X-Prize was won by SpaceShipOne in 2004, but it was only in 2021 that we saw the first 'commercial' space tourism flights in the 'few hundred thousand dollar' price range[82]. The industry looks likely to develop with the US as its centre and an increasing flight rate. Virgin Galactic is well placed to bring the first space tourism flights to Britain, but we do not expect more than a handful of UK flights a year by 2032.

The overall impact on the UK supply chain can be estimated. Let us assume that in 2032 the UK is the base for 30 orbital launches a year. This might be five operational spaceports each handling six launches, or some different combination, but it seems a reasonable high-end assumption if UK launch is successful. If the price in 2032 falls to say £5m in 2022 terms, due to price pressure and cost efficiency improvements – that is £150m total revenue. From this £150m input, our economic model estimates further supply chain impacts of £30m to the UK space industry and £80m to other UK suppliers.

Compared to a £16 billion industry, or a £4.3 billion upstream industry this is a small additional business. It may have more benefits as an enabler and inspiration than its direct economic impact.

[82] https://www.bbc.co.uk/news/business-58120009

7.6 Positioning the UK for Advantage in the Emerging Opportunities

The National Space Strategy identifies five Emerging Sectors in the in-orbit economy, and we have reviewed analysis of In-Orbit Servicing and Manufacturing, Space-Based Solar Power, and NASA's plans for Commercial LEO Destinations.

Delivering the NSS will require developing a full ecosystem of technology, regulation, products and customers and targeting resources at potential blockers and slow developing elements of the ecosystem. The UK does not have to do everything and should focus domestic developments on strategic areas where it can create advantage, but UK policymakers should understand how the ecosystem will come together and aim to develop UK industry into advantaged roles, rather than leaving this to chance.

This includes several types of capability in the supply chain, beyond those that exist today:

- Specific technical capabilities related to each opportunity, for example software to analyse the paths of space objects for SSA, control and propulsion systems for IOSM, power conversion and transmission for Space Based Solar Power.
- Capabilities for the assembly and operation of large structures in space, including challenges of station keeping, pointing and thermal control. Robotics, with remote control or automation, will be important to this. Space Environment Management will be needed to make space safe for large structures. Large-scale, low-cost launch capability will be required to lift the structures into space.
- Business capability and capacity to take on these large, complex programmes. This requires being able to bring together the necessary financial, human and physical resources with project management sufficient for the complexity of the task.

Although the UK lacks in home grown 'large space businesses', we have a good position in many ways for these areas.

- In the specific technical capabilities, we have some knowledge in many of the key areas, an excellent university base, and a record for research at the lower TRL levels. We need to ensure that these are used effectively and linked to development programmes.
- In large structures in space, we are in the same position as most nations, but we have a very strong advanced materials and manufacturing sector, and innovative engineering and construction sectors that could be harnessed for input. The UK has good robotics expertise outside space.
- The UK is not strong in large-scale launch due to geography and history, but the need to take large volumes to space opens the option to invest in a launch vehicle based on Reaction Engines' SABRE propulsion, which could reduce total system costs and leave the UK with a strategic technology and several billion-pound businesses in supply chain and operations.
- Communication will be essential for these enterprises, and the UK is strong in development photonics and optical communications, and secure communication technologies.

- In business capability, Airbus DS and Inmarsat are used to large satellite projects, but some of the opportunities are of a different order of magnitude. Development of an Airbus commercial airliner might be a closer analogy in scale and international reach. The UK also has a cadre of professional engineering firms experienced in very large infrastructure projects around the world: for example, AECOM, Arup, Atkins, Mott McDonald, Systra. It also has a key centre for raising finance, one of the reasons it has been chosen as a base by satellite businesses from Inmarsat and Intelsat to Avanti to OneWeb.

To take advantage of its position we think the UK should:

- **Support technical development programmes**, but use them to develop multiple areas at once, and business capability as well as technical capability. A programme might be designed to open up a UK environmental market by providing data-as-a-service for use by national and local government (and perhaps commercially for other markets), developing over a series of missions from UK components to a UK instrumentation subsystem (and similar for other subsystems), from a CubeSat to a 200kg UK satellite bus, and launched from a UK spaceport.
- **Engage relevant adjacent sectors and academia**. Many of the key developments in space can learn from Earth-bound analogues. These are often in areas where the UK has good expertise – for example energy, robotics, advanced materials and manufacturing, IT. Businesses and universities working in these areas should be contacted and brought into the programme. The benefits for them are not just financial – the inspiration and recruitment value of working with or in the space sector is significant.
- **Collaborate internationally**. The challenges of space debris, in-orbit manufacturing and solar power will not be solved by one nation acting alone. The UK should position itself to learn from and cooperate with others, for mutual benefit. We have a long history of working with NASA, ESA, other space agencies and international consortia to solve global challenges. We can continue this into new space markets.
- **Develop markets, not just technologies**, with the public sector acting as anchor tenant or creating the market though regulation. An ongoing market is much more attractive to investors than grants or other direct funding as it offers continuous income and growth, as found in the recent study of Innovative Public Procurement in Space[83] for UKSA and the Space Growth Partnership by BryceTech.

This can be started by BEIS working with other Government departments to identify where space technology can deliver on their objectives, and where this is best achieved through anchor tenancy (i.e. part of government buys a service), or through establishing a market by regulation (i.e. regulation creates a need for others to buy a service, for example for pollution monitoring).

[83] https://www.ukspace.org/wp-content/uploads/2021/11/Bryce-UK_Innovative-Procurement-in-Space-Phase-1-Summary-Report_Nov2021.pdf

Procurement models to support UK space sector growth.

Procurement Model	Attractiveness to Investors	Comment
Anchor tenancy	Very High	Cited most often by investors as a specific, highly credible approach to supporting sector growth, spurring industrial investment, and attracting private investment
Public-private partnership	High	Multiple successful examples (including UK Skynet PFI), though success dependent on execution, alignment with national goals
Targeted investment	High	Commercial stakeholder involvement cited as crucial for ensuring successful outcomes, adding credibility to investment appraisal, and increasing attractiveness for further financing
Export finance support	High	Potential for increased investment when leveraged appropriately, need for stronger risk appetite (esp. for <£100m funding needs)
R&D funding	Medium	Strategic alignment, complementary industry-academia engagement, and substantial funding (>£1m) aligned with broader procurement strategy can increase potential for successful outcomes
Grant funding	Medium/Low	Important tool that should continue to be leveraged for early-stage tech development. Limited attractiveness to investors, particularly for small grant sizes and companies that become overly dependent on grant funding

Figure 7.9: Public procurement models and their attractiveness to investors (Source: BryceTech)

7.7 Ground Segment

The Ground Segment is essential to all space missions and amounts to a significant cost and potential barrier, but we found only limited information about it. The one significant study[84] suggested that "the cost of ground segment over the entire satellite lifecycle can reach one third of the total cost for large programmes".

For GEO, antennas are relatively straightforward, being essentially fixed. But for LEO, they need to track, and requirements get more complex with high latitude locations needed for continuous contact with SSO and Polar orbit satellites, and the volume of tracking and data for constellations. For example, 16 dishes may be needed to maintain contact with 8 satellites in different orbit, with the dishes 30 metres apart to avoid interference, and all reliable enough to pivot across the sky every 5 minutes. There is considerable current investment in phased array flat-panel antennas, which are electronically steered, and can track several satellites at once. At present these are very expensive, but ultimately, like other electronics, their price is likely to fall.

Developing the ground segment is time and money consuming for site acquisition, antennas, connectivity and operation. Licensing can be a further challenge, although the UK is considered one of the easier regimes to deal with. Even so, NewSpace businesses can be caught out when their agile business models meet the reality of the slow deployment of ground stations.

[84] Market perspectives of Ground Segment as a Service (GSaaS), PWC, IAC 2020

This has led to the emergence of Ground Stations as a Service (GSaaS), either from companies operating their own networks (e.g. KSAT, Leaf Space) or aggregators who combine spare 'white space' capacity from multiple sources (e.g. Infostellar, RBC Signals).

The UK has not had a coordinated approach to the ground segment. This is exemplified by the near closure of Dundee Satellite Receiving Station when NERC terminated its funding. It was kept going by the efforts of volunteers and a fundraising campaign. It has now emerged as a new business, Dundee Satellite Station Limited, supported by Michelin Development. Ground station technology development in the UK is also considered to lag by industry experts we interviewed, partly because it does not fit in normal categories for grants. A concern was raised about capacity in the Ka and Ku bands, when combined with geography in the Southeast of England.

Several trends are sweeping through the ground segment:

- Demand to service more LEO, more SSO/Polar, and more constellation satellites, requiring global coverage
- Demand to handle greater volumes of data per satellite
- Desire for lower latency – quicker access to data from satellites (e.g. 15-30 minutes)
- Rise of Ground Segment as a Service
- Desire for increased security, especially with reprogrammable satellites
- Developing technologies: Flat panel (phased array) antennas, On-board processing/AI (which may reduce downlink needs), Intersatellite links, 'Plug and play' ground station capacity expansion, Optical/Laser communication, Quantum-proof and Quantum cryptography.

The ground segment will be critical to the success of the National Space Strategy, both civilian and military. This study did not have the resource or remit to probe one sector in detail, but a future study could consider:

- Current UK capabilities in the ground segment, both operating and in technology, and comparing UK technology position to other nations.
- Whether the ground segment poses any risks of holding back areas of the National Space Strategy.
- What the opportunities are for the UK and UK overseas territories.
- Develop a national ground segment strategy, identifying which activities can be left to the market and where UKSA, the Catapult or other bodies should take or coordinate action.

7.8 Creating New Markets for Satellite Applications

The UK has proven time and again that it can deliver new downstream applications effectively. For most applications, the technical capabilities are within the capabilities of the UK supply chain. From space, they use combinations of communications, Earth Observation and PNT, on the ground, as we saw in section 3, they use relatively conventional IT infrastructure. Free data from Copernicus and

Landsat (EO) and GPS/Galileo (PNT) has enabled a lot of applications and businesses, for example vehicle fleet monitoring and precision farming.

However, there are large potential markets where satellite applications could bring much value, but that remain undeveloped. Some of these are commercial markets where the potential is not yet fully realised, and some are public markets where either the benefit is a 'public good' or is a benefit that initially arises in the public sector (which could ultimately benefit taxpayers), but it is not currently procured.

These markets can be created or accelerated in several ways, described further in the previous section: Facilitation, public-private partnership, public procurement, or regulation. In some cases they can be used to raise money for the public purse rather than costing money – for example enabling border adjustment taxes, permit or pollution pricing or road pricing.

Figure 7.10: Example potential new and growth markets for satellite applications

Sector / Type	Example Market	Possible Interventions
Commercial	• Market intelligence • Asset monitoring • Fleet and shipment tracking • Identifying locations for renewable energy or energy storage facilities	• Engage with consulting and IT firms to promote satellite application capabilities • Engage with sectors to promote or develop opportunities
Public Goods	• Monitoring delivery of Net Biodiversity Gain • Carbon credits • Carbon border adjustment verification • Public Health applications	• Work with Government depts, LAs and developers or other businesses on pilot projects • Work with Government depts to establish regulations that would drive markets e.g. 'polluter pays' or monitoring requirements
Public sector services	• Public Health applications • Traffic monitoring • Air pollution monitoring • Road pricing	• A new round of pilot projects with public sector bodies 'SSGP2' • Develop portfolio of Local Authority services from different providers

Market creation for applications is powerful for two reasons. First, because it creates a strong ongoing incentive for businesspeople and investors. This is a crucial factor missing from a pure technology development programme. Without visibility of a market, their chief concern will be the 'valley of death' that so often occurs between the development of a technology and its adoption by customers. With certainty of a market, innovators will innovate, and investors will invest.

The second reason that market creation for applications is powerful is that it has cascade benefits through the whole supply chain. Applications require data, which require ground stations, which require satellites, which require launchers, which require all their myriad components. Where pieces of the puzzle are missing, it is markets for applications that can drive new satellite systems, and sometimes enterprising ways of realising them such as the SAR satellites in the Iceye constellation, or the Lacuna

IoT satellite network. Proactive market creation, in addition to creating value in the local markets also develops businesses that are ready for wider markets, just as SpaceX developed its Falcon 9 rocket for the NASA COTS (Commercial Orbital Transportation Services) and CRS (Commercial Resupply Services) contracts, and it has since become the most successful commercial launch vehicle.

7.9 Innovation

The UK Innovation Strategy 2021[85] describes the benefits of innovation, but highlights how progress has slowed and how UK R&D investment is below OECD average. It shows that the UK is ideally placed for innovation and sets out a strategy in '4 Pillars' to make the UK a global hub for innovation (Figure 7.11).

We have discussed innovation with people in the space sector and other sectors and conducted a small study on the 'Support that Enables Space Company Success' in which we interviewed 20 leaders from successful space-related businesses.

Four Pillars of the UK Innovation Strategy
• Pillar 1: Unleashing Business – We will fuel businesses who want to innovate • Pillar 2: People – We will make the UK the most exciting place for innovation talent. • Pillar 3: Institutions & Places – We will ensure our research, development and innovation institutions serve the needs of businesses and places across the UK. • Pillar 4: Missions & Technologies – We will stimulate innovation to tackle major challenges faced by the UK and the world and drive capability in key technologies.

Figure 7.11: Example potential new and growth markets for satellite applications

A common observation of the industry is that the UK is good at basic research, but can be poor at translating that into commercial businesses. UKRI for example spends only about 18% of its research budget on industrial research[86].

Despite this, we found 90% of the business we talked to had received a grant, and 65% of them considered it very important to their success (Figure 7.12). There is, however, some danger that a specific grant pulls a company towards the technology the funding body wants developed, not a solution to the problem a customer has. We would prefer to see grants for solutions to problems, perhaps awarded by competitive tender to maximise opportunity for innovation.

[85] https://www.gov.uk/government/publications/uk-innovation-strategy-leading-the-future-by-creating-it
[86] Based on Industrial research including Innovate UK £667m and the Industrial Strategy Fund £543m =£1210m, out of total UKRI budget £7908m less Science Infrastructure Capital £934m corporate expenditure £151m = £6823m. https://www.ukri.org/wp-content/uploads/2021/05/UKRI-270521-UKRI-Allocation-Explainer-2021-22-FINAL-PDF.pdf

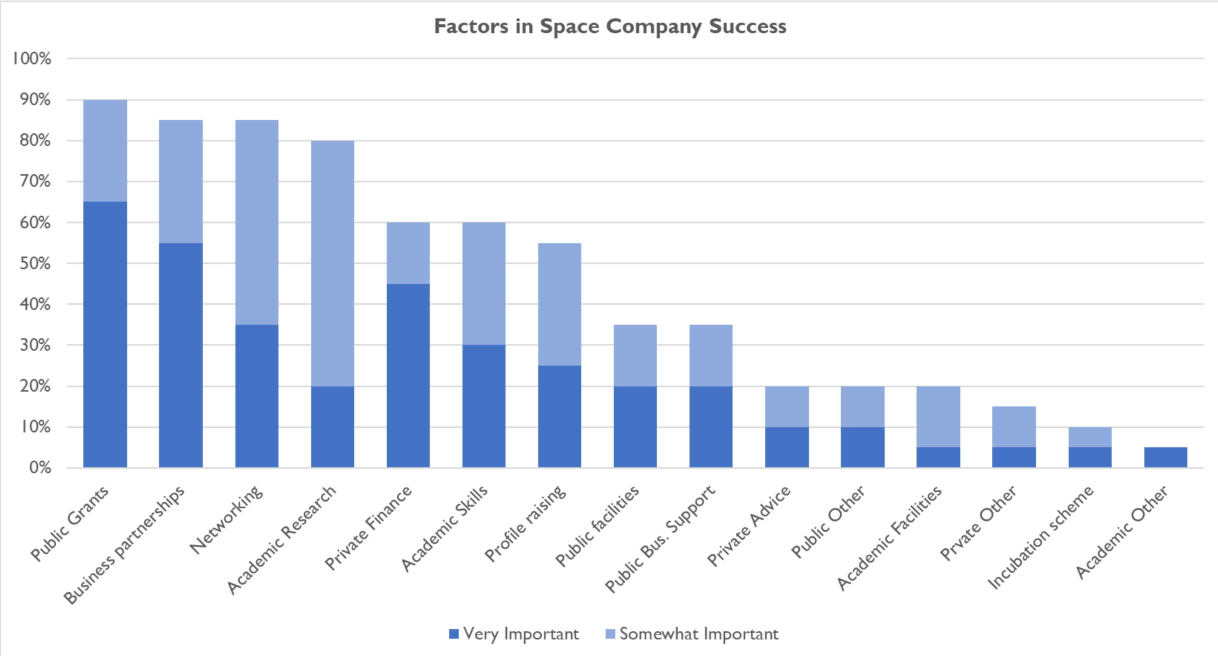

Figure 7.12 Factors in Space Company Success – How often are they important?

Academic research and access to academic skills or facilities also feature as valuable to overcoming technical hurdles in some cases. These were more specialised to individual circumstances.

Many of the challenges facing a business are commercial rather than technical. Even with a technically viable product, the journey to commercial success is not assured, and many innovations and businesses fail here. This is more a market or marketing problem than a technical one, and smaller businesses tackle it by seeking customers directly, through partners or seeking advice. It is not surprising then that 85% of our successful space companies noted 'Business Partnerships' and 'Networking' as being important to their success, and 'Profile raising' and 'Business support' also feature.

Collaboration is a key driver of innovation, and highlighted both in the 2021 Catapult Review and Red Kite's study. Networking and problem-focused collaborations, ideally including both commercial and academic sectors, are practical ways to increase innovation.

There are many supports for innovation that are not fully utilised, including grants, ESA technology development contracts and business support. There is an opportunity to improve communication and signposting and even assistance for these, particularly through the space clusters established or being established throughout the UK.

Procurement Frameworks
Procurement frameworks or dynamic purchasing systems provide a useful way to encourage innovation in procurement. They have three key features: • Define a market area: Legitimising and publicising what might be a novel area of supply (e.g. space-derived services).

- Develop a list of pre-qualified suppliers: Reducing risk for the buyers, and if the process is well-designed encourages innovative potential suppliers to participate.
- Define a procurement process, and sometimes targets for particular supplier segments: This helps to 'level the playing field' and if the process is well-designed keeps the administrative burden reasonable.

Use of procurement frameworks in the UK space sector is relatively new, and the results should be assessed. Below we describe three active frameworks in the sector.

Serapis – the DSTL (Defence Science and Technology Laboratory) framework[87]. This covers C4ISR (command, control, computers, communication, intelligence, surveillance and reconnaissance), space systems, synthetic environments and simulation technology and runs from 2019 to 2025. It is divided into 6 lots, each led by a prime contractor – the lead for Lot 2: Space is BAE Systems[88].

The Space framework has a consortium of BAE Systems, 4 SMEs and a further prime who will deliver up to 60% of the work. The other 40%+ will be let to the Supply Base by competition or direct award. This will comprise mostly SMEs (including micro-SMEs) and Academia, but will also include large businesses and existing defence suppliers. It is unclear how much of the work will actually be performed by SMEs. Satellite Applications Catapult, BAE and DSTL have been active in jointly marketing opportunities in this framework to SMEs.

CCS Space-Enabled and Geospatial Services Dynamic Purchasing System[89] (DPS) – Crown Commercial Service (CCS) has developed a DPS to benefit public services and support the National Space Strategy and Geospatial Strategy from 2021 to 2024. This covers satellite communications, geospatial data and services, UAV solutions, and upstream professional services. Buyers can buy almost any standard or bespoke service in these areas. Suppliers can register at any time.

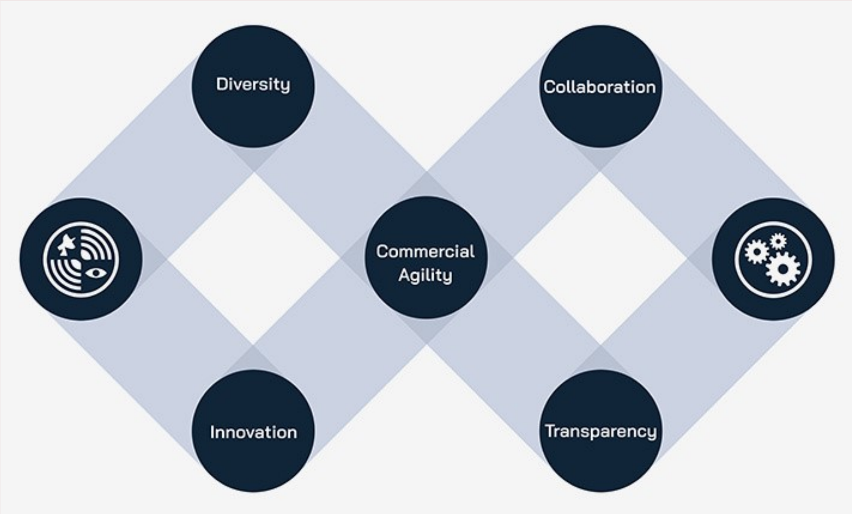

Figure 7.13: Objectives of the Serapis Framework

Satellite Applications Catapult has established a **Geospatial Capabilities Framework**[90] to identify capabilities that can support growing request for geospatial projects, some at short notice. The registration period for this closed in September 2021 and the framework will operate to 2023, with a possible extension from there. There are ten quite specific framework capabilities: change detection, object detection, population

[87] https://www.gov.uk/government/publications/dstl-science-and-technology-procurement-frameworks/serapis-framework
[88] https://www.baesystems.com/en/cybersecurity/serapis
[89] https://www.crowncommercial.gov.uk/agreements/RM6235
[90] https://www.newcivilengineer.com/latest/call-for-innovative-bids-to-benefit-infrastructure-through-geospatial-data-09-08-2021/

movements, critical infrastructure, climate, open-sourced intelligence, cartography & mapping, web GIS mapping, surge support for EO, Geospatial analysis or GIS, and modelling relevant for international development or disaster response.

Another model is an industry operated supplier framework, such as the aerospace and defence industry SC21 programme led by ADS and the Aerospace Growth Partnership and supported by key prime contractors. Companies commit to a journey of continuous improvement, using standard tools and techniques, and transparency, communication and collaboration. It helps suppliers to develop quality management and profile, and buyers to find supplier who have this. Over 14 years, 900 companies have participated, with 300 current participants[91].

7.10 Skills

Supply chains are made of companies but also of people – and people working in the space sector tend to boast very high skill levels. The Size & Health of the UK Space Industry 2020 study found that 77% of employees hold at least a bachelor's degree. On this measure, the average qualification level of space sector employees is higher than any sector covered by ONS Census data for England and Wales – and this holds for all the main segments of the space sector as well (manufacturing, operations, applications, and ancillary services).

This was very visible in the regional reports, of which 11 of 17 identified skills as a need to be addressed. In some cases specific skills were identified, such as radio frequency and software engineers, but in most cases, it was a concern that the overall growth in space and other high-technology sectors was outpacing the development of people qualified in science, technology and engineering subjects.

The sector competes with itself for a limited pool of diverse and highly specialised space engineering skills, and competes with the wider engineering and tech sectors for IT skills, project management and broader engineering skills. Recruitment difficulties are almost all for highly skilled professionals. The Space Skills Survey found that difficulty recruiting was "heavily weighted to an 'engineering professional' designation, with the second most frequent category being 'Information Technology and Telecommunications professional'". 32% of space companies reported difficulties retaining staff due to competition from other space companies, and 9% reported this due to competition from non-space firms. There is strong competition for software skills, particularly in Artificial Intelligence, Machine Learning, and associated software which are in high demand across a range of industries.

Growth of startups into mid-sized businesses will demand a pool of experienced staff for early scale up – the emergence of new competitive primes, major systems manufacturers or emerging segments at scale will demand expertise in large company management. The Skills Survey identified that "the industry is perceived to be culturally and ethnically diverse, welcoming many recruits from Europe and

[91] https://www.adsgroup.org.uk/membership/my-sectors/aerospace/sc21/

elsewhere in the world. However, there is a huge opportunity to meet skills needs by engaging more women – the survey found only 22% of people working in the space sector to be female.

The Space Census[92] by Space Skills Alliance and the Space Growth Partnership's Space Skills Advisory Panel also identified the opportunity to open pathways and increase the diversity of the sector, which would increase the available pool of talent. The survey showed the sector had only 29% women, 11% ethnic minorities (vs. 14% in population at large), and 8% disabled people (vs. 13% in wider workforce).

A critical issue is who pays for training. The benefits of employer delivered training are lost when an employee leaves the company and investment by an individual in specialist skills (e.g. through a post-graduate course) is risky and may not pay off in a fast-moving space sector environment. The Skills Survey highlights an "absence of conversion courses to allow people with relevant technical skills and qualifications to add a 'space' dimension to these". The Space Skills Survey considers a 'new entrant' programme. The solution seems to be to 'skill-down' the entry requirements to the sector to remove the barriers of highly specialist skills, engage in more training activities within the sector, and provide greater opportunities for skilled engineers and technologists to cross-over.

This suggests a potentially important role for Further Education (FE). Planned reforms to the and technical training system have been brought forward in the DfE's Skills for Jobs White Paper which focusses on STEM and higher-level technical skills. There are some specific ways that the space sector could engage:

- Space employers and trade associations engaging directly with National Skills Fund, Institutes of Technology, and T Levels to shape courses
- Engage with the Institute for Apprenticeships and Technical Education to ensure that employer-led standards in FE courses are suitable for the needs of the space sector
- Proactively seek to include space science disciplines into Institutes of Technology (many of which are already supported by space/aerospace employers – such as Airbus supporting the West of England IoT which specialises in health and life sciences, advanced engineering, high value manufacturing, digital and high technology)

The key is to normalise space and break down the walls that separate it from other disciplines so that talented people can move more easily into the industry through engineering and other disciplines.

The focus on engaging employers in the Skills for Jobs White Paper is at a local level through Local Skills Improvement Plans (LSIPs). This can be leveraged in some areas of high space intensity or high levels of space education (e.g. Leicester, Strathclyde), but may not suit the industry as a whole. Rather a national space skills approach may be required to spur FE courses as well as university courses through engagement with the Skills and Productivity Board (SPB).

[92] https://www.ukspace.org/first-results-from-the-2020-space-census/

7.11 Geography: The Benefits of Space Clusters

Clusters of space activity arise as a product of history, or by design, and our recent report on 8 international and 3 UK space clusters[93] shows a wide range of origin stories. In recent decades, recognition of the benefits of clusters has led to the more active creation and management of clusters, in space and other sectors.

Bringing businesses and other entities together in clusters creates three types benefit:

- Sharing – of large facilities, and of the infrastructure and resource pool that the cluster attracts.
- Matching – better and quicker matches of customers with suppliers, and of workers with jobs.
- Learning – Individuals and companies learning from each other in a larger and more diverse group

In the Oxford-Cambridge Arc, we saw these benefits acting on three scales:

Scale	*On site (up to 1km)*	*One hour travel (up to 60km)*	*National (up to 1000km)*
Cluster benefits observed	• Serendipitous meetings 'the coffee shop effect' • Easy to arrange meetings • Rapid repeat R&D/ testing use of facilities	• Regular suppliers • Employees (maximum commuting range) • Planned networking (maximum distance travelled to event)	• One-off journeys for a £100k or £100m satellite • Major collaborations e.g. Arc firm with University of Edinburgh • Major events e.g. UK Space Conference

Figure 7.14: Cluster benefits observed in the Oxford-Cambridge Arc Space sector

Some of those benefits arise 'on site', but many manifest in the ~one hour travel range that defines a clusters immediate zone of influence for attracting people and suppliers into its supply chain. But we note many links between the space business in different parts of the UK, even today. Large companies have sites in multiple regions (Airbus: Stevenage, Portsmouth, Harwell; Thales Alenia Space: Belfast, Bristol, Harwell). Parts for a satellite are assembled from across the country, and across the world, and then it may be shipped to test facilities at Harwell before going abroad (or soon to Cornwall, Scotland or Wales) for launch.

Improving Internet, video, and emerging virtual reality and augmented reality (VR/AR) technologies break down some of the need for physical presence and have found an important role, particularly after we have been forced to use them during the peak of the pandemic. The Space Enterprise Community[94] is an example of an online networking tool that helps people to find each other, events and opportunities, within and across clusters. As an extension of the Space Enterprise Community, the

[93] https://sa.catapult.org.uk/news/international-comparison-of-approaches-to-space-cluster-development/
[94] https://spaceenterprise.uk/

Satellite Applications Catapult has developed a number of Space Enterprise Labs (SEL), regional spaces for collaboration and innovation that are digitally inclusive. The Space Enterprise Labs provide users with hybrid physical and online access to resources, virtual demonstrations and Catapult experts.

Video links help clusters that are wide, have poor rural transport links, or want to save time or emissions to interact. But many of the cluster benefits still stand, and we expect and recommend continued geographic cluster development.

Recognising these different modes in the supply chain is important. If you are competing for business, you will want to have business development people close to your customer, ideally in the same site for those serendipitous meetings. Once you have a contract to supply, the high costs, 'uniqueness' and long timescales of the space industry have meant that location is not important, but as costs fall and volumes increase, closer location will become more valuable.

For the space sector, the UK Space Agency and Satellite Applications Catapult are building a UK-wide space ecosystem to bring together commercial, academic, research and government stakeholders to drive the growth of space activities across the UK.

An important element in this process has been the Satellite Applications Centres of Excellence (CoEx) programme, initiated in 2013 by the Satellite Applications Catapult to accelerate the development of satellite applications solutions in specific regions across the UK. Five clusters were created, linking stakeholders with one another and enabling the development of applications and solutions, as well as engaging the wider end user market. The UK Space Agency began supporting this programme in 2016 with grant funding provided to expand the capability and capacity of the programme.

Since 2019, the UK Space Agency and Satellite Applications Catapult have continued their partnership, with a long-term programme designed to accelerate the impact of space-related activities across the UK. In addition to the previous activities, this programme supports local stakeholders in developing new clusters based on local excellence and identifiable market opportunities. These new clusters will capitalise on specific opportunities to build and better utilise local capacity and will link to the wider, previously established national space ecosystem.

In the UK, clusters have each developed their own 'personality' and specialisations, but there is collaboration and movement between them. An organisation in need of support needs only reach out to 10 or so clusters (which are mostly part of the Catapult network), rather than searching hundreds of individual businesses. We believe this helps the UK space economy to function more effectively, contributing to working as a 'single national cluster'. With innovation often coming from the sharing of ideas, there is opportunity in increasing cross-cluster sharing. For example, contact between clusters and cluster coordinators, already happening in some cases, should become regular.

8. Recommendations and Action Plan

Reviewing the UK Space Supply Chain, it is clear there is a great breadth of capability, but the depth needs to be reinforced. The opportunities are large, as identified by the market studies referenced in this report and many others, and backed up by recent investments in the UK by domestic and international firms.

Our recommendations are developed from findings throughout this report, and aimed at supporting the National Space Strategy. They fall into three categories:

- Capability Enabler – Address the basic requirements of a growing sector for skills and finance.
- Capability Developers – Existing activities to build capability in the space supply chain.
- Capability Multipliers – Largely new activities that could significantly increase the capabilities of the UK space sector, often with limited cost.

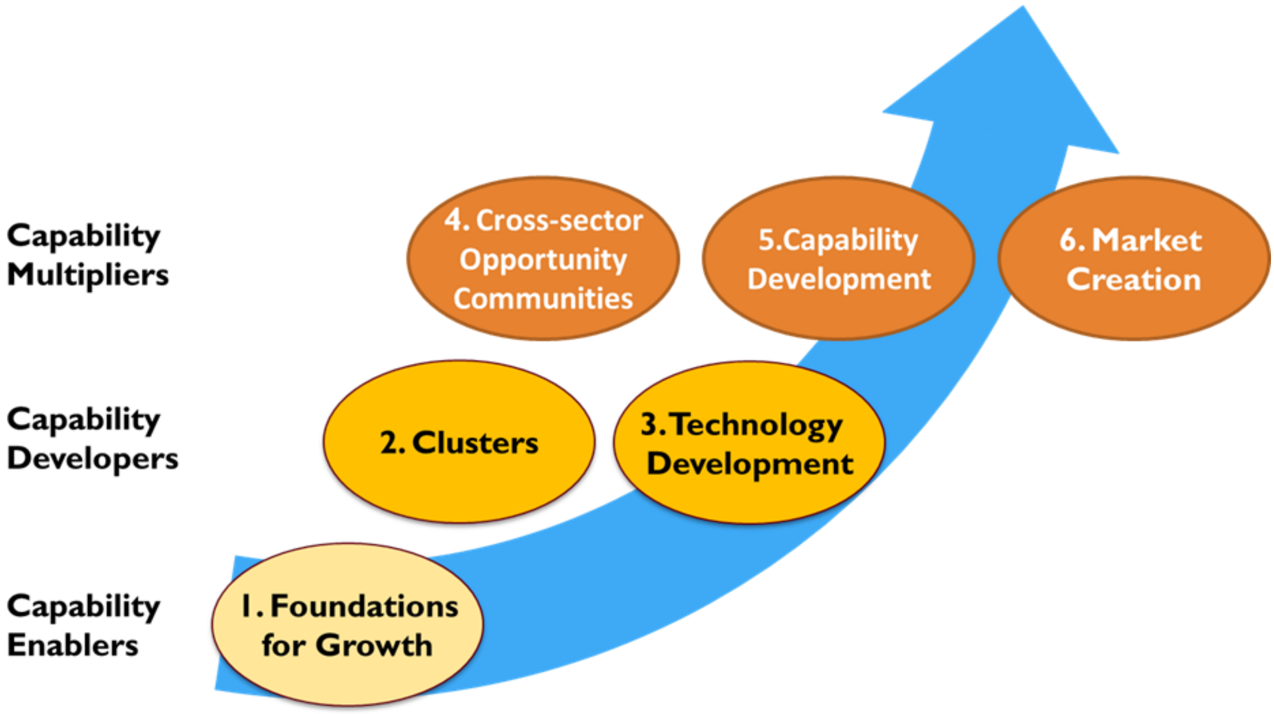

Figure 8.1: Six recommendations for the UK space supply chain

All the recommendations apply to both upstream and downstream. However, Capability development is slanted towards upstream where technology development programmes can be used to develop industry capabilities as well. Market creation has a downstream bias because there are excellent opportunities to drive industry development from the customer side in environmental markets.

Recommendation 1: Foundations for Growth

Improve access to skills and finance, with a plan that meets the growing needs of the sector.

Space sectors in most regions identified skills as a growing need in their supply chains, as the industry expands, and businesses were concerned that their experienced and trained staff were being recruited by other firms due to an overall shortage, causing a 'merry-go-round'. In some cases, for some skills, this need is immediate, but in other cases it is a concern about the long-term growing need across technology industries outpacing the supply of graduates and other people highly qualified in STEM subjects, with space being a particular issue due to its unique environment and technologies.

Ways to fill this gap include working with universities and colleges to create courses that fill specific needs, or that bring space closer to other sectors with cross-over courses. Another is to include skill-building in publicly funded development programmes, although this will not always be popular with bidders. For the long-term, the UK needs to increase the number of students entering STEM courses of all types at all levels, because many of the skills are transferable. The good news is that space can also offer back to the STEM education community high value in inspiration – many of today's space entrepreneurs were inspired by previous space programmes.

In finance, we noted that access to finance for space businesses was good in places (London, Edinburgh, Cambridge, Oxford), but not everywhere. Space is also not yet 'normalised' as an investment or lending opportunity.

Skills and finance are topics in their own right, beyond the strict definition of the 'supply chain', but essential foundations of growth for the industry. Other studies have examined them in further detail, and we do not attempt to replicate their level of analysis and recommendation here, only to identify some recommendations most relevant to the supply chain.

Action Plan

Ref	Action	Who	When
1.1	Identify local space skills needs and if of significant scale, develop plan with local FE/HE institutions to meet them, e.g. with conversion courses or degree-level apprenticeships. (Consider accessibility to sufficient number of students.)	Local space cluster with LEP & UKSA/ BEIS support	2022/3
1.2	Work with businesses to identify ways to help them expand the skills base, rather than driving the 'merry-go-round'	UKSA	2022/3
1.3	For long-term, develop plan to increase number of students in STEM subjects. Ensure training is accessible in all parts of UK and to people of all characteristics and backgrounds.	UKSA with DfE	2022/3 plan, Delivery ongoing
1.4	Develop space inspiration for STEM education and careers at all levels: projects, competitions, careers fairs, etc. Leverage local space clusters and resources (e.g. ESERO-UK) to deliver.	UKSA	2022/3

1.5	Engage institutions and societies that can support and provide additional engagement and inspiration	UKSA	2022-24
1.6	Ensure each space cluster has access to finance knowledge base and signposting available, through local or national resources. e.g. proposed 'Space Finance Hub'	Local space cluster and SA Catapult	2022/3
1.7	Connect with local angel/ venture investment networks. Make space a normal (but exciting!) investment opportunity.	Local space cluster and SA Catapult	2022/3

Recommendation 2: Space Clusters

Continue space cluster development and creation

Clusters of space activity, whether formed by history or design, have been a success, bringing their members additional opportunities, advice and resources. A simple measure of success is that space businesses in most UK regions without an operating cluster would like to see one set one up.

Clusters can take many forms, as we showed in section 7.11, but a cluster does need a certain 'critical mass' to be worthwhile. The Catapult and UKSA should take a strategic view and consider which regions and locations have sufficient density of activity to form an effective cluster, and what form this should take. The regional reports are often not 'natural' regions for clusters, which should follow space activity rather than administrative boundaries. Many locations have capabilities to offer (precision machining and IT seem almost ubiquitous) and would like a piece of the pie, but investments should be focused where they will have most value. Smaller sets of activity are best linked into larger clusters rather than attempting to build many sub-scale clusters.

Our recent national (and global) conversion to video conferencing may enable a more virtual format, but physical presence still has benefits. Business incubators are a key part of several clusters, notably the ESA BICs, and considering locations or access to these would be an important factor.

When in place, clusters should be developed and linked to local and distant capabilities. There is opportunity to improve contact with the local supply base, and with potential partners in other sectors (discussed further in Recommendation 4). The formation of clusters also makes it easier to create links between them, rather than between dispersed firms in a region. These factors are all important when the UK supply chain is currently composed of relatively many small businesses that often need to work together on a project.

Action Plan

Ref	Action	Who	When
2.1	Develop strategic view of where there is (or can be) sufficient space activity in an area to develop a space cluster and continue to extend the cluster network on this basis.	UKSA/ SA Catapult	2022/3

2.2	Develop a plan for each cluster to have e.g. Coffee shop, Meeting spaces, Regular events, Online meeting space/forum, Building 'sense of community', Access to skills and finance (see Recommendation 1)	UKSA/ SA Catapult	2022/3 2nd half
2.3	Consider access to business incubators/accelerators for each space cluster, including ESA BICs	UKSA/ SA Catapult/ ESA	2022/3 2nd half
2.4	Develop ways to link local knowledge of space supply chain to national data, e.g. cluster managers develop local networks and also review and input to UKSCC.	SA Catapult with local clusters	Test in 2022/3
2.5	Identify 'nationally useful capabilities' and promote them across the network.	Cluster managers/ SA Catapult	Test in 2022/3
2.6	Identify 'thematic clusters' across geography that might find value in becoming working groups in particular application or technology topics. (e.g. IOSM working group, Space Energy Initiative)	SA Catapult	Test in 2022/3
2.7	Run 'trade missions' between clusters or 'open days' or themed events to attract certain types of supplier and make new partnerships. Best if tied with ongoing partnership support programme.	SA Catapult	Test in 2022/3
2.8	Widen the range of participants involved in space community events – look for 'hooks' to engage people from related sectors. (See also Recommendation 4).	SA Catapult, UKSA	Test in 2022-24

Recommendation 3: Technology Development

Invest in technology development to accelerate progress, but aware of the dangers

There is a vital role for public investment in fundamental research and emerging technologies, and we include this recommendation to support it. However, in Recommendations 5 and 6 we show two alternative approaches that may be even more effective. For Technology Development in the space sector, we see two types of opportunity.

The first is developing technology that positions the UK as a key partner for emerging space markets – all of these are sufficiently large to require international partnerships. Currently visible emerging markets are:

- Environmental markets – Markets for greenhouse gas emissions and sequestration will be needed to facilitate the move to Net Zero by 2050, and satellite applications are likely to prove effective in measuring and monitoring for these, especially for cross-border issues. In addition, there are likely to be increasing need to monitor other forms of natural capital such as biodiversity, pollution, and act on problems such as road transport.
- In-Orbit Servicing and Manufacturing – where robotics, simulation, manoeuvring, manipulation and manufacturing technologies will be key
- Space-Based Solar Power – where energy conversion and the assembly and operation of large structures will be essential

- Next-generation reusable launch – Both the above, at volume, will need low-cost reusable launch. UK has unique technology in Reaction Engines SABRE, and a decision to make as to whether to fund its development into a commercial propulsion system and launch vehicle to serve this market. Given the timescales for this development are probably similar to those for a SBSP plant, the decision cannot be put off for too long.

The second is in accelerating the rate of proving technologies in space, or providing enabling data through demonstration missions. This is a key hurdle for many space businesses, and despite the CubeSat revolution, it is still time-consuming and expensive. A mission can prove multiple technologies on one flight, potentially with more risk, but this can be mitigated by design. A good example which spans both upstream and downstream is the Sunrise programme which includes novel beam-hopping technology, antennas, multibeam user terminals and de-orbiting technology.

There is a key warning alongside this recommendation, which is that technologies do not create markets. Many businesses, including those supported by grants, have developed a product, raised investment, but run out of cash before finding sufficient customers and revenues to cover their ongoing costs[95]. Understanding the potential market should be a criterion of investment, but this should be realistic, and it does not mean that funding should only be given to technologies within a year or two of marketability.

Action Plan

Ref	Action	Who	When
3.1	Use competitive tenders, and/or 75% to 100% funding for high-risk / low-TRL projects, including ESA projects.	BEIS, UKRI, ARIA	2022/3
3.2	Add higher public support to company R&D spend (e.g. additional R&D tax credit)	BEIS	Consider 2022/3
3.3	Continue and extend technology development support to upstream and downstream innovators, including the In-Orbit Demonstrator programme to help SMEs past the critical 'proven in space' threshold. Include multiple businesses/technologies on one flight where this can be done in balance with risks to widen the benefits. (See also Recommendation 5)	SA Catapult, UKSA	Ongoing
3.4	Develop technology development plans/roadmaps for IOSM and SBSP and identify key UK investments as part of those	UKSA/BEIS	2022-24
3.5	Ensure there is a UK decision roadmap for next generation launch, including SABRE/Skylon	UKSA/BEIS	2022-24
3.6	Ensure business grant recipients have future market potential and understanding of marketing and finance. But don't always require 'close to market' or immediate return on investment.	UKSA, SA Catapult, UKRI	2022/3 and ongoing

[95] The so called 'Valley of Death', named after the shape of the cashflow curve

Recommendation 4: Cross-sector Opportunity Communities

Reach out to related sectors that can unlock big space opportunities.

There big opportunities in space will be best realised by working in partnership with other sectors in which the UK already has world-class capabilities. These partners can bring resources, techniques and widen the skill base of the space sector.

Some examples of this can already be seen. Both the Manufacturing Technology Centre (MTC) near Coventry and The Welding Institute (TWI) in Cambridge have developed advanced techniques that have led them to sell services and products to space companies, including SpaceX. The IT industry already plays a huge role in collecting and processing Earth Observation, position and navigation data – consider the maps and images distributed by Google, Apple and Microsoft.

Communications technology has been a UK strength, and there are already links forming between the strong UK photonics and quantum sectors and space. These should be reinforced because they address growing space sector needs for data transmission volume, flexibility and security.

This can be extended further with a view to future market opportunities.

- For applications - Finance, insurance, consulting, and IT application development businesses, are keen to gain informational advantages in commerce and the green transition. Satellite data can provide this. This enables these businesses to improve their output, and would also increase the demand for space-based services. There would be longer term benefits as well. As demanding customers, the professional services would drive innovation and improvement. Services would filter out over time to their clients, through services, in systems, and to other businesses as people move on with their knowledge.
- For the emerging market of IOSM – Robotics, control technologies and simulation are essential to success. The UK has excellent capabilities of these, honed in demanding environments such as Connected and Autonomous Vehicles and in nuclear research, where rebuilds are performed by remote-controlled robot. Construction and engineering consultancies are now using digital twin simulations to ensure no conflicts in complex operating sites.
- For SBSP – Engagement with the energy sector will be crucial to ensure that new power fits with the national grid supplies.
- For both IOSM and SBSP – As space structures get larger, the experience of businesses that are familiar with very large construction projects, such as construction and engineering consultancies becomes valuable. These projects are not just technical challenges, but require marshalling human, financial, and physical resources on enormous scale and there are many mistakes made, and lessons learned.

Action Plan

Ref	Action	Who	When
4.1	Develop Finance, Consultancy and IT firms as early adopters of space derived data and services. (Further detail in London/Berkshire report Recommendations L3.1-L3.4)	UKSA/ SA Catapult	2022/3
4.2	Deepen engagement with the UK photonics/optical communication and quantum sectors to develop next generation satellite-to-Earth and satellite-to-satellite communication	UKSA/ SA Catapult	2022/3
4.3	Identify and engage with robotics, control, and simulation businesses as part of IOSM programme	SA Catapult, IOSM working group	2022
4.4	Engage with energy sector as part of SBSP initiative	Space Energy Initiative	2022
4.5	Engage with planning/engineering consultancies (Arup, Atkins, Mott McDonald, etc.) as a priority due to multiple potential joint opportunities: Use of EO data for planning/asset monitoring/etc., Simulation, Large programmes.	SA Catapult	Q2/3 2022
4.6	Reach out to major firms in precision engineering, nationally and close to each cluster, and get them interested in the potential of space. Aviation; Motor racing; Energy (turbines/electrical/electronics)	SA Catapult and clusters	2022/3
4.7	Identify early adopters for emerging markets e.g. pharma, optics(?) for in-space manufacturing. (Start with review of existing sources).	SA Catapult, UKSA, IOSM group	2022/3
4.8	Go to other sector conferences with a tailored 'opportunities with space' message e.g. Clean growth, Energy (esp. nuclear), Extractive, Auto, Rail, Logistics, Health, Life sciences, IT, Comms, Defence, etc.	SA Catapult, UKSA	2022 identify sectors, messages 2023 attend
4.9	Set up collaborative projects or 'exchange programmes' as affordable way to build key sector links. (~2-4 person-years each)[96]	SA Catapult	2022/3 ongoing

Recommendation 5: Capability Development

Use programmes to improve UK industry capability, not just technology

In Recommendation 3 we discussed the value of investment in Technology Development, but we have also seen that the UK space industry has some structural weaknesses. The return on that investment can be multiplied if it is used to build UK space industry capabilities as well.

Development programmes should be designed and let to develop the industry as well as the technology. They should help to grow UK space businesses from small to medium to large. The should help to address the lack of UK subsystem providers. They should encourage more of the UK's strong IT companies to get involved in satellite applications. They should improve the UK skills base. They should increase UK content overall.

[96] See 'Developing the Space Sector in the Oxford-Cambridge Arc, p99, 'Collaboration' medium scale ideas

There are considerations about fair competition here, but currently the upstream UK industry is dominated by one player, and it is difficult for others to compete for some contracts. Mechanisms exist to address this. A certain percentage of subcontracting to SMEs could be required in public contracts. ESA allows 5 marks[97] flexibility in the award of contracts if it helps to improve balance in industrial structure.

Capability development is a gradual process, and one effective way would be a multi-year, multi-stage collaborative development programme aiming towards a science, defence or commercial outcome, and one or more capability developments. For example, a UK SAR, SSA or SBSP programme, or one that supported the measures of the Environment Act for monitoring Net Biodiversity Gain or 'soil carbon'. These could involve several partners and build from a CubeSat to a small constellation of Minisats over several years, launched from the UK, and backed by a Government contract for the services (see Recommendation 6). This would enable several businesses to grow, improving both their technologies and their business delivery capabilities in a commercially sustainable manner, and to be ready for future market opportunities.

There are already some emerging opportunities for this in the Defence Space Strategy, for example the Titania and Prometheus 2 satellite contracts were awarded to In-Space, now owned by BAE Systems, which is now rapidly developing its capabilities as a UK satellite integrator and prime contractor, and more widely the opportunity of the Serapis framework. ESA contracts and UK civil contracts provide similar opportunities.

Capabilities need not come from existing space businesses, but could from other sectors moving in to the growing space sector (see Recommendation 4). One area that is less understood is the ground segment, as requirements are rapidly shifting, and we recommend further study to understand whether ground segment capability could hold back UK space ambitions in the future.

Action Plan

Ref	Action	Who	When
5.1	Make every significant technology development programme, an industry development programme. • Look for UK content and SME development opportunities in every contract – build them into RFPs • Look to develop UK firms towards subsystem provision • Look to develop UK skills, e.g. by incorporating apprenticeships and training in the programme	UKSA/BEIS	2022/3
5.2	Plan multi-stage capability development programmes, instead of 'one and done' technology development or grants. For example: UK SAR, SSA or 'Environment Act' constellation, a natural capital data cube, a satellite-data based 'digital twin' of the UK or the Earth.	UKSA/BEIS	2022/3

[97] We believe this is on a 100 point total scale.

5.3	Use defence and civil space contracts to develop a more balanced UK industry structure. Build UK and SME content, and UK industry development into RFPs.	UKSA/BEIS/MoD	2022/3
5.4	Monitor Serapis & CCS frameworks, and if successful extend use of framework contracts with targets to enhance innovation and capabilities, and for SME participation.	UKSA/BEIS/UKSpace SA Catapult	Ongoing
5.5	Review with ADS and UKSpace whether SC21 or a version of it fits the lower volume space industry	UKSA/UKSpace/ ADS	2022/3
5.6	Work with ESA to use ESA contracts to help develop UK industry structure.	UKSA/ESA	2022/3
5.7	Encourage more UK businesses to participate in ESA mandatory activities, where UK SMEs bid less frequently, but have a high success rate. e.g. Provide awareness of funding available and support for bids.	UKSA/SA Catapult	2022/3
5.8	Review future UK needs and capabilities in the ground segment to ensure this will not be a limit to the National Space Strategy ambitions.	UKSA/SA Catapult	2022/3

Recommendation 6: Create Markets

Be proactive in market creation, using regulation and public procurement as tools.

The potential of space applications is not fully realised. There are applications with public benefit that have not manifested because markets do not yet exist. The UK public sector can create or catalyse these markets, and in some cases, it is not only cheap – it can raise money for the Treasury.

Many opportunities for satellite applications to create public benefit, at present those that operate are usually as services paid by the public purse, sometime with some commercial revenue such as weather forecasts and climate monitoring from the Meteorological Office. But there is an opportunity to create far more value from satellite services if the right financial incentives – markets, in essence – were there to enable them.

There is an important aspect of this approach – it should encourage innovation and entrepreneurship, not restrict it. Thus, markets and invitations to tender should be designed to encourage SMEs and innovative approaches, rather than being prescriptive about methods (see the NASA COTS and CRS case study in section 6.2). These could be upstream or downstream – we have highlighted downstream because of some particularly clear opportunities.

- Monitoring the environment has never been more important, and satellites already play a great role. The Environment Act brings the requirement for 10% Net Biodiversity Gain and this will require monitoring. Water companies have been fined tens or hundreds of millions pounds for discharging sewage into rivers, but the full picture is not known. There is potential for satellites to make the monitoring of environmental legislation economic and effective, and could be paid for as a levy on development, or as a small cost relative to the fines raised or damages that it could avert.

- In the battle against climate change, satellites can monitor the sources and sinks of greenhouse gases. In some cases[98] this has already enabled pipeline leaks and illegal emission sources to be identified. Satellite data could also be used to set up carbon pricing and credit programmes. For example, monitoring foreign steel and cement production methods to apply appropriate border adjustments to enable a UK carbon tax. Or, incentivising farmers to adjust their techniques to increase the amount of carbon stored in UK soils. The services could be paid for with a share of the taxes or credit revenues.
- Satellite data could enable a UK road pricing scheme. Road pricing is now considered virtually essential to replace the £35 billion of annual fuel and vehicle taxes that will be lost to the Treasury after the transition to electric vehicles with the current tax system[99].
- Other opportunities have been identified for example in health, local government and spatial planning which we discuss in our report on the space sector in the Oxford-Cambridge Arc.

Launching these opportunities requires positive action from the public sector, usually either procurement or regulation. Procurement ideally takes place with the public sector acting as 'anchor tenant' to establish the service, allowing the supplier to prove themselves and allowing more customers, domestic and foreign, to join later. Procurement costs money, but a competitive tender for something the public sector needs assures good value. The contract is best set out as a 'functional requirement' to allow innovation, rather than specifying exact methods of delivery. It is this approach that enabled the growth of SpaceX from nascent rocket company to the successful space business it is today.

The other approach is regulation – while sounding like a burden, it's potential to create markets and the supply chains the go with them should not be ignored. Well designed regulations require businesses to act in a certain way, and can create new markets. Vehicle 'MoT' regulations not only ensure vehicles are safe, but they provide garages with a steady flow of income. Taxes on high-sugar drinks reduced consumption, but also spurred new formulations and raised tax revenues. There are already carbon credit markets, and emissions trading in the European 'cap-and-trade' scheme.

The space sector has its own environment to consider. Standards will have to be agreed internationally, but the UK taking a lead and establishing a good connection with regulation and service operators, as it has done with satcoms, will prove attractive to businesses considering where to locate.

BEIS, as the 'sponsor department' for civil space applications should work with other Government departments to identify how space can solve their problems, achieve their objectives, and what mechanisms and markets to put in place.

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[98] The ones we are aware of are non-UK

[99] https://publications.parliament.uk/pa/cm5802/cmselect/cmtrans/789/report.html

Action Plan

Ref	Action	Who	When
6.1	Work with Government departments to identify where space applications can help achieve their objectives.	BEIS	2022/3
6.2	Assess where enabling regulation or 'anchor tenant' procurement is needed to create markets (upstream and downstream).	BEIS/UKSA/ SA Catapult	2022/3
6.3	Identify sectors that would make good delivery partners and reach out to them via their own events and media (*cf* Recommendation 4.8).	BEIS/UKSA/ SA Catapult	2022/3
6.4	Consider 'Space for Smarter Government Programme 2' and developing a portfolio of services for Local Authorities.	UKSA/BEIS	2022/3 plan 2023/4 act
6.5	Assess whether Government can buy satellite data once, and then re-use it for multiples purposes.	UKSA/BEIS	2022/3
6.6	Pick out local case examples that can be copied nationally (e.g. 5G Rural Dorset, Northumberland Water use of AR over 5G).	SA Catapult/ UKSA	Ongoing
6.7	Work internationally to establish standards and regulations for Space Environment Management, and so create the basis for a new market.	UKSA/BEIS	Ongoing

Glossary of abbreviations

Abbreviation	Full Name
numbers	k: thousand 10^3, m: million 10^6, bn: billion 10^9
ADCS	Attitude Determination and Control System
AI	Artificial Intelligence
Airbus DS	Airbus Defence and Space – A major European space company
AIT	Assembly, Integration and Test – putting a satellite or system together and making sure it works
BIS	British Interplanetary Society, space advocacy organisation, founded 1933
CAGR	Compound Annual Growth Rate
CCD	Charge Coupled Device – a type of optical sensor
CLD	Commercially owned and operated LEO Destination – NASA term for a commercial space station
COTS	Commercial off the shelf – Readily available commercial components
COTS	Commercial Orbital Transportation Services – NASA contract to develop the capability to deliver cargo to the ISS on a commercial basis
CRS	Commercial Resupply Services – NASA contract to deliver cargo to the ISS on a commercial basis
CST	Commercial Space Technologies Limited
DPS	Dynamic Purchasing System – A flexible procurement system
DSTL	Defence Science and Technology Laboratory
DTH	Direct-to-Home – Satellite TV Broadcasting
EO	Earth Observation
ESA	European Space Agency
FE	Further Education
GDP	Gross Domestic Product
GEO	Geostationary Earth Orbit
GNOSIS	Global Network On Sustainability In Space
GNSS	Global Navigation Satellite System (includes USA GPS, EU Galileo and others)
GPS	Global Positioning System, the USA's GNSS
GVA	Gross Value Added
IOSM	In-Orbit Servicing and Manufacturing
IoT	Internet of Things
ISR	Intelligence, Surveillance and Reconnaissance
ISS	International Space Station – Humankind's largest structure in space to date. Continuously inhabited since 2 November 2000.
KTN	Knowledge Transfer Network – part of Innovate UK

Abbreviation	Full Name
LEO	Low Earth Orbit
LEP	Local Enterprise Partnership
LM	Lockheed Martin – A major American space company
LSIP	Local Skills Improvement Plans
NSS	National Space Strategy – Published by HM Government September 2021
PNT	Position, Navigation and Timing
OECD	Organisation for Economic Co-operation and Development
OMV	Orbital Manoeuvring Vehicle
ONS	Office of National Statistics
OSS	Oxford Space Systems – Manufacturer of deployable antenna structures
RAL	Rutherford Appleton Laboratory, facilities located at Harwell, Oxfordshire
RF	Radio Frequency
RFP	Request For Proposal
SAR	Synthetic Aperture Radar
SBSP	Space Based Solar Power
SDA	Space Domain Awareness, knowing what is where in space
SME	Small or Medium Enterprise – Generally a business with 1-249 employees.
SPB	Skills and Productivity Board
SSA	Space Situational Awareness, knowing what is where in space
SSO	Sun Synchronous Orbit
SSTL	Surrey Satellite Technology Limited – Originally a spin-out from University of Surrey, now a subsidiary of Airbus
STFC	Science and Technology Facilities Council
STEM	Science Technology Engineering and Maths, often in education
TAS	Thales Alenia Space – A major European space company
TRL	Technology Readiness Level, from 1-9 https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf
UAV	Unmanned Aerial Vehicle, commonly known as a 'drone'
UCL	University College, London University
UKSA	UK Space Agency
UKSCC	UK Space Capabilities Catalogue, developed by the Satellite Applications Catapult

The Space Enterprise Community platform is a collaboration between the Satellite Applications Catapult and the UK Space Agency (UKSA), designed to help commercial, academic, research and public sector stakeholders from across the UK space sector connect with one another.

Find out more and register at **www.spaceenterprise.uk.**

The Company is registered in England and Wales under company number 07964746 with its registered office at Electron Building, Fermi Avenue, Harwell Science and Innovation Campus, Didcot, Oxfordshire, OX11 0QR.