Upstream Space: A Galaxy of Capability

An Audit of Upstream Space Capability in The Oxfordshire-Cambridgeshire-MK-Herts Corridor; M3 Corridor & Solent; Greater East Midlands; Scotland; Wales; and Northern Ireland.

A Science and Innovation Audit Report sponsored by the Department for Business, Energy & Industrial Strategy

FULL REPORT

2018

Acknowledgements

The Science & Innovation Audit for Upstream Space is part of a suite of reports commissioned by the Department of Business, Energy & Industrial Strategy. The first wave was announced in 2015, the second in 2016, and the third – of which this report is a part – in 2017.

This report has been primarily authored and compiled by the Upstream Space SIA Partner Board, a consortium of organisations led by the UK Space Agency and representing a number of geographical regions across the UK where the Upstream Space sector is particularly active. The organisations who have directly contributed to the report are listed below, but the true number of organisations – the researchers, SMEs, academics and regional representatives who operate up and down the country – who have in some small way contributed to the broader intelligence making up this report are too numerous to mention, but without them this report would not have been possible.

The Partner Board has been supported with feedback and directional steer from the Upstream Space SIA Advisory Board, comprising of senior leaders from the Space Sector from across the geographical regions covered by the report. Furthermore, The Advisory Board strongly supports the intention of the UK Space Agency to further develop and maintain this audit, and in particular to extend the analysis to those areas not necessarily represented through the initial geographic composition of the Partner Board. A list of the Advisory Board members is included in Annex D.

Thanks must also go to Technopolis, who have provided the statistical data underpinning the thrust of the report, and the team at BEIS for their ongoing support.

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Glossary of Terms

ACS	Attitude Control System
AI	Artificial Intelligence
BTVLEP	Buckinghamshire Thames Valley LEP
CAGR	Compound Annual Growth Rate
DA	Devolved Administration
D2N2	Derby, Derbyshire, Notts & Nottingham LEP
DIT	Department for International Trade
EC	European Commission
EO	Earth Observation
ESA	European Space Agency
EU	European Union
FP7	7th Framework Programme
FP9	9th Framework Programme
GCSE	General Certificate of Secondary Education
GDP	Gross Domestic product
GEO	Geostationary Earth Orbit
GEOS	Geostationary Environmental Operational Satellite
GES	Goonhilly Earth Station
GL	Greater Lincolnshire LEP
GNSS	Global Navigation Satellite Services
GSTP	General Space Technology Programme
GVA	Gross Value Added
H2020	Horizon2020
HAPS	High Altitude Pseudo-Satellites
HEO	High Earth Orbit

HNC	Higher National Certificate
HND	Higher National Diploma
IGS	Innovation & Growth Strategy
IOC	Initial Operational Capacity
IUK	Innovate UK
JAXA	Japanese Space Agency
JEM	Japanese Exploration Module
JUICE	Jupiter Icy Moon Explorer
LEO	Low Earth Orbit
LEP	Local Enterprise Partnership
LLEP	Leicester & Leicestershire LEP
LQ	Location Quotient
MIRI	Mid-Infrared Instrument
NASA	National Aeronautical Space Administration
NERC	National Environmental Research Council
NOMAD	Nadir and Occultation for MArs Discovery
NSTP	National Space Technology Programme
OBC	On Board Computer
ONS	Office for National Statistics
PPP	Public-Private Partnership
PSA	Programme Support Action
R&D	Research & Development
SABRE	Synergetic Air Breathing Rocket Engine
SEMLEP	South East Midlands LEP
SLV	Small Launch Vehicle
SME	Small to Medium Enterprise

SMILES	Superconductive Sub-millimetre-Wave Limb Emission Sounder
SRC	Strategic Research Cluster
SSR	Sector Specialisation Ratio
STEM	Science, Technology, Engineering & Mathematics
TGO	Trace Gas Orbiter
TSTO	Two-Stage-To-Orbit
TTC	Tracking, Telemetry & Command
UKRI	UK Research & Innovation
UKSA	UK Space Agency

Foreword

The UK's space sector is vibrant, with a world-class workforce in research and industry pushing the boundaries of knowledge and understanding of our planet and universe and providing vital services in telecommunications, navigation and earth observation which underpin our daily lives.

In 2010, the space sector came together and published its first Innovation & Growth Strategy – an ambitious plan to grow to 10% of the global space market by 2030. Much of this growth is predicated on new uses of satellite data and services, but these data and services are underpinned by (and drive further innovation in) the upstream sector – the development, launch and control of spacecraft – be they in earth orbit or exploring our universe.

Established capabilities in the UK make us one of the global leaders in space technology – especially in the areas of digital satellite payloads, telecommunications satellite design and small satellites where UK is seen as a thought leader. The continued growth of our upstream space sector in the face of growing worldwide competition is fundamental to our shared aspirations for economic growth and provides a very visible indicator of UK global presence and reputation. Space, and in particular the upstream, also has an essential role in inspiring young people to become the UK's next generation of scientists and engineers, benefiting the whole of the UK economy.

The global space sector is evolving rapidly – with considerably more commercial interest and investment and a growing focus on providing low cost access to space. The space sector is already recognised by the Government as an important element of its Industrial Strategy[1] to create a more productive economy that works for everyone across the UK, with recent investments of £99m in the National Satellite Testing Facility at Harwell and £50m in a programme to enable new satellite launch services from the UK.

The sector remains hugely ambitious in its aspirations to reach its growth targets. Building upon previous work, the Space Growth Partnership, has recently published a revised Prosperity from Space[2] industry-led strategy which aims to:

- Double the value of space to wider industrial activities: from £250 billion to £500 billion
- Generate an extra £5 billion in exports and
- Attract £3 billion of inward investment

On top of this, the sector will actively encourage diversity and inclusion in its workforce by interacting with 1 million young people per year in a bid to increase interest in careers in Science, Technology, Engineering and Mathematics (STEM).

[1] https://www.gov.uk/government/publications/industrial-strategy-building-a-britain-fit-for-the-future
[2] http://www.ukspace.org/wp-content/uploads/2018/05/Prosperity-from-Space-strategy_2May2018.pdf

This first specific audit of upstream space activity has brought together a range of stakeholders from across the UK to focus on regional strengths and understand where investment and concentration of resources may fortify and prepare these assets for the future.

This audit has, for the first time, brought together stakeholders from across the parts of the United Kingdom with significant critical masses of upstream-space activity to focus on their strengths in and understand where investment and effort may fortify and prepare these assets for the future.

At the macro level, the strength of UK's space sector has historically been strongest within the Greater South East of England (in particular, Hertfordshire, Solent and M3 corridor). This Science & Innovation Audit (SIA), sponsored by the Department for Business, Energy & Industrial Strategy (BEIS), also highlights wider strengths in upstream space across the UK, a UK 'Nationwide Cluster' forming the backbone of an innovative, strong, and collaborative sector from the Central Belt of Scotland through to the Goonhilly Earth Station at Cornwall. Given the global nature of the space sector and technical excellence required within its supply chains, this SIA also demonstrates the importance of the connections within this 'Nationwide Cluster' and with the established successful industrial capability which is essential to ensure that the UK remains best positioned to be at the forefront of this global sector.

It is worth recognising that this audit is not intended at this stage to be a comprehensive national audit and is broadly confined to the geographic regions represented in the Consortium. It is therefore also recognised that key competencies within some areas are not currently included, but that future maintenance and development of this audit will expand both its geographic and technical scope.

This initial audit, then, allows us to derive some preliminary conclusions and recommendations:

- we should continue to build the connections and interactions between the strong established upstream sector and emerging capabilities from the wider 'UK Nationwide Cluster' this combination of strengths will help to position UK in new markets and fill competence gaps

- both earth observation and telecoms markets are seeing a step change, with massive increase in demand from Internet of Things; ubiquitous connectivity and 5G; and demand for fresh and accurate earth imagery from a range of sensors. The UK upstream sector must continue to build on its competences and innovation to take advantage of the coming market growth

- we should reinforce UK activities and competences for leadership of science and exploration missions – this helps to maintain strong links to the UK academic community, providing an inspirational backdrop supporting UK global reputation and development of the next generation of engineers, technicians and scientists in UK

- servicing and manufacture of space systems in orbit will become an increasingly attractive proposition in the next few years, together with the necessity to provide debris removal and other measures to protect the space environment. This is another area where UK is providing innovation and leadership – there is a critical window of opportunity to bring these capabilities to market.
- launch capability is currently missing from the UK upstream value chain – maintaining ongoing focus on launch systems is important to address a growing market and provide a holistic national capability
- The UK upstream sector must be ready to react to macro-economic changes and be able to respond by building new UK capability, driving exports and partnering globally on science and innovation.

The UK Space Agency and its partners are committed to extending this audit's geographical coverage where appropriate and maintaining it as a living document which will reflect how the UK sector is capitalising on the changes in the global sector, including, for example, new opportunities and supply chains which will develop as a result of the Government's commitment to establish the UK as a launching nation.

This audit provides compelling evidence of the sector's current strengths and vitality, as well as positioning the sector to shape the future and respond to upcoming opportunities.

Catherine Mealing-Jones
Director of Growth, UK Space Agency

1. Executive Summary

The UK has a rich and proud heritage in the global space sector. Since the 1950's UK has been an integral part of both the economic and scientific growth in space systems and space applications. From the early days of experimental satellite manufacture, UK is now producing the heart and essential systems for 25% of the worlds telecommunications satellites in what is now a mature commercial market. UK has contributed significantly as a member state within the European Space Agency, to space science, space exploration and earth observation missions, and is now a trusted prime contractor for global flagship missions such as Exomars Rover, Solar Orbiter and Biomass.

The UK has also embarked on unique and breathtaking adventures of our own, such as the iconic Black Arrow rocket, which flew successfully in 1971, to the Beagle 2, which landed on the surface of Mars in 2004. The re-invigoration of a National programme supporting future 'UK-own' and bilateral opportunities is a cornerstone of the recently submitted Space Sector Deal proposal.

Over the years the UK has had an extraordinary cornucopia of capability, demonstrating world-class expertise in a broad spectrum of fields at every step of the upstream space value chain, that process that designs, tests, manufactures and launches satellites and spacecraft, and then is able to operate them from Earth. However, in order to realise this, investments of time, effort and finance must be made across the UK's excellent industrial and academic base to ensure that these exciting developments keep pace with our competitors internationally and are effectively aligned so as to offer a sleek, coordinated suite of services and capability to our investors, users and partners.

Sky High Aspirations

Since 2000, the UK space sector has trebled in size, and grown at a rate of 8.1%, five times greater than the UK wider economy over the same period, while productivity is over three times the national sector average. Yet this is only the beginning.

In 2010, the Innovation & Growth Strategy (IGS) for Space outlined a challenging and inspirational target of growing the UK's share of the estimated £400 billion[3] global space market by 2030 from 6.5% to 10%. Space already is a UK success story; a strong presence in global commercial markets, a powerhouse of innovation, a bastion of engineering and scientific excellence, and can boast a world-class, highly productive workforce across many areas. As a result, the space sector supports 14% of UK GDP, some £250billion[4], which the

[3] Space IGS Update, July 2015, http://www.ukspace.org/wp-content/uploads/2015/07/Space-IGS-Report-Update-July-2015.pdf
[4] Satellite Applications Catapult Press Release, 11 May 2018

Space Growth Partnership aims to double to £500billion, attract £3billion of inward investment, and provide 100,000 new jobs.

To achieve the IGS targets, we must build on the sector’s core strengths and established market position, and in addition encourage companies to pursue new commercial opportunities from the UK, which offers an excellent location for space launch into in-demand polar orbits, with a world-leading satellite industry, and reputation for regulatory excellence. While the space industry in the UK is booming, much more needs to be done at pace to capture this intended market share.

The decision to leave the EU creates a particular need for agility. The UK must develop new and enduring international partnerships, while retaining the industrial corporates already embedded within the UK. We must also stimulate investment into UK businesses and attract new inward investment. The focus on facilities, innovation and skills to support rapid, volume production of mid-weight satellites in particular, is highly relevant. This in the context of Newspace trends towards constellations of smaller satellites, UK Launch status & the associated need to develop a robust supply chain, Brexit resilience and specifically the potential requirement to respond to the EU's potential abrogation of the UK's involvement in the Galileo Programme.

This audit is not intended at this stage to be a comprehensive national audit – and it is recognised that key competencies within some areas are not currently included. The Science & Innovation Audit for Upstream Space focuses on the strengths and aspirations of the regions currently covered, as well as identifying the gaps in capability, funding, skills or capacity. In doing this, it provides succour and strength to wider initiatives being pushed within the sector, such as the announcement by the Secretary of State for Business, Energy & Industrial Strategy at the 2018 Farnborough Airshow to support a Sector Deal for Space. This would firmly demonstrate support for the Space sector in this country, helping to maintain confidence and forward momentum in our established successful industrial base whilst also encouraging innovative and ground-breaking businesses and universities, so many of which are highlighted in this report.

The Science & Innovation Audit for Upstream Space will be aligned with the Sector Deal for Space to act as a call to investors to recognise the strength and depth that the UK Upstream Space sector offers – in particular in the context of the highly dynamic and growing space market where industrial and market position will become established in the next few years.

Approach

To identify the particular strengths of the UK’s Upstream Space sector, and ascertain exactly where extra value could be added, and how returns on investment could be maximised, we have adopted a three-pronged approach to this report.

Regional Engagement

The Partner Board is comprised of representatives from each of the seven geographical regions that make up the Consortium Partner Board, and which possess established or nascent Upstream Space activity. These representatives have gathered intelligence from their regional space networks relating to how local organisations have engaged with national and international partners, participated in international projects, programmes and missions, and have drawn down funding from various sources. They have also been able to provide data relating to the wider local economy and the availability of local assets and facilities pertinent to the Upstream Space sector, such as testing facilities.

Consultancy

The Partner Board has engaged with Technopolis and London Economics, for their expertise in, respectively, understanding the geographical caches relating to the Science & Innovation Audits, and understanding the segmentation and make-up of the space sector itself. London Economics are contracted by the UK Space Agency to deliver the biennial report *Size & Health of the UK Space Sector*, which was last printed in 2016, and delivers the definite high-level snapshot of the UK sector, offering invaluable breakdowns of upstream and downstream segments.

Market Reports

While consultancy has enabled us to drill down into the detail of the UK sector, we have procured a number of commercial reports in order to gain an overall view of the global factors pertinent to upstream space. The Satellite Applications Catapult have released a series of reports of the state of the small satellite market, while market research company BIS Research have conducted in-depth reviews into the state of the small and nanosatellite markets, as well as the small launch vehicle markets, while references to public domain material by Euroconsult are made. Further internal desk research has been undertaken in the areas of Earth Observation and Satcomms (Satellite telecommunications), the latter of which remains the driving force behind the majority of the sector, and which provides the lion's share of its energy and revenues.

Using this three-way approach we have identified the direction of travel for the existing and emerging upstream markets, and where research funding from the various funding sources is directed. Revenues in the upstream space sector come from (a) the commercial market – typically via major satellite operators such as Inmarsat, Eutelsat, SES etc; (b) institutional customers, primarily ESA and the EU; (c) government customers for defence and civil applications. A new customer base is emerging based around ‘new space’ entrepreneurial individuals and companies which may grow rapidly as a complement to existing owners and operators.

We have analysed the various technology domains where the UK is already playing a significant role and / or where funding has been directed for UK organisations, , and have sorted them into four domains:

- **Satellites & Vehicles**
  The platforms, spacecraft and their subsystems that are launched into space to perform tasks and provide services back on Earth. There are various types and sizes of satellites, with the UK exhibiting particular thrust and momentum in the core telecommunications and small satellite market. The UK has excellent facilities for the design, manufacture and testing of satellites at all stages of its development, but we are not the only nation with such sovereign capability. In a fast-changing market, investment must be made to ensure that what we have remains the best in the world, and ensuring our burgeoning small satellite industry is protected by creating robust regulations that are aligned with the UK’s developing launch capability.

- **Access To Space**
  Satellites, once tested and assembled, need to get to space. This requires particular infrastructure to act as a launch base, and also a launch vehicle which can carry the payload of satellite(s) into space. Currently the UK does not possess sovereign capability in this area. However, the UK now is accelerating towards provision of both of these services and capabilities. Protecting and developing testing facilities, such as the Westcott National Space Propulsion Centre, which has become a cluster of critical national strategic importance, is vital if the UK is able to nurture its own value chain into something that is robust, globally competitive and gives the UK a unique point of service for satellite users from across the world.

- **Ground Segmentation**
  Once in space, satellites require monitoring, management and operation from Earth. The Ground segment provides this. The UK has a small number of Ground stations and significant expertise in ground systems software and systems integration, but there is a need to grow capability to meet the technical demands of emerging satellites and spacecraft. Investing in the technologies and infrastructure required to enable increased connectivity, and cope with increased numbers of communications and TTC from constellations is a huge market need.

- **Enabling & Exploration Technologies**
  In orbit servicing; in orbit manufacture and protection of the space environment are fast becoming a necessity as well as an emerging commercial market. Technologies for robotics; refuelling; and engaging with active or inactive satellites are key for the

future. Similar underlying technologies are required for exploration missions involving planetary rovers and robots. The UK has globally recognised expertise in these areas. However, it is also a highly competitive market, and great effort must be made to ensure that certain facilities and infrastructure, which could offer not only world-class capability but also external streams of revenue for the space sector, are not left to wither on the vine.

These domains are explored in greater depth in the latter half of this report.

2. Introduction

Space helps us understand the world, turns our minds to the future, and keeps us thinking. It changes on a daily basis.

Every day Earth Observation satellites are sending down new information about the Earth's forests and cities, its deserts and farmlands, helping us plan for today and for tomorrow. Telecommunications satellites provide essential global connectivity enabling internet connectivity, TV broadcast and mobile telephony to centres of population and remote areas. Satellite navigation systems serve individual consumers and provide precise timing signals for banking and other applications. Satellite systems are vital for defence and security and contribute widely to safety of life.

Space inspires young people to take an in interest in science and engineering. A million UK children took part in projects inspired by Astronaut Tim Peake's Principia mission to the International Space station – including writing space diaries of their own, growing rocket from seeds that had been to space and building space buggies. For some of those children this may even be the start of a career in science, engineering or related fields; physics undergraduates consistently rank an interest in Space as one of the main reasons for studying the subject[5].

In the long term, space exploration may bring untold benefits. In 2010 Stephen Hawking said that he believed that 'the long-term future of the human race must be in space'.[6] If our destiny truly lies beyond the Earth, then further investment into Upstream will be the means by which this exhilarating process is accelerated, and finally realised.

The Upstream space sector is currently enjoying a major boost in visibility and ambition thanks to the efforts of visionary American company SpaceX and its founder, Elon Musk, amongst others. The company has attracted approximately 20% of its overall funding income from private investors such as Google, Fidelity, Draper Fisher Jurvetsen, Founders Fund, Valor Equity Partners and Capricorn. SpaceX has developed from having a 0% share of the satellite launch market in 2012 to an incredible projected 64% of the same market in 2018.[7] SpaceX and like-minded companies are helping to stimulate new markets, changing thinking across the established space ecosystem, and bringing new private investors – albeit

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[5] The Case for Space: Space Derived Impact and data, Oxford Economics, 2009

[6] I believe that the long-term future of the human race must be in space," Hawking said in a& 2010 interview with BigThink. "It will be difficult enough to avoid disaster on planet Earth in the next hundred years, let alone the next thousand, or million."

[7] Taken from testimony of Tim Hughes, Senior VP for Global Business & Government Affairs, SpaceX, to the US Senate Subcommittee on Space, Science & Technology.
https://www.popularmechanics.com/space/rockets/a27290/one-chart-spacex-dominate-rocket-launches/

that much of their expansion is underpinned by major US Department of Defence and institutional commitments as a way to foster innovation and reduce their own risk.

With all this in mind, it's clear that there are significant market, industrial and investment dynamics which have potential to impact Upstream Space. UK has significant attractions to respond in this environment (including a flexible and open regulatory regime) – further actions that can harness UK strengths will help to sustain market position and capitalise on growth forecasts.

2.1. BENEFITS OF UPSTREAM SPACE

Market forecasts indicate that downstream applications will be the major source of economic growth in the space sector in the coming years[8]. However, strong presence in the upstream sector is essential to secure a 'virtuous circle' of capability across the value chain. The detailed knowledge and competence that comes from upstream engagement underpins the development of standards and operations that are the basis of downstream end user applications.

For example, mastering the technology for space-based digital payloads allows a direct understanding of satellite operator needs for power and bandwidth flexibility, and being able to optimise this in an upstream design solution can prove decisive in a global competitive environment. Similarly, radar system competence is directly relevant to support delivery user applications related to surveillance, climate change and flood management.

The UK is a thought leader in downstream space-based applications, and it has a strong established upstream and emerging innovative capability. Continuing efforts to maintain and build this 'virtuous circle' in the UK will help to grow market position in the face of increasing global competition.

Upstream Space delivers a range of services to both public and private customers and users, bringing scientific and economic benefits and providing critical information to the security, meteorological and environmental sectors.

It provides infrastructure on which modern society depends. From multinational businesses such as Sky and Uber, to local farmers who use satellite data to help manage their crops, the products of upstream space have been developed and exploited to create capabilities that have become a part of everyday life. This will only increase as our understanding of how to use space data improves, enabling us to face ever more complex challenges, both on Earth and beyond.

[8] https://www.gov.uk/government/publications/space-growth-action-plan

In the science and planetary exploration domain, Upstream Space is what enables scientific investigation and pioneering. The engineering and manufacturing capabilities that have supported missions such as Rosetta, Mars Express, and Lisa Pathfinder have ensured that the science instruments are delivered safely into space, provided with resources to allow experiments and investigations to continue in the harshest of environments throughout the satellites' lifetime. Having major roles for this kind of mission in the UK allows close links to UK scientists, development of the UK supply chain and the ability to inspire young people through outreach and public media. Finally, upstream space has an almost unique ability to excite and inspire young people – our next generation of scientists and engineers not just in the space sector but across the whole UK economy.

2.2. HYPOTHESIS

Upstream Space is a maturing sector which is operating at levels of productivity higher than national average and generating substantive economic value as well as significant contributions to scientific and educational endeavour. The sector is facing a very dynamic market with high potential for growth and a complex external environment in the context of Brexit, global commercial competition and changing European institutional landscape.

As private sector companies continue to gather a foothold in growing upstream markets such as satellite launching, and emerging future markets such as exploration, construction, infrastructure assembly and mining, there is a unique opportunity for engineers, researchers, businesses and investors to get in on the ground floor.

The UK upstream sector has major assets that can contribute towards future success, relying also on cutting edge innovation, business entrepreneurship, export support, skills development and targeted investment to maximise potential of the collective UK effort. The Space Growth Partnership, in its Prosperity from Space strategy, has published proposals aimed at focusing the next steps to build future success. It is an extremely research-heavy sector at the cutting edge of the scientific and engineering arena. It returns value not only to the scientific community, but also economically, and is one of the very few sectors that continually and effortlessly captures the imagination of the public.

Harnessing diversity

The upstream space value chain across the UK has a wide range of diverse capabilities, all of which contribute to a thriving current industry base and help prepare for the future.

The UK Space Landscape created by the InnovateUK-funded Knowledge Transfer Network (http://space.ktnlandscapes.com/) reflects the following space manufacturing ecosystem:

- 1 complete space systems manufacturing organisation

- 40 companies involved with satellite and payloads manufacture
- 29 companies involved with launch vehicles and subsystems
- 19 ground systems and equipment suppliers
- 109 suppliers of materials and components
- 13 scientific and engineering support companies
- 4 providers of scientific instruments

This spread of capabilities includes a range of companies from a large system integrator with over 3500 staff to SMEs and start-up entrepreneurial businesses.

Connections exist within the community both on an operational project basis and through organisations such as the UKspace trade association. In recent years initiatives such as the Knowledge Transfer Network and UK Space Conference have helped to publish and promote UK industry and encourage interaction and mutual support. However, it is essential for future success that the connections within the wider 'UK Nationwide Cluster' and with the major established industry players are developed and targeted in the best interests of UK

Given the uncertainty in certain trade positions internationally, strengthening the UK's upstream capacity would help to maintain and grow the UK position as a viable and attractive service provider to international customers in emerging markets. For instance, the emergence of commercial spaceflight as a market is both being driven by and supports the development of new capabilities enabling greater access to space, the efforts in establishing at least one UK spaceport, and the evolving capability on the ground in mission management and satellite operations. Meanwhile, UK expertise in autonomous software development, satellite and payload manufacturing will support a whole raft of emerging upstream applications, such as on-orbit servicing, satellite assembly, and reconfiguration, resulting in new downstream markets and sources of revenue. And the UK's network of world-class systems-engineering and testing facilities must be exploited and better connected to enable every step of technology development, maturation, and testing; what's more, these facilities offer excellent potential for service provision to other sectors, which could provide a further stream of income.

Leveraging government investment to unlock private growth

To date the upstream sector has effectively leveraged institutional R&D investment to build strong positions in commercial markets. Notable examples include investment in telecoms satellite platform and payload technologies which has helped to position Airbus in UK as a major provider generating export revenues of the order of £300-400M pa. Historically UK government has channelled its institutional investment largely through ESA, taking advantage of shared investment with other space powers and using the expertise and programme management capability of the ESA organisation. This remains an extremely valuable and effective route to develop UK capability in all space sectors.

The recent joint working within the ‘Space Growth Partnership’ has resulted in a number of recommendations encapsulated in their “Prosperity from Space”[9] strategy document including a National Space programme which would complement the European institutional investment and further stimulate the upstream sector.

Whilst it is still expected that institutional investment will remain important to the sector as it continues to mature over the coming years, there is clearly increasing appetite for private sector investment in space. This is coming for example from ‘new space’ entrepreneurs and venture capitalists interested in the future commercialisation of space infrastructure, operations and services. The development of an attractive regulatory regime in UK to encourage inward investment has been a recent focus – efforts in this direction should be maintained to keep UK competitive advantage vs other space nations.

We therefore believe that every effort should be made to:

- Showcase the economic benefits of Upstream Space to potential inward investors
- Increase investment from both private and public sources to protect new infrastructure, such as test centres and spaceports, and to enable the fundamental and applied R&D activities to continue to thrive
- Continue to build connectivity and mutual support across the whole UK upstream sector, including established global players and the wider ‘UK Nationwide Cluster’
- Yet ensure activity at these individual, regional clusters, is doubled down and retains focus. Clusters grow organically, quickly and attract inward investment more effectively.
- Maintain R&D intensity through a dedicated and stable funding base for space manufacturing and ground segmentation technologies, and create the conditions in which companies are able to confidently re-invest in R&D.
- Support the UK’s shaping of new markets through improved awareness raising of emerging technologies that will plug the gaps in the UK’s value chain and drive down satellite manufacture costs to drive down the cost of downstream services
- Develop unique, strategic, industrially-focused infrastructure, such as the LOCAS (Low-Cost Access To Space) facility, with the potential to anchor business investment, and accelerate UK technical and manufacturing / production capability for ‘newspace’ markets.

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[9] http://www.ukspace.org/wp-content/uploads/2018/05/Prosperity-from-Space-strategy_2May2018.pdf

2.3. THE SPACE SECTOR

The UK Space Sector had a total income of £13.7billion in 2014/15, but economic analysis suggests that the wider UK GDP supported by satellite services (such as telecommunications, navigation, Earth observation, meteorology) exceeds £250bn[10]. As such, space is designated as constituting part of our critical national infrastructure[11], and is a crucial part of everyday life without ever being visible by the people who take advantage of the numerous services it provides.

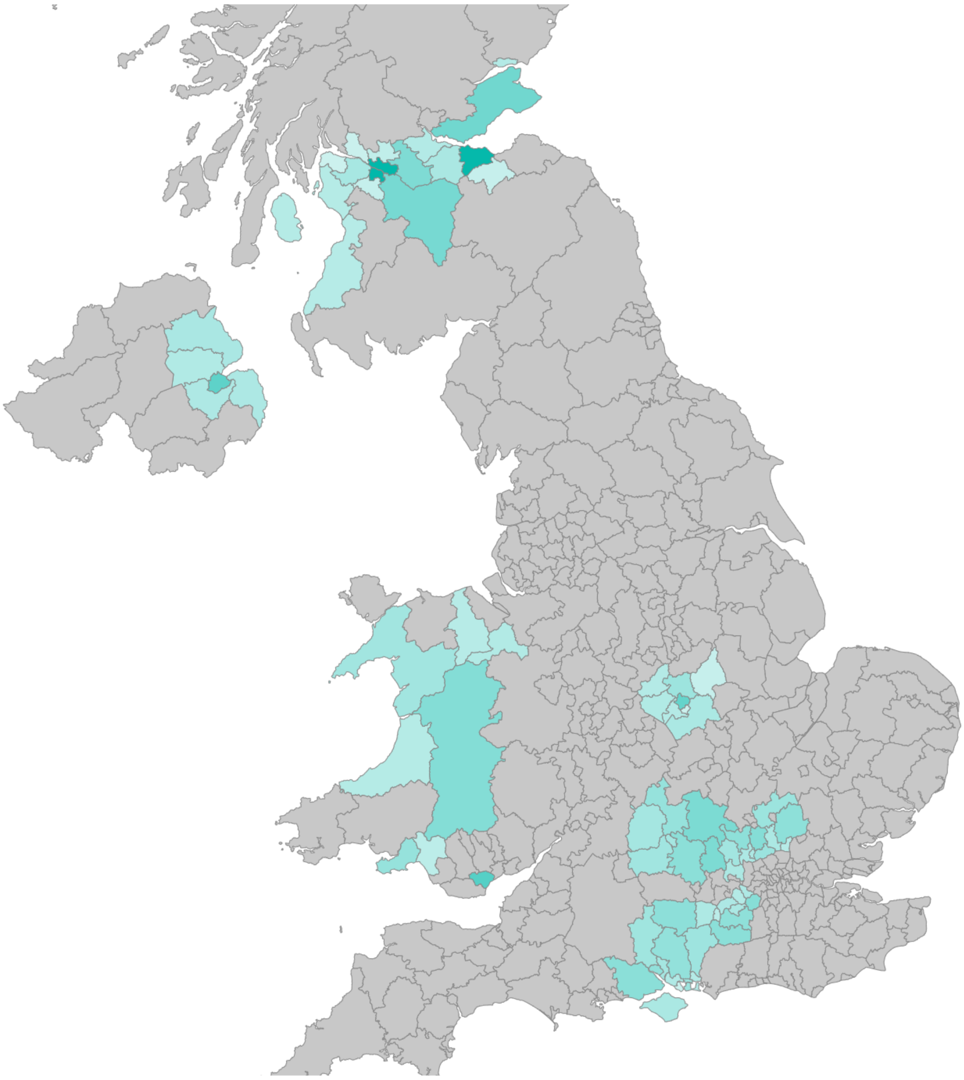


Image 1: The UK has a healthy and growing space sector. Whilst there is upstream space activity across much of the UK, this SIA covers the green highlighted regions.

[10] London Economics, The Size & Health of the UK Space Industry, December 2016

[11] The UK's critical national infrastructure is defined as: "Those critical elements of infrastructure, the loss or compromise of which could result in: a) major detrimental impact on the availability, integrity or delivery of essential services… and/or b) significant impact on national security, national defence, or the functioning of the state". Source: CPNI - http://www.cpni.gov.uk/about/cni/

WHAT IS UPSTREAM AND DOWNSTREAM SPACE?

The space sector is divided into two complementary segments. The segment that makes and sends objects (satellites, probes, spacecraft and rovers) into space is conventionally called "Upstream". The segment that uses these objects to deliver products and services on Earth for largely commercial (but also environmental and scientific) exploitation, such as telecoms, is called "Downstream". The upstream segment overwhelmingly consists of space manufacturing: the design, manufacture of spacecraft, payloads, systems, subsystems, and components, and the infrastructure required to launch and operate them from Earth. This Science & Innovation Audit focuses on that Upstream Segment.

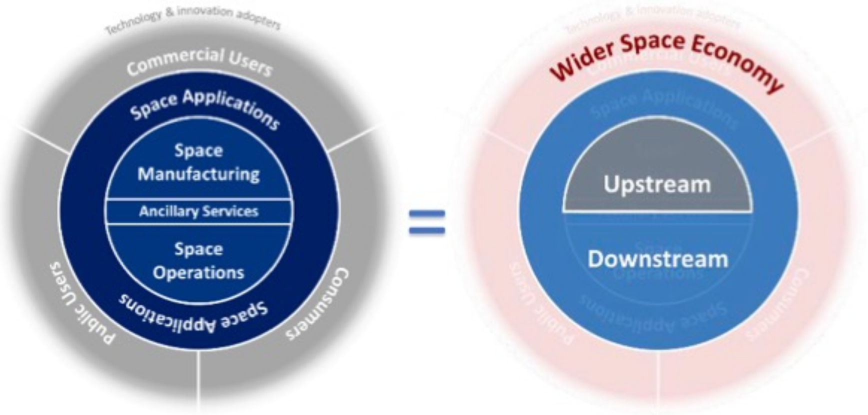


Image 2: where upstream and downstream sit in the wider space economy. Image credit: London Economics.

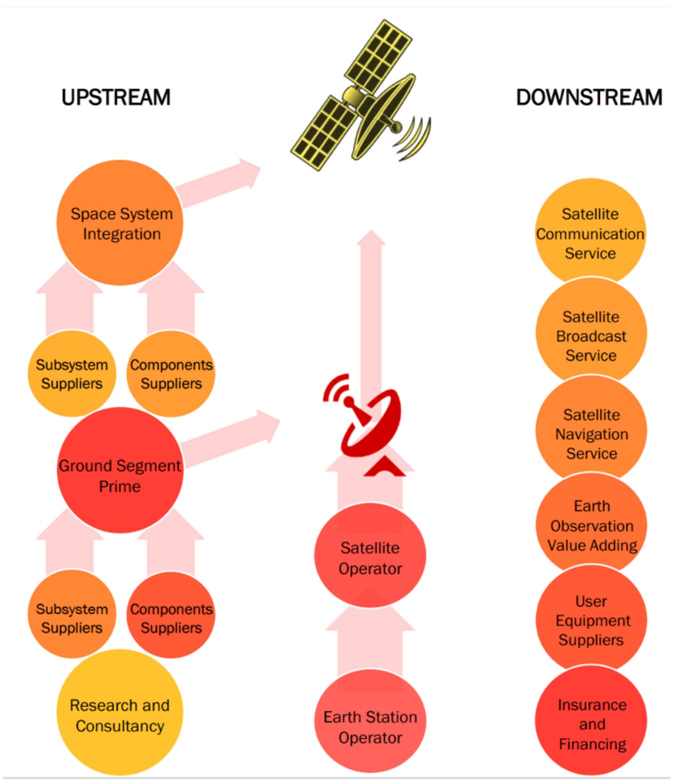


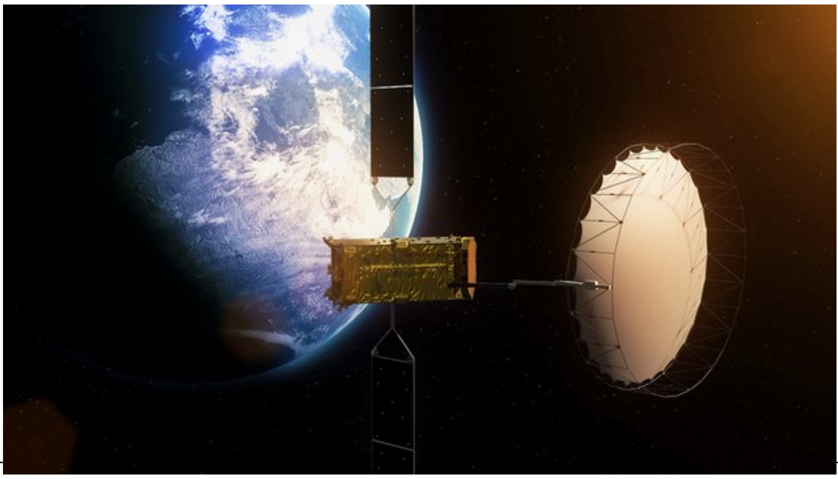
Image 3: The relationship between upstream and downstream. Image credit: UK Space Agency & BIS Research

The Virtuous Circle

The relationship between the Upstream and Downstream Segments is sometimes referred to as a "Virtuous Circle," owing to the complementary benefits each segments brings to the other. The most notable benefits brought to the Downstream segment by the Upstream segment are through the demonstration of new technologies operationally.

> For example, Satellite communications was one of the first commercial applications of space technology. In the early sixties **AT&T** developed the TELSTAR system whilst **NASA** contracted them for the RELAY and SYNCOM systems. In 1964 the International Telecommunications Satellite Organization (INTELSAT) was formed to deliver telephone circuits and TV services. Later, in 1979, **INMARSAT** was formed as the International Maritime Satellite Organization to provide safety services and communications to global maritime users. It became the first international satellite organization to be privatized in 1999, with Intelsat following in 2001. Today, a range of private satellite operators provide global communications and television to homes, businesses and mobile users. Each new generation of satellites brings new applications, such as ultra-fast internet on aircraft. Many of these technologies and services start as experiments in partnership with space agencies. The Alphasat mission, for example, allowed **Airbus** to demonstrate advances in digital signal processing which enables the finite RF spectrum resource to be re-used many times over to drive down costs per user. This technology is now being incorporated on the current generation of satellites including for Inmarsat.

The circle is completed when demand from downstream markets – such as requirements for higher sensitivity or resolution of data or reduced revisit times drives innovation back into the upstream. Improvements in technology drive new services – and the desire to improve these services fuels new developments in technology.



2.4. UPSTREAM SPACE – UK STRENGTHS

As Chapter 3 sets out in more detail, there are hotspots of Upstream Space activity across the UK. Together, these make up an Upstream Space Nationwide Cluster that is stronger together, while each retaining a unique regional suite of expertise and capabilities. This UK capability is able to capitalise on a number of unique UK assets:

Excellent research and support connections between industry and academia.

As so much of what Upstream space does is at the cutting edge of science and technology there is continual collaboration between business and academia. UK industry's strength here is built on a corresponding strength in UK universities, particularly in engineering, physics, meteorology and climate science. There is a constant flow back and forwards between the two sectors – of staff, of ideas and of work.

International collaboration

The UK Upstream Space Sector is deeply intertwined with its counterparts in the EU and further afield. This is true on an individual level – with people from across the world working in the UK sector and UK citizens gaining experience and skills from working abroad. The sector relies on an exceptionally highly educated and internationally mobile workforce.

The UK is one of the largest members of the European Space Agency – a collaboration which enables UK researchers and industry to participate in larger-scale missions than the UK would be able to affords on its own. In December 2016 the UK announced an allocation of more than €1.4 billion over the next five years to European Space Agency programmes covering, amongst other projects, the Biomass mission to measure the carbon stored in the world's forests; and the next phase of the ExoMars programme – a UK-assembled rover to answer the question of whether life has ever existed on Mars.[12]

The UK is also well placed to develop links outside Europe – notable successes include Surrey Satellite Technology Limited's relationship with China[13]. Development of existing and new relationships will be key to achieving the sector's ambitious growth and export targets. upstream sector growth in a post-Brexit environment. The sector is already working closely with the Department for International Trade (DIT), including through high value campaigns to the United States.

Whilst there will always be strong global collaborations (and supply chains) within upstream space, opportunities do exist for the UK to explore how much of this activity could be attracted to or developed in the UK.

[12] https://www.gov.uk/government/news/uk-commits-to-european-collaboration-on-science-and-exploration-satellite-technology-and-services

[13] https://www.sstl.co.uk/media-hub/latest-news/2018/sstl-and-21at-announce-new-earth-observation-data-

Collaboration between regions:

The areas covered in this audit are not the only places in the UK where good work is being done in Upstream Space, but together they form a UK 'Nationwide Cluster', the backbone of an innovative, strong, and highly interconnected and collaborative sector.

Attractive Regulatory Environment:

But there are other reasons why the UK is well-placed to provide newspace companies with the opportunity to succeed. Throughout recent history, the political and economic climate has been relatively stable and straightforward to navigate, while the UK is renowned for having regulatory excellence and a strong civil service complementing and supporting industry.

Skilled Workforce:

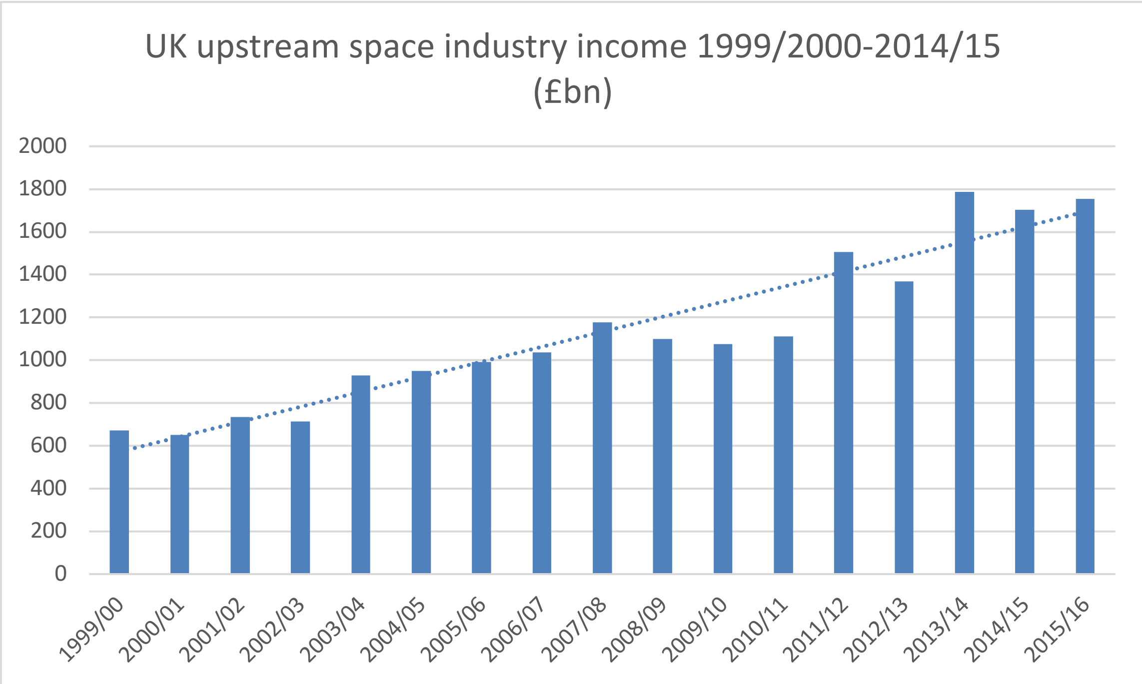
From a workforce perspective, the UK is respected throughout the world for having a highly capable and innovative community of scientists, engineers, innovators and businesspeople. This blend of skills is vital if the UK wants to realise its ambitions within the growing and emerging upstream space markets, and the wider IGS targets for 2030.

2.5. UPSTREAM SPACE –ECONOMIC CHARACTERISTICS

The UK's Upstream Space Nationwide Cluster is diverse, including both larger companies and a well-established supply chain of universities, smaller businesses and research institutes.

In 2016, the Upstream segment of the UK space sector had an income of £1.7bn (representing 12% of the total UK space industry) – having shown compound annual growth of 6.5% per annum since the 1999/2000 financial year.[14]

[14] UKSA, Size and Health, 2016.



Note: 2015/16 forecasted based on survey respondents' forecasts and analysis of annual reports.

Source: Derived from London Economics analysis, The Size & Health of the UK Space Industry, December 2016

Total employment (headcount) in the UK space industry indicated 38,522 jobs in 2014/15 having grown at a rate of 6.0% per annum since 2012/13 – more than three times greater than the employment growth rate in the overall UK economy (CAGR of 1.8%). Of this total, 8,575 jobs were in the upstream – which has outperformed the sector's growth with a CAGR of 7.7% per year over the same period.

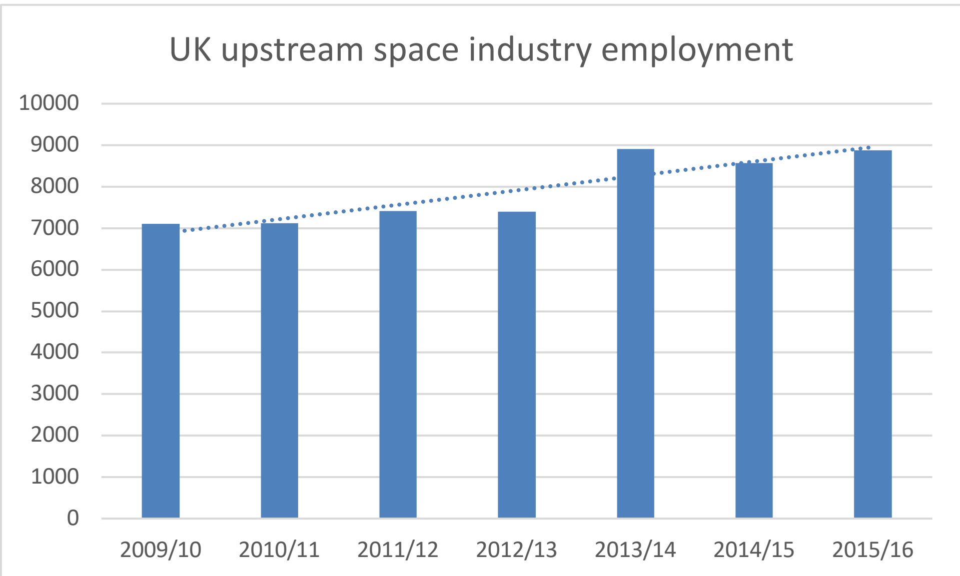


Table 1: Note: 2015/16 forecasted upon survey data and analysis of annual reports

Labour productivity for the upstream sector is £75,950 per employee – which reflects the sector's highly-skilled workforce. Within the space sector, most employees have undertaken university education, with 74% of employees possessing at least a first degree, 15% holding higher vocational qualifications and the remaining 11% having other qualifications, including space-specific diplomas gained in ESA or other settings.

As measured by the 'share of employees holding a higher degree, first degree or HNC/HND and equivalent qualifications', the average qualification level of space industry employees is higher than any sector covered by ONS Census data for England and Wales – and this applies both for the wider sector and the upstream segment.

The sector as a whole invests the equivalent of 8.1% of direct GVA in R&D against a UK economy average of 1.2%. R&D expenditure in 2014/15 stood at £415m or about 3.0% of total income in the industry. The Space Manufacturing segment is most R&D-intensive, reinvesting 14.3% of income on R&D; 62% of this R&D funding is sourced externally (i.e. research grants). This reflects the wider benefits accrued in the downstream space sector which rely upon innovation in the upstream.

Upstream GVA has experienced significant growth (both in nominal and real terms) since 2012/13, exhibiting a real compound growth rate of 18.0%.

While this report focuses upon the upstream segment, it is worth noting that the wider, general economy has been showing increased interest in downstream space applications, research and services. This then acts as another driver for the upstream segment, and also ensures that the upstream hotspots are well connected to other, downstream-focused parts of the country, as well as internationally, because space is a necessarily international, necessarily collaborative field of endeavour.

THE MULTIPLIER IMPACT

Space sector organizations source goods and services from UK-based companies outside the space industry and so generate activity in the rest of the economy (known as the 'indirect impact'). Individuals employed in the space industry and its suppliers spend their earnings in the UK, stimulating additional economic activity (the 'induced impact'). Together these impacts are known as the industry's **multiplier impact.**

The 2012 Size and Health of the Space Sector survey estimated the UK space industry's value-added multiplier to be 1.99 and its employment multiplier to be 3.50 – with the discrepancy explained by the industry's high productivity when compared to the UK average.

[15]

Upstream Space companies in the UK are serving both the institutional market (largely through the European Space Agency (ESA), and European Union) and also major commercial satellite operators such as Inmarsat, Eutelsat, SES, and Intelsat.

This established business model and customer base is continuing to evolve as the more mature commercial models of the satellite communications market begin to be adopted in domains such as earth observation.

- The 'newspace' revolution has already seen private sector upstream organizations – which are just as likely to attract funding from venture capitalists as from conventional agency sources – take the decision to make major investments in space.
- Costs are coming down. Classical geostationary satellites are now available with major increase in capacity (so called 'Terabit' spacecraft) thanks in part to the adoption Electric Orbit Raising (EOR) technology. Low Earth Orbit satellites in particular are getting smaller, cheaper and easier to launch, with cubesats and nanosats revolutionising the market.
- New capabilities such as Industry 4.0, which is shorthand for the introduction of new robotics, Artificial Intelligence (AI) and automated technologies into the manufacturing chain, should enable new manufacturing entrants and SMEs into the Upstream segment.
- Public-Private Partnerships (PPP) are predicted to become a more prominent model for a range of applications including 'new space' constellations for telecoms and earth observation.

[15] UKSA, Size and Health of the Space Sector, 2012.

The UK Value Chain

Thanks to the 2018 Space Industry Act British businesses will soon be able to compete in the commercial space race using UK spaceports. This ensures Britain will be capable of launching small satellites and scientific experiments from our own soil. This has the double advantage of enabling the UK to launch its own satellites and payloads for launch, but also offer a competitive service to other nations wishing to put their own spacecraft into orbit. Furthermore, the UK foresees launch capability taking advantage of emerging and future capabilities like hypersonic flight and high-speed point-to-point transport.[16] The unique and game-changing jet-rocket-hybrid SABRE (Synergetic Air-Breathing Rocket Engine), being developed by Oxfordshire-based **Reaction Engines**, will be a crucial element of this new market, which has the potential to impact the world in the same way as commercial aviation did in the first half of the twentieth century.

The UK Space Agency's Spaceflight Programme will help UK spaceports access a global market for launching small satellites worth £10 billion over 10 years and offer low gravity flights to advance cutting-edge science.[17]

However, public funding streams for Upstream space will still have an important role to play, driven by an intrinsic link between the need to procure proven technologies in platforms that will transport novel payload technologies into space. There are important positives from this. Having ESA as significant customer means that the UK Upstream industry can rely on a visionary and long-term source of funding. This in turn makes Upstream more attractive to investment, e.g. from venture capital.

In turn, we may see the competition/collaboration between public and private sectors leading to important new developments. For example, ESA's remit to advance science led it to land the Philae rover on a comet – and private sector companies are now working towards asteroid mining.

[16] https://www.gov.uk/government/news/new-laws-unlock-exciting-space-era-for-uk

[17] https://www.gov.uk/government/news/uk-space-launch-programme-receives-50-million-boost-in-governments-industrial-strategy

3. The UK Nationwide Cluster

This Upstream Space Science & Innovation Audit Report was initially conceived as consortium of Local Enterprise Partnerships (LEPs) wanting to effectively capture the Upstream Space capabilities in their regions. Because of this, the UK Nationwide Cluster captured in this report is not intended to reflect the UK's upstream capability in its entirety, but reflect those regions involved in its creation.

It remains the intention of the sector to use this initial audit as a foundation upon which to eventually build a holistic and comprehensive audit of the UK's capability in Upstream Space, and create a powerful picture of the Uk's end-to-end value chain.

This initial audit comprises seven distinct regions from across the UK: the Oxfordshire-Cambridgeshire and Hertfordshire corridor, the M3 Corridor and Solent, the Greater East Midlands, Scotland, Wales, and Northern Ireland. All three Devolved Administrations and a growing number of LEPs (including Hertfordshire, Leicester & Leicestershire, Enterprise M3, Oxfordshire, Buckinghamshire Thames Valley and Cornwall & Isles of Scilly) have recognised space as an important growth opportunity to their local economies.

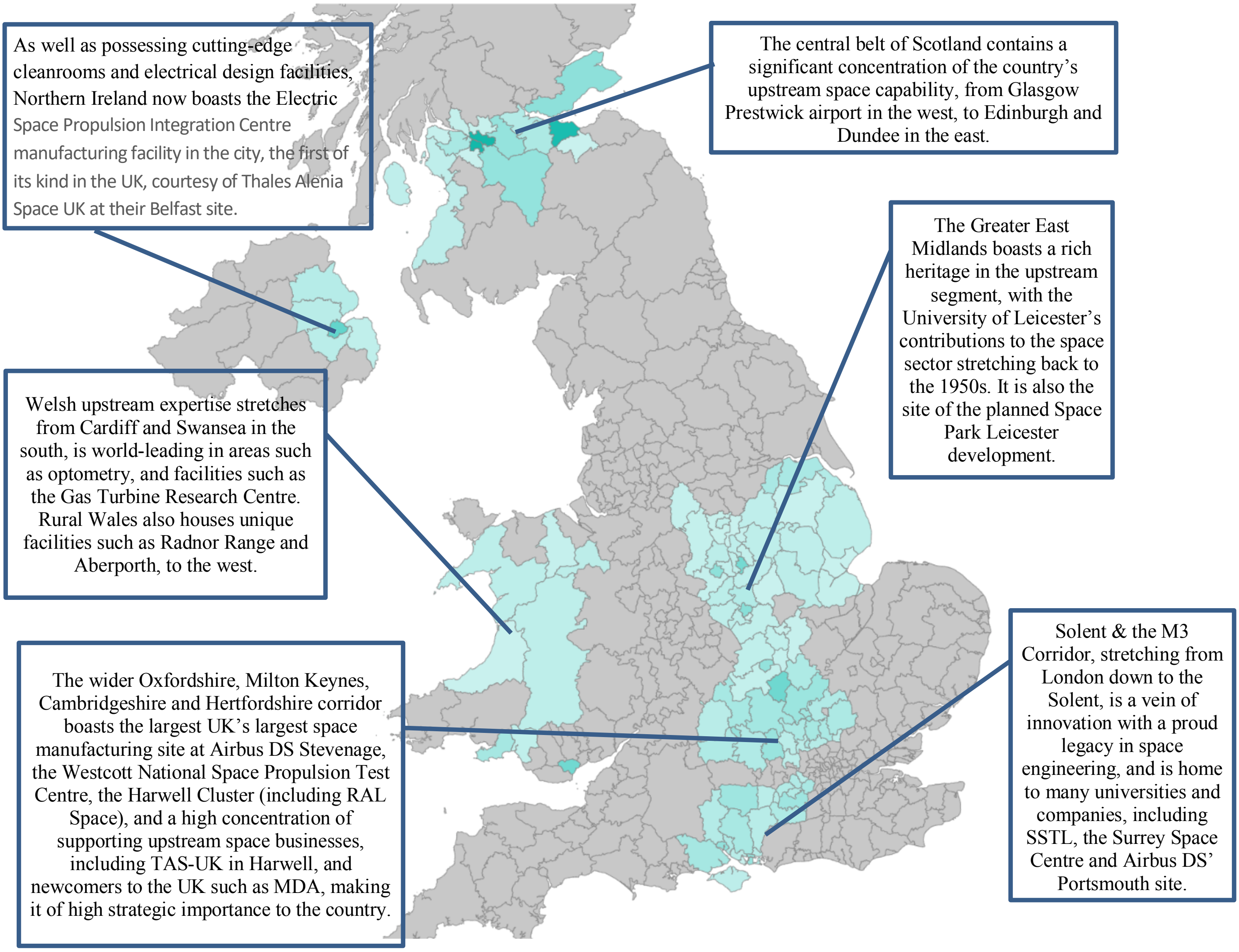


Image 5: Map of the UK, highlighting the regions making up the Upstream Space "UK Nationwide Cluster"

The Greater East Midlands, Oxfordshire-MK-Cambridgeshire Growth Corridor, Harwell Hub and Hertfordshire

At the heart of the UK, the **Greater East Midlands** (defined by 4 Local Enterprise *Partnerships- LLEP, D2N2, GL & SEMLEP*) has a GVA of £98Bn, underpinned by a strong industrial base and science and innovation infrastructure. The region's economy has a high proportion of manufacturing (16.5% of GVA[18]), including strengths in transport equipment and food and drink. The transport equipment manufacturing sector in the region includes aerospace, automotive and rail, and is 40% more productive in the East Midlands than for the UK as a whole -the sector employs over 26,000 people.

[18] European Commission, Regional Innovation Monitor Plus, East Midlands, https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/base-profile/east-midlands

The Greater East Midlands major cities and urban centres are Leicester, Nottingham, Derby, Northampton, Lincoln and Milton Keynes. GEM is at the heart of the UK's strategic transport network. The regional strategic road and rail networks such as the M6, the M1, the East Coast Mainline and the Midlands Mainline are of national importance. East Midlands Airport is second only to Heathrow in the volume of cargo flown each year.[19]

The region has a strong history of industrial innovation, from the world's first factory at Cromford Mill in Derbyshire (now a World Heritage Site), to development of the jet engine by Frank Whittle. Today, the GEM is home to some of the country's most innovative businesses (including Rolls-Royce, Siemens Industrial Turbomachinery and Alliance Boots) and its level of R&D expenditure is above the national average.[20] The GEM's ten universities are major players in the national research landscape, with strengths including space science, engineering and biological sciences. Other important players include the British Geological Survey, the Health and Safety Laboratory and six science/innovation parks.

The Greater East Midlands has a cluster of nationally important space activity. The University of Leicester enjoys worldwide recognition for its international research in space science, planetary exploration and earth observation science. Space Park Leicester is being developed as a science and innovation hub. The University of Nottingham is a world leader in space-based applications of position, navigation and timing, and hosts the UK national centre of excellence for GNSS. The National Space Centre in Leicester is a £60m science visitor centre attracting over 200,000 visitors annually, with over 10,000 students and their science teachers participating in the National Space Academy programmes and other space education initiatives (some of which are globally exported). GEM is also home to Space @ OU (Milton Keynes) with the Centre for Electronic Imaging (detector for Gaia, Euclid, JUICE), and the proposed Blue Abyss test and training centre for commercial aquatic and space research.

Westcott (located in an overlap between SEMLEP and BTVLEP) is home to an important cluster of chemical propulsion companies who also provide facilities for the propulsion research base. The UK Space Agency is funding development of the National Space Propulsion Test Facility at Westcott to provide new national facilities that support this important component of the upstream space sector.

[19] East Midlands Airport, About Us, Cargo, https://www.eastmidlandsairport.com/about-us/cargo/

[20] European Commission, Regional Innovation Monitor Plus, East Midlands, https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/base-profile/east-midlands

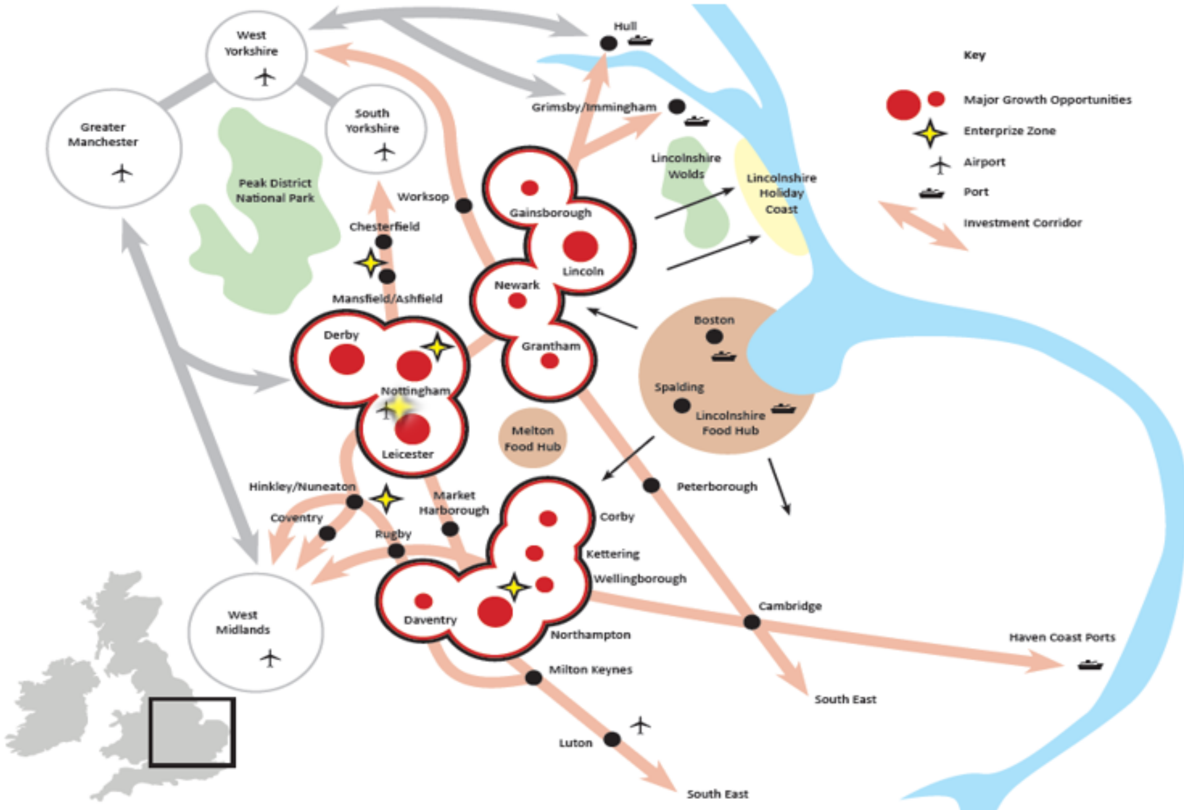


Image 6: Map of the Greater East Midlands, its main metropolitan areas and connections. Source: East Midlands councils.

Oxfordshire has long been world-leading centres for research and innovation across a wide range of technologies and sectors. It contains Oxford University, ranked number 1 in Europe for both research and commercialisation, large government investments, with over £2billion in internationally leading scientific facilities, especially at Harwell and Culham. Oxfordshire also possesses leading industry clusters in space and satellite applications, life sciences, scientific instrumentation and motorsport, and the largest investment fund for university spin-outs globally.

The University of Oxford ranks 1st in the world 2016-17 according to the Times Higher Education Supplement rankings, and 1st in the UK in 6 of the 15 science subjects in the Research Excellence Framework 2014. Within the county there are 14 national institutes and organisations, including the Satellite Applications Catapult, and five high-tech companies worth over $1billion. Overall, the area contains 33,000 enterprises, and the city of Oxford is the UK's 5th highest density city for digital technology businesses by turnover and has the 6th highest proportion of high-growth companies.

The University of Oxford is ranked 1st in the UK for Mathematical sciences; General engineering; Physics (by research output); Clinical medicine; Public health, Health services & Primary care; Psychology, Psychiatry and Neuroscience; Social work and Social policy; Philosophy; Earth systems and Environmental sciences; and 2nd for Electrical and Electronic engineering, Metallurgy and Materials - all subject areas which underpin the region’s excellence in developing and deploying quantum computing technologies, space-led data applications, autonomous vehicles and robotics, and digital health technologies.

At **Harwell**, the Rutherford Appleton Laboratory’s Space Science group (RAL Space) employs around 200 staff working on world-leading research and technology development, space test facilities, instrument and mission design, and studies of science and technology requirements for new missions. RAL Space has been involved in over 200 space missions. Much of their work is in collaboration with UK and international partners – and much of their funding is through external grants and contracts.

RAL Space’s space testing facility is located at the R100 site on the Harwell campus. The building is being developed and occupied in a phased approach. Phase 1, which expanded the RAL Space test facilities including two new 5m diameter Space Test Chambers along with a vibration facility, clean rooms and AIV (Assembly, Integration and Verification) control room was opened in July 2015. These enhanced facilities will be used for important future projects including ESA’s Sentinel 4 mission as part of Europe’s Copernicus programme. In November 2017, the Government announced an additional £99m investment into these National Satellite Test facilities as part of the Industrial Strategy Challenge Fund.

There are approximately 15 national research and technology organisations in Oxfordshire, conducting world-leading research in specific application areas. Of them, the following are relevant to upstream space:

- The Satellite Applications Catapult
- Faraday Institution
- ISIS Neutron & Muon Spallation Source, STFC
- The Central Laser Facility, STFC
- European Centre for Space Applications and Telecommunications (ECSAT)
- Networked Quantum Information Technologies (NQIT) Hub.

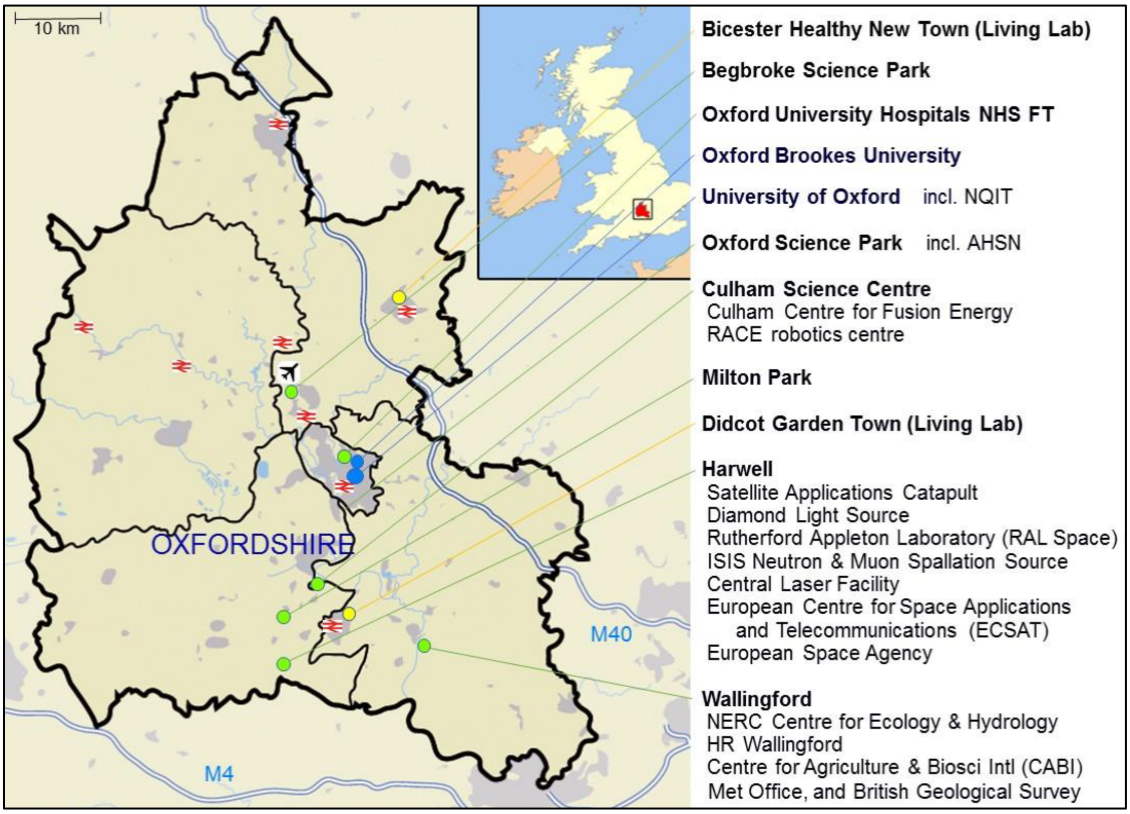


Image 7: Map of Oxfordshire and the Harwell Hub

Hertfordshire has been part of upstream space since the 1960's when the British Blue Streak rocket was built by Hawker Siddeley Dynamics. The company has evolved into Airbus Defence and Space (Airbus DS), housed in the same buildings, and today Airbus DS teams focus on the design and manufacture of advanced satellites and systems for telecommunications, earth observation, and navigation and science programmes. Airbus DS builds a quarter of the world's telecommunications satellites and leads flagship ESA projects such as the ExoMars Rover, Solar Orbiter and Biomass. They also support the UK's military satellite communications services to the UK armed forces, including mobile voice, video, internet and broadcast communications. Delivered through the Skynet 5 constellation, these services also meet the needs of other military and government users like NATO. There are over 1200 employees in Stevenage, with more across the UK.

The Hertfordshire LEP has been extremely supportive of upstream space activity in the region, helping to focus skills development, cross sector connectivity and local environment evolution. Herts LEP notably sponsored the build of the 'Airbus Foundation Discovery Space' – a unique STEM education centre providing inspiration to the next generation of engineers, technicians and scientists, based on engagement with the ExoMars Rover project activities at Airbus.

Solent & the M3 Corridor

The Solent economy has a population of over 1.2 million of which 63% were of working age, 50,000 businesses, local GVA of £27.8 billion, and is part of wider South East economy valued at £240 billion GVA (and is anticipated to be £44 billion by 2036)21. According to Solent LEP the Solent region "has a range of assets that are globally renowned, a strong SME and skills base, and a thriving research community through its universities and research institutions"22.

Image 8: The M3 Corridor region, encompassing the Enterprise M3 catchment area and the New Forest.

Portsmouth supports a high-tech defence and advanced manufacturing cluster in aerospace and space, including companies such as Airbus DS, BAE Systems, GE Aviation Systems and QinetiQ.

The Airbus site in Portsmouth employees over 1000 people and specialises in digital payloads for telecommunication satellites, as well as instruments for spacecraft including low-cost radars.

The Enterprise M3 region has a population of over 1.6 million, with 86,500 businesses as well as global businesses such as AXA Wealth, Motorola and BP, local GVA of £41.98 billion GVA (2012) and is considered a key workforce artery to London's economy. With its proximity to Heathrow, Gatwick and Southampton airports and host to Farnborough Airport - one of Europe's premier business aviation airports - it is a well-connected region that is at the heart of a transportation hub connecting UK businesses to the rest of the world. The high altitude pseudo-satellite (HAPS) programme of Airbus, Zephyr, is based at Farnborough Airport

[21] https://solentlep.org.uk/media/1887/solent-lep-baseline-forecasts-and-the-implications-of-brexit.pdf
[22] https://solentlep.org.uk/the-solent/economic-outlook/

EM3 has a high concentration of knowledge-based industries such as computing, digital media, aerospace, defence, pharmaceuticals, advanced engineering and professional services. It has also identified 8 niche sectors that include 5G telecommunications, satellite technologies, advanced aerospace & automotive manufacturing, advanced materials & nanotechnology and photonics[23].

Together, these two regions form part of Innovation South, (a region that comprises 6 Local Enterprise Partnerships and stretches across the South Coast see map) which defines itself as “a globalised region, with high value, digitally-enabled innovation; a powerhouse of research strengths; a strong commercialisation culture; and dynamic businesses and industries to match.”

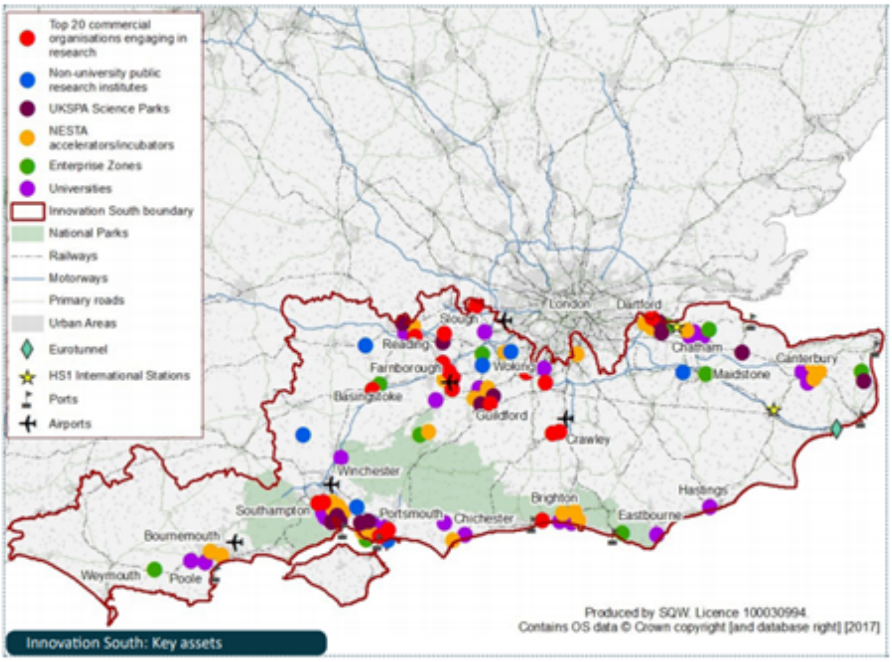


Image 9: The Innovation South region, plus its assets.[24]

Innovation South has a total economic output of £225.3 billion which equates to approximately 13.7% of national output and is home to more than one in ten people from the UK with a population of over 8.6 million of which 5.3 million are of working age. In this same region there are 16 universities - a powerful diversity including Southampton, the UK’s number 1 for engineering, and Surrey’s internationally renowned 5G Innovation Centre.

[23] https://enterprisem3growthhub.co.uk/em3-sectors

[24] Image source: INNOVATION SOUTH - A POWERHOUSE OF WORLD CLASS STRENGTHS IN DIGITAL ENABLING TECHNOLOGIES, A Science & Innovation Audit Report Sponsored by BEIS https://www.enterprisem3.org.uk/sites/default/files/Innovation%20South%20Summary%20Report_0.PDF

Scotland

Scotland has a proud manufacturing heritage. The country has an innovative and diverse manufacturing sector, boasting world-class dynamic companies competing in international markets.

Scotland's wide-ranging manufacturing industry plays a central role in sustaining and growing the economy. The products they create represent over 50% of the country's international exports across all sectors and 54% of the expenditure on R&D. The 189,000 people employed by manufacturing companies in Scotland are at the heart of the high skills – high wage economy with average earnings in the manufacturing sector above the Scottish average. What's more, the manufacturing sector of Scotland delivered £10billion of exports in Q1 of 2018, demonstrating growth of 7.4%, the highest figure for any UK region.

In the space industry, Scotland's central belt undertakes more upstream space activity by volume of craft than other parts of the UK, and Glasgow alone builds more satellites than any other European City[25] thanks to local activities of Clyde Space and Spire. With respect to the upstream sector, Scotland is home to 23% of the industry in space manufacturing, compared to 17%. The UK space industry has strong presence in Scotland with 18% of the UK space industry workforce based there. It is further supported by the reputable research expertise, with Scotland being ranked as number 1 in the World University Rankings for space sciences. Scottish University space interests include Glasgow, Strathclyde and Edinburgh, and national and international research and technology organisations based in country include the UK Astronomy Technology Centre (UK ATC), the Centre of Excellence for Sensor and Imaging Systems technologies (CENSIS), the HVM Catapult's Advanced Forming Research Centre; Lightweight Manufacturing Centre, the National Manufacturing Institute for Scotland and Fraunhofer Centre for Applied Photonics.

Scottish industry has set out its aspiration to rapidly expand to become a £4 billion industry by 2030 and play host to at least one UK Spaceport, an ambition which was confirmed at the 2018 Farnborough Airshow, where Government Industrial Strategy funding was confirmed for the development of a vertical launch spaceport in Sutherland, on the north coast of Scotland, by **Lockheed Martin**.

Wales

Space and space-related activity in Wales takes place across what is known as the "Arc of Innovation", a swathe of institutions and business that swing westwards from the southern cities of Cardiff and Swansea to Cardigan Bay and then northwards to Broughton. Traditionally most high-value manufacturing and engineering work in Wales has focussed

[25] www.scotsman.com/future-scotland/tech/glasgow-builds-more-satellites-than-any-other-european-city-1-4354219

upon the aerospace sector, where the regional expertise is world-class. Yet there are some areas of technology spillover from aerospace to upstream space, for example in the field of advanced materials, energy and power systems, and fluid dynamics.

There are also some technical areas particular to space where Welsh assets and research institutions can boast to be genuinely world-class; for example, its work in optics and coatings, particularly the work being done at the Universities of Cardiff and Glyndwr in the fields of Terahertz optics and quasi-optics, and TK Instruments, whose quasi-optical systems and sub-systems for spectroscopy and remote sensing have been adopted for JAXA's JEM/SMILES mission, and for the Planck Cosmic Microwave Background observatory mission launched in 2009 by ESA.

Image 10: Map of Wales

Northern Ireland

Northern Ireland has a proud heritage of engineering excellence. The regional aerospace cluster contributes around £1.3bn to the UK aerospace industry. Northern Ireland is Europe's 8th largest aerospace region in revenue terms. The region's innovative and skilled companies are involved in every major aircraft programme globally.

The Northern Ireland Space Special Interest Group (NISSIG), hosted by ADS (NI), was created to initially provide a voice for regional engineering and research stakeholders to promote their respective capabilities and identify opportunities for business and research growth and development within the space sector.

The Institute of Electronics, Communications & Information Technology (ECIT), part of the School of Electronics, Electrical Engineering and Computer Science (EEECS) at Queen's University Belfast, established in 2004, is a 4000 sqm purpose-built research and innovation centre. Research at EEECS aims to enhance the way technology is used in satellite communication, health services, data security and many other related areas. The High Frequency Electronics Circuits cluster at ECIT pioneers Research Excellence in Satellite Applications, but also draws upon capability and expertise from other groups and teams within ECIT, including data analytics, cyber security and embedded systems.

More recently, Thales Alenia Space demonstrated their investment in the future of the UK Space industry and Belfast by opening the new electric **Space Propulsion Integration Centre** manufacturing facility in the city in 2017, the first of its kind in the UK. The facility represents a major milestone in the development of space design and manufacturing capability for Thales in the UK since the establishment in 2014 of Thales Alenia Space in the UK.

Rest Of The UK

While the majority of the UK's upstream capability rests within the UK Nationwide Cluster nest of regions, there are a handful of significant outliers, such as the **Mullard Space Science Laboratory,** situated outside Dorking, Surrey within Coast to Capital LEP but adjacent to the Solent & M3 corridor and **Imperial College**, situated in central London. Both institutions have a long and prosperous history in the field of upstream space, having contributed to numerous ESA space science missions in the past by developing unique spacecraft sensors and instrumentation for scientific investigation, as well as undertaking research in various other upstream fields, such as robotics, AI, and materials.

In Cornwall, **Goonhilly Earth Station** sits just north of Lizard, the southernmost point of the British mainland. Goonhilly is the most significant satellite control site in the UK and is expanding its business and capability. Situated on a 164-acre site, there is extensive existing infrastructure, as well as space to grow and erect new control systems as capability and bandwidth needs change and evolve over the coming years.

The Lie of the Land

This Science & Innovation Audit demonstrates that the UK's range of assets, facilities and capability is broad and deep across upstream space, which underlines the notion of a UK Nationwide Cluster.

It is worth reiterating that the UK possesses an almost complete end-to-end value chain, and is investing heavily to fill the gaps that do remain to offer a unique, cradle-to-grave suits of services to spacecraft and satellite operators. It is clear that emerging capability is quite widely distributed alongside the established centres of competence and, while there is no need to centralise that capability, ensuring that the knowledge of these products and capabilities is widely available is critical.

4. Strengths in Science & Innovation

Science and innovation is fundamental to Upstream Space. The constituent elements of the Upstream segment (space manufacturing, and some ancillary services)[26] are heavily dependent upon investment into R&D, which comes from intramural and extramural sources.

Underpinning research and development funding for Upstream Space originates from industry investment, the UK Space Agency, Innovate UK, the UK Research Councils, the European Commission, the European Space Agency - and can also come from private sources outside the classical space sector.

Space manufacturing: the most R&D intensive activity

In 2014/15, across the whole of the UK space sector, £415m or 3% of total income, was invested in R&D - but the proportion varies according to the different parts of the value chain. Indeed, **the Space Manufacturing** segment was the most R&D intensive within the sector, reinvesting **14.3%** of its income on R&D. In monetary terms this equates to around **40%** of the industry's entire expenditure on R&D.

Overall, **8.1%** of the entire space sector's direct GVA is invested into R&D. However, if we split the sector into the predesignated segments, we find that Space manufacturing, where the vast majority of upstream activity resides, the figure skyrockets to **31.6%**, which is the highest of any sector[27]. With the average of all industry investment into R&D standing at **1.24%** of GVA, space manufacturing therefore invests more than **25** times the national average. This, then, showcases the extent to which the upstream sector must invest in R&D, and corral investment from other sources, in order to succeed.

Table 2: The R&D Intensity of the Space Manufacturing Sector

Industry	**R&D expenditure**	**Total GVA**	**R&D as % of GVA**
	£m		
Pharmaceuticals	3,924	13,329	29.4%
Computer, electronic and optical products	866	11,352	7.6%
Chemicals and chemical products	682	9,137	7.5%

[26] *Space Manufacturing* is defined as any design or manufacturing aspect of spacecraft, launch vehicles, payloads, systems, subsystems, components, materials, ground support systems and equipment, scientific and engineering support, fundamental and applied research. *Ancillary services* is defined as insurance, financial and legal services, software and IT services, market research and consultancy, business incubation and development, and policymaking, regulation and oversight. These definitions are in accordance with the Size & Health Internal Report, 2016, London Economics.

[27] Figures based on UKSA Research, derived from statistical data from the *Size and Health of the Space Sector report*, London Economics, 2016

All industries	19,935	1,612,210	1.2%
Information and communication	307	99,641	0.3%
Financial and insurance activities	375	132,644	0.3%
Space	**415**	**5,132**	**8.1%**
Space Manufacturing	***164***	***518.98***	***31.6%***

A strong R&D focus is essential to support new technologies and products meeting ever extending market and customer demands. Close attention needs to be paid to ensure the specific constraints of the space environment (for example radiation and temperature tolerance) can be met. Space equipment is subject to extensive qualification testing and is expected to meet rigorous standards coming from institutions, customers or industry itself.

Table kkkmm. jm3: R&D reinvestment in the Upstream Sector[28]

Segment	Internal			External			Total		
	£m	% of GVA	% of income	£m	% of GVA	% of income	£m	% of GVA	% of income
Space Manufacturing	63	12.1%	5.5%	101	19.5%	8.8%	**164**	31.6%	**14.3%**
Ancillary Services	18	6.3%	4.5%	5	1.7%	1.2%	**23**	8.0%	**5.8%**

4.1. EXCELLENCE IN SCIENCE & RESEARCH

Within the areas covered by this SIA there are twenty universities, a third of which are part of the prestigious Russell Group. Given that the UK Nationwide Cluster represents 16%[29] of the UK geographical regions, upstream space activity is concentrated in areas that are renowned for their excellence in scientific and engineering research. The twenty universities include **Southampton**, the UK's number 1 rated university for engineering; **Leicester**, which has enjoyed a worldwide reputation for excellence in space science research since the 1950s; **Loughborough**, which has been awarded funds from the UK Space Agency to help small business develop space applications for their technologies; **Surrey**, home to the

[28] Size & Health Internal Report, 2016, London Economics
[29] With respect to the number of local authorities taken to fall within the SIA geographical area.

renowned **Surrey Space Centre** (SSC) and coordinator of the **FAIR-Space** (Future AI & Robotics for Space) Hub. **Cranfield University** also has a strong pedigree in offering not only postgraduate courses in space science & engineering, but also applied research in the development of software algorithms for vision-based autonomous GNC systems used for satellites, other spacecraft, and other autonomous vehicles, and novel systems such as the De-Orbiting Sail.

However, it should also be noted that there are many esteemed research institutes which do not fall within the area covered by this SIA (as defined by LEP / DA boundaries), such as the **Mullard Space Science Laboratory**, (part of UCL), which is leading the development of PanCam (panoramic camera) for ESA's ExoMars Rover and has contributed to several ESA programmes since the 1960s; or **Queen Mary University of London**, which is leading the international Hiperloc-EP project to develop electrical propulsion capability for large satellite constellations. The **University of Birmingham** also possesses a strong history in upstream space, having participated in ESA projects developing instrumentation for future gravity scientific space-based research, as well as being leading players in the Space-Time Explorer and QUantum Equivalence Principle Space Test (STE-QUEST) and participating in the Space Atomic Gravity Explorer (SAGE) consortium, which has a primary objective of detecting gravitational waves in new frequency ranges.

Upstream Space requires highly specific subject matter knowledge. As such, there are **12** universities in the UK offering space-specific undergraduate and postgraduate science and/or engineering courses, and ten of these universities fall within the UK Nationwide Cluster.

Established in Excellence

The 'UK Nationwide Cluster' is made up of regions where the Location Quotient (a statistical metric used to predict excellence in a particular geographical area) is above the national average in all STEM subject areas in terms of scientific output, number of researchers, and doctorals awarded.

We may be adopting a 'UK Nationwide Cluster' approach to geographical area covered by this audit's consortium members, but it is still axiomatic that the upstream sector must necessarily be concentrated in regions with excellent research to realise its ambitions. It is a combination of industrial heritage and academic excellence that has helped to concentrate the sector in a few distinct regions. In short, there are very clear reasons for the space sector being situated in this very particular 'UK Nationwide Cluster' of regions.

About Location Quotients and Sector Specialisation Ratios

Location quotients (LQs) provide a way of show whether the partnership area has a higher concentration of research activity relative to the UK average. A more detailed explanation on how LQs are derived is provided in Annex B. In short however, an LQ of 1 indicates that research activity under a topic is as heavily concentrated in the partnership area as it is across the comparator geography overall (the UK in this case). An LQ greater than 1 indicates that a given topic accounts for a larger share of all the partnership area's research activity than would be expected when compared to the UK average. In other words, LQs substantially greater than 1 signal a level of activity/specialisation that exceeds what would normally be expected nationally. More narrowly defined topics can display LQ values that are more volatile, so comparison across topics should not be taken literally.

Whereas in most Audit areas the he Location Quotient (LQ) is used as an effective means of understanding the relative effectiveness of local outputs in a size-agnostic manner, the Upstream Space "Nationwide Cluster" nature of this audit necessitates a slightly different approach, which we are labelling the **Sector Specialisation Ratio (SSR)**.

The SSR is calculated as the ratio between the statistics for the Upstream Space UK Nationwide Cluster, and those for the whole of the UK. For example, where the whole of the UK has produced 4025 (100%) scientific outputs across its entire 418 locales, and the UK Nationwide Cluster has produced 1342 (33.2%) across the 67 locales highlighted in the audit, it transpires that the UK Nationwide Cluster has produced twice as many outputs per local authority. Therefore the SSR is 2:1. The ratios are then converted to decimals (to two decimal places): so, the final statistic for the above example would be 2.0, meaning the UK Nationwide Cluster is performing at twice the level of the national average. An SRR of 1.0 would mean the UK Nationwide Cluster is in line with the national average, while an SRR of 0.5 means the UK Nationwide Cluster is half as effective as the national average in this area.

It must be stressed that while this does not indicate that all of these outputs, researchers and doctoral students relate to specifically Upstream Space content, it shows that the Upstream Space sector is concentrated in areas where these disciplines are particularly strong. It therefore supports the Audit hypothesis that there is common and interconnected scientific strength across the Upstream Space regions.

Table 4: Sector Specialisation Ratios of the Upstream Sector Compared to UK averages

Research Area	Scientific Output			Number of FTE Researchers			Doctorals Awarded		
	Upstream Space SIA regions	Whole of UK	SSR	Upstream Space SIA regions	UK	SSR	Upstream Space SIA regions	UK	SSR
Electrical and electronic engineering, Metallurgy & Materials	1342	4025	**2.0**	350	1229	**1.67**	1073	4753	**1.45**
Physics	2113	6446	**2.0**	571	2044	**1.6**	1217	4197	**1.8**
General Engineering	2710	8679	**2.0**	763	1071	**4.4**	1601	3750	**2.67**
Chemistry	1460	4698	**1.9**	383	2447	**1.0**	1464	5458	**1.69**
Computer Science & Informatics	2101	7651	**1.67**	544	1930	**1.74**	1057	2523	**2.5**
Mathematical Sciences	1890	6994	**1.75**	525	1703	**2.0**	695	3591	**1.25**
Aeronautical, Mathematical, Chemical and Manufacturing Engineering	905	4143	**1.3**	262	1152	**1.5**	595	3541	**1.0**

What is clear is that the Upstream Space sector is active in regions which predominantly perform above the national average across the majority of the major scientific disciplines. The prolificacy of the UK Nationwide Cluster's peer-reviewed scientific output is well above the national average in all the major scientific disciplines, and with respect to the number of full-time researchers, the SIA audited regions also outperform the UK as a whole, especially in the general engineering and mathematical disciplines.

Further analysis of the performance of the audited SIA regions can be found in Annex B, which provides an in-depth analysis by Technopolis of funding by topic across Upstream Space for the audited regions. It should be noted that additional R&D funding is also available in the UK through the UK Space Agency's National Space Technology Programme (NSTP) and ESA's General Space Technology Programme (GSTP) – this information is not currently included within the Gateway to Research. We will endeavour to provide this further analysis in future versions of this SIA.

Case Study: Space Park Leicester

Space Park Leicester is an ambitious initiative to develop a global hub and collaborative community based on space and space-enabled technologies. It will be a brand new centre for the analysis and commercialisation of space enabled data and space mission development.

Based in Leicester, near the National Space Centre, **the Space Park is a partnership** between the University of Leicester, the City and the Leicester and Leicestershire Economic Partnership (LLEP). It will host both industry and world recognised in research and technology organisations, such as the Leicester Institute for Space and Earth Observation and National Centre for Earth Observation, for business partnering and collaboration. Its Pioneer Park/Waterside location was recently granted **Enterprise Zone status**, offering further benefits to businesses locating on to the Space Park.

A key element of the Space Park will be the creation of a "Low Cost Access to Space Facility" (LOCAS), to support industry needs for batch production of spacecraft for mega constellations at a rate of 10-20+ per year. The Facility would support an estimated 1360 jobs and contribute £440.0 million in GVA in the first five years of operation. It would also attract global businesses to develop new space satellite capability in the region.

LOCAS Infrastructure
A satellite integration and test facility designed specifically for constellations of spacecraft would facilitate the mass production of small, low-cost satellites on a "build to print" basis. LOCAS will focus on the production and testing of small, micro & nano-satellites. The addition of the LOCAS facility would see Space Park Leicester evolve into a UK hub that would be complementary to the Scottish central belt and proposed Moine spaceport.

The Space Park will contribute to the skills agenda through undergraduate and postgraduate courses, and also through apprenticeships, higher apprenticeships and continuing professional development opportunities, including:

- **Research and development opportunities**
- **Access to, and analysis of, space-enabled data**
- **Skills for industry**

4.2. INTERNATIONAL STANDING OF UPSTREAM SPACE

The UK's reputation as a world-class player in the space sector is well known, and has been for several decades. In spite of not having a national programme of research like many of our peer nations such as the USA, Germany, France and Japan, the UK's grass-roots capability, spread across its academic and industrial base across the UK Nationwide Cluster, has ensured that it has been at the heart of a number of flagship space programmes over the years.

The UK's entry into the space race was with the Ariel project, which comprised six satellite launches by NASA between 1962 and 1979. Since then, the UK upstream space sector has contributed to dozens of flagship missions by ESA, including the ESRO series for exploring the particle-rich and radiation environments of space; Giotto, which intercepted Halley's comet; the impending Mercury orbiter Bepi-Colombo, set to launch in October 2018, the Aeolus wind lidar satellite due for launch in August 2018, Solar Orbiter and Exomars Rover, while the UK has already positioned itself to be part of next generation missions such as ESA's Sample Fetch Rover, which is explored in greater detail in Chapter 10.

The UK's Heritage in Upstream Space

Since the very earliest missions conducted by the European Space Agency, UK business and researchers have offered unique expertise and capabilities, from the development of instrumentation for specific scientific purposes, to acting as industrial primes for the final assembly of the spacecraft and/or payloads. Since the 1967 launch of ESRO-2, UK organisations have participated in over thirty different ESA missions, including iconic spacecraft such as GEOS, Giotto, Huygens, Mars Express, and Rosetta.

Furthermore, the Mars Express mission also featured the Mars lander Beagle 2, developed entirely by the UK for astrobiological purposes. While Beagle 2 was unable to communicate with Earth after two solar panels failed to deploy, it demonstrated the UK's end-to-end UK value chain. The mission was led by **Open University**, and featured participation from **University of Leicester**, **Astrium**, **Martin-Baker**, **Logica**, **Scisys**, **University of Aberystwyth**, and **McLaren Applied Technologies**.

Image 5: The UK-built Beagle 2 Lander landed successfully on Mars, but two of its solar arrays failed to deploy. Nevertheless, the lander retains iconic status within the UK. Image credit: ESA.

The UK continues to build upon this heritage today, contributing to a number of flagship space programmes and projects, and supporting emerging technologies that will enable the next generation of space science and exploration missions, which in turn will generate huge rewards in the downstream sector.

4.3. INNOVATION STRENGTH, GROWTH POINTS AND THREATS

Unlike some other nations with comparable space heritage and aspirations, the UK does not have technical and research capabilities within its national space agency. Instead, the UK retains strengths within its industrial and academic base. This gives it the advantage of having the flexibility and agility to adapt to scalable projects, unconstrained by Government, and leaves commercial space investment decisions to the movers and shakers within industry who have the most experience in doing so. It also creates a healthy environment for SMEs and new entrants to the market, who can benefit from Government support without being chained to it politically. The Space Growth Partnership has proposed that this support should be expanded by the UK establishing a “National Space Programme” budget which its de-centralised research & development community in industry and academia could draw upon.

On the flip side, a centralised research capability in the vein of, say, the French, German or Italian models from within Europe, has the benefit of protecting key assets from the vicissitudes of the market, whilst ensuring that technological and political strengths are more closely aligned, allowing for some very long-term investment decisions to be protected from the political winds. Recent investment decisions pertaining to the **National Satellite Test Centre**, and the **National Space Propulsion Test Centre** at Westcott suggest that the UK is taking some steps in the direction of its European counterparts. Building upon this, long term planning and support for UK launch infrastructure, and ground segmentation infrastructure, such as space gateways, control stations and VSATs, is seen as crucial in order to ensure that current UK aspirations and activities provide world-class space services and products for generations.

The UK is also seeing local funding being used to develop locally (and nationally) significant infrastructure – as exemplified at **Space Park Leicester and Goonhilly Earth Station**.

Facilitating Progress

Where things do look healthy for the UK is in its possession of a variety of world-class space facilities offering testing, testbeds, modelling and simulation, and demonstration services and capabilities. However, these facilities are not always necessarily joined-up, and therefore offering a converged, strategic service for the sector. High-performance computing expertise in Edinburgh is not necessarily connected to, say, the **Harwell Robotics**

& Autonomy Facility, though there are at least theoretical connections that could be mapped across the two. As the upstream markets grow, there is a strategic need to ensure that the various facilities, which together are a powerful exhibition of systems engineering capability for the design, manufacture and testing of satellites, systems and vehicles, are networked in a light-touch way, ensuring that the array of technical expertise is not lost to those organisations, particularly SMEs, who may require it. The UK has begun to address this issue through the publication in 2017 of the UK Space Facilities review[30].

There are examples of how academic and industrial clusters are working well, for example the **High Value Manufacturing Catapult**, which brings together end-to-end capability across various design and manufacturing techniques for a multitude of sectors and applications; and the **FAIR-Space** Hub, hosted by the **University of Surrey**, but which encompasses many different academic, facility and industrial partners to knit together a functioning value chain of capability for the purposes of collaborative development activities for robotics and AI technologies in space applications.

This, then, is an example of how the national nature of the Upstream Space sector in this country carries both advantages (the flexibility and autonomy to operate without the centralised hand of Government,), and disadvantages (the fact that the various organisations and businesses are not necessarily always wed together or even aware of their existence). Regional clustering mitigates some of this by ensuring that new entrants are able to set up shop in locations that are conducive to the sector and which offer pertinent facilities and service, such as at Harwell. The UK's National Space Policy recognises the importance and encourages the development of these local clusters[31]. However, a broader, UK national directory of capability, and efforts to collaborate and network between the various clusters and organisations at a strategic level, is also essential to help ensure that everybody is aware of everybody else's activities. The aforementioned KTN (http://space.ktnlandscapes.com/) contribute to this, and this Science & Innovation Audit will add further weight.

Space Returning To Earth

One area where Upstream Space is well set to yield further returns on investment is through the provision of services, capabilities and facilities to other sectors. This is known as the "spillover" effect and is a highly useful indicator of how valuable a sector is not only to its own users, but also to the wider economy and national consciousness.

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30 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/665552/UK_Space_Facilities_Review_December_2017.pdf

31 UK National Space Policy 2015 (https://www.gov.uk/government/publications/national-space-policy)

Analysis by Oxford Economics has already indicated that the spillover effect of Upstream Space is around 70%[32]. That is to say, every £1 invested in the Upstream Space sector yields 70p of GDP *in other sectors*, on top of the returns generated within the Space sector itself and its downstream applications.

Case Study: Space-Enabled Technology - Medicine

The University of Leicester has adapted both upstream technologies and the knowledge intrinsic in space engineering to develop what is deemed "Space Enabled Technology". Examples include a portable gamma-ray imager for use in wards and operating sensors to image radio-isotope doped tissues including cancers for treatment and surgery. This device arose from developments of the CCD focal plane for the XMM mission launched in 1999.

This device has recently attracted investors and has entered clinical trials at Queens Medical Centre Nottingham. Other recent applications include a ventricular heart assist pump to treat heart failure. This uses space engineering knowledge to engineer a small compact system, this is at proof of concept stage with initial animal trials underway. Other areas of application at Leicester include other medical devices such as measurement of urine flow in patients through to forensics imaging.

Case Study: Space Cots

Oxford Space Structures, with assistance from ESA's Business Incubation Centre, have used the unfurling mechanism from their satellite systems to create a lightweight, easy-to-use and robust baby's travel cot – the SpaceCot!

Existing travel cots are bulky; typically they weigh over 11kg, need a car to transport, and take several minutes to set up. The SpaceCot weighs only 3.5kg, takes under 10 seconds to erect or collapse, using only one hand, and is highly stable, appearing more robust than any existing model.

The travel cot market is worth £60m in the UK and perhaps ten times this worldwide (UK Source: Mintel). This small market has seen limited innovation in the last 15 years, but the collaboration of ESA and OSS has shown that innovation can come from unlikely places.

Conclusions:

- The UK possesses an excellent research base, with the UK Nationwide cluster boasting some of the world's best-ranked universities, and the UK's best ranked universities for engineering.
- Space manufacturing is the most R&D-intensive sector in the country. The sector requires constant, high-level investment into R&D to deliver the technologies needed for current and future missions and applications.
- Space has the potential to have huge spillover benefits to the wider economy and society, resulting in greater returns to the exchequer.

[32] The Case for Space: Space Derived Impact and data, Oxford Economics, 2009

5. Science & Innovation Talent

Currently, space-specific education is undertaken at few organisations across the UK, but the majority of space specific undergraduate and postgraduate tertiary education courses are to be found at universities that fall within the Upstream Space UK Nationwide Cluster.

Table 6: Space Related University Courses in the geographical area of this SIA[33]

Space related courses available (2018-19)			
University	**Course / Programme**	**Degree**	**Qualification**
Aberystwyth University	Physics with Planetary and Space Physics	Undergraduate	Bachelor of Science (with Honours) - BSc (Hons)
Aberystwyth University	Physics with Planetary and Space Physics	Undergraduate	Master of Physics - Mphys
Aberystwyth University	Space Science and Robotics	Undergraduate	Master of Physics - Mphys
Aberystwyth University	Space Science and Robotics	Undergraduate	Bachelor of Science (with Honours) - BSc (Hons)
Cranfield University	Astronautics and Space Engineering	Postgraduate	MSc
King's College London, University of London	Space Physiology and Health	Postgraduate	MSc
Kingston University	Aerospace Engineering, Astronautics & Space Technology	Undergraduate	Master of Engineering (with Honours) - MEng (Hon)
Kingston University	Aerospace Engineering, Astronautics & Space Technology	Undergraduate	Bachelor of Engineering (with Honours) - BEng (Hon)
Kingston University	Aerospace Engineering, Astronautics & Space Technology (4-year SW)	Undergraduate	Bachelor of Engineering (with Honours) - BEng (Hon)
Kingston University	Aerospace Engineering, Astronautics & Space Technology (5-year SW)	Undergraduate	Master of Engineering (with Honours) - MEng (Hon)
Open University	Space Science (K28)	Postgraduate	Postgraduate Certificate - PgCert
Open University	Space Science and Technology	Postgraduate	MSc | Postgraduate Diploma - PgDip
University of Bath	Electronic Engineering with Space Science Technology	Undergraduate	Bachelor of Engineering (with Honours) - BEng (Hon)
University of Bath	Electronic Engineering with Space Science Technology	Undergraduate	Master of Engineering (with Honours) - MEng (Hon)
University of Bath	Electronic Engineering with Space Science Technology (Sandwich)	Undergraduate	Bachelor of Engineering (with Honours) - BEng (Hon)
University of Hertfordshire	Aerospace Engineering with Space Technology	Undergraduate	Master of Engineering (with Honours) - MEng (Hon)
University of Hertfordshire	Aerospace Engineering with Space Technology	Undergraduate	Bachelor of Engineering (with Honours) - BEng (Hon)
University of Kent	Astronomy, Space Science and Astrophysics	Undergraduate	Bachelor of Science (with Honours) - BSc (Hons)
University of Kent	Astronomy, Space Science and Astrophysics (MPhys 4 years)	Undergraduate	Master of Physics - Mphys
University of Kent	Astronomy, Space Science and Astrophysics with a Year in Industry	Undergraduate	Bachelor of Science (with Honours) - BSc (Hons)
University of Leicester	Physics with Space Science	Undergraduate	Bachelor of Science (with Honours) - BSc (Hons)
University of Leicester	Physics with Space Science	Undergraduate	Master in Physics (with Honours) - MPhys (Hons)
University of Leicester	Space Exploration Systems	Postgraduate	MSc | Postgraduate Diploma - PgDip
University of Nottingham	Engineering Surveying and Space Geodesy	Postgraduate	Doctor of Philosophy - PhD
University of Southampton	Physics with Space Science (4 years)	Undergraduate	Master of Physics - Mphys
University of Southampton	Space Systems Engineering	Postgraduate	MSc
University of Surrey	Electronic Engineering with Space Systems	Undergraduate	Bachelor of Engineering (with Honours) - BEng (Hon) - Full time
University of Surrey	Electronic Engineering with Space Systems	Undergraduate	Bachelor of Engineering (with Honours) - BEng (Hon) - Sandwich
University of Surrey	Electronic Engineering with Space Systems	Undergraduate	Master of Engineering (with Honours) - MEng (Hon) - Full time
University of Surrey	Electronic Engineering with Space Systems	Undergraduate	Master of Engineering (with Honours) - MEng (Hon) - Sandwich
University of Surrey	Space Engineering	Postgraduate	MSc

These space-specific courses only produce a small number of industry-ready individuals each year. When companies in the upstream sector are seeking to grow, and grow quickly, this creates a substantial skills gap needed to be plugged. SMEs, who don't necessarily have the marquee name and therefore ability to attract graduates as a multinational company, need to be able to attract high quality individuals, and so an increased flow of such people from universities is highly desirable for the sector as a whole. There is further complexity added to this picture by the fact that, while the more prestigious companies are able to attract graduates easily, they may still struggle to attract engineers and scientists with 5-10 years of industrial experience for more complex roles.

On the face of it, space exploration and the potential for unique and pioneering scientific discoveries at the very edges of, and beyond, human understanding, should act as a sufficient lure for budding scientists and engineers. Yet romanticism must be married with pragmatism. The fact is that highly proficient engineers and scientists are at just as likely to

[33] Technopolis SIA Data, 2018– a number of other UK universities outside of this SIA geography also provide under- and postgraduate training relevant to upstream space

be wooed by the prospect of the glitz and salaries of the financial services sector in London, or the UK's burgeoning gaming industry, as they are by the space sector.

The Partner Board has identified some of the gaps in the educational landscape. All spacecraft hardware requires detailed, specific materials and metallurgic knowledge, and currently there is no space materials potgraduate course offered in the UK; yet, with the growth of businesses developing small launchers and vehicles in the UK, this seems an obvious gap that will need to be plugged if these businesses are to meet their growth aspirations. Specialist knowledge and skills in magnetics, radiation, environmental vacuum conditioning, safety, RF (radio frequency), research engineers, and other areas are also required and in short supply.

One method to help prepare young engineers for an industrial career in Upstream Space would be for industry to work with universities more closely, and on a more long-term basis, to inform them of the specifications of space-grade qualification of products.

In the field of exploration technologies, robotics is very well represented throughout the UK. Robotics and Autonomous Systems has enjoyed a lot of good press and support in recent years.

The UK has an excellent pedigree in the field of AI research, but again there is a distinct skills shortage given that AI is a specialised subfield sitting at the intersection between two fields – mathematics and software engineering – which are already undersupplied with respect to qualified individuals. In her 2017 report Growing the Artificial Intelligence Industry in the UK, Professor Dame Wendy Hall made six recommendations specifically addressing the skills gap in AI[34].

[34] Growing the Artificial Intelligence Industry in the UK, Dame Wendy Hall, 15 October, 2017 - https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/652097/Growing_the_artificial_intelligence_industry_in_the_UK.pdf

Recommendations to Improve the Supply of Skills

- Government, industry and academia must embrace the value and importance of a diverse workforce for AI, and should work together to develop public information aimed at breaking down stereotypes and broadening participation.
- Industry should sponsor a major programme of students to pursue Masters level courses in AI, with an initial cohort of 300 students.
- Universities should explore with employers and students the potential demand for one-year conversion Masters degrees in AI for graduates in subjects other than computing and data science.
- Government and universities should create, at a minimum, an additional 200 PhD places dedicated to AI at leading universities. As the UK trains and attracts additional academic talent, this number should grow continually year on year.
- Universities should encourage the development of advanced credit-bearing AI MOOCs and online Continuing Professional Development courses leading to MScs for people with STEM qualifications to gain more specialist knowledge.
- An International fellowship programme for AI in the UK should be created in partnership with the Alan Turing Institute: the Turing AI Fellowships. This should be supported by a targeted fund for identifying and recruiting the best talent, and by ensuring that the UK is open to any and all of the eligible experts from around the world.

Given that AI *must* play a part in future autonomous space systems if we are to develop spacecraft, robots and probes that can explore and exploit deep space and other worlds, it seems incumbent upon the space industry, its investors and supporters across Government to adopt the thinking behind these recommendations.

While specific work has been done in the field of AI in this respect, it is but one part of the bigger picture, and more concentrated work needs to be done across the various STEM areas that feed into the Upstream Space sector. This can’t easily be rectified at university; indeed, some universities report of having to offer new undergraduates remedial mathematics upon their arrival to bring them up to scratch. The solution, therefore, must be applied earlier, in secondary education, to ensure not only the quality of the STEM foundation, but also that a desire to learn and work in these areas is instilled in children while they are still at school. Because the basic STEM foundation knowledge is applicable across a wide spread of sectors, there is a danger that graduate skills can be lost to other areas. For example, there is a trend of graduate astrophysicists migrating into Environmental Analytics; the skillset is highly similar (ie the ability to analyse big datasets), but there are relatively few jobs in astrophysics, whereas there are many in environmental analytics.

Overall, this lack of supply of skilled engineers, mathematicians and physicists definitely constitutes a threat for cutting-edge technology businesses. The small amount of space-specific university courses (see Table 6, above) means that some delta-level education is often required for graduates and postgraduates to gain the singular skills required to work on high-grade space engineering projects in industry. Furthermore, if an undergraduate does decide to specialise in a particular topic, this may come at the expense of certain fundamental areas of study, which makes it a difficult compromise. However, most companies, with the exception of very large multinationals, are unable to afford to upskill individuals and graduates from university level to this degree. Simply put, companies who need experience tend to advertise for experienced professionals. Those graduates who are taken on often move on after a couple of years to progress their own careers, and even companies such as Airbus have provided anecdotal evidence that they lose some of their graduates around the 3-5 year mark. This isn't necessarily a problem if they then migrate into the supply chain and SME network, but could be if they bleed into other sectors entirely.

The growth of the upstream segment in the coming years should give academic institutions the confidence to expand space-specific content, modules and courses to satisfy this skills gap, but this will need to be underpinned by academic funding and teaching staff.

Some businesses have strong links with their local universities. An excellent example is the Rolls-Royce **University Technology Centre** (UTC) in Loughborough. The UTC is a strategic partnership between academia and industry set-up to investigate combustion and aerothermal processes. Over 12 test facilities provide researchers with the opportunity to operate test rigs of various sizes and over a range of temperatures and pressures. In total the group has supervised in excess of 50 successful PhD candidates and the research activities have led to almost 200 journal publications, over 260 conference papers and the award of numerous worldwide patents.

Other companies have developed good outreach programmes as a means of engaging with potential recruits, such as **Oxford Space Systems**, who are marrying good publicity with an effective narrative. **Airbus** has over 100 outreach ambassadors at its Stevenage and Portsmouth sites interacting with local schools and has implemented the Airbus Foundation Discovery Space STEM centre alongside the Exomars Rover test facility. Essentially, these are the approaches the industry as a whole could consider adopting to ensure that the fundamental wonder that space generates among the general public is translated into a desire to dig into the detail of the sector a little more – and the Space Growth Partnership has proposed that industry will support 1 million STEM engagements per year as part of its Prosperity from Space strategy.

There is a sense that sector engagement with the **STEM** (Science, technology, Engineering & Mathematics) subjects at Secondary Level & 'A' level is enthusiastic and well-intentioned, but not necessarily strategic. Since 2009 14-16 year-old pupils have been able to study for a GCSE in Astronomy, but there is no strong evidence to suggest that this influences take up in higher education, and such early specialisation may even have an adverse effect by not allowing students to lay the solid, broad foundation across the STEM disciplines, upon which specialisation can be built. A feeling persists that there is a need for an overarching strategy, supported by Government, that joins the dots together between the excitement that space is able to generate, the role(s) that industry plays, and what schoolchildren need to do in order to access a career in space.

Finally, there is an ongoing challenge to increase the diversity and inclusivity of the workforce, not only in the Upstream Space sector but across many of the STEM-based industries. The Upstream Space sector is relatively small compared with some other sectors, and there is a sense that most of the players of note come to know one another across the country, perhaps giving the impression of a closed club.

Conclusions

- Space-specific education is generally of an excellent quality, but within the SIA audit region the number if courses offered is relatively low, and therefore produces fewer graduates than is needed by a growing industry, despite the attractiveness of the marquee name of some organisations operating in the sector.
- Strategic overhaul is being pushed via the 21 recommendations produced in the UK Space Agency’s proposals for the “People, Skills and Culture” element of the Space Sector Deal, which proposes significant and long-lasting mutual commitments from Government, industry and academia to address some of the fundamental shortages and imbalances in the talent pool available to space.
- Investment into space-related science & engineering courses will yield great economic benefits by preparing the future generation of engineers for the rigours of industrial work.
- Enticing undergraduates into the space sector is not enough. Young people need to be engaged as early as possible in order to ensure they lay solid foundations in the scientific and mathematical disciplines before they enter university and begin specialisation.
- Government is promoting skills to meet the Innovation Growth Strategy targets of creating 100,000 new jobs (with 25,000 of those occurring in the upstream segment) in space by 2030.
- Cross fertilisation between high tech upstream space companies and other innovative, entrepreneurial sectors is essential to enabling innovation, and understand exploiting cross-sector synergies (or lack of them).

6. The Funding Landscape

In the period 2007 – 2017, 1529 R&D projects were funded by the UK Research Councils and Innovate UK (formerly the Technology Strategy Board) relating to space technologies, systems and capabilities, to the tune of £891.84million.[35]

The research conducted by Technopolis for the Upstream Space SIA report collated and categorised these projects according to a simplified version of the 25 Technology Domains as delineated by ESA[36], resulting in six broad categories:

- On-Board Data Systems
- Spacecraft Electrical Power
- Payload & Systems (including electromagnetic technologies and techniques, and space weather compatibility)
- Space Systems Control
- Automation, Telepresence, Robotics and Optoelectronics
- Aerothermodynamics

Risk versus Reward

One of the quirks of upstream space in particular is the business model afforded by the institutional customer model (ESA, NASA and other national space administrations). Because ESA offers up to 100% funding through its General Space Technology Programme[37], this is frequently a much more attractive option than trying to bid for equivalent funding from the UK's primary funding body for industrial R&D, **Innovate UK (IUK)**, or even the European Commission's Research Framework Programme, Horizon2020 (H2020). However, as we have mentioned already, much of the investment into new R&D comes from industry's own revenues, meaning that funding for R&D is frequently subject to business cases. GSTP may de-risk institutional developments, but for larger, commercial R&D programmes, co-funding is a more widely adopted model.

Both IUK and the EU offer funding at 50% for businesses larger than SMEs. For upstream space businesses this is a simple choice, and where returns on investment have not traditionally been easy to identify (at least, not for a great many years), businesses opt for

[35] This figure encompasses upstream and downstream technologies and developments, and also fundamental research that are described as having potential applications in space; for example, abstracts for research into carbon composites materials may contain links to space applications, but also other sectors such as aerospace, Formula One, etc. Therefore these are broad brush figures. Source: Technopolis.
[36] The 25 Technology Domains have been simplified into six by Technopolis to make the breakdown of funding easier to follow and understand. For a full breakdown of the thematic modelling used to arrive at these six themes, as well as an understanding of the 25 Technology Domains as demarked by ESA, please see Annex
[37] For competitive tenders only. ESA also offers funding at 50% or 75% for non-competitive submissions.

ESA funding at 100%, saving them money and significantly de-risking their work, but without the commercialised push that accompanies EU and IUK research projects. ESA also offer a specific channel of funding for telecoms R&D through their ARTES (Advanced Research in Telecommunications Systems) Atlas programme. Atlas is intended to bridge the 'valley of death' where commercial satellite operators are unwilling to be the first customer for new technology developments that do not have proven in-orbit heritage. The programme encourages a commercial operator to be a first customer through the risk mitigation of ensuring that the programme will have the supervision and support of the expert ESA technical and quality teams to give the customer increased confidence in the product. ESA will also 50/50 co-fund the first proto-flight model hardware in order to incentivise the operator to participate.

ARTES Case Study: Airbus DS Ku-Band Multi-Port Amplifier

A Multi-Port Amplifier MPA is an innovative development that allows a telecommunications satellite to very flexibly allocate its transmit power between different antenna coverages and frequency channels and has been identified as a key enabling technology for future advanced flexible telecommunications satellites. In 2013 Airbus DS was awarded an Artes 5.2 contract supported by the UK government to develop a ground demonstration model of an 8x8 Ku-Band multiport amplifier. No other satellite manufacturer has such a product and the Airbus DS development was possible thanks to an innovative patented in-orbit calibration technique. For the activity, Airbus DS teamed with a number of UK suppliers including Micro Metalsmiths (now Sylatech) who designed an innovative high-power phase matched waveguide combiner/divider network. Micro Metalsmiths were an SME who had not worked in Space before. The tests on the MPA demonstrator were very successful. In 2014 Eutlesat issued a request for proposals for an advanced telecommunications satellite called Eutelsat 172B which included a requirement for a flexible multi-spot beam payload to provide broadband services to aircraft crossing the Pacific Ocean. This requirement was idealy suited to an MPA which allows the satellite power to be dynamically allocated between the beams covering the ocean to match the rapidly changing patterns of air traffic. Thanks to the MPA demonstrator programme, Airbus DS were confident enough to bid an MPA based solution to Eutelsat and the contract was won thanks to this capability. Eutesat 172B will be the first telecommunication satellite to fly a Ku-Band MPA and the payload has been integrated and is currently undergoing test at the Airbus DS Portsmouth site. Thanks to the UK investment in their capabilities, Sylatech were able to secure the contracts for all the combiner/divider networks on the Eutelsat 172B programme.

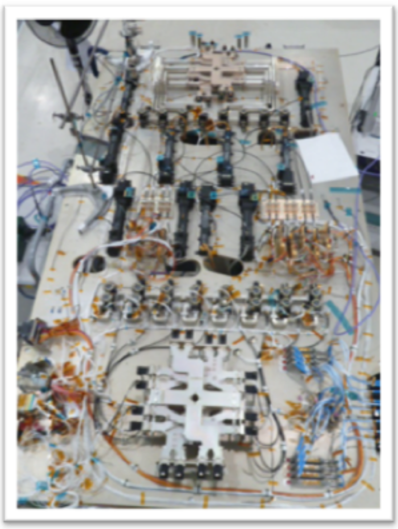


Image 11: The Ku-Band MPA demonstrator developed under Artes 5.2. Image credit: Airbus DS

Were this element of risk not mitigated by such initiatives, it could create a rather more conservative and slow-moving environment around upstream space, so it is important that support is provided. The main reason for this is because businesses cannot realistically be expected to write business cases for investment into research programmes where the commercialisation, and therefore returns, might not be seen for decades in the future and, more pertinently, that up to now, satellites have not been fixable once in orbit.

However, this risk-averse stance towards investment may be changing due to the fact that the constellations and small satellites markets are set to grow, and grow quickly, over the coming years. This should shorten the ROI turnaround time significantly, given the lower cost and manufacturing times for small satellites. The redundancy element of constellations also represents a paradigm shift with respect to risk; for example, **OneWeb** are aiming to launch hundreds of small satellites to orbit as part of their constellation, whist retaining hundreds more on Earth as spares. This type of redundancy has simply been unheard of and impossible in the conventional satcomms markets, and promises to be a game-changer.

The growth of the small satellites and launcher markets represents an immediate opportunity, and represents an area where upstream space businesses should be able to bid into H2020 and IUK calls with confidence that the commercialisation aspect of the technology will be realised, and realised quickly. Conversely, the funding bodies must realise that these opportunities represent a small temporal window of opportunity, and that funding ought to be directed to these areas in the immediate future.

Other, more long-term and speculative markets, such as deep space exploration, manned interplanetary missions and In-Situ Resource Utilisation (ISRU) to create infrastructure on other worlds, cannot be measured or estimated with any degree of accuracy. However, to make such extreme challenges a reality, it seems doubtful that the conservative orientation of industry is likely to make these scenarios a reality in the timeframes being cited.

The entry of SpaceX into the launch market has changed this to a degree. SpaceX have attracted funding from private VC investors, and as explained above, are thought to be on the cusp of turning an operational profit. Nevertheless, SpaceX are demonstrating that it is indeed possible to turn a profit from the launch and exploration subsectors and, with enough push and investment, it can be done in a relatively short time period. But the real trailblazers here will be large Space Agencies with institutional funding, and who can support large-scale PPP ventures.

UK newspace businesses are taking a lead from this and are working hard to attract investment from private sources. Again, this is primarily to unlock short-term rewards in the launch and satellite markets, but access to those long-term markets could be unlocked through the introduction of new funding models, such as VCs and angel investment, and PPPs.

Institutional Push

In some areas, businesses can be influenced to engage with matched-funding competitions, such as those offered by IUK and H2020, by the institutional customer base itself. This is extremely helpful in trying to develop new standards for certain technologies, which will be necessary to unlock the next generation of space missions and accelerate the ability of humanity to access new space markets such as deep space mining.

The H2020-funded Strategic Research Cluster (SRC) in Space Robotics is a multi-layered suite of industrial research projects to develop a series of "common" building block technologies for the future applications of robotics in space. Because the specification for the capabilities is being driven by ESA and national space administrations in Europe, there is an understanding that the technologies themselves will be used in future mission scenarios, while the fact that the programme is funded by the EC mandates the commercialisation aspect of it.

This has enabled the programme to develop standardised technologies such as autonomy architectures, open source operating systems for robot control, physical interconnectors, and plug n' play sensor boards.

Because of the inherent risks in developing standardised technologies (such as legacy issues, the possibility of multiple standards, obsolescence), industry can be reticent about embarking on such projects. However, this SRC model has attracted strong interest from across the European space robotics community. The UK has featured strongly in the SRC so far, with **Airbus DS**, **Thales Alenia Space** (TAS-UK), the **University of Strathclyde**, **GMV UK**, **Scisys**, and **King's College London** all successfully participating in the programme. This model could be adopted at a national, or even regional level, to make best use of the end-to-end value chain that the UK possesses in the upstream sector.

SMEs

SMEs, being numerous and scattered across the UK, have mixed experiences with respect to accessing funding. ESA, IUK and the EU all have attempted to streamline and simplify the means to access funding in recent years, and with some success. However, this top-down approach is not enough, and it seems that a bottom-up approach, of directly assisting SMEs at source is of greater help to them. Because of bandwidth and time constraints, SMEs cannot invest the same amount of effort into funding bids as large organisations, who may have entire teams dedicated to bid writing.

Harwell acts as a cluster for innovative SMEs and has attracted a number of space tech startups. As well as offering access to some of the region's – and the UK's – most prestigious companies, the location enables companies to take advantage of the local business services, including those offered by the **Satellite Applications Catapult**, and **ESA's Business**

Incubation Unit, which include guidance on access to finance and funding, mentoring, de-risking, and assistance with access to specialist facilities. These invaluable services will help to further strengthen the region's depth of expertise and capability by ensuring SMEs are given the right start in life.

The UK Government intends to replicate the "Harwell effect" elsewhere throughout the country by creating more of these tightly focused clusters to act as magnets and incubators for innovative businesses, offering them support, funding and access to vital facilities and services.

Industrial Challenges

The Industrial Strategy Challenge Fund released £92million in R&D funding for investigations into robotics operating in harsh environments. The case for space was presented at the Challenge scoping workshops, highlighting the need for robotics, AI, swarming and advanced manipulation and control systems for future robotically-enabled markets, such as deep space mining, exploration and on-orbit servicing.

The National Space Technology Programme

The NSTP, funded by the **UK Space Agency**, aims to de-risk the efforts of companies and universities to develop new technologies and concepts across a range of technology areas.

Grants range from £10k for Exploratory Ideas, to £1million for Flagship projects that ordinarily seek to mature technology to TRL (Technology Readiness Level) 5 or above. The size of grant allows for greater range of project focus. However, there is a sense that there is little alignment across research projects, and that providing the programme with a greater sense of systems-integration so that technologies can be developed for particular applications and/or missions.

European Programmes

Research activity in the European Framework Programme for research (2007-2017)

The EU data portal does not differentiate between upstream and downstream space, meaning any data has to be treated with care in order to derive any meaning from it. For example, the most successful three organisations in the UK with respect to participation in EU-funded Space research projects are: Natural Environment Research Council (NERC), with 17 participations; the European Centre for Medium-Range Weather Forecasts (15); and the Met Office (15), all of whose research interests are almost exclusively weighted towards downstream (Earth Observation) activities, and crucially fall outside the Upstream Space cluster of geographic regions, so can be disregarded for the purposes of this study. Removing other prominent downstream developers and service providers (Infoterra (9 participations), Cambridge Environmental Research Consultants (4), Specto Natura (4), The Department of Environment and Rural Affairs (4), and Argans Ltd (3)) means we are left with a truer picture of the ability of Upstream Space organisations within the SIA area to obtain EU funding, but one that is only slightly more encouraging.

The resultant picture reveals that the Upstream Space hotspot locales have successfully participated in Space projects 67 times (across 67 locales) out of a UK total of 215 (across 418 locales). Using the Sector Specialisation Ratio (SSR) calculation as explained above, this provides a ratio of 2:1 in favour of the Upstream Space regions. That is, the regional Upstream Space hotspots are twice as likely to obtain EU funding as the whole of the UK. Furthermore, the research institutions and companies which are particularly prominent in Upstream Space have been successful multiple times in obtaining EU funding. This suggests that there is a keen understanding of EC processes and bid-writing protocols within these hotspots, and that businesses and researchers seeking to take advantage of EU funding for Upstream Space would do well to stay connected with these institutions.

The following tables provide analysis of publicly-funded research and innovation activity in space research over the period 2007 to 2017, for grants funded via the EU Framework Programme. For comparative purposes, the tables also summarise the situation for publicly funded research in any area relevant to the 'Space' topic more broadly.

The area covered by this SIA compares favourably to the UK as a whole in terms of activity levels in European-funded space research projects. The SIA area accounts for over a third of all UK participants in all European-funded space projects (36%), and commands nearly half (46%) of the total European funding given space project participants in the UK. The SIA area's LQs of 1.15 for participants in all space projects, and 1.04 for participant funding in all space projects also illustrates that space activity is more heavily concentrated in the SIA area than might typically be expected at the UK level.

The data also reveal a certain specialism in some space sub-sectors. As Table 10 shows, the SIA is particularly strong in aerothermodynamics – the LQs of 1.57 for project participants and 1.39 for participant funding show the SIA area has a much higher concentration of aerothermodynamic activity than might typically be expected (i.e. relative to the national average). The SIA area also performs strongly with respect to space control, accounting for 71% of project participants and 95% of funding to project participants in the sector, albeit that the UK as a whole has little European funded research in this area.

Although the SIA compares favourably to the rest of the UK with regards to participation in European space research projects, it seems less strong at leading European research projects concerning space. As shown in Table 8, the SIA area has an LQ of 0.99 for leading European space projects, putting its performance only in line with the UK as a whole. Furthermore, the

LQ of 0.16 for funding received by space project leads shows that the SIA area's share of European funding in the sector is low when compared to the national average.[38]

Table 7: Space SIA organisations as project leads for UKRI-funded research projects. Source: Technopolis Group, using Gateway to Research data and semantic text analysis powered by SpazioDati

	Projects led from the SIA	***% of UK projects***	***LQ***	***Value of projects led from SIA (£m)***	***% of UK funding***	***LQ***
Space (all)	1529	31.53%	1.17	891.84	35.94%	1.26
On-Board Data Systems	16	25.81%	0.96	19.06	2.21%	0.08
Spacecraft Electrical Power	8	25.00%	0.93	5.33	12.93%	0.45
RF Payload and Systems, including electromagnetic technologies and techniques and space weather (electromagnetic compatibility)	100	29.07%	1.08	31.12	22.42%	0.79
Space System Control	5	31.25%	1.16	0.28	15.31%	0.54
Automation, Telepresence & Robotics, and optoelectronics	16	41.03%	1.52	9.42	43.39%	1.52
Aerothermodynamics	58	29.90%	1.11	32.34	25.86%	0.91
All topics	**18019**	**26.95%**	**--**	**8228.38**	**28.49%**	**--**

Table 8 Space SIA organisations as project participants for UKRI-funded research projects

	Projects with participants from the SIA	***% of UK projects***	***LQ***	***Value of projects with participants from the SIA (£m)***	***% of UK funding***	***LQ***
Space (all)	1955	40.30%	1.20	1320.55	53.21%	1.21
On-Board Data Systems	23	37.10%	1.10	7.93	34.09%	0.78
Spacecraft Electrical Power	14	43.75%	1.30	14.40	34.94%	0.80
RF Payload and Systems, including electromagnetic technologies and techniques and space weather (electromagnetic compatibility)	135	39.24%	1.17	55.05	39.66%	0.90

[38] All data, Technopolis, see Annex B.

Space System Control	9	56.25%	1.67	0.61	33.34%	0.76
Automation, Telepresence & Robotics, and optoelectronics	16	41.03%	1.22	9.42	43.39%	0.99
Aerothermodynamics	84	43.30%	1.29	67.80	54.21%	1.23
All topics	**22503**	**33.60%**	--	**12701.24**	**43.92%**	--

Source: Technopolis Group, using Gateway to Research data and semantic text analysis powered by SpazioDati

Table 9: SIA organisations as project leads for EU-funded research projects[39]

	Projects led from the SIA	***% of UK projects***	***LQ***	***Value of projects led from SIA (£m)***	***% of UK funding***	***LQ***
Space (all)	92	9.88%	0.99	115.54	4.54%	0.16
On-Board Data Systems	3	17.65%	1.76	2.03	8.29%	0.29
Spacecraft Electrical Power	--	--	--	--	--	--
RF Payload and Systems, including electromagnetic technologies and techniques and space weather (electromagnetic compatibility)	9	6.16%	0.61	13.91	4.49%	0.16
Space System Control	2	28.57%	2.85	6.05	37.59%	1.32
Automation, Telepresence & Robotics, and optoelectronics	--	--	--	--	--	--
Aerothermodynamics	11	13.25%	1.32	22.67	8.30%	0.29
All topics	**1361**	**10.02%**	--	**1666.56**	**4.41%**	--

Table 10: Space SIA organisations as project participants in EU-funded research projects[40]

	Projects with participants from the SIA	***% of UK projects***	***LQ***	***Value of projects with participants from the SIA (£m)***	***% of UK funding***	***LQ***
Space (all)	375	36.23%	1.15	1252.49	45.84%	1.04
On-Board Data Systems	7	38.89%	1.23	12.85	45.94%	1.05
Spacecraft Electrical Power	10	41.67%	1.32	68.33	73.88%	1.68
RF Payload and Systems, including electromagnetic technologies and techniques and space weather (electromagnetic compatibility)	55	33.54%	1.07	145.17	42.22%	0.96

[39] Source: Technopolis Group, using EU Framework Programme grant data and semantic text analysis powered by SpazioDati
[40] Source: Technopolis Group, using EU Framework Programme grant data and semantic text analysis powered by SpazioDati

Space System Control	5	71.43%	2.27	15.32	95.22%	2.17
Automation, Telepresence & Robotics, and optoelectronics	9	50.00%	1.59	21.93	54.48%	1.24
Aerothermodynamics	44	49.44%	1.57	173.26	61.08%	1.39
All topics	**4796**	**31.49%**	--	**17140.96**	**42.24%**	--

Funding Shortfall, and the Brexit Threat

Marquee investment decisions such as those listed above must also be complemented by funding at the research base to enable R&D intensity to remain at the requisitely high level for upstream space. Funding comes from UKRI, including IUK, and also from the UK Space Agency's NSTP, but there is a sense from the research base that the available funding for upstream space R&D activities falls desperately short if where it needs to be. The NSTP offers grants that allow companies and universities to undertake activities ranging in scale from proof-of-concepts and exploratory ideas, to flagship projects, while IUK and UKRI have offered grants for upstream activities, but they are relatively small.

For example, Table 5 above shows that over the period 2007 – 2017, the total amount of funding the UK has won from the EU, either as project coordinators or participants, far outstrips the total funding awarded by UK funding bodies for the same technical areas. For example, the total amount of funding drawn down by coordinators and participants within UK funding programmes for space control systems is £0.89million. But grants from the EU across the same period for the same technical theme total £21.37million. An analysis of the figures from Tables 5, 6, 8 and 9 shows that for all the technical groupings bar On-Board Data Systems, the amount of funding drawn down by UK upstream space organisations outweighs that drawn down from UK sources. While the UK can participate in H2020 until the end of the programme period, the relationship between the UK and the EU27 with respect to the FP9 funding programme is not yet finalised, and this represents a risk to both funding and international collaboration. The Space Growth Partnership has proposed a significant injection of funding into the UK space sector through a national programme. What is clear is that this funding for industry and academia must be properly thought through to ensure that sufficient funding is directed to each of the key technical areas of upstream space.

In any case, the type and size of the majority of grants offered by IUK and the EU, in most cases, may be sufficient to develop standalone products or technologies, but are not sufficient for developing entire system-level scientific and engineering products which are integrated in a long-term, visionary manner. In other words, funding a series of standalone products is not as effective as funding an entire suite of technologies that are built with fundamental systems integration in mind. There is an interesting exception, which is offering a new model for collaborative R&D. The **Strategic Research Cluster in Space Robotics**, funded by the EC's H2020 programme, is steering and enabling the development of a series of products, software and hardware that is fundamentally "common" and therefore capable of being integrated with one another at the systems and platform level. This model for R&D, which takes place over several rounds of funding calls, therefore allowing researchers to build on what has gone before, helps to develop standards, keeps the end-uses firmly in mind, and breaks down barriers to commercialisation, such as modularity, and develops capability across the industrial and academic base. This model is providing €39.5million of EU operational grants for space robotics alone in H2020, with potentially more via FP9.

The success so far of this model suggests that serious consideration should be given to this model of collaboration within the UK for various areas of technological R&D, as it would help to focus funding, strengthen the network, and ensure the relevance of the projects by firmly anchoring them to a predefined end-goal mission and/or application scenario, thereby also de-risking the investments made by industry.

Future EU Research

The UK's exit from the European Union has created some uncertainty with respect to the UK's participation in the framework programmes of research, including the current Horizon2020 programme, and the proposed FP9 programme. However, the Joint Report of December 2017 stipulated that the UK remains eligible to submit, participate, coordinate and collaborate in European Commission-funded projects of research, until the end of the current framework period.[41]

Even so, the UK's participation in the FP9 programme represents a more severe threat, despite ongoing negotiations being made by the UK Government. Over the period 2007 - 2017 EU grants for won by UK coordinators and participants of Upstream Space R&D projects totalled £481.02million, compared with £252.75million of UK grants[42]. Thus the EU has provided 65.5%, almost two-thirds, of all funding for upstream space activity in the UK over the last ten years. Whatever the result of the Brexit negotiations, industry and academia require assurances about where the future source(s) of funding for fundamental and applied R&D. Otherwise, the lack of research funding could seriously underline the drive to grow the UK's upstream space sector and give our international competitors a huge advantage by forcing research organisations to relocate to where research funding is readily available.

Further coverage of significant European activity, including Galileo and Copernicus, is anticipated for future iterations of the report.

[41] That is to say, the UK remains eligible to bid into any H2020 Call, up to and including the final 2020 call, and will be able to draw down funding until the end of that project funding period. So, for example, if the project is grant is awarded in 2020 and the project ends in 2023, the UK participants will be able to claim their funding for the entire duration of that project, until it ends in 2023. https://ec.europa.eu/commission/sites/beta-political/files/joint_report.pdf

[42] Source: Technopolis Group, UKSA research

As stated earlier, the UK's exit from the EU has no effect on its membership of the European Space Agency.

Conclusions

- With respect to space-related programmes, the SIA region of the UK Nationwide Cluster outperforms the rest of the UK when it comes to accessing UK funding, leading and participating in research projects
- EU funding has accounted for 65.5% of all funding for UK organisations across the period 2007 – 2017. Brexit and the uncertainty around the UK's relationship with the FP9 programme represents a huge threat.
- New models of collaborative R&D, such as the Strategic Research Cluster model, could be explored to help add focus and commercialisation to upstream space research at a national level.
- The upstream segment is extremely adept at securing funding, but can be conservative when it comes to matched funding programmes for far-future technologicies, owing to the long term ROI.
- Institutional push can influence industry to investigate technical areas it might otherwise ignore.
- VC and private capital will be a critical part of the new space markets. Visionary investors will gain a foothold in potentially huge growth markets, as well as the prestige of operating in the newspace economy.

7. Satellites and Spacecraft

Satellites and spacecraft are, simply put, the objects built to do a job in space. Commercial satellite assets typically provide connectivity and TV broadcast or earth observation imagery. Institutional satellites conduct Earth and space science and exploratory probes, such as the Voyager spacecraft, or infrastructure, such as the Hubble telescope and the International Space Station.

Case Study: EutelSat Quantum

Eutelsat Quantum is a pioneering mission that will influence how telecom satellites are procured and manufactured in Europe. Eutelsat Quantum, which is being developed at Airbus DS' site in Portsmouth, provides a shift from custom-designed, one-off payloads to a more generic approach, providing the world's first geostationary telecommunications satellite that will be fully reconfigurable in orbit.

The satellite will provide unprecedented in-orbit reconfigurability in coverage, frequency and power, allowing complete mission rehaul, including orbital position, paving the way for a paradigm shift in the building of telecommunications satellites. It is seen as a better solution compared to existing geostationary platforms in that it will provide:

- agility in responding to changes in geographical or performance market demand, during satellite manufacturing or after launch, and addressing emerging business opportunities; and
- more efficient use of satellite resources and customised allocation of resources to time-variant requests.

Eutelsat Quantum will be software-defined; a suite of powerful operational software ensures that the payload resources are used as efficiently as possible, whilst the software will predict, operate and manage the on-board configuration and reconfiguration of the satellite.

Eutelsat is also noteworthy for being developed under a public-private partnership between the European Space Agency (ESA), Airbus and satellite operator Eutelsat. Airbus also is the manufacturing partner, alongside Surrey Satellite Technology (SSTL).

Image 12: The cleanroom facilities at Airbus DS Portsmouth are being used for the assembly of EutelSat Quantum. Image source: Airbus DS

[43]

[43] https://www.esa.int/Our_Activities/Telecommunications_Integrated_Applications/Quantum

The satellite market is characterised by customer sales propositions that comprise one or more satellites, typically including a ground control system and which may or may not include launch (delivery on ground vs delivery in orbit). Wider turnkey system sales propositions are also possible, including network management or data processing systems linked to end user applications. The satellite or turnkey system customer sale will be based on a supply chain delivering satellite subsystems, equipment, software and services.

The UK has capability across the value chain and is able to deliver solutions appropriate for large geostationary systems through to cubesat / nanosats. This ecosystem has matured significantly over recent years, with products and skills in key satellite subsystems and components including: Payload, Power System, Propulsion Systems[44], Structures, Telecommunications, OBC (On-Board Computer) and Attitude Control Systems. Primes, or system integrators will have a supply chain and/or in-house capability that accordingly encompasses each of these areas. This level of expertise and experience in UK has been built with limited public sector investment compared with other nations, who typically have national programmes alongside ESA and EC contributions. As noted above, the Space Growth Partnership is strongly advocating that the UK would benefit significantly from establishing a National Space Programme budget which could addressing the depth of capability, help the sector adapt to (and drive) new markets and potentially address missing critical mass/sovereign capability in a certain areas.

The largest upstream market traditionally has been telecommunications, which rely upon large, geostationary satellites. This has been the case for a number of years now, but the emerging constellation/small satellite market is resulting in some uncertainty on the eventual balance between geostationary and constellation systems. The classical business model for telecoms satellites is based on a small series of large geostationary satellites being manufactured to deliver high performance over a lifetime of typically 12-15 years. This is driven largely by the economics of access to space whereby it makes sense to maximise the exploitation of launcher mass and volume. Most recently the business model has evolved through the adoption of Electric Orbit Raising which has been pioneered by the UK – this approach allows substantially more payload capability to be delivered but with a longer transfer time to reach final orbit. Further opportunities to develop and challenge the classical business models will come through the progressive adoption of COTS technologies, and the advent of Industry 4.0 (the widespread adoption of robotics, AI (Artificial Intelligence), additive layer manufacturing (otherwise known as 3D-printing) and automation into the design and manufacturing industries, which will enable businesses to create "Batch Sizes of One", bespoke small spacecraft at low cost, with leaner supply chains, more affordable and readily available. High quality, reliability and availability of the

[44] Once a satellite is in space, it requires in-space propulsion systems to maintain positioning, station-keeping, reaction and attitude control, and pointing. Chemical propulsion (CP) remains the most conventional means of propulsion, but has low specific impulse (the ratio of thrust to mass of propellant) so is rather inefficient. While alternative forms of propulsion (electrical and cryogenic) are being developed, chemical propulsion technology is likely to be around for a while yet, meaning that areas such as increased thrust, catalyst life, efficiency and process handling for hazardous propellant such as fluorinated compounds.

satellite systems will continue to be strong drivers for the established satellite operators. Further robotic capability enabling on-orbit servicing, on-orbit assembly and construction, and reconfigurable satellites (with respect to both software and hardware) is also promising to give the satcomms market a shot in the arm.

7.1. THE STATE OF THE MARKET

The global satellite market was valued at $260.5billion in 2016. This includes satellite manufacturing, ground equipment, government space budgets, and launches. This also includes the downstream satellite services sector, which accounted for $127.7billion[45], meaning that the upstream segmentation of the satellite sector was worth $132.3billion.[46]

Euroconsult anticipates that 300 satellites with a mass over 50 kg will be launched on average each year by 2026 for government agencies and commercial organizations worldwide.[47] This is a threefold increase over the past decade as the satellite market experiences a paradigm shift with the rise of small satellites and mega constellations, such as that of OneWeb.

The 3,000 satellites over 50 kg to be launched over 2017–2026 should represent a market of $304 billion for the space industry in terms of building and launching, an average of $30 billion per year (up 25% over past decade). A price decrease is visible in this core market of the space industry, driven by 23 commercial constellations launching a total of 1,800 small satellites (of which about 1,000 for OneWeb) into low or medium Earth orbits for communications or Earth observation.

In the commercial space sector, Euroconsult believes that about 2,000 satellites will be launched over the decade, of which about half solely for OneWeb[48]. Almost two-thirds of the commercial space market of $65 billion will remain concentrated in geostationary orbit, the destination of 150 new satellites for communications and broadcasting services. The 1,800 satellites to be launched into non-geostationary orbits for the 23 constellations to collect or transport data should represent a market of $2 billion per year on average over the decade.

[45] It is worth noting that the figure quoted here refers to the cost price of the satellites themselves to the downstream markets, not the value of those markets themselves. For example, the size of the global telecommunications market alone in 2016 was estimated to be $1,318billion (Source: Statista, *Global Revenue from telecommunications services, 2005 – 2019*, www.statista.com/statistics/268628/worldwide-revenue-from-telecommunications-services-since-2005/#0)

[46] Statistics from US Satellite Industries Association (SIA), 2017 annual report.

[47] *Satellites To be Built And Launched, 20th Edition,* Euroconsult, http://www.euroconsult-ec.com/11_October_2017

[48] *Satellites To be Built And Launched, 20th Edition,* Euroconsult, http://www.euroconsult-ec.com/11_October_2017

Image 13: Overview of future satellite > 50kg. Image credit: Euroconsult

Geostationary Telecommunications Satellites

In 2016, customers worldwide purchased a total of thirteen geostationary telecommunications (satcomms) satellites. This is a downturn when compared to the period between 2004 and 2015, when between twenty and twenty-five of such satellites were purchased each year[49].

This can be explained in part by the emergence of business and technical innovations in the small satellite sector, and in particular the OneWeb constellation concept which has given commercial operators reason to pause and assess strategy and product procurement policy. The extent to which small satellites and constellations can deliver high-quality performance, coverage and service at lower throughput costs and higher maintainability in the longer term is yet to be demonstrated.

[49] Satellite 2017 Conference Press Briefing, March 7th 2017, delivered by Mark Spiwak, president of Boeing Satellite Systems International.

Case Study: SES 12 Digital Processed Payload

Airbus DS UK submitted a successful proposal for a 'Digital Processed Payload' to ESA as part of the ARTES Atlas programme for in-orbit demonstration of innovative telecommunication satellite technology developments.

With the support of the UK Space Agency and Innovate UK, Airbus DS were able to propose a digital processed payload solution to the satellite operator SES of Luxembourg. While SES are one of the world's major satellite operators, the satellite they were procuring called SES 12 was their first digital processed payload for high date rate satellite broadband applications. The satellite procurement was an open competition with a number of overseas satellite manufacturers also bidding. The main competitor was Boeing of the USA who had already sold similar digital processed payloads to Intelsat and were thus seen as the world leader for this type of satellite. The ESA support to the Airbus technical solution was a key differentiator in enabling Airbus to win the satellite contract in the Summer of 2014. SES subsequently awarded Airbus a follow-on contract for a second similar satellite SES 14 in 2015.

Artes 34 Digital Processed Payload Return on Investment:
The following table illustrate the ROI achieved on the SES 12 Artes activity. (calculated with an exchange rate of £1 to €1.3). The Initial UK government investment of £5.8m was matched with industry confounding to give a 2:1 ROI on the initial processor development. Thanks to this activity the first contract was secured and the total value of to the UK of the complete SES 12 payload was £123m (including the Digital Processor activity) and the overall satellite work order for the UK (including platform wrk performed in Stevenage) was £123m.

SES 12 Digital Processed Payload	Total Value	ROI
Artes 34 Digital Processed Payload - UK Artes contribution	£5.8m	
With Industry Co-funding of Activity	£11.6m	2:1
Payload UK Work Order (including digital processor)	£105m	18:1
Satellite UK Work Order (including the payload)	£123m	21:1
SES12 and SES 14 Total UK work order	£212m	37:1

Image 14: SES Payload Integration at Portsmouth, 2016

Geostationary telecommunications satellites remains a market of huge, strategic significance to the UK. The UK possesses a 25% share of the global market, delivering hundreds of millions of pounds to the economy each year, and providing the backbone of many vital telecommunications services throughout the UK and the wider world.

Furthermore, technological advancements in the satcomms markets are providing new significance and capability to these platforms. The EuTelSat Quantum Satellite, being developed at Airbus DS Portsmouth, is the world's first satellite capable of being fully reconfigurable in orbit, affording customers huge flexibility with respect to resource management, bandwidth, power and spectrum. EuTelSat Quantum is also an embodiment of one of the newspace business models, having been developed under a PPP initiative with support from ESA, the UK Space Agency and Airbus DS. In a demonstration of the attractiveness of this capability, the majority of EuTelSat Quantum’s capacity has already been purchased (by American operator Peraton, who primarily operate in the defence, security and cyber domains).

Satcomms is also poised – and uniquely positioned – to serve emerging markets of enormous value. While fibre optic broadband is an excellent and attractive product for many consumers, and may encroach upon a portion of the traditional satcomms broadband market, fibre will not be able to offer ubiquity of connectivity. It is only through the combination of new satcomms capability with 5G connectivity, along with the service provided by GNSS, that markets such as autonomous vehicles – a market projected to grow at a CAGR of 21.36% between 2017 and 2022, and at 68.94% between 2025 and 2030[50] – will become a reality.

Furthermore, even though the UK Government has rightly hailed its achievement of hitting its targets of delivering fibre optic broadband connectivity to 95% of the country[51], we must seek to serve the wider world. Many more isolated, rural parts of the world may not necessarily be served well by fibre, and will require 5G-enabled satcomms capability to provide certain connected services.

All this points to the fact that satcomms seems highly likely to be a robust and relevant market for years to come, and the UK must make all efforts to shore up and protect this unique capability.

Small Satellites

[50] Semi-Autonomous and Autonomous Vehicles Market… Global Forecast 2022 to 2030, Vehicles, MarketsAndMarkets, https://www.marketsandmarkets.com/Market-Reports/near-autonomous-passenger-car-market-1220.html?gclid=Cj0KCQjwpvzZBRCbARIsACe8vyIjiUF1y8drg-S9FhgUa5XEiMBVgvkXNcDaYuuDRdLLzfgPq_48OXEaAuWNEALw_wcB

[51] As part of the Government’s Broadband Delivery UK programme, https://www.gov.uk/broadband-delivery-uk

Technology trends and a forecast reduction in launch costs are increasing focus on the construction of low-cost, smaller satellites. Small satellites are classified as possessing below 500kg of wet mass. Within this mass range, there are three distinct subcategories, each with their own unique characteristics, advantages and applications.

Minisatellites: 100kg – 500kg
Microsatellites: 10kg – 100kg
Nanosatellites: 1kg – 10kg

There are two further categories, *Picosatellites* (0.1kg – 1kg) and *Femtosatellites* (10g – 100g). The markets for these types of satellites are small and still rather embryonic, but we do give some consideration to them below, as there are signs that it may become another growth market.

The small satellite market continues to grow healthily. Presently, small satellites are used for a variety of applications: weather monitoring, surveillance, EO, navigation, communication, meteorology, and more.

The UK generated a revenue stream associated with small satellites of $32.5million in 2017, and this is set to grow to $143.7million by 2021, or an 11% share of the European small satellite market. IN plain monetary terms, this revenue stream is lower than European competitor countries Germany ($326.7million of revenue, 25% of market share), France ($226.1million, 17.3%), and Russia ($309million, 23.7%) but compares favourably with Spain ($91.5million, 7%). However, the UK outperforms all of its European neighbours with respect to the projected CAGR for the next four years (2018-2021); the UK's projected CAGR of 45.1% comfortably beats Germany (33.4%), France (24%), Spain (29.4%), and Russia (32.1%). The markets seem to agree that the UK, owing to its combination of commitments to excellent upstream satellite manufacturing prowess and the infrastructure necessary to launch those satellites, will grow exceedingly quickly over the coming years, representing an enormous and unique opportunity for investors.

Not only this, but the UK's projected CAGR of 45.1% for the next five years is higher than any other major country or region on the planet. Only Canada (45%) can compete with such robust growth.[52]

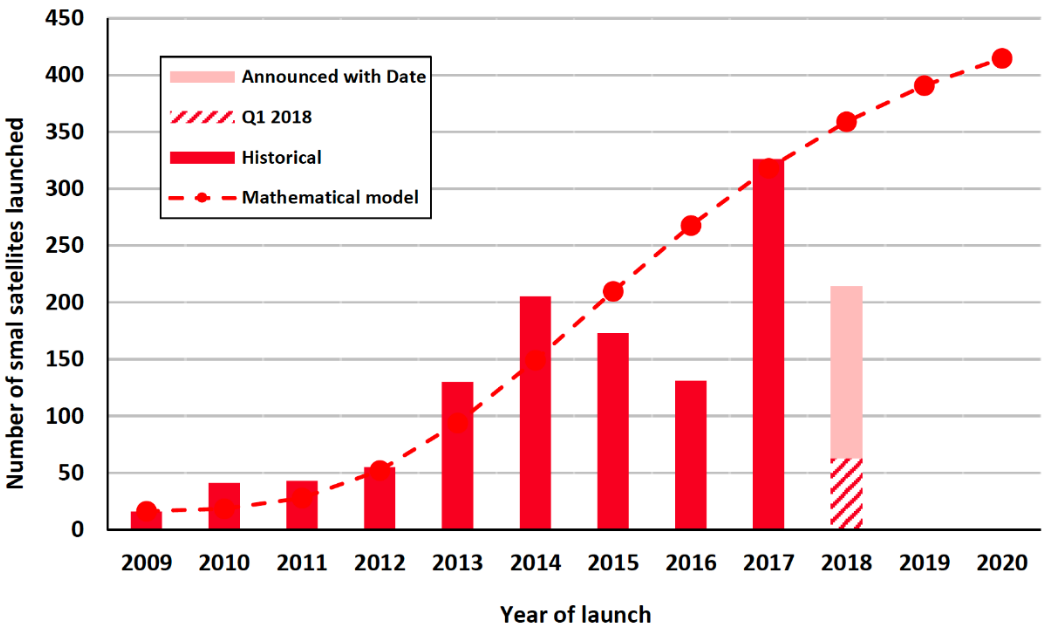
In the future, small satellites look to be the preferred vehicle of choice for nations seeking to develop their own Global Navigation Satellite System (GNSS), and offer new telecommunications services, such as connection to the Internet of Things. The built-in redundancy of constellations also makes them an attractive proposition for operators.

In Q1 of 2018, 63 small satellites were launched, which is more than the whole of 2012, and while the actual (projected) figure in 2018 lies below the growth curve formulated by the

[52] Source: *Global Small Satellites Market Analysis and Forecast*, 2017, BIS Research

mathematical model, the significant launches associated with OneWeb and announcements of further constellation launches will continue to drive the trends for growth.

Table 11: Small Satellites launched, historical and projected.[53]



The growth shows no sign of stopping. Over the next ten years, 3,600 small satellites are expected to be launched[54] by a variety of different countries. In terms of value, the global small satellite market accounted for $2.53billion in 2016 and is projected to reach $10.1billion by 2021, at a CAGR of 31.9%.[55]

With respect to the subsectors of the small satellite market, the payloads market represents the greatest value and potential for growth. In 2016 the payloads subsystems market was valued at $615.9million, and is expected to grow at the highest CAGR of all subsystem markets, to wit 34.6% between the years 2017-2021, which will result in it having a 27% share of the entire market. The second highest contributor to the small satellite market will be the On-Board Computer (OBC) market. The UK possesses world-leading players in both of these subsystem markets, as well as the other subsystem markets of propulsion, structures, attitude control systems, ground segmentation, and power.

Established satellite manufacturers are looking to enter the small satellite market. **Airbus DS** is a significant investor and partner with UK-US startup **OneWeb** and has led the development of radical production approaches and satellite design with the aim of

[53] Table courtesy of Satellite Applications Catapult, Small Satellite Market Intelligence, Q1 2018.
[54] Source: *Global Small Satellites Market Analysis and Forecast*, 2017, BIS Research
[55] Source: *Global Small Satellites Market Analysis and Forecast*, 2017, BIS Research

launching 900 small satellites into orbit to provide global broadband internet coverage, for even the most remote and poverty-stricken regions of the globe

Further detail about the market growth within the various subcategories of small satellite can be found in Annex C of this report.

Table 12: Projected value of small satellite subsystem markets in $millions[56]

By Subsystem	2016	2017	2018	2019	2020	2021	CAGR % (2016-2021)
Payload	615.9	617.1	1,528.0	1,881.9	2,239.3	2,725.7	34.6
Structure	230.1	228.9	563.8	691.8	821.3	998.8	34.1
Telecommunication	251.3	246.2	597.1	721.4	843.4	1,009.9	32.1
On-Board Computer	515.7	503.2	1,215.3	1,462.2	1,702.2	2,029.9	31.5
Power System	336.2	320.7	757.2	890.6	1,013.6	1,181.6	28.6
Attitude Control System	290.7	287.0	701.0	853.2	1,004.7	1,211.9	33.0
Propulsion System	288.2	270.9	630.3	730.6	819.3	941.2	26.7
Total	2,528.1	2,474.1	5,992.6	7,231.7	8,443.8	10,098.8	31.9

Service In Space

While the small satellite market grows, the commercial and institutional upstream market continues to require large satellites and spacecraft to do long-term jobs. But to mitigate obsolescence, satellite end of life and the potential Kessler Syndrome[57], giant leaps are being made to develop the capability to develop servicer satellites and spacecraft, which will be able to service other satellites while they remain on orbit. This may mean undertaking repairs, exchanging active payload modules, refuelling, or performing other hardware and software fixes that are not possible from the ground segment, and also clearing “Dead” spacecraft from orbit by moving them to a graveyard orbit well out of the way of operational orbits using a variety of technologies. Services provision is also expected in the area of in-space manufacture and assembly, as currently there are limitations to what can be put in space owing to the size and mass constraints of single deployable structures that

[56] Source: *Global Small Satellites Market Analysis and Forecast*, 2017, BIS Research

[57] The **Kessler syndrome** (also called the **Kessler effect**, **collisional cascading** or **ablation cascade**), proposed by the NASA scientist Donald J. Kessler in 1978, is a scenario in which the density of objects in low earth orbit (LEO) is high enough that collisions between objects could cause a cascade where each collision generates space debris that increases the likelihood of further collisions. One implication is that the distribution of debris in orbit could render space activities and the use of satellites in specific orbital ranges infeasible for many generations - https://en.wikipedia.org/wiki/Kessler_syndrome

can be fit into spacecraft fairings. By allowing structures, equipment and infrastructure to be built robotically in space, much larger structures can be achieved, which will in turn unlock further applications.

The opportunity for in-space services is huge, with estimates at the size of the market set at $3billion, though again there is uncertainty about the future of the market; if the small satellite market takes a portion of the geostationary market, there is a possibility that on-orbit servicing (at least, for the geostationary communications satellite market) will become redundant by the time the technology is fully viable.

Satellites in Low-Earth Orbit (LEO) may become a viable market for orbital servicing, but not for the foreseeable future. The lower-cost of launching LEO satellites, couple with their relatively short lifespan and – given the emergence of satellite constellations – the ease of replacing them, means that servicing them does not constitute a viable business model at present.

The most immediate market opportunity, and where the UK demonstrates great capability, is in on-orbit servicing of satellites and spacecraft. However, there is no current legal or regulatory need for operators to service their satellites in this way in space; current space law dictates that manufacturers and/or operators are responsible for the safe and secure operation of the satellite, but not whether or not the satellite must be removed from orbit. This lack of regulation is driving concerns around maintaining “clean space”, not to mention the potentially disastrous effects of the Kessler Syndrome. Presently efforts are being made within regulatory frameworks to understand this area better, but there is an expectation that at some point operators will be compelled to take responsibility for their space-based assets once they reach the end of their life. When this happens, developers of on-orbit servicing technologies will find their capabilities in demand, so it makes sense to support such developments now.

Despite these issues with respect to regulation, initial steps have been made by American businesses such as **SpaceLogistics**, and **Orbital ATK**, who are scheduled to launch the first servicer spacecraft, MEV-1, in early 2019, which will conduct rendezvous, proximity operations and docking with IntelSat-901 in a graveyard orbit. The Space Robotics SRC in the EU is also making significant advances in in-space servicing, with **Thales Alenia Space-UK** among others helping to develop standardised plug-and-play sensor suites and on-board sensor data processing units to unlock the potential of this market.

These technologies, which may help to push through greater adoption of standardisation in the upstream segment, will be highly transferable to other space sectors, such as on-orbit assembly, deep space mining and extraction, and satellite reconfiguration. These rather more long-term aspirations are explored in Chapter 8 of this report, Enabling and Exploration Technologies.

7.2. SCIENCE AND INNOVATION ASSETS

The UK has retained and developed world-renowned capability in the design, build and assembly of satellites of all sizes. As well as the prime contractors and system integrators, there is a strong and capable supply chain for both the upstream and downstream markets, with several small companies and universities offering excellent capability and there is capability from all regions of the country.

Much of the UK's satellite design and manufacturing capability is located within the "Greater East Midlands, Oxfordshire-MK-Cambridgeshire Growth Corridor, and Harwell Hub and Hertfordshire" (principally Stevenage) , the Solent & M3 Corridor and the Central Belt of Scotland, though the supply chain and various facilities stretches much farther, to all parts of the UK Nationwide Cluster.

Image 15: The Environmental Test Facility at RAL Space, Harwell

Airbus Defence and Space is the UK's largest space company, employing over 3,000 staff across the country. It has major sites supporting space activities in Stevenage and Portsmouth. Stevenage provides the mechanical platform for the highly successful Eurostar telecommunications satellite series (over 100 models now in orbit) and is prime contractor for some of the most challenging science and exploration missions in the world including Lisa Pathfinder; Exomars Rover; Biomass; Solar Orbiter and Aeolus. Stevenage has world recognised capabilities in digitial processing, satellite antennas, structures, proplusion and mechanisms. The Portsmouth site complements Stevenage, focusing on advanced RF and electronics systems for telecoms satellite payloads, radar systems and ground segment for telecoms and navigation. Airbus DS has also made overtures into the small satellite market through its joint venture with **OneWeb**. Airbus DS also has a significant stake in the High Altitude Pseudo-Satellites (HAPS) market, creating a new facility for its Zephyr product line.

Further along the M3 Corridor, **Surrey Satellites Technology Ltd** (owned by Airbus, yet operated as an independent company under that umbrella) have been recognised a world-leader in the small satellite sector for many years. They have a broad range of capability, having had over 150 satellites launched, from 3.6kg nanosatellites to 660kg satellites, and they possess a 40% share of the global small satellite market. They also possess a significant mission control centre, from which they currently operate 19 satellites, and have end-to-end capability in the design, manufacture and operation of those satellites across their Guildford and Bordon bases.

Also at Surrey, and potentially complementing the UK's capability in Satcomms, is the **Surrey 5G Innovation Centre**, a joint venture between leading academics and industrial partners to develop the infrastructure required to roll out 5G connectivity across the country. This capability is essential if the satcomms market is to provide the connectivity required for new markets such as autonomous vehicles and the Internet of Things, and there is a huge opportunity for the space industry to align themselves with this drive.

A few miles northwest of Guildford is Farnborough, and the home of **QinetiQ**, who provide a broad range of services across several areas of aerospace, defence and space. QinetiQ have a strong focus upon R&D, and has market penetration across the world, including into the American public sector, though the UK Government remains its primary source of revenue.

The **Science & Technologies Facilities Council** owns the **Small Satellite (Assembly, Integration and Testing) Facility** at the Harwell hub. This is closely integrated with the **RAL Space R100 National Satellite Test Facility (NSTF)**, which contains clean rooms for large satellite preparation and solar array deployment, vibration and pyro-shock testing, acoustic and structural dynamics testing, vacuum chambers and Compound Antenna Test Ranges (CATR), as well as vacuum chambers and optical science payloads. The NSTF was granted a huge boost in 2017 by the announcement of an £99million grant from the Industrial Strategy Challenge Fund to support the UK's ongoing commitment to the design, testing, verification and manufacture of small satellites to meet the growing demand.

The UK Space Agency has supported the ongoing development of the **National Space Propulsion Test Centre** at Westcott, to offer companies access to world-class thrust testing facilities. The Centre possesses hydrogen infrastructure testing facilities through the presence of **Reaction Engines**. It also possesses 5G and Antenna test facilities.

In Oxfordshire, **ABSL Space Systems**, recently acquired **by EnerSys**, the American global leader in energy storage, are a leader in space batteries and at their Abingdon site they possess TVac, classrooms and electrical testing facilities.

Because of the growth in the small satellite market, satellite design and manufacture is an area where SMEs are able to get a foothold in the market. There are a number of SMEs taking advantage of these market conditions. The Harwell hub, and particularly the **Satellite Applications Catapult**, have made for a very welcoming atmosphere and environment for SMEs hoping to successfully enter the satellite market. **Open Cosmos** build Cubesats as well as communication constellations, while **Oxford Space Structures** have deployable antennas and deployable structures, as well as novel use of composites for in-orbit deployment. Guildford-based **Earth-I** are developing a constellation that provides high-definition, full-colour video footage from space.

Component, system and satellite testing facilities are also available at **Queen's University Belfast** and **Ulster University** in Northern Ireland, and both institutions also offer services and facilities enabling mechanical design and development for satellite systems and subsystems. At Queen's University, state-of-the-art cleanrooms and space electrical design and development facilities are also offered.

In Scotland, **Clyde Space** are also recognised as being a world-class innovator and supplier of small satellite systems and their subsystems (including payloads) and components. They also possess the end-to-end capability to develop cubesats and small satellites, with an average of 6 satellites built each month at their Glasgow base. Also in Glasgow are **Spire Global**, who are the first company in the UK and Europe provide an end-to-end cubesat development and data service offering, and Alba Orbital, who are building and launching some of the world's most advanced picosatellites for EO and telecoms purposes, as well as offering mission and educational outreach packages for training and development purposes.

Case Study: The Higgs Centre for Innovation

The Higgs Centre for Innovation is a ground-breaking new facility applying business incubation best practice and space testing facility into wider commercial impact. Built on the site of the Royal Observatory Edinburgh and supported by the expertise of the STFC's UK Astronomy Technology Centre, the centre was officially opened in May 2018 by Nobel Prize-winning scientist Professor Peter Higgs. The facilities at the Higgs Centre, designed for collaborative use by industry, academia and research institutions will include a comprehensive suite of space test facilities small satellites and components, providing:

- Dedicated secure labs with ISO 5-7 clean rooms
- Optical metrology and calibration facilities
- Thermal and cryo-vacuum chambers
- Vibration testing
- FlatSat nanobed for integration testing

Image 16: The Higgs Centre, built on the site of the Royal Observatory Edinburgh. Image credit: Higgs Centre.

Also in Scotland is the newly-opened **Higgs Centre** (see the Case Study, above), which opened in May 2018 to act as a business incubation centre as well as providing test facilities for small satellites.

In the Electrical Propulsion[58] (EP) field the UK possesses several important players, including **QinetiQ** and **Queen Mary University London**. Electric Propulsion system design, manufacture and test facilities are also offered by the **University of Southampton**. Further west, **Thales Alenia Space UK** also offer both chemical and electrical propulsion expertise

[58] electrical propulsion offers a higher specific impulse than conventional, chemical propulsion technology, and so is likely to be taken up for next generation missions as the technology matures into operability.

which is being leveraged by ESA for NeoSat, part of ESA's next generation telecommunciations satellite programme (ARTES), and in 2017 opened their **Electric Propulsion Manufacturing and Test Facility** in Northern Ireland, the first of its type in the UK.

The UK's participation as a project leader in the EPIC (Electric Propulsion Innovation & Competitiveness) PSA, funded by the EC, ensures that the UK remains influential and at the forefront of new innovations in this area. As constellations become more popular, EP systems, with their higher efficiencies, are likely to become a more attractive proposition to operators.

Small satellite constellations require new technologies regarding telemetry, tracking and command (TTC). Advanced, better connected networks for the ground segment are therefore needed, while greater autonomy and robotics capabilities are required for spacecraft. The UK possesses good capability in the TTC area thanks to **Goonhilly Earth Station** (GES), but there is a need to improve upon this capability in order to complement new platforms with the requisite operational control on the ground. GES possesses open systems, data sharing and common TTC capabilities, which can be used to for distributed systems using formation flying satellites. Goonhilly's full capabilities are explored in Chapter 9.

Despite this wealth of expertise, there remains a need to make access to facilities easier, especially for new entrants to the market, so as to encourage new ideas and rapid development and also more affordable. While the various facilities throughout the UK are owned and/or operated by different stakeholders and organisations, aligning, cataloguing and advertising the various facilities in one easily-accessible place (for example, online) would be a desirable service to provide industry.

Lastly, there is a feeling that although the UK satellite manufacturer and developer supply chain has a strong presence throughout the UK and Europe, there could be greater penetration within the American market, which stills leads the way in the small satellite market, and also the Asian markets, which are expected to grow most quickly in the next five years.

Conclusions:

- UK satellite capability is being complemented by new launch vehicles, and ground station capability.
- The UK's growth in the small satellite market is set to outstrip that of every other major satellite-producing nation on Earth over the next five years, with the possible exception of Canada. The sector has to align itself with respect to regulations and technology to ensure that the market is effectively unlocked for companies, and that

investors recognise that there is a unique window of opportunity to get in on the ground floor in many new companies and markets, such as in-space services.

- The traditional satcomms market is sustained – but growth may be experiencing some atypical slowdown at present. With the advent of new technologies in space, such as reconfigurable satellites, and on ground, such as 5G connectivity and autonomous vehicles, growth looks set to increase, and UK interests and sovereign capabilities must be protected.

- Non-traditional investment models, including PPP, are already emerging. Further alignment between industry and Government to help de-risk developments is highly likely and recommended.

- Regulators and insurers ought to work closely with Government and industry to reduce barriers to successful market entry.

- UK and European presence and coverage is very good, but with the exception of large multinationals, penetration into non-European overseas markets could be improved.

8. Access to Space

Introduction

The UK has historically been a world-class player in the satellite market, providing the design, manufacture, assembling, integration and testing capabilities required to build high-quality, robust satellites for a wide spectrum of applications. Yet for any spacecraft to do its job, it needs access to space.

The term "Access to Space" refers to the technologies, capabilities, products, services and infrastructure needed to launch – and keep – vehicles in space. As scientific endeavour in space relies upon putting satellites and spacecraft into orbit, it is axiomatic that institutional users, such as the European Space Agency must have access to space. This means having certain sovereign capabilities which enable launches.

Traditionally, launch vehicles such as multi-stage rockets have been the sole preserve of upstream markets and customers, but the emergence of SpaceX and their development of the Falcon range of launch vehicles has shown that private sector entities are also able to enter successfully into this market. In 2013 SpaceX entered the launch market with 7% of launches, and is projected to operate 64% of all launches in 2018 assuming all launches go ahead as scheduled (see Table 13, below). This has been achieved through the relatively inexpensive cost to launch Falcon 9 Rockets, and Space X's ongoing demonstration of its ability to land its rockets autonomously.

However, the lowering launch costs alone will not lead to substantially lowered programme costs overall, and so lower costs of the launch vehicle itself is a desirable outcome. This in turn puts pressure on manufacturers. A target launch price of around $30,000 per kilogram is being cited by major operators in the satellite sector[59]. Thus, for deploying 100 kg of payload, ideally the selling price of SLV should be in the range of $3 million. However, presently SLVs possess a much higher selling price.

The major challenges for small satellite manufacturers and users have up until now been the availability of space within the launch fairings and busses for payloads in heavy launch vehicles. Also, because small satellites are launched as a secondary payload on heavy launch vehicles, satellite operators are beholden to launch schedules beyond their control, meaning they are often subject to delays and unfavourable timetables. This means there is currently an unmet need for a greater number of not only launch sites, but Small Launch Vehicles (SLVs) offering a range of different solutions and services to small satellite operators. The UK is, uniquely, positioning itself to provide a range of solutions to not one but both of these problems.

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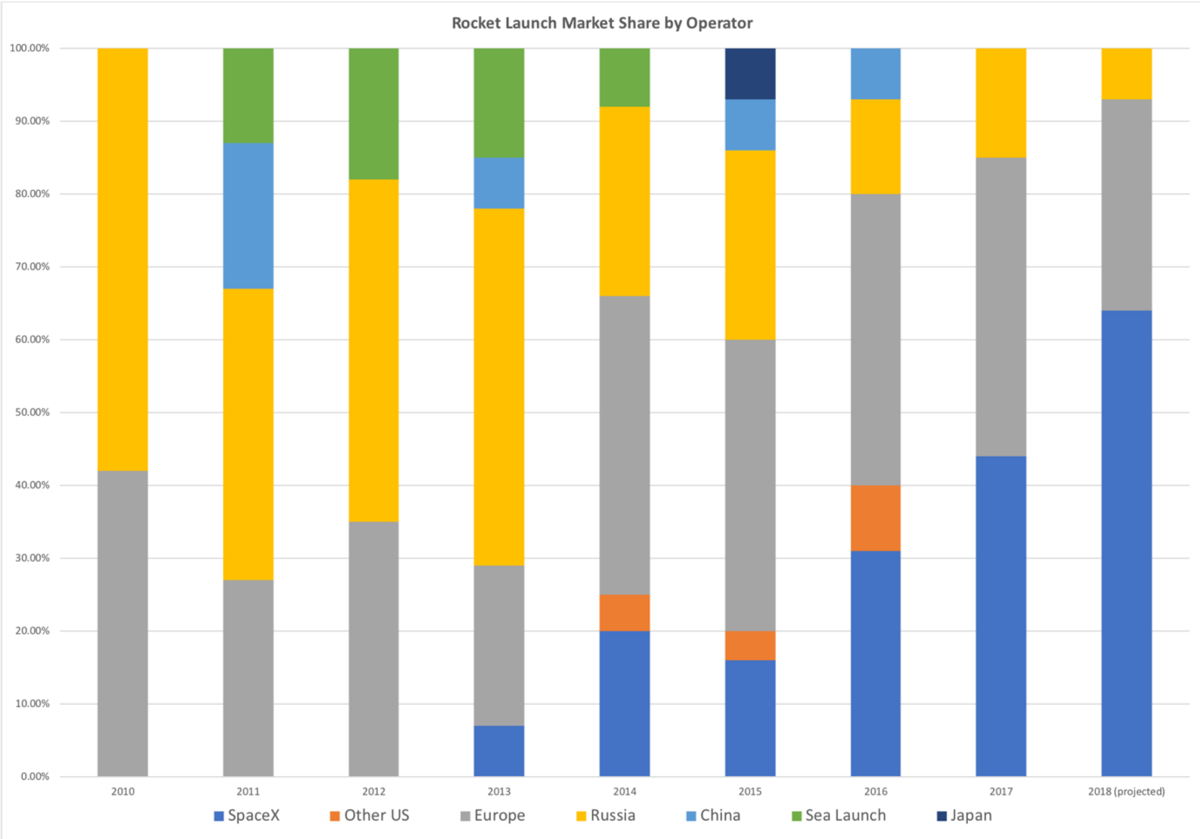
[59] *Global Small Launchers Market – Analysis & Forecast, BIS Research, 2017*

Table 13: How the share of the rocket launch market has shifted over the past decade.[60]



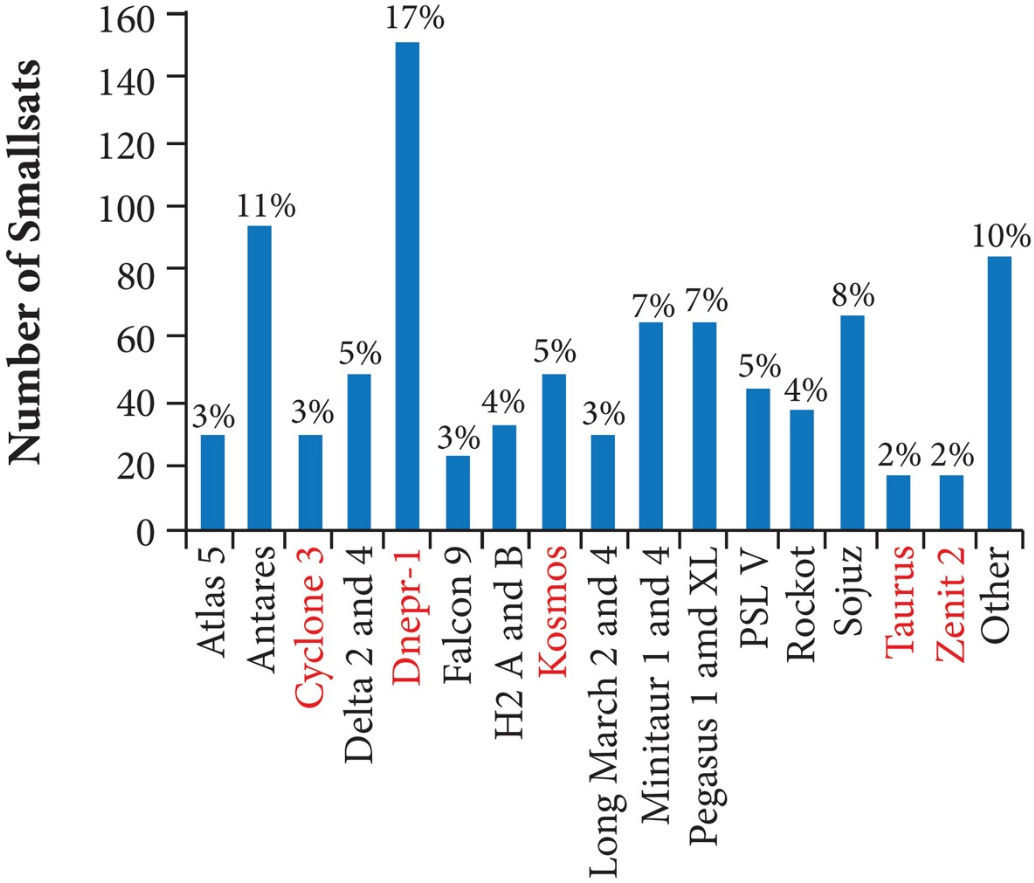
8.1. THE STATE OF THE MARKET

In the period 1994 to 2014, over twenty different launch vehicles have been used to launch the 863 small satellites (wet mass of less than 500kg) launched into orbit (see Table 14, below)[61]. Since mid-2014, a new era of small satellite launches and operations has seemed to be in evidence. Sixteen new launch vehicles have successfully flown since then, with a large number still under development across a variety of different nations. Space agencies and industries from countries as diverse as Iran, Korea and India are developing small launch vehicles. The UK is another country with serious, mature aspirations to build a suite of small launch vehicles, and this capability is being complemented by equally serious work being done to create a series of spaceports in the UK, and ground segmentation.

[60] SpaceX presentation to US Senate Subcommittee on Space, Science and Technology, 13 July 2017.

[61] *Status and Trends of Smallsats and Their Launch Vehicles — An Up-to-date Review, Journal of Aerospace Technology & Management*, October 2017, www.scielo.br

Table 14: The various launch vehicles used to launch small satellites between 1994 and 2014. Source:



These legacy vehicles contained state-of-the-art technologies for their time, such as gas generator propulsion systems, and cryogenic liquid oxygen and hydrogen fuels. However, the current generation of SLVs either currently operational or in development, have evolved technologically, and are using next-generation technologies that are helping to make SLVs a more cost-effective option for satellite operators.

Table 15: Small Launch Vehicle Technical Evolution. Source: BIS Research

Parameter	2010	2016
Material and Structure	Aluminium, steel, alloy, titanium, composite overwrap, metallic isogrid	Fibre-reinforced plastics and carbon-composite
Avionics	Inertial navigation with electronic component miniaturization, ring laser gyros, electromechanical actuators	Guidance, Navigation and Control (GNC), Integrated Avionics Test Facility (IATF), and telemetry
Guidance and Accuracy	Apogee and inclination <1%	
Propulsion System	Gas generator, staged combustion	Liquid booster propellant, electronic propulsion
Fuels (First Stage)	Cryogenic liquid oxygen and hydrogen, liquid oxygen and kerosene	Hydrazine, unsymmetrical dimethylhydrazine, and nitric acid
Thrust (Liquid Fuelled First Stage)	4150.19 kN	2,271 kN
Specific impulse Isp (First Stage)	410 seconds	284 seconds
Computers and Computational Capability	Solid state, 20 MHz operation	Solid State, 3 GHz operation

8.2. SCIENCE AND INNOVATION ASSETS

The UK has had a share of the launch market in the past, albeit a small one. The Black Arrow Rocket, developed by Saunders-Roe and Westland Aircraft, flew four times between 1969 and 1971, eventually launching the Prospero satellite into Low-Earth Orbit in its only successful flight. This remains the only example of the UK successfully launching a satellite into orbit. Shortly afterwards, the Black Arrow programme was mothballed on cost grounds, essentially abrogating the ability to launch vehicles into space as a sovereign capability.

Recently, however, there have been significant leaps in the willingness and ability of the UK to re-join this market in a major way.

It seems appropriate that we should open this section by mentioning the work being done by **Horizon AS**, who are currently developing and testing Black Arrow 2 at the **National Space Propulsion Test Centre** at Westcott, a few miles north-east of Oxford. Black Arrow 2 is a small launch vehicle that is marrying a plethora of cutting edge technologies to create greener, more affordable access to space for the delivery of satellites to orbit, and scientific payloads to the ISS. Black Arrow 2 will achieve Initial Operational Capability (IOC) once it has obtained its Operational Certification Audit, scheduled to be in 2020, one year after the first test flights have been completed.

Westcott is traditionally the home of propulsion testing in the UK and is also the location for the development and ground testing segments of the SABRE (Synergetic Air-Breathing Rocket Engine) programme by **Reaction Engines**, whose headquarters are twenty miles south-east of Westcott, in Abingdon. Whereas Black Arrow 2 will be used as a launcher to deliver payloads to orbit, the SABRE engine is designed to power a variety of orbital and suborbital spacecraft and aircraft, and conventional stratospheric aircraft. It has been developed over a number of years thanks to a combination of UK Government and EU funding, and has a heritage that stretches back to the 1980s.

Case Study: The National Space Propulsion Test Centre, Westcott

Westcott, Buckinghamshire, has long been the home of rocket propulsion testing in the UK, and has recently benefitted from an injection of capital from the UK Government to establish the National Space Propulsion Test Centre.

The facility will allow UK companies and academia to test and develop space propulsion engines by adding new capabilities and services for the UK space sector. The Government funding will:

- create a new vacuum facility at the Westcott propulsion test site. When used together with the existing industry owned rocket firing test cells, this will allow the simulation of high altitude testing of thrusters up to 2kN
- upgrade an existing industry owned test chamber to improve capabilities in the 25N thrust range
- open the facilities, alongside a smaller 1N thruster test chamber at the site, for the community to use

The UK's **Science and Technology Facilities Council (**STFC), through **RAL Space**, will act as an independent broker for facility access.

Image 17: an aerial view of Westcott Venture Park. Image credit: Westcott Venture park.

While SABRE and Black Arrow 2 are understandably marquee names, having been able to draw upon the UK's industrial heritage in different ways, there are a number of other companies who are also using unique approaches to achieve the visionary aim of creating a new type of launch vehicle. In London, in conjunction with counterparts in Copenhagen, **Orbex** has developed a European orbital micro-launch system featuring low-carbon, low-weight and high performance for small and nanosatellites. The Edinburgh-based business **Skyrora** is developing two new launch vehicles – Skyrora I and Skyrora XL – which are also drawing upon Black Arrow's heritage, as well as the world-famous expertise of Ukrainian engineers in Dnipro, which used to be the epicentre of the Soviet Union's space activities and now acts as a space-focussed business cluster and incubator. Skyrora I and XL are being designed also to meet the growing need for small satellite launches. Finally, **Orbital Access**, another Scottish business based at Glasgow Prestwick, are developing the re-usable Two-Stage To Orbit (TSTO) spaceplane Orbital 500R, which will enable payloads of up to 500kg to be delivered to orbit quickly, efficiently, while driving down the costs of launch. The spaceplane will fortify its commercial space applications by offering specialist transport services to the commercial space industry.

The development and testing of these new launch vehicles and launch products will add fundamental new and unique sovereign capabilities to the UK value chain. These are complemented by the UK Spaceflight Programme, a UK Space Agency initiative which endeavours to provide the UK with the launch infrastructure necessary to send those new vehicles and products to space. This is what will add real, transformative power to the UK access to space industry, and enable investors in this area to accelerate returns to helping to give priority access to launch to UK vehicles and payloads.

All this leads to the most significant development for the UK in this area, which is the announcement at the 2018 Farnborough Airshow that the UK Space Agency has approved the development of the UK's first spaceport, Space Hub Sutherland, for vertical launch at the northern coast of Scotland. **Lockheed Martin** have been awarded the initial contract and funding from the **UK Space Agency** to develop the technologies and launch operations on site. The site is expected to be operational by the early 2020s, with six launches supported each year.

The UK Space Agency has ringfenced further funding for more investigation into the viability and development of horizontal launch infrastructure and capability, to allow spaceplane launches, or deployment of spacecraft from aircraft.

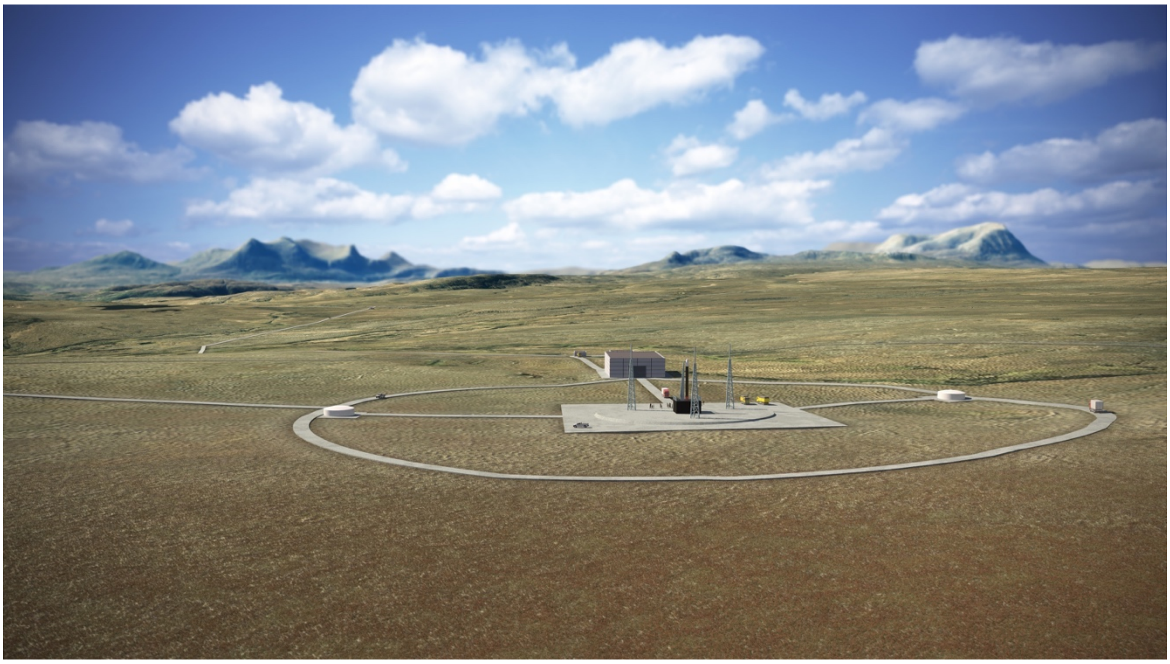


Image 18: An artist's impression of the proposed Spaceport at the Moine, Sutherland, in the Scottish Highlands. Image credit: Perfect Circle JV.

The approach currently taken by the UK Government is that any site that can meet the safety and regulatory aspects of spaceflight would be eligible to apply for a licence to establish a spaceport, meaning the UK may in fact end up in possession of more than one spaceport.

The Research Base

The development and testing of new launch vehicles requires a vast array of testing capability. While the National Space Propulsion Facility at Westcott is the epicentre of chemical propulsion testing in the UK, in fact there are a variety of facilities and assets dotted around the UK Nationwide Cluster, each offering unique capabilities and services.

Scotland's visionary aspirations of hosting at several UK spaceports, is complemented by the location of the **Centre for Future Air-Space Transportation Technology** (C-FASTT). C-FASTT is a research centre at the **University of Strathclyde**, established in 2010 with the intention of revolutionising future air and space travel by undertaking the long-term planning and research required to make access to space easier, lower cost and more efficient.

Thales-Alenia-Space (TAS-UK) have taken advantage of NSTP funding to develop their own launch system called MicroLaunch which, by generating thrust via energy transmitted wirelessly from a specialised ground station, could launch over 1000 small satellites a year by 2030.

The **Gas Turbine Research Centre (GTRC)** in Cardiff is capable of generating model validation and/or development for propulsion systems, a crucial part of de-risking testing processes. The GTRC contributes to a number of technology impact areas, such as power generation, propulsion, and alternative fuels.

Forty miles west of Cardiff and the GTRC, **Swansea University** boasts a mobile rocket test stand used to demonstrate rocket propulsion principles, as part of the "Space Propulsion and Power Systems" module within the university's Space Stream.

In the East Midlands, the **Advanced Structural Dynamics Evaluation Centre** (ASDEC), hosted by **HORIBO-MIRA** near Nuneaton, offers structural analysis of engines and vehicle casings being subjected to extreme temperatures and vibrations. Its measurement techniques, using Laser Doppler vibrometers, enable greater accuracy, resolution and speed are world-class; ASDEC is only one of three facilities in the world to offer this capability. This makes ASDEC invaluable to the players in the aerospace and space industries developing wings, engines, payloads and vehicles, and has been used to test the structural integrity and dynamics of ESA's Bepi-Colombo mission.

Nearby, at **Loughborough University**, three research groups tackle Access To Space topics: Propulsion & Energy Systems, Applied Aerodynamics, and Structural Dynamics and Acoustics. These groups have access to high quality research & innovation infrastructure, including Aeronautical propulsion test cells, high pressure test cells, the Dynamics and Control Lab, the **Low-Speed Aerodynamics Lab**, and the **Rolls-Royce UTC** Lab.

Conclusions:

- There are a number of new launch vehicles being developed by the UK.
- The small launch market is set to grow, and shows strong interdependencies with the growing small satellite and ground segmentation markets.
- The UK Spaceflight programme completes this value chain, and offers a powerful accelerant to new, end-to-end, sovereign capability within the UK.
- UK Spaceports should not cannibalise each other's capability in their quest to be competitive. Offering a variety of launch services across the UK would cater for the various growing satellite and launch markets, and best serve the interests of the country.
- There is strong evidence suggesting that SpaceX *et al* are now demonstrating profit margins, and therefore private capital investment as a viable method of financing the upstream sector.

9. Ground Segment

Once the Satellites have been built and transported to space by the launch vehicle, it is the job of the ground segment to operate manage and control the mission.

Like the space sector as a whole, ground segment is split into both upstream and downstream elements. The downstream element encompasses consumer equipment (satellite TV dishes; satellite phones and mobile phone terminals; broadband satellite dishes; radio equipment; and standalone hardware for GNSS, such as in-car satnavs. What remains is the upstream element, and encompasses GNSS infrastructure, network gateways, control stations, and Very Small Aperture Terminals (VSATs). As ever, for the purposes of this report we shall we focussing on the upstream element.

The data that satellites produce reaches Earth through radio waves, whose signal can be as weak as a light-bulb millions of miles away by the time it arrives. ‘Ground stations’ also known as ‘Earth stations’ are the highly specialised radio stations that able to use parabolic antennae to detect those messages reliably. It is then the role of the wide Ground Segment to process the data received from the instruments and sensors of the satellite, to disseminate and archive any products or reports generated by the mission.

Crucially, the Ground Station also has to be able to send instructions back to the satellites. This is because for satellites to remain useful it has to be possible to adjust their trajectory and alter their functioning from earth. Without that process, without effective ground stations, satellites would have a significantly shorter useful life. To do this successfully, Ground Stations and broader Ground Stations need to be built to be sufficiently adaptable to enable bespoke control and management of a mission – and the people working with them have to have the breadth and depth of skills and expertise that will enable them to deal not just to the challenges that can be forecast on launch day but also to those that develop later on.

In this context, it is particularly important to set out the market trends for ground stations – because we are in the middle of a high-stakes transformation of their role.

Changing Roles

The traditional role of Ground Stations was technically complex but straightforward in terms of its purpose.

The UK has long had a historic strength in ground station technology. BT’s Madley Communications Centre has tracked satellites since 1975, while the Goonhilly ground station in Cornwall was built in 1962 to pick up signals from the Telstar communications satellites. These helped transmit (and in Madley’s case still do help transmit) television programmes, telephone messages, and even fax messages, from one part of the globe to another. They were and are hugely ambitious technologically – a key part of a hugely significant commercial sector – at the same time it is also true that the basic conceptual model within which this kind of ground station operate is simple enough. Information developed on Earth (whether this is a news bulletin or a phone conversation) is transmitted via satellite to another part of the Earth.

With the rapid growth in fibre optic cables to transmit telecoms data that traditional ground station role may be in decline, but a broader view of the sector brings out sound reasons for optimism about future growth – which is why our forecasts for ground sections show year on year growth for the next few years.

Networking, between ground stations, and between the ground and space, is increasingly complex and plays a growing role in the satellite communications ecosystem. Platforms need to respond to a number of key trends in the industry like the transition to Tbps (Terabit per second) satellites, the advent of constellations, new satellite features like beam forming or new business architectures, such as the Virtual Network Operator (VNO), which will take advantage of advances in AI and autonomy. Consumers, both commercial and individual, are becoming more demanding with respect to data requirements, connected services via apps, and the desire to be connected everywhere with the highest levels of quality.

International companies such as **OneWeb** and **WorldVu** are intent on using constellations to deliver a variety of services, including telecoms. This would impose new challenges to ground stations, which would have to adapt to newer and evolving operational requirements, shifting from a model whereby each station tracked a relatively small and constant number of satellite signals to one where each station would be expected to keep track of a far greater and more rapidly changing number of satellite signals.

Furthermore, we are, as a society, already reliant upon satellites, to the extent that has already been mentioned; namely, that space is a part of the UK's critical national infrastructure, which therefore includes ground stations. The ground segmentation is used not just to relay information from one part of the Earth to another but also to reveal information about the Earth. Our use of the data generated by Earth Observation satellites is increasing, which is translated into meaningful information by ground stations. All of this helps to provide critical information for the growing global challenges of climate change, the plasticisation of the ocean, and ever more complex defence and security challenges.

The Ground Stations of the future will have to be able to respond to rapid change both in terms of what kind of satellites they track and in terms of what those satellites do. The UK's ability to succeed in this opportunity-rich and challenging future rests on the strength of its science and innovation base.

Earth Observation

Satellites give us a new way of seeing the world. Today, images of our planet from orbit are acquired continuously; they have become powerful scientific tools to enable better understanding and improved management of the Earth and its environment. Earth observation images show the world through a wide-enough frame so that complete large-scale phenomena can be observed to an accuracy and entirety it would take an army of ground-level observers to match. A single satellite image has the potential to show the spread of air pollution across a continent, the precise damage done in a region struck by an earthquake or forest fires, or the entire span of a 500-km hurricane from the calmness of its eye to its outermost storm fronts.

9.1. THE STATE OF THE MARKET

Reflecting the wider space sector as a whole, the majority of the market for the ground segmentation is taken up by the downstream segment. The entire market was valued at $113.4billion in 2017, with the downstream element worth $103.1billion. Of that, consumer equipment was worth $18.5billion and GNSS infrastructure was worth $84.6billion.

The upstream element (space gateways, control stations, and VSATs), was valued at $10.3billion[62], and revenues grew at a rate of 7% between 2016 and 2017.

With the overall satellite industry growing, driven largely by technical advances in, and demands for, smaller satellites and constellations, satellites are able to host more services and bandwidth prices are decreasing steadily. This is good news for operators om the ground, but does not tell the whole story, as the ground segment cannot simply grow on bandwidth alone; it is the effectiveness and efficiency of how that increased connectivity is exploited and used that ultimately drives the industry forward.

VSAT platforms (modems + baseband) are the fastest growing element in ground equipment, with the market set to expand at a double-digit CAGR to offer over $2billion in annual revenues by 2026.

[62] All statistics, 2017 State of the Satellite Industry Report, Bryce for SIA (Satellite Industries of America), 2017, https://www.sia.org/wp-content/uploads/2017/07/SIA-SSIR-2017.pdf

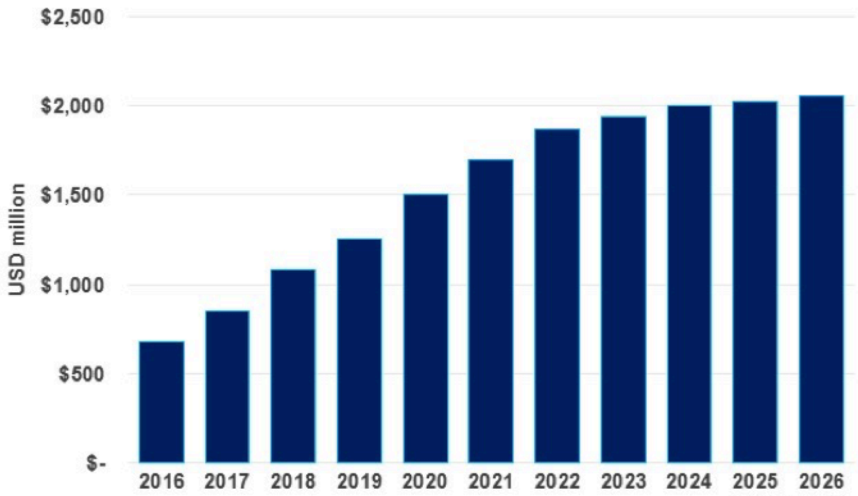


Table 16: Satellite Modems and baseband equipment market to 2026.

Space assets are improving dramatically. From satellites hosting tens of 36-MHz transponders distributed in a couple of beams with a throughput of a couple of Gbps, today's satellites carry new payloads illuminating hundreds of beams of much larger GHz transponders generating 100s of Gbps or even Tbps. The ground segment must meet all these new technical requirements managing wider and more numerous carriers dealing with a booming number of terminals generating upwardly scaling throughputs. All this without forgetting the cost considerations as CAPEX investment cannot scale with performance if it must stay within reasonable limits.

The adoption of HTS is also triggering new business models. Satellite Operators now integrate investment in the ground segment to facilitate the adoption of their services. This sets new requirements for VSAT platforms in terms of creating the networking ecosystem for resellers to be able to integrate their value-added services through virtualized networks. Furthermore, each service provider has a very different customer profile meaning that the ground segment must be able to serve a wide array of applications from the same platform.

Communication Highs

Bandwidth efficiency used to be a major differentiator among VSAT platforms, but with all major platforms incorporating DVB-S2X (one of the satellite digital broadcasting standards, which is approaching its physical limit), higher layers of communications are being pursued. Cellular Backhaul, a growth area, is one of the most demanding applications in this sense. Video is clearly the driver behind the capacity boom such that vendors are developing local cache solutions to minimize the traffic that actually needs to be sent through the pipe. With **Earth-I** being one of the leading purveyors of such a service, the ground segmentation must be sure that not only bandwidth but the subsequent connectivity is managed effectively.

Network management is also gaining relevance as one of the most important aspects in VSAT platforms. And here, mobility is arguably the most demanding vertical in this sense. Ensuring the SLAs for individual aircraft and fleets of aircraft migrating among multiple beams, satellites and regions, all this with different layers of priority for data is a challenge of massive complexity. This will only get more labyrinthine with the arrival of flexible satellites and multi-orbit constellations.

Ground and Space, Hand in Hand

With bandwidth pricing decreasing rapidly, the ground segment must be integrated into the wider strategic picture for the development of the sector. In the upstream sector, control stations and space gateways must stay connected with space manufacturers and engineers to ensure that designs, tests, operations and services are all aligned.

In the case of the UK and its aspirations of achieving a complete end-to-end value chain, this is more important, and yet more achievable, than ever. The UK has the capacity, the infrastructure and the expertise across its industrial base, but there must be an effort to ensure that ground segmentation, which is so heavily visible in the downstream segment, is more visible to upstream developers. In this way, capability can be developed and delivered in tandem, so that assets in space are used to their optimum capacity, and the greatest value is derived for satellite users and customers.

9.2. SCIENCE AND INNOVATION ASSETS

The size and of ground segmentation means that only a handful of organisations have the capability and infrastructure to be able to offer significant upstream ground segmentation services. What the UK does have, it uses extremely well. However, infrastructure and software that is able to cope with the demands placed upon it by evolving services in space is required.

The UK's primary Space Gateway is Goonhilly Earth Station (GES). Goonhilly has a long history of service in the Space sector, having been involved in the first transatlantic TV transmissions in 1962, helped to birth IntelSat, EutelSat and InmarSat, and the internet, as networks on the American Coasts were linked to Europe.

Goonhilly is now a private entity and continues to expand its commercial satellite communication service portfolio. It offers world-leading capability in private sector deep space communications.

In an excellent echo of the SpaceX newspace business model, Goonhilly has acted as a magnet for major private capital investment programme, which has recently been backed by UK Government support: GES Ltd has been given "Enterprise Zone" status – the government's flagship programme for technology parks which will bring significant additional capital investment and offer benefits to incoming customers.

Goonhilly offers a range of services and facilities, from being a Satellite Communications Teleport, a mission control centre for LISA Pathfinder, as well as advanced manufacturing facilities for telecommunications projects and products. The site itself spans 164 acres in southern Cornwall and is set to grow by building several new antennae to its deep space inventory, thus supporting new missions and commercial markets.

Elsewhere, the **RAL Space Ground Station**, which receives satellite data from antennae at Harwell and at Chibolton, has a track record of working closely with academia and industry, providing services and software for the precision control of telescope systems. The specialist work of the RAL Radio Frequency (RF) experts, scientists and software engineers is reinforced by their access to the broader RAL Space expertise in data management, and their geographic coincidence to the Harwell cluster means that they offer unparalleled access for smaller companies to mission control systems. Given the proximity of the RAL Space Ground Station to the National Satellite Test Centre, and the Westcott National Propulsion Test Centre, its strategic value should not be underestimated as it helps this regional cluster alone offer a very competitive and tightly-knit value chain of upstream services and expertise.

Other organisations offer specific and singular expertise. **CGI-UK** offers significant expertise in mission control, having led the control systems software for over 200 satellite missions, as well as being at the heart of the Galileo programme, and having a number of team members on the fight control team of the Rosetta probe and its Philae lander as it travelled through the Solar System for a decade.

The **National Air Traffic Services** (NATS) has sites in Hampshire, on the M3 Corridor, and Prestwick, at the west end of the Scottish central belt, and offers satellite secure communications, safety-related site control systems, satellite communications network maintenance systems, security and cyber security monitoring and defences, as well as safety-related ground systems, such as those for EGNOS (European Geostationary Navigation Overly Service). The latter example is significant, as NATS successfully demonstrated the first example of how EGNOS – a navigation service for aviation and shipping – could be used commercially. NATS showed aircraft could primarily use EGNOS for extra accuracy and safety for runway approaches and landing in low visibility conditions – an ideal, low-cost solution for smaller airfields and airports in inclement conditions.

Isardsat, the EO service provider, has a UK subsidiary office in Guildford, and offers capabilities for the design, and maintenance of civil remote sensing instruments, from the development of algorithms for data processing, as well as calibration and maintenance once the spacecraft is in orbit. Finally, IsardSAT performs studies for scientific applications with the data acquired by these instruments and develops customised services using EO data.

It is a significant participant in the Copernicus programme as it possesses ground processors for the satellite Sentinel-6, and undertakes mission performance operations for Sentinel-3.

Conclusions

- Upstream ground platforms and control stations must evolve to meet the future technical and business requirements. There is a huge market opportunity for optimal solutions.
- Focusing on implementing the physical layer of ground segmentation (terminals, gateways) to obtain the best Mbps/MHz figure of merit is no longer enough. Acceleration, compression, virtualization and other applications today are critical to stay competitive.
- The ground segment must be more strategically aligned with the satellite manufacturing sector in order to develop and deliver the requisite operational capabilities from the ground up. Geographical proximity certainly helps in this respect.
- Further investment will be needed to develop new ground services to operate and manage the new breed of assets expected to orbit the Earth in the coming years.

10. Enabling and Exploration Technologies

It has been established that emerging markets in commercial access to space, and the growing satellite launch market, are being tackled head on by UK industry. But there is another fundamental aspect to the upstream segment which, like the launch market, traditionally has been dominated by the institutional market. The exploration of space. Moreover, the exploration and exploitation of space. If we hark back to Professor Stephen Hawking's comments quoted at the beginning of this report, we're reminded of the growing feeling that if humanity is to continue to thrive, or even survive, then we need to re-engage with our propensity and need to push back barriers of knowledge and discovery; that ultimately we will need to explore and use the resources that lie in space.

To date, exploration spacecraft and missions have been conducted either as exclusive or joint endeavours between national space agencies. However, there is evidence that markets – enormous markets – for deep space exploration and exploitation will eventually emerge, though not for many years. Nevertheless, some of the emerging technologies foreseen to be required have already been developed in some of the more audacious and best-known space missions of recent years.

Exploration technologies are those technologies required by humans and spacecraft to explore and exploit other worlds. And enabling technologies are those technologies that underpin everything else in the spacecraft system, whether the spacecraft is used as a commercial satellite, or an exploratory one. This chapter, then, focuses on a combination of robotics, manipulators, artificial intelligence and autonomy frameworks, energy and power systems, modelling & simulation systems, in-situ resource utilisation (ISRU), sensors, and software and new platforms, such as rovers, landers, and other robots.

Rosetta

Rosetta was one of ESA's flagship missions from the last two decades, which chase, go into orbit around, and land on a comet. It is currently studying the Jupiter-family comet 67P/Churyumov-Gerasimenko with a combination of remote sensing and in situ measurements. In 2014, Rosetta's lander Philae was deployed to the surface to image and sample the comet nucleus, while the Rosetta orbiter tracked the comet, examining its behaviour as it approached its perihelion (its closest point to. the Sun).

For the Rosetta Orbiter, **Imperial College London** led the investigation into the RPC (Rosetta Plasma Consortium) PIU (Plasma Interface Unit). For the Philae lander, the **Open University** in Milton Keynes led the development of the Modulus Ptolemy, an instrument featuring drill and sampling systems for making in-situ isotopic measurements and analysis of solar system bodies, so as to greater understand the geochemistry of light elements such as oxygen, carbon, hydrogen and nitrogen. The **UK Space Agency** also was a member of the Rosetta mission Steering Committee.

ExoMars

The UK is the second largest contributor to ExoMars, the European Space Agency's flagship programme to search for the evidence of whether Mars does, or ever has, harboured life. The programme is comprised of two stages: the Martian Orbiter and Schiapirelli Lander, which launched in 2016, and the Mars Rover, scheduled to launch in 2020. Various UK partners are providing unique and world-leading expertise in several aspects of both ExoMars stages.

Airbus DS are the prime contractor for the rover build, and as such provide the development programme with the use of its unique Mars Yard V&V testbed in Stevenage to test the rover instrumentation, software, autonomy. Airbus DS also are providing the locomotion and GNC (Guidance, Navigation & Control) systems for the vehicle.

Thales Alenia Space UK are also a major contributor to the rover programme, supplying it with its Reaction Control System (RCS), which provides the rover with a crucial tool in its armoury for traversing the Martian landscape; namely, enabling the rover to control its attitude and trajectory throughout its traverse.

PanCam (the rover's panoramic camera system which will provide imagery of the Martian surface, and enable digital terrain reconstruction) is led by UCL's **Mullard Space Science Laboratory** (MSSL), and supported by the **University of Aberystwyth**, **Birkbeck College** and the **University of Leicester**.

The **University of Leicester**, **Bradford University** and **Rutherford Appleton Laboratory (RAL Space)**, are key players in the development of the CCD camera on the Raman Laser Spectrometer (Raman LIBS) which can detect the presence of chemical compounds including minerals and also specific types of "biomarkers" – chemicals indicative of past or present life – that are produced by primitive micro-organisms to enable them to adapt to life in extreme environments.

The **Open University** is participating in the development of the NOMAD (Nadir And Occultation For Mars Discovery) instrument, a spectrometer set to be part of the payload of the Mars Trace Gas Orbiter element of the mission. NOMAD will sample and analyse the Martian atmosphere to reveal its elemental components. [63]

[63] *PanCam… Open University: UK Space Agency website,* https://www.gov.uk/government/case-studies/exomars

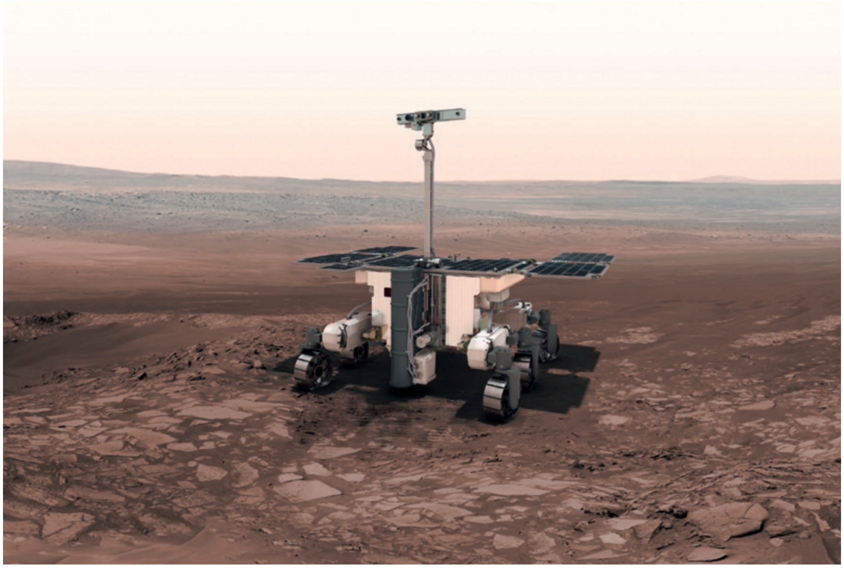


Image 19: The ExoMars Rover, which features technology from various UK organisations.

Sample Return Missions

One of the outcomes from ExoMars will be a greater understanding of the requirements necessary for the next generation of ESA missions, namely Lunar Polar Sample Return, Mars Sample Return, and Phobos Sample Return.

The UK's involvement in ExoMars positions it well with respect to these missions, and UK industry is targeting these missions through the further development of robotics and AI, new rover concepts and architecture, and sampling and curation systems both remote and on Earth.

JUICE (JUpiter ICy moons Explorer)

JUICE is the first large-class mission in ESA's Cosmic Vision 2015-2025 programme. Planned for launch in 2022 and arrival at Jupiter in 2029, it will spend at least three years making detailed observations of the giant gaseous planet Jupiter and three of its largest moons, Ganymede, Callisto and Europa.

The UK is leading the magnetometer instrument with **Imperial College London** as the principal investigator. The **University of Leicester** is providing engineering support to development of the instrument in terms of mechanical and thermal design and modelling of the mission radiation environment.

MIRI James Webb Space Telescope

MIRI or Mid-Infra Red instrument is the ESA contribution to the James Webb Space Telescope (JWST). The JWST will be a large infrared telescope with a 6.5-meter primary mirror. The telescope will be launched on an Ariane 5 rocket from French Guiana in 2020. It will be the premier observatory of the next decade, serving thousands of astronomers worldwide. It will study every phase in the history of our Universe, ranging from the first luminous glows after the Big Bang, to the formation of solar systems capable of supporting life on planets like Earth, to the evolution of our own Solar System.

The science goals of JWST require a versatile mid-infrared instrument covering the 5-28.5 µm wavelength range with a wide field of view for imaging through broad and narrow band filters, low resolution spectroscopy from 5-10µm, moderate resolution spectroscopy, and high dynamic range coronography. MIRI is designed to provide all of these functions in a single instrument.

MIRI is both an imager and spectrograph working in wavelength range of 5 to 20 microns. The instrument is led by the **Astronomy Technology Centre** in Edinburgh as principal investigator. The **University of Leicester** is leading the mechanical and thermal design of the instrument and its support structure and is supporting the environmental tests on the spacecraft during environmental tests in the USA.

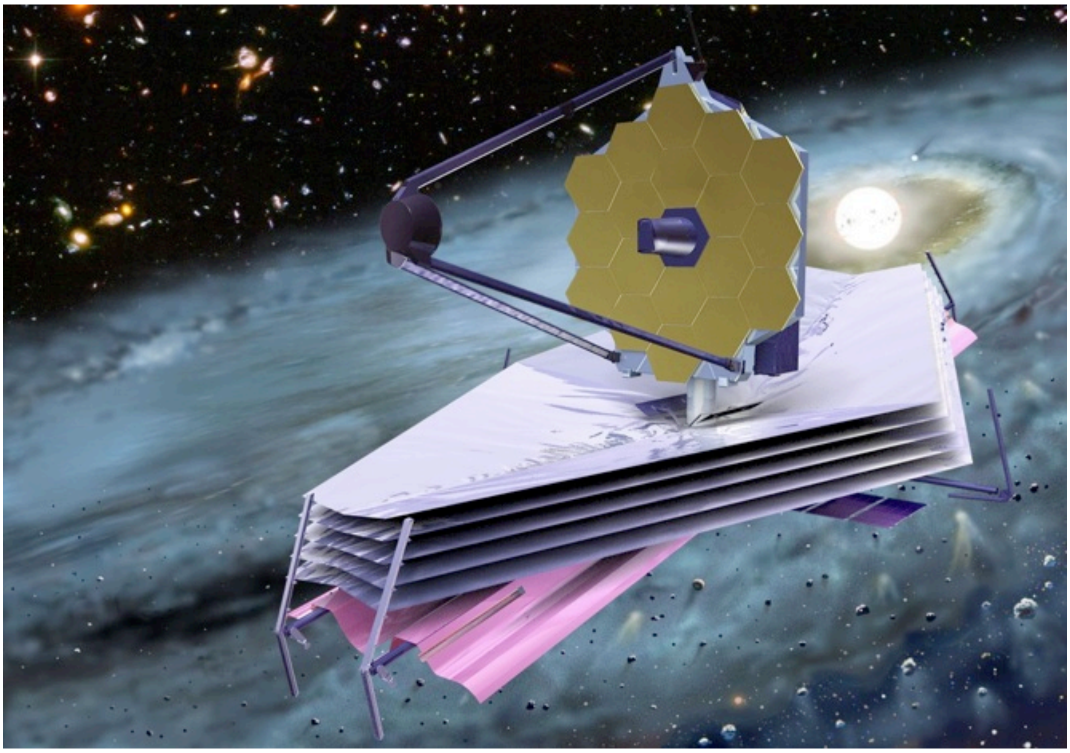


Image 20: The James Webb Telescope represents a globally collaborative effort, with the UK playing a significant role.

SolO (Solar Orbiter)

Solar Orbiter is a mission dedicated to solar and heliospheric physics. It was selected as the first medium-class mission of ESA's Cosmic Vision 2015-2025 Programme. The programme outlines key scientific questions which need to be answered about the development of planets and the emergence of life, how the Solar System works, the origins of the Universe, and the fundamental physics at work in the Universe.

The UK has a significant stake in the project. **Airbus DS** is the prime contractor for the project, and its Vacuum UV exposure testing facility was built specifically for this mission; the facility can expose a 50x50mm sample to broadband light, ranging from the vacuum UV to the far infrared.

Developments for the magnetometer are being led by **Imperial College London**, while **Mullard Space Science Laboratory** are leading the development of the Solar Wind Plasma Analyser.

Image 21: The Mid Infrared Instrument (MIRI) is tested at RAL Space

BepiColombo Mercury Orbiter

BepiColombo is one of the cornerstone missions of the European Space Agency (ESA), in cooperation with Japan, and will provide the most complete exploration of Mercury to date. It is due for launch in October 2018. The mission consists of two separate spacecraft that will orbit the planet. ESA is building one of the main spacecraft, the Mercury Planetary Orbiter (MPO), and the Japanese space agency JAXA contributes the other, the Mercury Magnetospheric Orbiter (MMO). BepiColombo will help to reveal information on the composition and history of Mercury, as well as general information on the formation of the rocky planets, including the Earth.

MIXS consists of two channels; MIXS-C a collimator providing efficient flux collection over a broad range of energies with a wide field of view for planetary mapping and MIXS-T, an imaging telescope with a narrow field of view for high spatial resolution measurements of the surface. MIXS has a companion instrument the SIXS (Solar Intensity X-ray Spectrometer) being developed by the University of Helsinki which will perform measurements of X-rays and particles of solar origin. The combination of these instruments will provide details on the elemental composition of the surface layer of Mercury.

The **University of Leicester** are providing the Principal Investigation, development, production and calibration of the MIXS optics, calibration of focal plane detector, construction and test of the MIXS instrument, and flight data analysis.

MetOp SG

MetOp-SG (MetOp Second Generation programme) refers to the second generation of Earth Observation operations undertaken by the MetOp-SG-A and MetOp-SG-B satellites, set for launch in 2021 and 2022 respectively. MetOp-SG aims to obtain consistent, long-term data of uniform quality via remote sensing, to be used to operational meteorology services and climate monitoring state analysis, forecasting and operational service provision, in the context of the EUMETSAT's EPS-SG system.

The Millimetre Technology (MMT) Group at **RAL Space** are presently leading the development of a number of Front End Receivers for the MetOp-SG programme, at frequencies from 166 GHz to 325 GHz. Global measurements from the Microwave Sounder (MWS) instrument will enable the development of better numerical weather prediction models, leading to better weather forecasts. The Microwave Imager (MWI) will provide improved now-casting data on rainfall and snow, while the Ice Cloud Imager (ICI) will, for the first time, provide qualitative data on the composition of ice clouds which are believed to have a key role in Earth's climate. **Airbus DS** in Stevenage are also developing the optics system for the MetOp-SG programme, and significant funding from ESA and UKRI has been drawn down by both RAL Space and Airbus DS to achieve these developments.

10.1. THE STATE OF THE MARKET

For scientific, institutional missions such as those described above, the market is conservative and stable. ESA has provided extensive details of its Cosmic Vision 2021-2025 Programme, for which many of the R&D and scientific investigations are underway. The role of UK organisations in many of these projects are already understood, ensuring that the rich heritage of upstream space in the UK continues.

In the commercial markets, however, the picture is more complex. Unlike the Launcher, Satellite and Ground Station Market, it is somewhat more difficult to provide a granular definition of what the market value for enabling technologies is. Better, therefore, to understand enabling technologies as necessary sub-sectors within the upstream space segment as a whole: the subsectors must necessarily grow if the small satellite market, launcher and ground segmentation markets are to grow.

It is easier to consider the individual spacecraft and satellite sub-sectors individually rather than as one, though there is a logic in categorising them under the Enabling & Exploration Technologies, as they will have to demonstrate collective growth in order to satisfy both the markets exhibiting high, short-term growth, and the yet-to-emerge, long-term markets. Below, then, we will consider the individual technologies required for current and future spacecraft (excluding payloads, which have been covered in Chapter 7):

- Materials & Structures
- TTC (Telemetry, Tracking & Command)
- OBC (On-Board Computers)
- Power Systems
- Attitude Control Systems
- Propulsion Systems
- Robotics and software

Materials & Structures

Satellite structures undergo a thorough design and verification process before fabrication is started. However, developments in Cubesat technologies in the 1990s and 2000s reduced the cost of satellite structural design & manufacture, and now there are several organisations developing advanced spacecraft bus designs, which allow for increased flexibility for payloads, and minimised mass and size. Structures accounted for around 9.1% of the global small satellite and subsector market in 2016, and is projected to account for 9.9% of the market by 2021[64].

In cash terms, this means the structures subsector had a market value of $230.1million in 2016, and is projected to reach $998.8million in 2021, a CAGR of 34.1%[65].

[64] *Global Small Satellite Market – Analysis & Forecast, BIS Research, 2017* & *Global Nano Satellite Market – Analysis & Forecast, BIS Research 2017*
[65] As above.

This growth can be accounted for by the advances in 3D-printing technology and its widening availability throughout the supply chain, driving down costs whilst retaining and, indeed, even improving performance.

Telemetry, Tracking & Command

As covered in Chapter 9, Telemetry, Tracking & Command is something that must be controlled by the ground segmentation, but spacecraft – be they used for upstream instiutional or downstream markets – must also possess on-board TTC capability in order to maintain excellent communications links with Earth or, in the future, with other space-based infrastructure such as space stations, planetary orbiters, landers and rovers.

A TTC subsystem must abide by communication protocols, meaning spacecraft and ground stations must adhere to the same standardized frequency, bandwidth, data rate, and modulation scheme. The TTC subsector market for small satellites stood at 9.9% of the entire market and is set to grow a nominal amount to take 10.0% of the market by 2021. The TTC subsector was valued at $251.3million in 2016, and projected to be $1,009.9million in 2021[66].

The growth of market share is small because advancements in TTC are set to be incremental in this time, rather than expected to be disruptive. However, with innovations such as the high-definition colour video footage being offered by Guildford-based Earth-I, as well as other multimedia services offered at high data rates, TTC capability requirements may increase if such services are strongly demanded in the market and may affect market share, though the growth of the subsector in value terms looks strong.

One area of opportunity for the UK is in Software-Defined Radios (SDRs), communications systems that are adaptive and reconfigurable so as to reduce interference and increase the number of possible comms channels. SDRs are not widely used at present but could be an opportunity, along with S/X (deep-space radio and microwave communications signals) band stations. In its ambition to support new TTC technologies and capabilities, **Goonhilly Earth Station** is well placed to support businesses working in this field.

On-Board Computing

The OBC refers to the computing subsystem on board a satellite, spacecraft or rover that handles the avionics, software, software payloads, operating systems and processing tasks. OBCs consist of microprocessor boards (including memory, processors, chips and interconnectors providing interfaces to the individual objects within the spacecraft architecture), DC/AC power conversion capability, telecommunication decoding, and interfaces with other avionics systems. Modern OBCs may also possess advanced autonomy features, such as decision-making / deliberative capability, path-planning, and execution of

[66] As above.

tasks, while Chip-on-Chip technology is helping to reduce the size and complexity of processing boards and OBCs.

In 2016 the OBC subsector accounted for 20.4% of the overall market, and this is expected to fall very slightly to 20.1% by 2021. However, the value of the sector is expected to display healthy growth; in 2016 it was valued at $515.7million, and it is projected to be worth $2,029.9million by 2021. The primary capability requirements for the subsector are the need for high-performance field-programmable gate arrays (FPGA), High capacity Static Random-Access Memory (SRAM) memories, and Efficient wireless bus topologies.

Power Systems

Spacecraft require on-board power systems to enable their various on-board capabilities. Power systems comprise power sources, energy storage systems, power regulation and control, and distribution systems. Interfaces with autonomy software are likely to be increasingly required in the future to enable the spacecraft to autonomously manage its own resources, especially when operating in remote parts of the Solar System, such as Martian caverns or in deep space.

Batteries and solar power is typically used on spacecraft and rovers, with RTGs (Radioisotope thermoelectric generator) also used for long-term, low-power uses. However, power systems are heavy, often accounting for a third of the system's entire mass. Therefore, lightweight batteries are highly desirable, and this need is driving much of the investigative work in this area. Nuclear power sources, based upon the isotope Americium-241, are being investigated as a viable power source, as its half-life of 432.2 years and its ready availability as a by-product of plutonium (making it, essentially, nuclear waste) and isotopic purity makes it a desirable source of power for very long-term exploration missions. However, its high price tag ($1,500 per gram) means heavy investment is required to make serious applied research projects viable in this area.

The power subsector was valued at $336.2million in 2016, and is projected to reach $1,181.6million by 2021. This translates as a 13.3% share of the overall market in 2016, and 11.7% in 2021. Compared to other subsectors this is moderate growth, yet still stable.

Attitude Control Systems

Spacecraft, especially satellites in service, need to remain stable in orbit, and rely on accurate positioning to ensure that the satellite's sensors and instruments are angled correct with respect to the orbit and Earth. Attitude Control Systems are responsible for this.

Small satellites using what are known as multiple narrow-beam antennas[67] require tight pointing accuracies to ensure adequate antenna gain. This is anticipated to be a technique required of constellations and therefore represents high potential growth in the subsector market. Additionally, the increase in the utilization of momentum-based attitude control system actuators to meet their pointing requirements is expected to drive the growth of the small satellites market for ACS capabilities.

The ACS subsector market was valued at $290.7million in 2016, and took an 11.5% share of the total subsector market. This is projected to be $1,211.9million in 2021, at a market share of 12%.

Propulsion Systems

All spacecraft, probes and satellites require the ability to propel themselves once stationed in space, and as described in Chapter 7, the propulsion system provides this capability. A propulsion system consists of a source of mechanical power, and a propulsor, comprising an engine or a motor as the power source, wheels, axles, propellers, and a propulsive nozzle to generate the force. Presently, most of the small satellites are propelled by forcing a gas from the rear of the vehicle at an extremely high speed, known as chemical propulsion, but great advances are being made in electric propulsion, which uses a variety of techniques such as cryogenics and electromagnetism to spray pressurised ions through a nozzle to generate extremely high speeds.

As with power, propulsion fuel (propellant) takes up significant space and mass, which makes the margins for propellant in small satellites extremely tight. Resultantly, there is a need for more efficient propulsion systems and, given the small satellites are experiencing a strong growth in numbers, there is work being done in both chemical and electrical propulsion subsectors to achieve these new efficiencies.

The propulsion systems subsector market was valued at $288.2million in 2016, and took an 11.4% share of the total subsector market. This is projected to be $941.2million in 2021, at a market share of 9.3%. The growth in cash terms is moderate, but the fall in market share may be attributed to the fact that the main driver for propulsion systems is the need to reduce the amount of mass and space it accounts for on the spacecraft.

[67] Using a technique known as MIMO (Multiple Input, Multiple Output) antennas, which break down high data-rate signals into multiple low-rate data signals which are then picked up by receiving antennae and then recombined to reform the data.

Robotics and Autonomy

Robotics have played a role in space for quite some time now, but almost exclusively for institutional missions, such as the Space Shuttle programme, the assembly of the International Space Station, and various interplanetary missions.

We are now at a point in time where development of robotics and intelligent autonomy systems (ie, on-board systems that can take operational decisions pertaining to a spacecraft's mission without human intervention) has reached a level that is commercially exploitable. As such, there are no reliable figures relating to the size of the robotics market at present, given that the commercial applications are only due to become a reality over the next few years.

However, the applications are clear. On-orbit servicing, on-orbit assembly, and the physical reconfiguration of satellites are all orbital use cases which are highly desirable from a commercial perspective, allowing assets to become longer-lived, flexible and adaptable with respect to function and mission, while robotic assembly systems will enable larger pieces of infrastructure to be built in space.

In a planetary context, improved robotics and autonomy systems will enable robots and rovers to undertake longer traverses, increasing the scientific and economic return from such missions. Ultimately, robots will be able to land on foreign bodies for the purposes of deep space mining, and collaborate without humans-in-the-loop to build infrastructure on the surface of other bodies within the Solar System (or perhaps even beyond) for the purposes of colonisation.

Robotics and autonomy encompasses a wide suite of technologies, such as mechatronics, manipulation, locomotion, autonomy, data fusion, and much more besides. The UK possesses particular expertise in the development of sensor data processing, on-board computer systems, GNC, rover build, V&V and systems engineering, and autonomous systems.

10.2. SCIENCE AND INNOVATION ASSETS

The UK's suite of capability in Enabling and Exploration technologies is fairly evenly distributed across the UK Nationwide Cluster, encompassing a wide variety of laboratories, industrial facilities, testbeds and systems engineering. The UK Government has an excellent recent record of supporting the facilities and systems engineering infrastructure that underpin many aspects of the upstream space segment, and therefore are of high strategic value to the UK.

Spillover Case Study: Space Solutions and Manufacturing Productivity

The Future Photonics Hub, based at Southampton University, have developed radiation-tolerant fibre for ESA science applications. Making the fibre tolerant to the high radiation levels found in space required scientists to develop new chemical compositions in the fibre materials to avoid those impacted by radiation. The same compositional approaches are now applied in the latest optical fibre for very higher power fibre laser to avoid degradation in use (via photo-darkening).

Operations in the extreme environments of space are driving fundamental innovation in material and manufacturing process design, that have now been widely applied to much higher volume terrestrial applications, which stress components in different ways, but can leverage those solutions original designed for space.

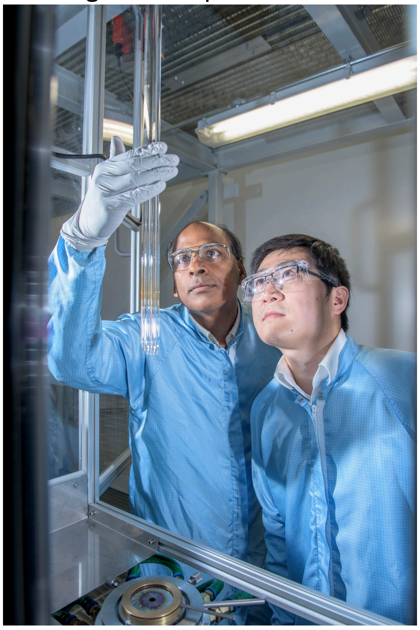


Image 22: Fibres developed at Southampton University's Future Photonics Hub are being applied in terrestrial manufacturing. Image credit: University of Southampton.

Of particular interest is the recent injection of £100million into the **National Space Test Facility**, as mentioned in Chapter 7, and the £4million injection into the **National Space Propulsion Facility** at Westcott.

Photonics, or the manipulation of light technologies, are expected to bring a raft of benefits across the enabling and exploration subsectors, by replacing or enhancing conventional electrical approaches in TTC, sensors, Guidance, Navigation & Control by reducing the size, weight, power, and increasing efficiencies and performance across all on-board systems. The **Future Photonics Hub**, hosted by the **University of Southampton** and **University of Sheffield**, is applying this new technology to space, and is able to take advantage of the University of Southampton's excellent links to the space industry.

Clyde Space, SSTL and **Airbus DS** have all demonstrated excellence in the development of structures, power systems, ACS and propulsion systems for small and nanosatellites.

One of the UK's strongest hands is in its software engineering capability. This has been at the heart of many historic scientific missions, such as **CGI-UK**'s provision of onboard software for the Rosetta Philae probe and the Beagle 2 lander. The Leatherhead-based firm, which also possesses a London office, also offers intelligent process automation for Remotely Piloted Aircraft and the Internet of Things (IoT).

King's College London (KCL) offers world-class capability in development of mathematical algorithmic abstraction and logic that is fundamental to the decision-making capability of an autonomy framework. KCL's fundamental expertise in this area is applicable to many scenarios and sectors, and is currently being developed and exploited by the European Robotic Goal-Orientated (ERGO) Controller project. ERGO features significant UK contributions from Bristol-based **Scisys**, who provide world-leading novelty detection capability for planetary rovers and other autonomous vehicles which is critical not only for upstream scientific missions but future commercial robotic exploration and mining operations. **GMV UK**, who in 2014 established a Harwell office as part of their international suite of sites, offer expertise in coding and software engineering, and from their Stevenage site **Airbus DS** provide unique abilities in Guidance, Navigation and Control (GNC), developed from their significant contributions to the ExoMars project. While the expertise of these organisations is without question, there is a sense that delivering greater capability in these fields in the coming years will be difficult owing to the skills shortage alluded to in Chapter 5. The excellence of the UK academic base in the field of computer science means that graduates are, understandably, attracted to other high-value sectors such as financial services and gaming.

As well as contributing to ERGO, **Airbus DS** designs, develops and manufactures equipment for provides world-leading expertise in exploration purposes, including the lightweight robot arm, sensor suites, and are one of the main systems integrators and assemblers for planetary rovers. Users of the latter form of platform also are able to take advantage of Airbus's cutting-edge indoor Mars Yard and mission control centre, which possesses unique properties enabling engineers to accurately simulate Martian and planetary conditions and test rover capability in locomotion, GNC and perception, controlled using both adjustable autonomous functions, as well as telemetry. The site was used as part of the Meteron project, which saw a Mars rover directly controlled from orbit by astronauts on board the ISS, to simulate how rovers might be controlled on future missions from astronauts situated in Martian orbit.

A smaller Martian rover testing facility can be found at the **University of Surrey** in Guildford, whose **STAR** (Surrey Technology for Autonomous systems and Robotics) **Labs** possesses laboratories for testing rover traction, locomotion, and soil interaction, as well as investigating biomimetic mechanisms (mimicking biological systems for robotics), drills and samplers, penetrators for scientific investigation and sampling. The University of Surrey also hosts the **FAIR-Space Hub** (Facility for AI & Robotics in Space), an academic research cluster funded by EPSRC and UKSA, who also sit upon the Advisory and Steering Boards. The facility was funded in response to the UK Government's £92million fund to investigate robotics in extreme environments. FAIR-Space has also received private sector investment and business development funding, and is dedicated to developing robotics with very strong commercial potential.

Also in the Guildford region are **SSTL**, whose end-to-end competencies in the design, verification and fabrication of satellites means they have extensive and proven knowledge in suites of satellite avionics, software and system design support, power management and batteries, on board computers and data handling capabilities for satellite subsystems and satellite operations. All of this capability has been demonstrated in flight, for example to Russian company NPP VNIIEM Corporation for their KANOPUS-V satellite programmes. They also leverage their proximity to the University of Surrey to good effect, and together they have collaborated to develop low-cost GNC and sensor architecture.

In Oxfordshire, also based at Harwell, are Canadian firms **Neptec**, who have developed robots for medical and space applications, and **MDA**, who have recently established their UK operations at the hub. MDA's ambition is to develop cleanroom facilities that are complementary to their Canadian sites, for the development of spacecraft design and manufacture, as well as robotic systems. Also on site, **ABSL** possesses capability in low-temperature batteries and other specialised power storage expertise, critical for space systems and platforms. **Oxford Space Structures** leads the way in deployable antennas, booms and other structures mountable upon spacecraft. A little way east, in Bedford, **Lockheed Ampthill** are expert at Atmospheric re-entry and inflatable structures.

More broadly, structures and materials developments are supported by the **High Value Manufacturing Catapult** network, which covers the breadth of the UK. The Catapult comprises the **Advanced Forming Research Centre** (AFRC) in Strathclyde; the **Advanced Manufacturing Research Centre** (AMRC) hosted by the **University of Sheffield**; the **Centre for Process Innovation** (CPI) in Redcar; the **Manufacturing Technology Centre** in Coventry; the **National Composites Centre** in Bristol; the **Nuclear AMRC** in Rotherham; and the **Warwick Manufacturing Group**, also based in Coventry. With growing reliance upon additive layer manufacturing (3D-printing) processes, and a need to reduce mass and size, it is increasingly important that excellent connections are made across these networks. SMEs in particular must be able to take advantage of the services and capabilities afforded by these centres of excellence.

High Performance Computing is crucial to exploration and the application of advanced software and AI. The **Edinburgh Parallel Computing Centre** has the capability to lend high performance computing, and they have a good track record in European and domestic research projects, but their links with the space sector could be grown, and it may be recommended that further links between such supporting organisations as this if the upstream sector is able to achieve greater efficiencies and on-board computing capability. Further west along the Scottish Central Belt, the **University of Glasgow** has developed sensor capability able to measure the motion of objects with nanometre precision, across thousands of seconds, which was used for the Optical bench Interferometer on ESA's LISA Pathfinder mission to detect gravity waves.

RAL Space hosts the **Harwell Robotics & Autonomy Facility** (HRAF), a nascent initiative to provide systems engineering capability for the high-level testing of autonomous systems and robotics software. Funding for HRAF was provided by ESA, who also harbour aspirations that HRAF should develop in-house capability to handle, scientifically test and curate extra-terrestrial materials that have been returned from such missions as the Mars Sample-Return mission, a joint NASA-ESA operation scheduled for some point between 2022 and 2030.

HRAF sets out to provide enabling modelling & simulation combined with a data archive accumulated from tests from various scenarios not only from the space sector, but also terrestrial sectors utilising robotics. The logic behind HRAF showcased how space-specific facilities could be used to support other sectors, therefore opening up a new business model for the upstream sector, if proven successful. So far HRAF has hosted a handful of pilot projects, which have demonstrated V&V methodologies for a variety of planetary rover and terrestrial applications. However, further funding is required to enable HRAF to grow beyond its current remit and scope of pilot studies.

Conclusions

- The UK possesses truly world-class capability in a range of enabling and exploration technologies, which is distributed fairly evenly across the country.
- UK possesses singular expertise in software engineering, with a globally recognised academic base, but space faces stiff competition from other sectors when it comes to recruiting good quality engineers.
- The UK has a strong track record of delivering various enabling technologies for upstream, institutional missions, and which show applicability in new markets.
- Enabling and exploration subsector markets will grow slowly but with stability over the coming years in line with the wider growing market, and represent good opportunities for investors looking for lower-risk returns.
- Landscaping mapping has made sense of much of the UK's spread of capability and is a potential route for investors to identify potential investment opportunities.

11. Conclusions

The UK's Upstream space sector is highly productive, commercially and scientifically successful and highly innovative; as such, the space sector plays well as a growth opportunity within the UK Government's Industrial strategy.

Space manufacturing is the most R&D-intensive sector in the UK, driven by the sector's requirement for high levels of investment to deliver the technologies needed for space missions and applications. The industrial base within the sector is supported by an excellent research base for upstream space, with the UK Nationwide cluster boasting some of the UK and world's best-ranked universities.

As well as being an important sector both in its own right and as part of the wider space value chain, space has the potential to have huge spillover benefits to the wider economy and society, resulting in greater returns to the exchequer. The upstream space sector needs to remain alert as the UK Government agrees a number of sector deals across the UK economy as the technology crossovers between sectors may provide future opportunities.

Future workforce

The UK Space sector is highly qualified – this places pressures on the sector as the total supply of physics graduates in the UK will not meet the sector's expected demands for 100,000 new employees by 2030.

Space-related science & engineering courses yield great economic benefits by preparing the future generation of engineers for the rigours of industrial work – both within the space sector and those who establish careers in the wider STEM economy. However, this leakage to other sectors exacerbates an existing shortage; the supply of qualified scientists and engineers needs to be significantly increased in order to meet the sector's growth aspirations. The Space Growth Partnership is formulating proposals to address this skills gap, including industry supporting one million engagements per year with young people at all levels to inspire and encourage them to consider careers in STEM.

Research

The UK's Research Base for Upstream Space is uniformly excellent, with some of the world's best-ranked universities, and the UK's best-ranked universities for science and engineering, falling in the UK Nationwide Cluster. This is backed up by a range of excellent assets and facilities.

Upstream Space outperforms the rest of the UK when it comes to accessing UK funding, leading and participating in research projects. However, the majority of fundamental and applied research funding for upstream space has come from the EU over the last decade, and Brexit represents a very real and imminent threat to sources of R&D funding for UK academic and industrial researchers. With negotiations for FP9 underway, certainty is crucial if the R&D intensity is to be successfully maintained.

If the requisite funding is secured, there are new models of collaborative R&D, such as Strategic Research Clusters, which serve to provide focus and an overview of systems integration, as well as being influenced institutionally, helping to push industry into researching areas they otherwise might not.

Growth Potential

The UK possesses world-leading capability in the design, manufacture and test of satellites of all sizes. With the advent of new technologies such as reconfigurable satellites, 5G connectivity and autonomous vehicles, the satcomms market looks set to grow, and UK interests and sovereign capabilities must be protected.

The UK's small satellite market growth is set to outstrip that of almost every other major satellite-producing nation on Earth over the next five years. There is a unique window of opportunity for investors to get in on the ground floor now.

The UK does well in UK and European markets, but with the exception of large multinationals, penetration of non-European overseas markets could be improved. Regulators and insurers can help businesses to overcome barriers to entering the market by working closely with Government and industry.

There is strong interdependence between the satellite, access to space and ground segmentation markets, and intelligent alignment between these subsectors needs to be managed well to help the sector grow and embed its end-to-end value chain. For example, UK Spaceports should not unnecessarily duplicate capability in their quest to be competitive. Offering a variety of launch services across the UK would best serve the interests of the country. Similarly, the ground segment must be more strategically aligned with the satellite manufacturing sector in order to develop and deliver the requisite operational capabilities from the ground up.

The UK possesses truly world-class capability in a range of enabling and exploration technologies, with singular expertise in software engineering and autonomous systems, which show applicability in new markets.

This SIA has made sense of much of the UK's spread of capability, and is a potential route for investors to identify potential investment opportunities.

We recognise that this SIA provides a snapshot in a fast-changing landscape. The SIA partners are keen to maintain and update this report to provide a comprehensive ongoing view of the sector.