SEEKING RESOLUTION: GROWING THE UK SMALL SATELLITE INDUSTRY.

Institution of MECHANICAL ENGINEERS

Improving the world through engineering

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SATELLITE-BASED EARTH OBSERVATION OFFERS US THE ABILITY TO GATHER VAST AMOUNTS OF DATA ABOUT THE PLANET'S PHYSICAL, CHEMICAL AND BIOLOGICAL SYSTEMS.

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This report has been produced in the context of the Institution's strategic themes of Energy, Environment, Education, Healthcare, Manufacturing and Transport and its vision of 'Improving the world through engineering'.

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EXECUTIVE SUMMARY

EARTH OBSERVATION SATELLITES – PROTECTING THE WORLD FROM DISASTER

Earth's atmosphere, oceans and landscapes are constantly changing as a result of natural phenomena and continued human activity. Global economic losses due to natural disasters alone have exceeded £64.2bn every year since 2010[1]. Beyond the immediate and often devastating outcomes, these disasters also have a knock-on effect on global supply chains, businesses, governments, and civilisation as a whole. In order for society to better protect itself against these occurrences, decision and policy makers require up-to-date scientific and numerical information about the planet to assist in implementing recovery plans and monitoring natural changes as they occur[2,3].

Satellite-based Earth Observation (EO) offers us the ability to gather, almost instantaneously, vast amounts of data about the planet's physical, chemical and biological systems. Indeed, the latest series of European MeteoSat geosynchronous satellites can provide meteorologists with updates on cyclones and storm fronts every 60 seconds. More recently, EO satellite technology has been developed to identify disease outbreaks and even help determine insurance pay-outs.

Thus far, the data produced by EO satellites has been mainly used for scientific purposes, using large, expensive observing missions. However, as our needs have grown, so new innovations and technological advances have been made in both satellite size and image resolution, as well as in the applications which use the terabytes of data they produce[4,5].

UK SPACE INDUSTRY – 2030 GROWTH STRATEGY

The UK has what many consider to be one of the most innovative and cost effective space sectors of any nation in the world, supporting approximately 106,000 jobs[6] (34,500 of which are directly employed and 72,000 which are indirect jobs through supply chain) and turning over £11.8bn in 2012/13. While broadcasting remains the dominant industry within the UK space sector (74% employment; 72% turnover 2012/13[6]), earth observation remains a small but important sector. The global market for selling EO data is expected to reach a value of £1.8bn by 2020[7] based on developing new technologies and big data analytics.

In 2010 the UK published its first Space Innovation and Growth Strategy (IGS)[8]. The primary objective of the IGS is to capture 10% of the £400bn global space market by 2030, helping create a further 100,000 jobs. The consequent establishment of the UK Space Agency (UKSA), together with the IGS's updated strategies in 2014[9] and 2015[10], has resulted in growing opportunities for space technologies in the UK. Further, the Satellite Applications Catapult, established in 2013 to accelerate the take-up of emerging satellite technologies, is leading the IGS's call to action, through its strategic plan focusing on the challenges of both the modern and developing worlds[11].

The aim of this report is to provide some context to the market for satellites by way of EO, and to highlight some of the barriers and opportunities facing the satellite industry as the UK strives to meet these ambitious growth targets.

BARRIERS TO INNOVATION IN THE SATELLITE INDUSTRY

We are on the brink of a technological step change, as new innovations and applications emerge across multiple markets. Satellite data has become the ubiquitous driver of international policy and strategic planning; helping governments and the private sector make decisions on critical environmental challenges. Yet, economic and business opportunities are being missed as a result of fragmented collaboration between key stakeholders, restrictive regulations and directives, and a lack of understanding of the benefits of EO in the wider community. Crucially we are facing a looming skills shortage that will undermine all growth plans. This is particularly true of small-satellite manufacturers and more critically, current non-space markets who could potentially benefit from access to satellite data. The goals of the IGS, UKSA and the Satellite Catapult will remain out of reach if the following barriers to innovation are not overcome.

Fragmented Collaboration

The Satellite Applications Catapult has achieved significant impetus through its 'Satellites4Everyone' programme. Its industry-led Satellite Finance Network has engaged 150 members with £20m being made available to support satellite SMEs. Nevertheless, there continues to be a lack of private financing and venture capital particularly in EO. This is in part due to the risk of costly space missions, uncertainties as to future restrictions on EO satellite data, and a lack of understanding of the high-value returns from EO satellite build and operation. Additionally, developing nations are luring small businesses with the opportunity to create new technology without the financial and regulatory burdens levied in the UK.

Misalignment between key public sector organisations such as the Centre for EO Instrumentation, the National Centre for Earth Observation, Innovate UK and the Research Councils (RC) continues to hamper the effective use of public funding, particularly for SMEs and start-ups in the satellite EO industry.

Restrictive regulations

The UK Outer Space Act (OSA), which covers the launch and operation liability laws for satellite operators is now 30 years old, yet regulatory and legal pressures have changed much over that time. Simplification of the legal conventions for liability is now needed and the UK OSA must be revised to acknowledge technological advancements and the changing nature of space usage. This is particularly apparent for EO small-satellite operators and Technical Readiness Level (TRL) 3–6 start-ups, who are unfairly penalised by having the same regulations applied to them as to larger satellites. A balance between enabling innovation through well-managed licensing and providing high quality satellites must be found.

An example is that despite providing £52bn per year to the UK economy, radio frequency spectrum (used in satellite communications) is a scarce resource for small-satellite operators. While the UKSA has recently signed an agreement with the Office of Communications (Ofcom) to address the issue of spectrum licencing and Ofcom has launched a consultation with stakeholders, there is an immediate need for spectrum frequency sharing to be implemented. This barrier must be addressed by Ofcom and the UK Spectrum Policy Forum to ensure parity between existing incumbent long-term operators and the newer smaller, short-term ones.

The UK is the only launching nation to require satellite operators to pay for third-party liability (TPL) which is a major blocker for SMEs and start-ups to license and launch their satellites. Growth can only be stimulated if TPL insurance is ended and the Government finds a more appropriate solution, based on more up-to-date knowledge of large and small-satellite operation.

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Global economic losses due to natural disasters alone have exceeded £64.2bn every year since 2010.

Lack of Understanding of Benefits

A recent EU Directive on the commercial use of high-resolution EO Satellite data[12] has been dropped as a result of conflicting opinion between member states. Yet there remains concern among UK satellite operators and downstream service providers as to the economic implications of expected future regulations. DEFRA (who are responsible for UK EO applications policy) and the UKSA must ensure the UK remains at the forefront of any future EO regulation development. In the medium term, the UK must look to its export control regulations (which are controlled by the Export Controls Organisation) to ensure a sensible balance between data protection and commercial data use.

We are right to be concerned about the future management of open access data and how higher-resolution images could give rise to security and privacy issues. While the UKSA is to be commended for its commitment to ensuring a balance between national security and sector growth, a visionary approach to the way we exploit very high resolution EO data needs to be adopted within the next five years to allay fears.

Looming skills shortage

There has been little in the way of public engagement with the UK space industry over the last 30 years. It has been shown through public surveys that society feels disengaged from the UK space industry and have no concept of the impact space-related technologies have on their daily lives. Indeed, most are unaware that the UK has a space industry at all. If the UK is to develop its commercial activities in space and gain wholehearted support from society, it must ensure that any policies and strategic plans attract the necessary talent.

The speed with which the small-satellite sector is growing is increasing the strain on the recruitment pipeline. Opportunities exist for organisations such as the Satellite Applications Catapult to create greater visibility and expansion of its intern programme (the Space Internship Network (SpIN)) to enable undergraduates, graduates and professional engineers to seek placements and possible jobs within the industry. Additional investment to support SMEs should be found through Innovate UK competition funding.

RECOMMENDATIONS

The Institution of Mechanical Engineers recognises there is an immediate need to develop the UK satellite sector and create innovative business models which will support the growing small-satellite industry for the next 40 years. We therefore call upon:

UK Space Agency to:

- Fully revise the 30-year-old Outer Space Act to provide more flexible and simplified launch and operations licences for small-satellite operators. Additionally, support SMEs and TRL 3-6 satellite operators through a dedicated advisory team for small satellite license applicants.
- Align with other nations and end the third-party liability for small satellite operators.
- Continue to take a pro-active stance on future EU directives on EO data, by working with DEFRA to clearly define the UK position. Work to control access to data through the Export Controls Organisation and the Department for Business, Innovation & Skills, and amend the export licencing regulations to include dissemination of data.
- Develop a programme of public engagement and dialogue on satellite EO and data usage with emphasis on personal security and privacy. Provide more access to satellite imagery and data through web-based portals, social media channels and improved engagement with the press. An increase in funding and broadening the scope of the 'Space for All' community programme would support this initiative.

Satellite Applications Catapult to:

- Work with universities, industry and Innovate UK to enlarge the existing SpIN programme to include year-long funded placements for undergraduates, graduates, post-doctorates and professional engineers. The programme should look to increase its numbers to 1,000 a year over the next five years and to sustain this level until 2030.
- Continue its involvement in the Satellite Finance Network with an aim to increase the money available to SMEs from £20m to £70m over the next five years. Engage with the venture capital and other finance and investment companies outside the satellite sector to create a joint programme of competition funding with Innovate UK.

Ofcom to:

- Work with the UK Spectrum Policy Forum to address Spectrum licencing for all small satellite operators. Ofcom and industry must find mutually acceptable solutions to the limited spectrum bands and look to Licenced Shared Access (LSA) as a means of relieving the pressure on spectrum use.

Research Councils to:

- Work with HEFCE to create a long-term strategy to attract young people into the space sector. This could be achieved by incentivising universities to create more sandwich degree programmes in space-related subjects as well as providing space options on existing degree courses such as mechanical, electronic and IT degrees.
- Engage with the satellite industry to develop a focused strategy for space technology research; moving away from space being an enabler of other technologies, to being a funded stream in its own right.

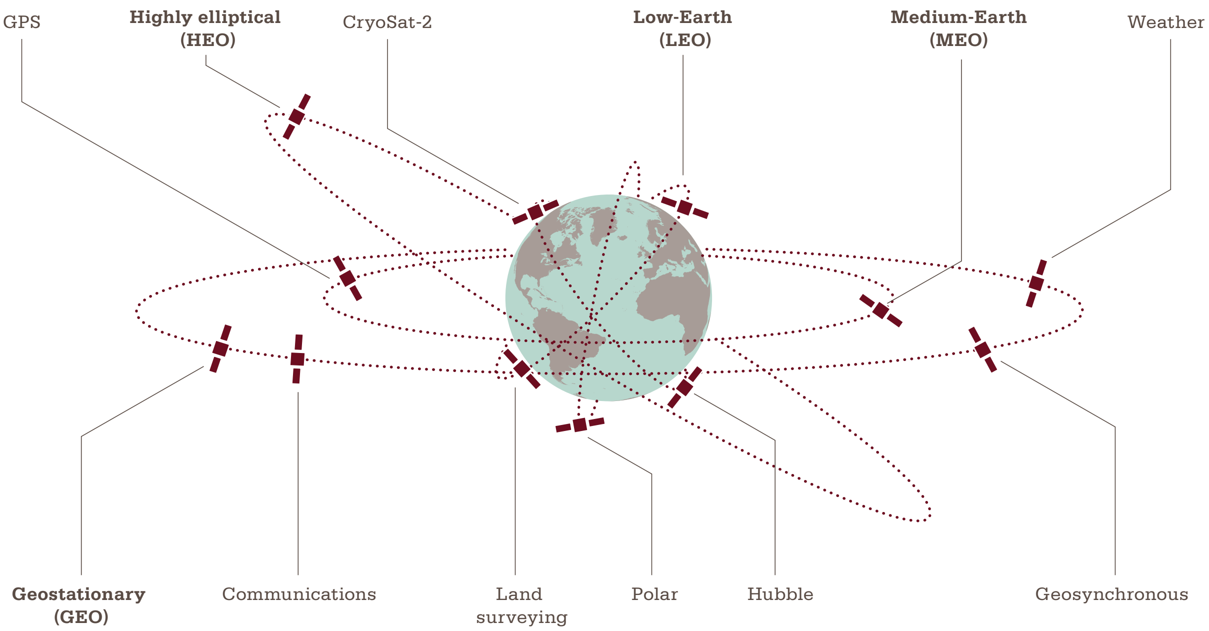
Since 1957, over 6,600 satellites have been launched.

INTRODUCTION

For 92 days in 1957, the world was gripped by the alien, yet strangely familiar beeping of the first man-made object to orbit the Earth: Sputnik-1. This unique feat of engineering and technology was the first artificial Earth satellite. Despite its diminutive size it was to launch the human race on a global mission to explore the vastness of space in a way that just a few years before, could only have been imagined. A mere 15 years later 12 people had been to the lunar surface and back.

Now, 58 years on, over 6,600 satellites have been launched. The latest estimates are that 3,600 remain in orbit. Of those, about 1,000 are operational; the rest continue to orbit as space debris. Approximately 500 operational satellites are in Low Earth Orbit (LEO, 160-2,000km), 50 are in Medium Earth Orbit (MEO, between LEO and Geostationary Earth Orbit, GEO), and the rest are in either GEO some 36,000km from Earth or in Highly Elliptical Orbits HEO (**Figure 1**).[13,14,15]

Figure 1: Satellite Orbits around the Planet



Without the engineering expertise and ground-breaking technological innovations which came from the initial space race of the mid-20th century, many of the things that we take for granted in our everyday lives would not exist, such as satellite television, mobile phone services, weather forecasts and GPS navigation. Space has also been a driver for other technologies such as scratch-resistant lenses, fire-resistant materials, electronic circuits and chips, laser eye surgery and dynamic artificial limbs.

Despite the USA and Russia being the most prominent developers of these technologies, the UK has been consistently contributing to the space community for the last 30 years. In fact, UK technology now orbits Saturn, Mars, Venus, the Sun and Moon, in addition to many Earth-orbiting satellites and space observatories.

Medium Earth orbit (MEO)

Sometimes called Intermediate Circular Orbit (ICO), this is the region of space between 2,000km (1,243mi) above Earth and 35,786km (22,236mi). The orbital periods of MEO satellites range from about two to nearly 24 hours. Satellites in this region are used for navigation, communication and geodetic/space environment science. The most common altitude is approximately 20,200km (12,552mi), which yields an orbital period of 12 hours, as used, for example, by the Global Positioning System (GPS). Other satellites in MEO include Glonass and Galileo constellations. Communications satellites that cover the North and South Pole are also put in MEO.

Low Earth Orbit (LEO)

A majority of artificial satellites are placed in LEO, making one complete revolution around Earth in about 90 minutes. A low Earth orbit is the simplest and cheapest for satellite placement. Since it requires less energy to place a satellite into an LEO and the LEO satellite needs less-powerful amplifiers for successful transmission, LEO is still used for many communication applications. It provides high bandwidth and low communication time lag (latency), but satellites in LEO will not be visible from any given point on Earth at all times. Unlike geostationary satellites, a network (or ‘constellation’) of satellites is required to provide continuous coverage.

EO satellites and spy satellites use LEO, as they are able to see the surface of Earth more clearly. They are also able to traverse the surface of Earth.

The International Space Station is in an LEO about 400km (250mi) above Earth’s surface.

Some communications satellites including the Iridium phone system use LEO.

Remote sensing satellites can also take advantage of sun-synchronous LEO orbits at an altitude of about 800km (500mi) and near polar inclination. ENVISAT is one example of an EO satellite that used this particular type of LEO.

THE SIGNIFICANCE OF SATELLITES

Satellites penetrate all aspects of our lives through industrial, academic, governmental, commercial and private applications. Satellites are becoming increasingly important for public safety, economic growth and quality of life: Navigation satellites form the backbone of our emergency, aviation, and logistics systems, as well as guidance in cars and personal handheld devices. Television is delivered and distributed via geostationary satellites and weather forecasting relies on EO and remote sensing satellites.

The UK space sector is unique in that, following Government budget cuts in the late 1970s, no co-ordinated civil space programme existed until the announcement of the UKSA and its first missions: UKube-1 and TechDemoSat-1, in 2010. However, despite this the UK has been a global leader in major aspects of satellite systems for over 40 years.

The space satellite sector helps deliver three main types of services which have impact on economic wellbeing

The public market: acquires space assets for the delivery of public services and evidence for creating public policy. These include environmental change, meteorology, emergency response and defence capabilities.

The commercial market: where private or semi-private firms provide space-based services or space-enabled products to other firms or consumers. There are three main sectors in this market; telecommunications (fixed and mobile services, and television), EO services (such as weather mapping) and location-based services (such as satellite-enabled navigation tools).

Scientific exploration: increase our store of scientific knowledge, sending probes into other planets, carrying out manned space exploration and help us understand the earth through EO. These types of assets do not always translate directly into commercial or public sector applications, but do enable the acquisition of further knowledge required to create future applications.

The UK space industry supports approximately 106,000 jobs, employing a highly skilled manufacturing workforce. The sector grew at about 9–10% per annum in real terms between 2000 and 2010 with a turnover of £11.8bn in 2012/13[6,8]. Productivity in the sector is about 2¾ times greater than the average for UK manufacturing, and 3½ times the average for the economy as a whole[16]. A 2012 Oxford Economics report highlighted that, between 2011 and 2020, the satellite navigation industry alone is expected to generate a value-added contribution to the UK worth £1.45bn[17].

In 2010, the UK published the first Space Innovation and Growth Strategy (IGS)[8] with the backing of industry, academia and Government, with the common objective of transforming the UK's space sector to capture 10% of the £400bn global market by 2030. In order to achieve this, the IGS made a series of recommendations, which are being followed up through the Space Growth Action Plan[9]. The establishment of the UK Space Agency (UKSA) together with the IGS has resulted in growing momentum behind opportunities for space in the UK.

While the satellite industry has benefited from continued growth and technical innovation over the last 58 years, we are now on the brink of a step change. New innovations and applications are being applied across multiple markets, to rapidly respond to social change and deliver services from major conurbations to remote rural areas, supporting integrated transport, the digital economy and a sustainable future[11]. For example, in providing the satellite payloads for the first in a series of large commercial navigation satellites[18], as well as high-tech applications services, the UK is a significant contributor to and beneficiary of the Galileo programme. There is also now an increasing demand for access to space, driven by educational, amateur hardware developers and start-ups that have innovative business models for providing space data and services. These developers are building on commoditised consumer electronics and lower-cost accessibility to space through small modular satellites.

Thousands of small satellites will be flown in the next few years to provide these services, allowing SME businesses of all sizes to offer low-cost, low-mass, satellite platforms. The Institution of Mechanical Engineers recognises that engineers will play a significant role in guaranteeing the satellite industry reaches the IGS goal, through the design and innovation of new platforms and the processing and application of collected data. This report will provide some context to the market by way of earth observation (EO), to highlight some of the barriers and opportunities facing the satellite industry, as the UK strives to meet its ambitious growth targets.

The UK space industry supports approximately 106,000 jobs.

THE SATELLITE CATAPULT

The Space IGS set out the need for a satellite applications-focused centre as part of the Innovate UK Catapult programme. The Satellite Applications Catapult, based in Harwell, Oxfordshire was founded in 2013. Its role is to provide expertise and facilities to assist companies both in and looking to the space industry to develop and demonstrate new products, services and technologies. Primarily focused on satellite telecommunications, navigation and EO services, the Catapult is currently developing both upstream and downstream demonstrators to assist in maritime, transportation and smart city applications.

In the UK, the development of the space industry is focused through the Harwell Space Gateway, a cluster of agencies including RAL Space, European Space Agency (ESA) and their UK business incubation centre (BIC), and the European Centre for Space Applications and Telecommunications (ECSAT). The Harwell site is supported by the Science and Technology Facilities Council (STFC), the UK Atomic Energy Authority and Harwell Oxford Developments to stimulate new businesses, including those that exploit space data. In total over 40 space organisations are located at Harwell, including the UKSA and many SMEs. The ESA BIC also currently incubates 13 small businesses focused on exploiting downstream applications of space data and technology.

EARTH OBSERVATION: INFORMATION FROM SPACE

There is an urgent need for a globally coordinated agenda to enable us to observe the Earth's eco-systems. This was internationally recognised at the World Summit on Sustainable Development in South Africa in 2002[19]. The scientific and commercial value of satellite EO and its potential to benefit society has increased considerably as instrumentation has become more accurate, producing a global library of data that is three times more accurate than that of a half-century ago[20]. Earth-observing satellites have long been a critical, operational underpinning element of meteorology and weather forecasting as well as providing world-class climate science. Land and ocean observing satellites have been used since the 1970s, primarily for scientific purposes; however, their value is becoming more widely recognised through satellite imagery in Google Maps and elsewhere. Governments are increasingly relying on space-based data for addressing policy priority areas such as resource management, transportation and national defence.

The European Commission has long recognised the opportunity available from EO and has spent almost two decades developing the world-leading Copernicus programme. The first of these satellites (Sentinel 1) launched last year with five more planned by 2019; the full complement of satellites is expected to deliver 8 terabytes of data daily.

More recently, small satellites have been providing more affordable space infrastructure that delivers good-quality EO data. The small-satellite approach (which has its origins in the UK) is a highly effective model for achieving more frequent geographic coverage from space.

What is Earth Observation?

The term "Earth Observation" refers to measurements from space of the various components of the system Earth eg oceans, land surface, solid Earth, biosphere, cryosphere, atmosphere and ionosphere, and their interactions.

FROM UP THERE TO DOWN HERE

Successful satellite missions are made up of a chain of activities beginning with the manufacturers of space infrastructure including the satellite itself, ground stations and software. At the other end of the chain are the providers of space-enabled services, such as weather forecasts, satellite television and navigation. The satellite sector can be divided broadly into two main sections: upstream and downstream services (**Figure 2**).

Upstream sector

The upstream sector provides the technology required to exploit space and consists of organisations that manufacture satellites and satellite components and provide services that enable the launch of systems into space. The satellite and payload manufacture makes up the biggest employment sector (approx. 36% of the total workforce) with 33% of the total industry turnover[6].

The UK has a long and extensive history of state-of-the-art space science instrumentation design and manufacture. Particular strengths have been demonstrated in:

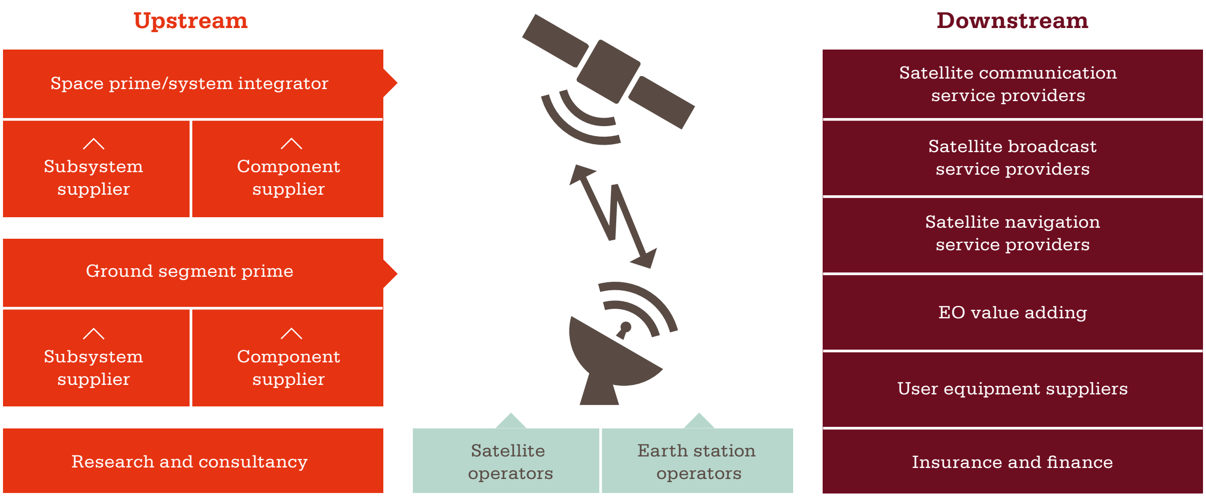
- sub-millimetre imaging[i]
- spectroscopy[ii,iii,iv]
- optical imagers[v,vi]
- detectors and their respective optics[vii,viii,ix,x]
- focal plane arrays[xi,xii]

British space instrumentation and sensors have been designed for use in myriad space environments such as:

- magnetometry[xiii,xiv]
- high-energy particles[xv]
- radiation monitoring[xvi]
- x-ray imaging[xvii,xviii]

Other strengths have been demonstrated in:

- solar cell technology[xix]
- robotics and image processing[xx,xxi]
- RF equipment[xxii] and GNSS payloads[xxiii]
- instrument data handling and electronic control systems[xxiv,xxv,xxvi,xxvii]



SUPPLY CHAIN

Downstream services

Downstream companies use the products from the satellite infrastructure to provide services for a wide range of businesses both inside and outside the space industry. These range from products and services which can only be delivered through space, to those which complement and compete with terrestrial equivalents[16,21]. The downstream sector makes up 89% of the total UK space industry turnover (£10.8bn). Downstream applications demand different requirements from each platform; a trade-off against cost factors including the price of launch and platform capability, both intrinsically linked to the satellite size.

Modern web-based technologies also provide very capable processing and dissemination platforms, at low cost and with an inherent capacity to address a global market. As a result, we now see innovative and agile start-ups exploiting these technologies to change the economics and accessibility of satellite data.

Downstream Capabilities

The UK has advanced capabilities in many satellite reception, data handling and operations technologies, with particular strengths in satellite communications equipment[22,23] satellite broadband and voice services and terminals[24,25], direct-to-home television hardware and services[26] and air and ground satellite communications equipment and infrastructure[23,27].

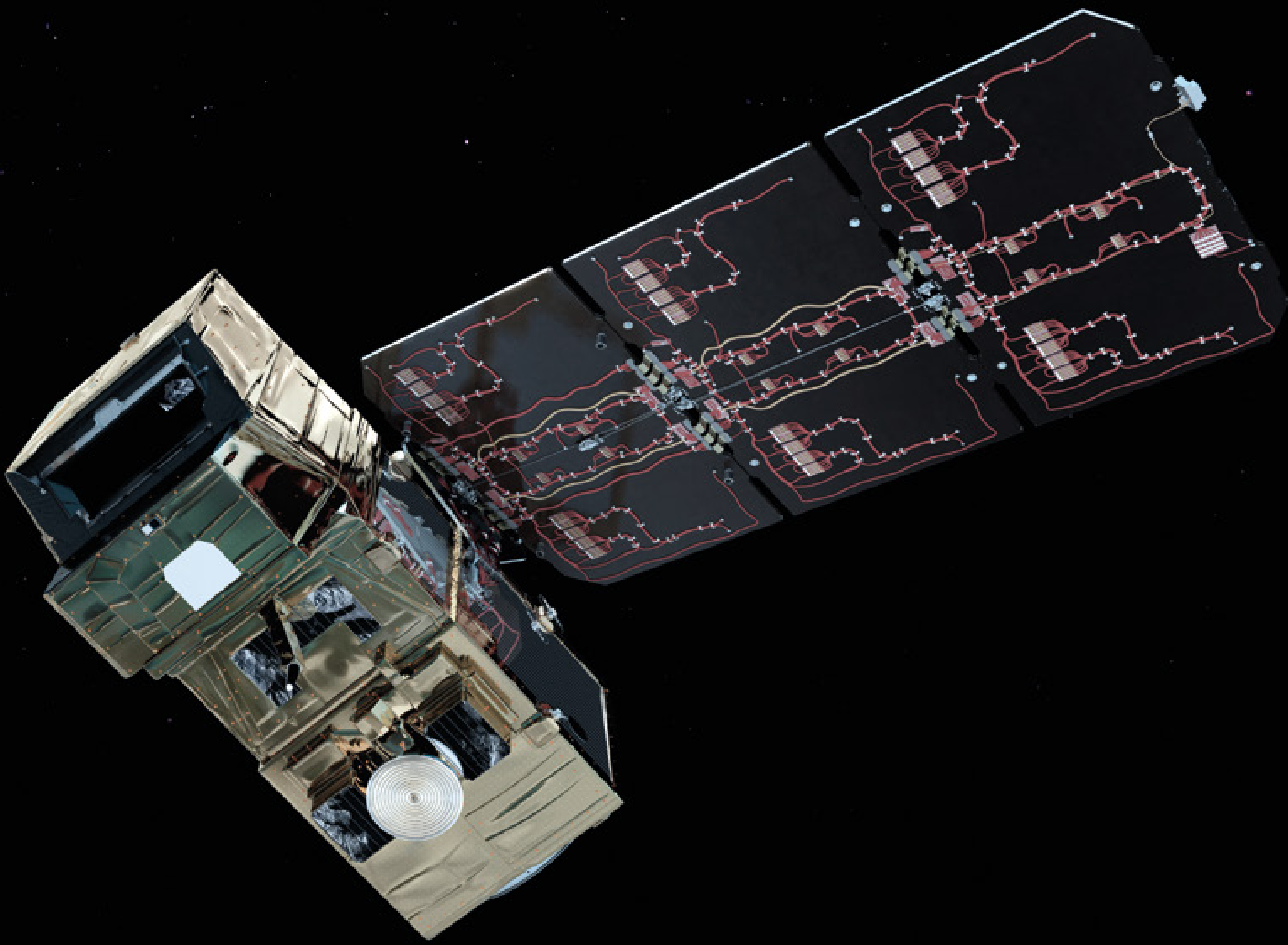
Global Navigation Satellite System (GNSS) test and simulation software and hardware is manufactured in the UK, to assist with the development of novel new applications. The UK also boasts an extensive and well-established industry that provides mission planning and operations software, ground segment simulation and data acquisition and processing services for space science and EO satellite systemsh[28–32].

The UK has a well-established upstream supply chain industry, which consists of a very small number of highly-specialised manufacturing companies. This is due, in part, to the high tolerances required for such precision technology which is on a par with Formula 1. Upstream and downstream operators are supported by myriad highly specialised companies, including providers of R&D services, finance and insurance for systems launch and operation, and user equipment suppliers for downstream operations[21].

In total, nearly £144m is spent on UK manufacturers and service providers each year in the satellite industry, split among roughly 400 businesses, of which half are SMEs. Of its £0.7bn turnover, Airbus Defence & Space flows 60% of this down to its supply chain[33].

The high cost and long timescales typical of the incumbent space industry are primarily due to the risk adversity associated with satellite development programmes. This has been for good reason; getting a platform to orbit, in particular those at geostationary altitudes, is a costly endeavour and failures cannot be rectified easily. However, innovative approaches to design, exploiting COTS technologies, standardisation of launch vehicle integration and increased availability of piggy-back launches to sub-optimal orbits are enabling greater access to space and new uses for satellite data. This new approach is dependent on an iterative development programme: build, fly, learn, revise and fly again, and one which is heavily reliant upon the satellite industry's supply chains.

The UK has been a global leader in major aspects of satellite systems for over 40 years.



SATELLITE MANUFACTURING: A MATTER OF SCALE

Today's satellite operators can select from a vast range of platforms, from large (over 1,000kg), high-cost, -reliability and -capability systems to smaller (<500kg), simpler and cheaper units. The cost of getting into space is however, extremely expensive, almost as costly as the satellite itself. Each satellite clearly is designed for a specific task – enabling it to be built as small and as light as possible[34].

Satellite terminology	Mass range
Large satellite	>1000kg
Medium satellite	500kg–1000kg
Small satellite	<500kg
Minisatellite	100kg–500kg
Microsatellite	10kg–100kg
Nano/micro satellites	1kg–50kg
Nanosatellite	1kg–10kg
Picosatellite	100g–1kg
Femtosatellite	10g–100g

LARGE SATELLITES

For the foreseeable future, the large satellite market will dominate upstream manufacture. Telecommunications satellites typically have the highest power demands of all satellite services (although this transfers to EO, science and exploration satellites). Fundamentally, the amplification demands of a transceiver in GEO requires the platform to be large enough to supply the necessary power with increasingly larger solar arrays and the demand for more sensitive (and therefore larger) antenna reflectors. For example, Alphasat is a 6.6 tonne spacecraft, capable of handling 750 discrete communications channels, it has a 40m solar array that generates 12kW of power and an 11m diameter deployable antenna reflector.

Small satellites <500kg

Nano-satellites <10kg

Clyde Space
3U CubeSat/5kg
100x100x300mm
UKube-1

Planet Labs
3U CubeSat/5kg
100x100x300mm
Dove

Micro-satellites 10kg–50kg

Dauria Aerospace
16U CubSat Auriga/20kg
246x246x545mm
Concept

SSTL
SSTL-X50/50kg
530x430x400mm
Concept

Small-satellites 50kg–500kg

Skybox Imaging
SkySat/83kg
600x600x600mm
SkySat-1

SSTL
SSTL-150/150kg
911x699x773mm
TDS-1

SMALL SATELLITES

While the size of large satellites is measured in power, the size of small satellites is normally measured by their mass. Small satellites have the ability to collect retrieve, store and process the equivalent of large-satellite data-sets, processing as much as 1 terabyte of data a day[35]. Small Satellites are generally used as technical demonstrators, such as HD video for EO[36]. They are almost exclusively used in LEO, where surplus mass on the launch vehicle is more flexible than in the case of a challenging GEO injection.

In the early 2000s, the UK based SSTL launched its first commercial EO satellite, the 90kg AlSat-1 owned by institutions in Algeria, China, Nigeria, and Turkey. This constituted the first of five similar small satellites that formed the Disaster Monitoring Constellation (DMC)[37]. Despite not being able to meet the highest of EO resolution standards, small satellite platforms can offer widespread coverage through constellations of more affordable spacecraft.

CubeSat

A CubeSat is a type of miniaturised satellite used primarily for space research. First defined in 1999, it typically has a volume of one litre ($100mm^3$), has a mass of no more than 1.33kg and typically uses commercial Components Off-The-Shelf (COTS) parts for its electronics.

NANO-SATELLITES

The first CubeSat nano-satellites were launched in 2003 and as of April 2015, 342 have been launched. The concept of the CubeSat is the reverse of the large-satellite cycle, where instead of adding more and more capability to a platform, the spacecraft is stripped back to the bare minimum needed to reduce launch cost. Many Cubesats have been built and operated by university student teams, with little or no experience in building space-rated technology, using cheap COTS components. Today, a basic CubeSat can be built and delivered to orbit for under £150,000[38]. Across the world, a new industry in CubeSat components has developed to serve this new market. These companies offer various inter-compatible avionics systems, structures and solar panels that can be combined into a basic satellite.

Disaster Monitoring Constellation (DMC)

In 2002, the first DMC was established through a partnership of organisations wishing to share EO data for disaster response. The DMC is a constellation of EO satellites constructed by Surrey Satellite Technology Ltd (SSTL) and operated on behalf of the Algerian, Chinese, Nigerian, Turkish and British governments by DMC International Imaging (DMCii). The UK Space Agency contributed to the DMC with early funding support for one of the first DMC missions.

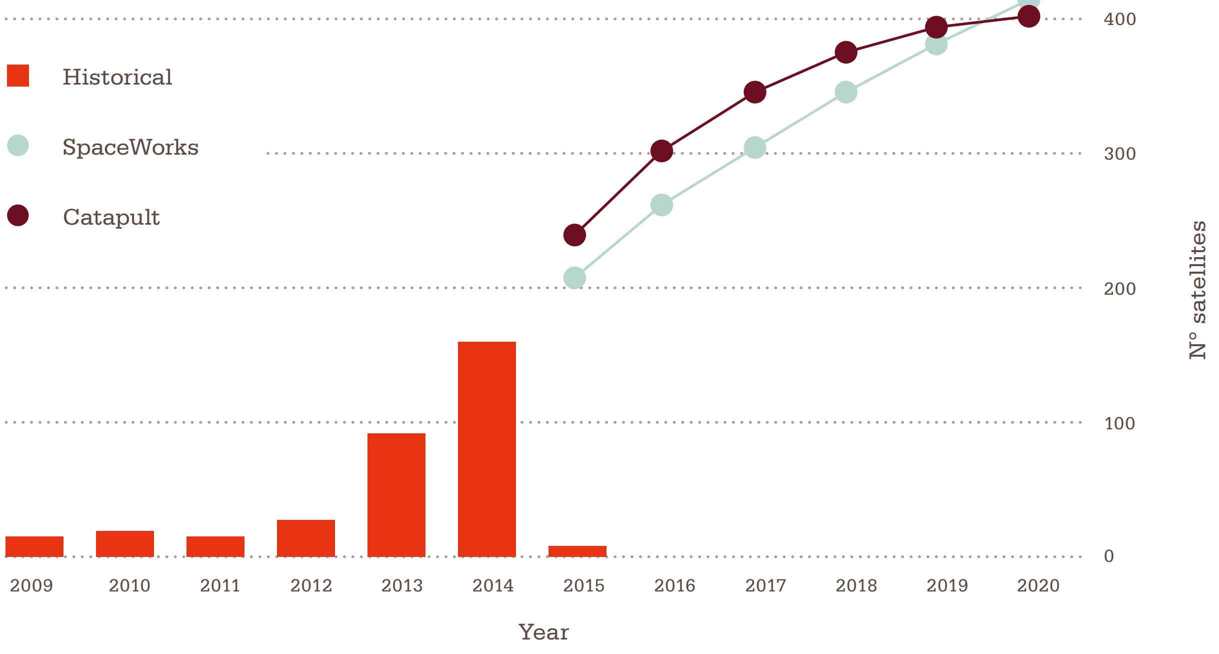
The constellation is a first-of-its-kind international collaboration aimed at leveraging international investment. The DMC provides a powerful source of satellite imagery with reduced image revisit times and encourages data sharing for disaster response.

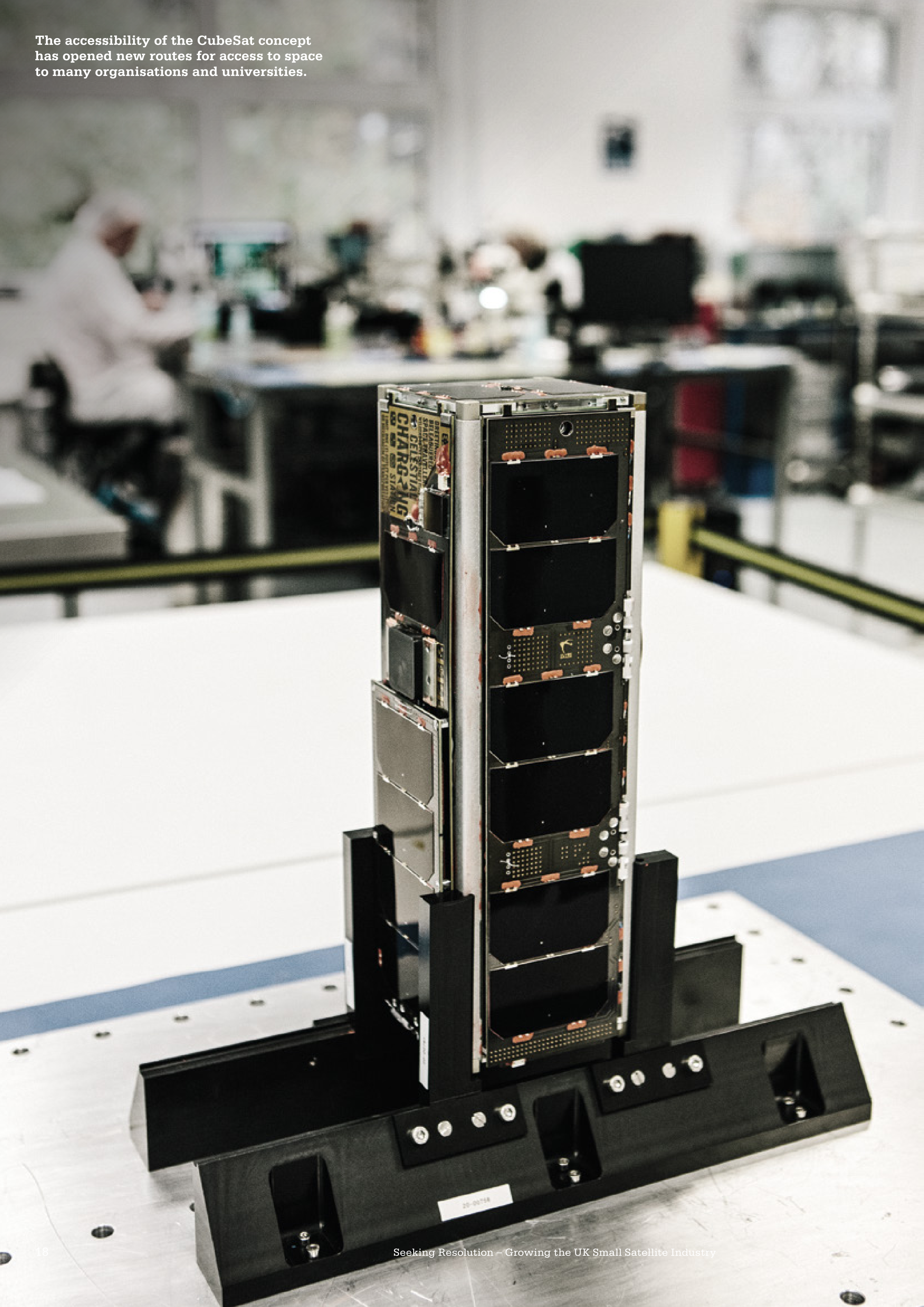
Since 2005 the DMC has contributed more than 500 images in response to over 250 disasters. The DMC does this as a contribution to the International Charter, Space and Major Disasters – agencies from 14 countries provide satellite imagery at no cost for disaster response.

Through its lifetime, the DMC has included nine commercial and civilian satellites from six countries. In addition to disaster response, the data has been used for large-scale mapping programs, agricultural monitoring, forest management and many other applications.

The DMC is a flagship achievement conceived in the UK and an example of the type of innovation that sets the UK apart in both the upstream and downstream elements of the space sector.

Nano/micro satellites projections





The accessibility of the CubeSat concept has opened new routes for access to space to many organisations and universities.

UK SATELLITE MARKETS

There was a time when national pride was the significant driving force for a country's satellite missions; however, that has changed and nearly all satellite customers of any size now see performance that can support both operational and commercial services, as the principal requirement. The customer base has also evolved from select, wealthy, government entities to smaller organisations and emerging economies. In fact, today, space is becoming accessible to all through both big and small business sectors, creating new market opportunities upstream and downstream. This has been stimulated by mobile internet access, maps services, social and online media, and is of obvious interest to online mapping and location-based service companies, such as Facebook, Apple, Google and Microsoft. Many of these new businesses are not UK-owned, but opportunities lie in the demand both for upstream technologies and the downstream services that exploit them. Traditionally, the industry is divided along two business sectors: large and small satellites. These businesses offer different capabilities and services depending on the application. To achieve the IGS plan, the UK must challenge strong international competition from both Europe and other global players. Upstream technologies must capture the exponential growth seen in electronic system performance over the past decade. This will push forward the capabilities of our most sophisticated satellites, while still meeting the stringent reliability constraints typical of a high-value satellite design. At the other end of the scale, the recent surge in launches of small satellites offers an opportunity for more direct exploitation of low-cost technologies. In downstream industries, certain satellite service markets, such as direct-to-home television, are now quite mature. However, this is complemented by growing demand for new services, such as internet access, Earth observation data and traffic monitoring.

BIG BUSINESSES

Well-established, substantial space infrastructure providers in the UK have experienced great success over the last 20 years and are expected to be key players in reaching the UK's growth objectives. Airbus D&S, in particular, has delivered some of the world's largest and most powerful telecommunications satellites and payloads for a number of international customers; the signal-processing unit for Alphasat (launched in 2013) is a prime example. UK satellite communications owner/operator Inmarsat, contributed £222m to the development of the Alphasat platform in a public-private partnership with ESA[39]. Alphasat was an addition to the existing Inmarsat fleet of 750 communications channels, serving Europe, the Middle East and Africa. Leveraging private investment to deliver this service opened many new downstream opportunities for businesses particularly dependent on satellite telecommunications services.

On the downstream side, satellite TV service providers such as Sky TV use these telecommunications satellites, providing direct-to-home (DTH) TV providing 40% of the satellite TV output across the UK and Ireland[40], generating £7.6bn in revenues and contributing £6bn to UK GDP. Sky TV uses a number of third-party satellites, namely the Astra and Eutelsat platforms, which were built, in part, in the UK.

These examples capture some of the largest businesses in the UK space sector. Many other businesses either contribute to the upstream supply chain, or benefit from the exploitation of the resulting downstream satellite services[41].

SMALL BUSINESSES

The satellite market is mature and ripe for disruption by emerging technology. It is becoming ever more accessible to and affordable for start-ups who want to fly their own missions. The UK also has a track record of challenging the traditional big business paradigms of space through low-cost, small alternatives, with UK universities leading the way in developing new applications. Surrey Satellite Technology Ltd (SSTL)[42] is a prime example of this, beginning as a spin-out of the University of Surrey. The founders of SSTL built on the success of UoSAT-1 and UoSAT-2 in the late 1970s to deliver low-cost, low-mass (50–60kg) satellites to an international customer base. These satellites could be launched 'piggy-backed' with larger satellites at a fraction of the cost. This has opened access to space to a multitude of new users, including educational institutions and other nations interested in establishing their own space capabilities. SSTL has since gone on to deliver over 40 satellites in the 30 years since its formation.

Clyde Space too, has built its business based on demand for the smallest of satellites; nano-satellites. It was the prime integrator for the UK's first national CubeSat mission, UKube-1, responsible for the design and integration of the spacecraft and its various payloads. This experience has since enabled Clyde Space to win further business as platform supplier to new commercial and scientific CubeSat missions, including Outernet, Spire and ESA Picasso[43].

The accessibility of the CubeSat concept has opened new routes for access to space to many other organisations and universities, including UCL, Surrey, Cranfield[44], Warwick[45], Strathclyde[46] and the independent Amateur Satellite group, Amsat-UK, whose 'messaging' CubeSat Funcube-1 launched in 2013[47].

Landsat

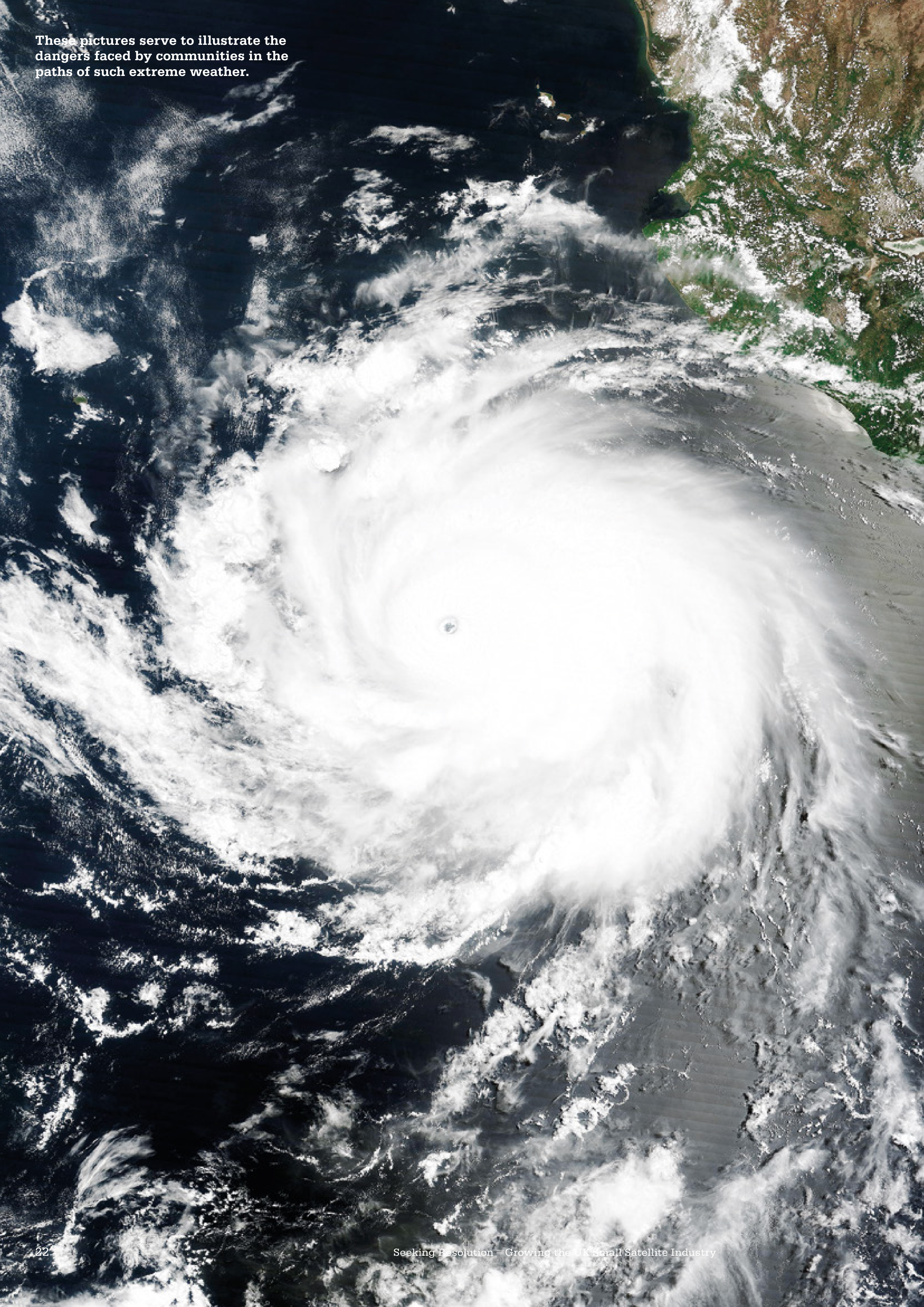
The single longest-running EO programme, beginning in 1973. It orbits Earth in 16 days, recording images of the same spot on the surface at regular intervals, giving scientists the opportunity to look at crop cycles, as well as the growth of cities, changes in forest usage, and monitoring the impact of floods, fires and other disasters. Such information is used to provide the foundation for important decision-making that determines how cities are planned, how communications and transport functions, how farmers plant and harvest, and many other critical areas of development are planned.

NEW MARKETS: "NEWSPACE"

It is considered that integrated observing systems and a harmonisation of the large and small-satellite markets will occur over the next 20 years. As small-satellite technology grows and matures and satellite constellations increase, the data they provide will complement that already provided by the larger satellite systems. This will afford downstream services the opportunity to grow their commercial and open-access businesses, combining different types of observation technique to provide a broader range of imagery. New business models, with greater user-led technologies and services, will emerge that will make it easier for non-experts to access EO data via online services.

The case to refocus small satellite use from technology demonstration (TRL 6) to commercial use (TRL 9) represents a shift in how small businesses are using satellites today. We are at a stage where new businesses can own the entire end-to-end satellite data service using low-cost, small satellites and terrestrial data processing and technology platforms, via the web. These new businesses are accepting greater risk by omitting individual test programmes and insurance, traditionally required by the incumbent industry. This change in the industry is often referred to as the 'NewSpace' approach, where small SMEs can build business offerings by using simple terrestrial technologies.

This is true of EO applications, where the term 'agile aerospace'[48] was coined by early pioneer, Planet Labs, based in the USA. By launching EO satellites in constellations, they deliver open-access images of the entire Earth's surface on a daily basis. To date, Planet Labs has launched nearly 100 Earth imaging satellites. These spacecraft have a typical lifetime of four months and can be constructed in under two weeks[49–51].



These pictures serve to illustrate the dangers faced by communities in the paths of such extreme weather.

EARTH OBSERVATION: INNOVATING SATELLITE APPLICATIONS

Satellite-based EO brings together the fields of science and engineering in a way that provides us with a unique view of our surroundings. Some of the most familiar and recognizable EO images are the dramatic pictures of hurricanes and cyclones taken from space. These pictures serve to illustrate the dangers faced by communities in the paths of such extreme weather. As scientists have gained experience in studying the Earth through satellite observation, they have identified new technological needs, propelled engineers to develop more quantitative and accurate measurement equipment, and have developed ever-more sophisticated methods of data collation. Satellite Earth observation therefore, forms a central pillar in achieving the UK's strategic plan[20,52,53].

THE EO MARKET

At the beginning of 2015 that there were 268 individual EO satellite missions, either operating or planned for launch in the next 15 years[54]. EO accounts for 28% (£911m) of ESA's yearly budget, with approximately £80m of that coming from the UKSA (27% of UKSA's budget)[55]. The annual value of the manufacturing market for EO platforms (both large and small) is estimated to reach £4.4bn[56] by 2023.

The downstream EO sector only makes up 3% of the overall UK space industry employment in 2012/13, with a turnover of just 1% of the total £11.8bn[6]. It is estimated that the commercial EO data market will reach a value of £1.8bn by 2020[7]. By that time small-satellite technology could be capable of producing very-high to medium resolution data, with an estimated market value of £970m[57]. It is predicted that the growing use of EO nano/micro-satellites, could yield an estimated market value of £260m over the next five years[57,58].

EO DATA EXPLOITATION

Currently, EO satellite manufacturers typically provide equipment based on specific locations. This results in some high cost data being wasted by capturing large quantities of the surrounding areas that is not needed. This often restricts data access to only the wealthiest customers: large corporations (such as Google), or governments. New innovations in both EO technology and business, have the potential to drive towards more widely available, high-resolution, data which can be refreshed on a daily basis and is available to consumers at affordable prices. There are two mechanisms by which improved exploitation of EO data could be achieved:

- Building on existing programmes and implementing greater open data policies (eg Landsat and Copernicus)
- Creating small, low-cost EO missions used to reduce infrastructure costs and therefore the cost of data (DMC)

To successfully exploit applications and service provision, improved access to networks of data is required and this can be achieved only through open access.

The EU's Copernicus programme will launch a range of satellite sensors this decade to monitor the state of the Planet.

- Sentinel-1A: Radar's advantage is its all-weather observing capability, seeing through cloud. It was launched 2014.
- Sentinel-2: Multi-wavelength detectors, principally to study land changes. The next satellite to go into orbit.
- Sentinel-3: Similar to S2, but tuned to observe ocean properties and behaviour. May be launched at the end of 2015.
- Sentinel-4: An atmospheric sensor on a high-orbiting weather satellite to give a global perspective on gases such as ozone.
- Sentinel-5: Another atmospheric sensor, but on a low-orbiting weather satellite, to help monitor air quality.
- Sentinel-6: The future European name for the Jason sea-surface height mission jointly run with the Americans.

By 30th April 2015 a total of 6700 users had downloaded 805,315 products (993TB of data) from the Copernicus database.

The Copernicus programme

ESA's Copernicus programme co-ordinates the delivery of data from 30 satellites. Currently, ESA is developing a new family of satellites, called Sentinels (large 1,200kg satellites, manufactured by Airbus D&S), which will contribute to the worldwide Global Earth Observation System of Systems (GEOSS). Sentinel-2 data will produce approximately 600Gb of raw data per day and will be downlinked using a high-speed laser. Once processed into useable data products, there will be approximately 1.7Tb of data per day – the equivalent of several hundred DVD movies. Sentinel-2 (launched in 2015) offers the ability to take continuous images of any surface and provide a continuous flow of data. This is unlike previous EO satellites, which were able only to take isolated images that had to be pieced back together to get a complete picture[59].

The service Sentinel provides is unique, as it makes no distinction between public, commercial and scientific use. Open access to the data will maximise the operating time of satellites while ensuring the widest range of applications benefit. The hope is that it will stimulate the uptake of information, increase scientific research as well as promote growth in EO markets. Future large-scale EO programmes will also implement open data policies, to encourage the exploitation of the data generated[53]. It should not preclude commercialisation of some aspects of useful data, but a portion of low-level data should be made available at no more than the cost of reproduction.

Landsat is a good example of this: where restrictive commercialisation of data led to a steep drop in their use for both scientific and commercial applications, which recovered once the open data access policy was returned[20].

WHY DOES EO MATTER?

In 2005 the GEO was established to create a Global Earth Observation System of Systems (GEOSS)[19] that would link Earth observation resources worldwide. The GEO identified a number of challenges facing society, which are now being addressed using EO satellites. However, in the case of Hurricane Katrina in 2005, even though the information collated from satellite observation was highly accurate and readily available, response at all levels of the US Government was slow, demonstrating that accurate data does not always lead to better decision-making[5]. Even today, with the benefit of geographic information and sophisticated imaging processing software and GPS, incorporating EO into Government agency resource management can be difficult. Public budgets often do not include enough funds for processing of data, and the cultural and communication barriers between space researchers and data users are often difficult to overcome. If EO is to have any impact these barriers to its development and use must be overcome.

CryoSat-2

CryoSat-2 is a medium-size (approx. 720kg) polar-orbiting satellite that carries a primary instrument called SIRAL; a novel radar altimeter which can operate in a synthetic aperture mode, and which has a second antenna which allows interferometric operation.

The focus of the mission is on science and research. The aim is to provide accurate measurements of ice mass loss and thickness for both continental polar ice-sheets and sea-ice. This will enable climate models to be validated, including estimates of sea-level change. The mission concept was originally proposed by University College London.

In addition to the hardware for CryoSat being novel, the on-ground processing software was created specifically for the mission. University College London and the Centre for Polar Observation and Monitoring provided the expertise for the science and engineering algorithms.

CryoSat is a prime example of UK industry and academia working together from the initial proposal, through the design, build and operations phases, and exploitation of the data for research purposes. The mission is currently capable of providing near real-time measurements of sea-ice thickness in the Arctic Ocean, which is of use to shipping.

Satellite EO is producing valuable data on urban growth by regularly collating images.

MEASURING LAND-USE CHANGE (DEFORESTATION)

More than 1.6bn people worldwide depend on forests for jobs, food, medicine and fuel, yet the illegal logging trade is stripping the land of more than 100,000,000m^3 of timber each year. This illegal trade is estimated to be worth between £19bn and £64bn annually, with global markets losing £6.4bn each year in tax income.

Satellite EO is enabling large-area imaging of forests (forest stock mapping). Wide area coverage and the use of radar mean that the issue of cloud coverage is considerably reduced, making comparison between consecutive images much easier; building valuable historical records of stock, degradation and illegal practices.[60]

MARITIME AND OCEAN MONITORING

As the oceans cover 71% of Earth's surface, radar and optical EO imagery are invaluable in monitoring maritime activity and oceanography. The flexibility of these Earth Observation systems allows ships and other vessels to be detected and classified using Automatic Identification Systems (AIS) and tracking applications via Synthetic Aperture Radar (SAR), as it is not susceptible to cloud cover. Satellite EO can be used to detect ships involved in oil spills and also illegal tank flushing at sea for example. In addition, satellites can detect when an AIS signal has been turned off (often a sign of illegal fishing).

Wild-caught fish is a primary food source for over 3bn people. In the UK alone, consumption of fish was approximately 416,000 tonnes in 2012 (about 0.5% of world's total). Illegal, unreported and unregulated (IUU) fishing is a worldwide problem, which costs the global economy an estimated £15.2bn every year.

DEFRA and the UK Fisheries Departments have already recognised the need for a fishing vessel tracking solution through their pilot project, Environmentally Responsible Fishing, and are now seeking to access information to prevent illegal fishing. While still in its early stages of development, the Satellite Applications Catapult has developed a prototype of the Information Analysis Platform, WatchRoom. The application will use available satellite data in combination with vessel data, to automate surveillance, and detect IUU in real time. As a spin-off from this application, the UK public will be able to access the data to look at the origin of the fish they are buying.

MONITORING URBAN GROWTH

By 2050, 70% of the world's population is expected to live in urban areas, two thirds of them in low and middle-income economies. The exponential growth of our cities over the coming century will result in flooding, increased demand on public services, pressures on emergency services and the need for disease management planning. "Soil sealing" (covering the soil with impermeable layers of materials such as stone and concrete) can lead to floods, as water can no longer drain away. The EC Joint Research Centre estimates that four million tonnes of wheat are lost every year due to the loss of farming land to urbanisation and soil sealing. That's an area the size of Cyprus paved over every ten years. Satellite EO is providing valuable data on urban growth by regularly collating images. These pictures can be combined with flood models, soil models, digital elevation models and rainfall data to produce accurate information regarding our urban environment. This data can also be combined with census information to estimate population growth, or provide rapid casualty estimates after natural disasters.

MANAGING ENERGY SOURCES

By 2050, global demand for energy will have doubled, while water and food demand is set to increase by over 50%*. The International Energy Agency (IEA) estimated that if a global effort were made to boost energy efficiency, a saving of £358bn could be made by 2030.

Energy providers rely on demand models to forecast electricity production. These demand forecasts are heavily driven by metrological changes. Satellite EO data has the capability to improve forecasting, which in turn improves energy demand forecasts leading to greater efficiency and energy savings. More accurate forecasts have led to improvements in production and distribution of energy and have shown that less energy needs to be available, thereby lowering costs.

*Renewable energy in the water, energy & food nexus, International Renewable Energy Agency (IRENA), 2015

AGRICULTURAL MANAGEMENT

Nearly all crops can be assessed for their health using satellite data. The crops can be monitored by looking at changes in their chlorophyll levels. As a crop grows or there are changes in the plant's health, so the level of chlorophyll changes. A numerical value can be given dependant of the volume of chlorophyll called the Normalised Differential Vegetation Index (NDVI) classification. By using EO satellites, crop producers have been given the opportunity to pinpoint areas of concern and apply fertiliser and water appropriately. The data can also be used to assess water consumption and where pests are destroying plants. This type of analysis has been shown to save farmers significant amounts of money on fertiliser, particularly in developing countries. The organisation SOYLSense estimates that UK farmers save an average of £27 per hectare on fertiliser use and see a 3–8% increase in crop yield when satellite imagery is used. The reduction in fertilisers and pesticides also results in both economic and environmental benefits for the wider community.

If the UK continues to charge according to application and not size, then many satellite operators will go elsewhere to launch their equipment.

BARRIERS TO INNOVATION

Despite the clear benefits of EO, there are significant barriers that stand in the way of progress, these being:

- Regulation in a growing market
- Investment and financial support
- Education and skills
- Public awareness

If the UK is to achieve the IGS goals, then these barriers must be addressed. The Institution of Mechanical Engineers believes that greater engagement between the UK satellite industry stakeholders is the key to ensuring a successful industry for the future.

REGULATION IN A GROWING MARKET

To capitalise on the global opportunities in the satellite industry, there are several factors that must be considered and addressed to facilitate the growth of innovative new satellite businesses in the UK.

1. The increasing regulatory pressure on organisations that are launching and operating satellites.
2. The lack of available spectrum for radio in telemetry, tracking, and command (TT&C).
3. The mismanagement of the spacecraft classification process, launch and disposal licensing and consideration of liability for other space users.
4. The fragmented regulation of downstream data, particularly for EO.

All these factors are now being further compounded by the increasing demand for large-satellite constellations and small-satellites on short duration flights.

There is a complex minefield of international agreement frameworks, directives and laws which must be considered before a satellite ever launches[61]. Different nations co-ordinate these regulations in differing ways and a variety of costs are involved, the magnitude of which depends on the intended satellite application and the owner's and operator's nationality. Furthermore, there is the restrictive third-party liability insurance, to indemnify the Government from compensating spacecraft owners, should a UK-owned satellite collide with that of another nation's. This forest of red tape is hamstringing potential satellite operators in the UK which could have a ripple effect through the entire industry, resulting in the UK failing to secure new business and market share.

While it is acknowledged that the satellite industry could not function without detailed and comprehensive regulation, it must be recognised that if the industry is to fulfil its goal of 10% world market share, then methods that promote the responsible exploitation of space assets, must be found.

Launching state responsibility

The United Nations Declaration of Legal Principles Governing the Activities of States in the Exploration of Space[62] defines the UK as a 'launching state'. This means the UK Government is responsible for any British organisations or citizens within the UK or one of its overseas territories, launching, procuring the launching of, or operating a space object in outer space. This responsibility is captured in the Outer Space Act (OSA) 1986, which transfers the liability of the UK Government to the organisations or individuals by granting them a licence. In other words, the UK Government transfers its absolute liability to pay compensation for damages to the licensee.[63]

Historically, at the time of implementation of the OSA, this assignment of liability was driven by space activities where the mainly governmental spacecraft were large and potentially a threat for ground or air assets. That is, debris may survive re-entry into the atmosphere and impact objects in the skies, seas or on land (with a chance of impact estimated to be one in 2,000[64]). Importantly, it was defined at a time when space activities were seen primarily as a state rather than commercial activity, and therefore decisions were made without the foresight of the emergence of both a major UK commercial space sector and small satellites. As a consequence, some aspects of the UK regulation have the potential to preclude small-satellite operators and start-ups in the future and do not take into consideration the growing constellation market.

The Institution recognises that the updating of regulation is an ongoing and complex process, however the 30-year-old Outer Space Act must now be revised to acknowledge the advancement of technology and the changing nature of space usage as well as simplifying the legal conventions for liability. The UK risks losing business and falling behind other nations if it is not.

Legal Implications of Impact

Collision in orbit is less explicitly defined in the OSA implementation, as it is fault-based. However, a legal definition does not currently exist for fault within the context of the Liability Convention. To date, there have been no instances where the Liability Convention has been applied. The closest example is a single event in 2009, where the defunct Russian satellite Cosmos 2251 and the operational US satellite Iridium 33 collided. This created a total of 1,788 new pieces of debris. Three years later, the two parties were still trying to blame each other; Russia by asserting that it did not have an obligation under international law to dispose of Cosmos 2251 after it became derelict and the USA by contending that it did not have an obligation to avoid the collision, even if was aware that such a collision would occur. The issue with such cases is that any resulting claim has to be made from state to state via diplomatic channels, which would invariably become mired in complex international commercial and political factors.

Launch & Operating Licensing

In the UK, licence fees are £6,500 per application and are non-refundable; this is not dependent on satellite size. The UKSA has partially recognised that in the case of a licensee intending to license a constellation of small satellites, the fees may be negotiable to a certain extent. While this fee for a one-off, multi-million pound large spacecraft might be negligible to a licensee, it is a significant sum of money for a small or nano-satellite operator, which in itself only costs tens to hundreds of thousands of pounds to build. If the UK continues to charge according to application not size then many satellite operators will go elsewhere to launch their equipment. Clearly, the cost of licensing needs to be revisited by the UKSA to ensure that small-scale operators can better afford to launch and operate their spacecraft.

UNOOSA Convention on International Liability for Damage Caused by Space Objects

A launching State shall be absolutely liable to pay compensation for damage caused by its space object on the surface of the Earth or to aircraft in flight.

And Article III:
In the event of damage being caused elsewhere than on the surface of the Earth to a space object of one launching State or to persons or property on board such a space object by a space object of another launching State, the latter shall be liable only if the damage is due to its fault or the fault of persons for whom it is responsible.

Liability under the Outer Space Act 1986

A statute enacted as primary legislation by the UK Government. It constitutes the legal basis for the regulation of activities in outer space carried out by organisations or individuals established in the UK or one of its overseas territories. It confers licensing and other powers on the Secretary of State for Business, Innovation & Skills acting through the UK Space Agency.

The Act seeks to ensure compliance with the UK's obligations under international treaties and principles covering the use of outer space, including liability for damage caused by space objects, the registration of objects launched into outer space and the principles for the remote sensing of Earth.

Spectrum Licencing

Each country has its own way of managing spectrum and there is no single 'best practice' for licensing. Licences to use individual frequency bands are issued to organisations for commercial services such as television, radio and mobile telecommunications, as well as other wireless applications such as financial services or online shopping. The Government owns and manages radio frequency spectrum in the UK through the Office of Communications (OfCom). OfCom is responsible for civilian use of spectrum and developing policies to ensure that the spectrum is used effectively. The MOD continues to manage the spectrum which is designated primarily for military use.

Governments that avoid restrictive requirements to spectrum licensing create the best conditions for operators to adopt new technologies and develop new services[65]. Currently around 29% of spectrum is being shared between public sector and private sector users and was estimated to contribute £52bn to the economy in 2011[66]. The UK government would like to see this contribution doubled by 2025, but this will only be achieved if there is an increase in the sharing of existing spectrum band.

Publicly-funded satellite applications such as weather forecasting, predicting flooding, monitoring climate change, are all difficult to quantify in economic terms. If Ofcom is to make best use of spectrum bands then they must find a consistent approach to get the best value for money from competing uses for single spectrum bands[67]. In its stakeholder consultation of 2013, the government felt that a revised regulatory framework to accommodate Licensed Shared Access (LSA) was not needed. It did however recognise that the current regulatory framework, where frequencies were available on a time- and location-limited basis, is not working. This is increasingly affecting small satellite users who only require short-duration licences, and this situation will only get worse[67].

The industry-led UK Spectrum Policy Forum (SPF), was created in 2013 to challenge Government and OfCom on the priorities for spectrum management. To date, little progress has been made on addressing the issue of spectrum licensing. However, Ofcom have recently put out a consultation document[68] to look at industry's requirements for satellite spectrum usage, due to be published in 2016. Whilst this is warmly welcomed, it should be emphasised that any agreed changes will take a number of years to implement. Short- to medium- term solutions must therefore be found to ease the pressure on spectrum usage. The UK must demonstrate intelligent leadership in promoting the best use of spectrum by maximising its remaining resources and encouraging existing users to release spectrum bands they no longer need. OfCom must work with industry to implement LSA and ensure that new and existing users can cohabit in the same spectrum band without interfering with each other.

Third-party liability

Notwithstanding the cost of buying the license, a licensee must also indemnify the UK Government with respect to damage or loss arising out of activities carried out by the licensee's satellite. The Government also requires the licensee to insure itself against damage or loss suffered by third parties[69–71]. This is called third-party liability (TPL) and involves two parts;

- The licensee has to be a beneficiary of the Launcher TPL Policy. This incurs a premium which is at the discretion of the payload operator.
- The satellite owner or operator has to get its own TPL insurance cover for every year of operation until the licensee can demonstrate its satellite will de-orbit. (The UN Outer Space Treaty (OST) guidelines states that all spacecraft launched to LEO should re-enter the atmosphere within 25 years of launch).

In the very improbable case that there is ground or in-orbit damage, the licensee's insurance will reimburse the UK Government up to £43m[72]. However, this responsibility and liability regime is not implemented in the same way by any other launching states; for instance, the USA Government assumes responsibility for this liability.

TPL insurance has been a blocker for SMEs and start-ups, intending to launch small satellites, to license their own assets. If growth is to be stimulated, TPL insurance must be ended. The Government, through the UKSA, must assess the liability policies established in other countries and determine a possible solution to this problem, based on more up-to-date knowledge of large and small-satellite operation.

Space debris: risk-based satellite legislation

As a result of access to data becoming more affordable, greater numbers of organisations are wishing to launch satellites. This is re-igniting the debate on the responsible utilisation of space and in particular the issue of satellites becoming space debris. So how can we responsibly operate in space and maximise its exploitation in a sustainable fashion?

Small satellites are perceived as a significant threat to larger satellite operation as they are more difficult to track from the ground and are less likely to include propulsion devices for collision avoidance. In reality, the actual risk is much lower due to their small cross-sectional area which reduces the probability of collision. The other potential risk is the probability of their surviving atmospheric re-entry and impacting assets on the ground. Small-satellites have negligible probability of any components surviving re-entry, as they will be entirely disintegrated before reaching altitudes that might concern either aircraft operators or persons on the ground.

A handful of countries (Spain, USA, China, Germany & Belgium) have found suitable solutions to this problem and take on the liability of impact on behalf of their small-satellite operators, in return for the development of high-growth commercial opportunities. The current UK regulatory regime regarding responsible satellite operation would benefit from similar revision to its definition to distinguish between the operation and behavior of large- and small-satellites.

Standard spatial resolution for Earth Observation satellites

- Medium-resolution visible imagery (10m to 100m resolution)
- High-resolution visible imagery (2m to 5m resolution)
- Very-high visible imagery (sub 1m to 1.5m resolution)

Regulation of downstream data

The commoditisation of space technology, low-cost access to space, innovative business models and availability of private investment is creating a shift in interest, from upstream platform technology to the downstream applications markets. Furthermore, the pricing of data is becoming increasingly competitive. This changing market landscape is creating an environment in which downstream applications service providers can thrive and develop new services that have real-world value.

In 2014 the US Government relaxed regulations on the sale of commercially available EO data. The restriction focuses on the sale of imagery of resolution better than 300mm, rather than the previous 500mm. Europe however, has been unable to find consensus amongst its member states regarding dissemination of EO data and has recently abandoned plans for an EU directive[73]. This directive would have seen a move toward increased regulatory barriers for access to very high-resolution data. Whilst plans exist to revisit the directive in 2016, there remains concern amongst satellite operators, the scientific community and downstream service providers that economic opportunity will be stifled if restrictions are placed on these data in the future. Such legislation could inhibit timely access to, or lessen the quality of, the data applications providers can access. This could potentially result in UK commercial providers losing out to other countries. In the intervening time between redrafting of the directive, the UK must determine its stance on EO data regulation; how it will be implemented nationally and who will incur the costs.

Presently, the UK controls access to data via the export licencing organisation through BIS, with data usage conditions imposed on the exported satellite itself. However, the current export control regulations do not take into account data dissemination. If the UK space agency wished to continue to implement this method of data control then the export licencing regulations must be amended to include dissemination of data.

Security of EO data

From a scientific and exploratory point of view, the idea of open access to EO data is an exciting one. However, the issues of security and privacy of data are ones which wider society is most concerned about. If data is readily available, who has access? Issues such as data interception and fraudulent use of data come high on the public agenda. For example, Google Maps is a widely accepted application of EO data, however when Street View was introduced there was significant backlash in the UK, pertaining to public privacy and security of data.

So far, little focus has been given to this concern regarding EO data; there is no mention of privacy in the IGS strategic plan for example. By its very nature any future directive will cover the issue of access and distinguish between high- and low-resolution data as being the dividing line between open access and that for commercial purposes only. If a directive such as this is to become effective, the policy will need to reflect not only the impact of trading data but also the control and manipulation of data from a security point of view. The UK must ensure that open access to EO data does not cause a backlash from wider society.

INVESTMENT AND FINANCIAL SUPPORT

Even though building satellite systems may be technically and financially beneficial for the economy, moving into operational use can be extremely difficult. The UKSA was set up to manage the UK's centralised national space budget and act as a focal point for the UK's involvement in European and global space programmes. Social, demographic and economic factors together with technological and political developments, are likely to have a significant impact on EO revenues over the coming years. In addition, the development of new services such as those for the insurance industry are expected to extend the demand for these services to non-space related users.[74] The question arises, how can the satellite industry stimulate both public and private investment? This state of affairs has come about because EO data has both public and private uses[5]. On the one hand accurate prediction of severe weather can help to reduce the economic and social costs of weather-related disasters, but on the other, better information induces businesses to invest in loss-reduction activities.

Private investment

Access to space by independent organisations has traditionally been challenging; technologically, financially and bureaucratically. Risk-adverseness in the industry has been driven by the mantra "failure is not an option" and the high-value investments into the spacecraft themselves. However, growth in consumer electronics devices, has resulted in a significant reduction in the cost of developing smaller satellites enabling businesses to be more robust to the inherent dangers of launch or platform failure.

This shift in the industry paradigm has given start-ups the freedom to own their entire value-chain, from space assets, to operations and data acquisition, processing and service provision. Some of the newer companies are even operating at costs within the realm of private investment; both angel and venture capital. Exploiting this new approach is important to the growth agenda and sustainment of UK leadership in the global space market.

But there are still significant financial challenges and SMEs continue to find it difficult to engage with private finance and investment. In this time of austerity, UK investors in particular continue to be averse to the risks of costly space missions, and a lack of understanding of the high-value returns from satellite build and operation continues to inhibit private investment. Additionally, developing nations and those willing to invest money abroad, in the up- and downstream sectors, are drawing money away from the UK market. This could potentially trigger a mass exodus of small businesses to where money is more readily available. If these barriers to private investment are to be lifted, the UK, through UKSA and trade bodies such as UKSpace, will need to support the continued growth of SMEs and combine existing business models with new concepts and technologies to enable private investment to take place.

Public investment

The UKSA's EO strategy for 2013 to 2016 is to focus on European space programmes, to secure funding and projects for academia and industry, and provide financial returns for Government. It will also build on UK environmental research and climate applications to leverage further investment and growth in EO data products and services. There are also major opportunities to become global leaders in Synthetic Aperture Radar (SAR) technology and exploitation, and increase the UK's knowledge and expertise in small, low-cost missions.

There has been a considerable increase in financial support from the Government over past few years. This has come in the form of research grants, chiefly in new upstream technologies in EO. However this funding is often spread very thinly, particularly across academic institutions. EO is seen as an enabling technology and does not always benefit from direct funding; instead the piece of technology or the application receives the funding, resulting in academics having to find monies from a number of funding bodies.

Additionally, industry, traditionally seen as a source of funding for academics, is not at this time willing to pay for research to develop new technologies; instead wanting results quicker than a university can produce them. There is often little or no alignment between industrial and academic timelines and often academia receives no financial remuneration for the marketable technology.

Work remains to be done to establish coordinated funding opportunities across the Research Councils (RCs) EPSRC, NERC etc. Furthermore, alignment between the RCs, UKSA and Government funding programmes is needed, as they are still not comprehensive enough to bridge the valley of death between TRL3 and TRL6 (UKSA funds covering TRL2-3 and 6-7, Innovate UK covering TRL6-9). Greater uniformity of funding packages, alignment of funding streams and greater transparency of funding protocols are needed to enable academia to access finance in a timely manner. Innovate UK and CEOI should develop additional satellite technology challenges focused specifically on the TRL 3-6, technical demonstrator phase, to enable academic research to be fully tested.

Cross-sector engagement

Key to growing investment is to engage businesses outside the immediate space industry. Initiatives, such as 'Satellites4Everyone' must be developed further through greater collaboration between the Satellite Applications Catapult, UKSA, Local Enterprise Partnerships, trade associations and the Knowledge Transfer Network. Using EO as a means to communicate the possibilities of up and downstream investment would be a successful way to grow cross-sector engagement. The Milton Keynes 'KeyneEye' urban planning programme is a prime example of a non-space sector organisation benefiting from EO data to develop tools for town planners.

The Space for Smarter Government programme hopes to enable services for smarter, more-efficient operations while making use of existing investment. The Government aspires to be one of the first to drive growth through satellite-derived products and services, focusing on environment, local authorities, transport and natural hazards risk management. It plans to achieve this by developing awareness of space amongst Government agencies to enable policy development across departments.

Cross-sector Engagement

Examples of cross-sector business partnerships include:

- **Creation for New Concept Always Connected Mobile Medical Screening Vehicle** – RSAC and Hampshire Hub Partners. To demonstrate to local government the potential of a portfolio of EO-based flood information products, such as rapid-response flood maps.
- **Coastal Sentry and Roof Watch** – Ecometrica; Defra, DECC, EA and local authorities. Prototype and demonstrate benefits of satellites in the detection of damage caused by severe-weather events, including erosion and damage to buildings. Pre-identify areas of risk and look for potential erosion and landslides.
- **Local Authority Air Quality Hotspot Mapper** – University of Leicester; Leicester and Northampton City Councils. A feasibility study as a precursor to a national service that could supply satellite air-quality data to local authorities, giving them a more detailed picture of air pollution sources and impacts.

EDUCATION & SKILLS

Unlike any other technical sector the space industry is in a unique position, in that it has played its part in our science fiction long before it became science fact. Every generation has had its space heroes: Flash Gordon (1934), Dr Who (1963), John Crichton (1999) and this intertwining of fictional protagonists with the real-life exploits of early pioneers such as Yuri Gagarin, Aleksei Leonov and John Glenn have made space exploration more meaningful to society than any other. Anecdotal evidence has shown that space inspires great curiosity in the young[76]. In a survey from 2009 it was shown that 9% of children wanted to become an astronaut; fourth in popularity, after footballer, pop star and actor[77,78]. With the IGS commitment to increase the UK share of the global space market there must be an analogous growth in the labour force[9].

Whilst the UK space sector continues to grow and attract highly skilled personnel, the domestic supply is limited and an increasing number of degree-qualified engineers and technicians are being recruited from overseas[78]. It is recognised that while large companies will continue to grow, regardless of the sector, it is growth amongst university start-ups and SMEs that is required if the UK space and ultimately the satellite industry is to maintain its global standing. The question then arises, in a time of skills shortages and a near empty pipeline of engineers[79,80], can the space industry compete with other engineering sectors to attract this workforce?

Launching a career in space

Part of the appeal of the space industry is the vast array of jobs and opportunities available. This has been particularly noticeable in downstream data processing businesses, where staff levels are growing much faster than for upstream manufacturing employers[9]. Yet the perception still persists that the UK 'does not do space' and that the space industry exists only in the USA.

There is also a real dislocation between the aspirations of graduates to obtain employment and the number of jobs that are available within certain companies. The main issue is that students apply to well-known companies and often do not consider the large percentage of SMEs within the sector. They either do not realise they can get the same experience, or they think the job will not be as stimulating or financially beneficial. Other industries have already been successful in providing opportunities for bigger companies to pass on surplus job applicants into their supply chain. Clearly, there are opportunities to replicate this model in the space sector. Trade organisations such as UKSpace must lead on this to bring the industry together to consolidate job opportunities and improve retention; safeguarding the workforce across the industry towards 2030.

Taking on an undergraduate is a double-edged sword for most SMEs and start-ups. Larger organisations often have very well-developed graduate recruitment programmes, but very few smaller companies can afford complex professional development schemes. They often cannot justify the cost of employing an undergraduate for a year (at a cost of £20k–£25k) when balanced against the amount of useful work they might produce. There are however, opportunities for organisations such as the Satellite Applications Catapult and universities to support SMEs looking to provide placements and ultimately graduate jobs[81].

Schools & the National Space Academy

The UK already has a range of formal and informal space-related education and outreach activities[78], provided by the Space Education and Skills Working Group, co-chaired by the Department for Education (DfE) and the UKSA, and includes representatives from BIS, STFC and ESERO-UK.

The National Space Academy (NSA) was established in 2010, for the purposes of creating a new Higher Apprenticeship in Space Engineering[. The objective of the NSA is to grow the UK science and engineering skills pool through a programme of master classes, CPD training and careers events. The initial three-year pilot Space Academy programme began in 2011 and proved to be successful in boosting student attainment, teacher effectiveness and influencing students in selecting STEM subjects at A-level. Future apprenticeship demands are intended to be met by a number of space colleges – Loughborough, being the first of these. Courses began in early 2014, and it hopes to attract several hundred apprentices over the next three to five years[16].

Whilst this progress has been welcomed by the space and satellite industry, the sector cannot continue to wait a further ten or more years for this generation of children to enter the labour market nor will it produce the tens of thousands of people the industry needs. Focus therefore must be given to the existing education pipeline.

Universities

There are approximately 23 major universities offering degrees in astronomy and space-related sciences and engineering, including Leicester, Surrey, Newcastle, Southampton, Cranfield, and Mullard SSL, part of UCL. Students can study a range of subjects from space robotics, systems design and launch vehicles to astrophysics, planetary sciences and solar physics. Sandwich degree programmes and internships are an essential part of the engineering degree and one which universities much include if they are to produce highly skilled graduates and retain interest in the space and satellite sector.

Presently, universities can charge up to £4,500 for a student during their sandwich year, although a guideline fee of £1,000 was suggested by the Wilson review[82]. Universities must continue to ensure that every student has access to an industrial placement or some period of time in industry during their degree yet this administrative fee often discourages students from taking a year out. Student uptake will only be achieved if the burden of placement-year tuition fees is significantly reduced in line with that recommended by Wilson[82].

The Satellite Applications Catapult set up the Space Internship Network (SpIN) in 2013, to provide eight-week internships for undergraduates[xxix]. However only 93 students took up posts over the first two years of the programme with only 20 or so companies offering projects; clearly not enough when considering over 400 students applied for a SpIN post in its first year. If the Catapult is to facilitate an increase in the number of undergraduates taking up these placements, then it must do more to raise the profile of the SpIN programme by engaging businesses and provide greater numbers of placements from both inside and outside the space industry.

To achieve this, the SpIN programme must be broadened to include year-long placements which would be more financially beneficial to businesses. Bodies such as Innovate UK must work with the Catapult to set up funding competitions to provide additional financial support to SMEs to encourage them to provide placements. These places must also be open to professional engineers looking to re-train, thus deepening the pool of potential employees. It is conceivable that the numbers of SpIN placements could be increased to 1,000 a year over the next fifteen years. Whilst this would not fill the industry skills pipeline by 2030, it would go some way to providing much needed workforce in the short to medium term.

Research

Despite significant investments from industry through Knowledge Transfer Partnerships (KTP) and industrial research postgraduate studies, there continues to be a need for post graduates and post-doctoral students to undertake industrial research[82]. This can be achieved only through a strong research community which feeds future developments in both upstream and downstream sectors. Yet research funding for space technology remains scattered and spread too thinly among academic institutions. The UKSA must ensure that opportunities continue to be open to UK research to participate in global space activities and that access to ESA funding is made easier. It is vital that the Higher Education Funding Council for England (HEFCE) and the Research Councils are part of this process, and that funding is focused on a range of space sectors, including EO technologies and processes.

“ ”

Space is something which we need to get people involved with, rather than just wondering at… but if we’re going to keep exploring, and keep funding the institutions that explore, people need to see it as something they can actively do.[75]

PUBLIC AWARENESS

The argument for the exploration of space is an easy one for most scientists and engineers. The space industry has created myriad jobs across multiple sectors, generating business growth and investment across the globe. It has driven technological innovation for decades, contributing to advances in materials, manufacturing techniques, biomedicine and even understanding the ageing process. It has also been one of the key drivers for young people wishing to enter the STEM sector. Google was the first to open the minds of the wider public to using EO for everyday purposes.

Surveys and polls carried out over the last fifteen years have been both minimal and limited in their investigation. No research has been carried out to look at the public's opinion of satellite technologies, their applications or the data they are collecting. Most public opinion has been gathered from online forums and opinion polls, with only one deliberative dialogue activity carried out in 2006. The last academic study on space-related technologies and public opinion focused on space tourism and was published over a decade ago. The 2013 review of available information on the views and values of the public towards space, carried out by Sciencewise[83], has shown that the public have mixed views on the UK space industry, but broadly, support the idea of space exploration and developing space-related technologies when it has societal relevance.

In general, the surveys showed that the public feel disengaged from the space industry and have no concept of the impact space-related technologies have on their daily lives. Indeed, most are unaware that the UK has a space industry at all. The link between investing in space exploration and the economic contribution that space-based technology makes to the UK was not made by those surveyed. In the deliberative dialogue held in 2006 by ESA, the representative panel of people were not aware of the amount of money the UK contributed to the European space programme, and they felt that the UK Government should be held responsible for informing the public of the cost to the public purse[83].

The perception of EO is currently hampered by the adversarial discussions concerning climate change. While climate monitoring is an important aspect, there are a number of less-visible ways that EO impacts society at large. Agricultural monitoring for example, where farmers are able to use wide-area data products to check on crop health and maturation. This type of application has a direct impact on the quality and price of produce on the supermarket shelves. Safety is another important area; Meteosat satellites were used to track the ash plumes from the Icelandic volcano eruptions, so that airlines could make safe flight plans. If the UK is to develop its commercial activities in space and gain wholehearted support from the general public, it must ensure that any policies and strategic plans that are created include a comprehensive understanding of how society feels about the space industry and its future in the UK.

'Space for All' is a community funding scheme set up in 2014 by the Government, to provide small grants (up to a maximum of £5,000) to groups for use in developing space inspiration and learning programmes that support the work of ESERO-UK. The idea behind the scheme is part of the UK space strategy to increase awareness of the UK's space programme and the role it plays in everyday life. In addition, the UKSA, along with UKSpace and the National Space Centre must provide a fully funded programme for public dialogue. This will sit alongside the Space for All programme to ensure that society 'gets behind' the use of public funds to support the industry. Space technology & exploration must be framed in a way that makes it understandable and applicable to everyday life. Information must be presented in a creative way with well-conversant and clear messages. This can be achieved through a combination of traditional engagement methods with social media channels and improved engagement with the press.

Space technology and exploration must be framed in a way that makes it understandable and applicable to everyday life.

WHAT NEEDS TO BE DONE

If the UK space industry is to achieve its goal of a 10% global market and 100,000 increase in workforce share by 2030, then it needs to take advantage of its satellite heritage in upstream infrastructure and downstream service provision. It must be innovative in tapping new market opportunities, as well as disrupting existing ones. The UK must challenge strong international competition in large satellites and capitalise on the recent surge in small satellite development.

Education & skills

Greater profile-raising of the SpIN programme is needed across the UK space industry and beyond. The opportunity for funding competitions should be explored and the burden of placement year tuition fees must be reduced.

Investment

The UK, through agencies and trade bodies, needs to support SME continued growth by combining existing business models with new concepts and technologies to enable private investment to take place and business to remain in the UK.

The UK must continue to invest in innovation through existing programmes such as those provided by the UK Space Agency, CEOI, Innovate UK and European Space Agency, but greater levels of alignment between these organisations must be established to ensure more effective use of public funding.

Funding

Funding is currently spread too thinly across academic institutions. UKSA must ensure that opportunities continue to be open to UK research and access to ESA funding is made easier, particularly for EO technologies.

Work remains to be done to establish coordinated funding opportunities across the Research Councils (RC) EPSRC, NERC etc. ESA and UKSA must look to tackle the problem of access to funding for SMEs. Innovate UK and CEOI should develop additional satellite technology challenges at the TRL 3-6, to enable academic research to be sufficiently tested to attract private investment.

Regulation & the EU directive

The 30-year-old OSA must be revised to acknowledge the advancement of technology and the changing nature of space usage as well as simplifying the legal conventions for liability. Spectrum regulation that will not only support the existing incumbents but will also accommodate the smaller, short-term operators must be developed through Ofcom and trade bodies such as the UK Spectrum Policy Forum. The Government must assess the liability policies established in other countries and determine a possible solution to TPL and other licensing issues, based on more up-to-date knowledge of large and small-satellite markets.

A visionary approach to the way we exploit very high resolution EO data needs to be adopted. This can be achieved only through open access. The UKSA must ensure that they drive any future consultation processes on EO regulation.

Social awareness

If the UK is to develop its commercial activities in space and gain wholehearted support from the general public, it must ensure that any policies and strategic plans that are created, include a comprehensive understanding of how society feels about the space industry and its future in the UK. The UKSA, along with UKSpace and the National Space Centre must provide a funded programme for public dialogue with the UK general public if they are to ensure that society will 'get behind' the use of public funds to support the industry in the coming years.

RECOMMENDATIONS

The Institution of Mechanical Engineers recognises there is an immediate need to develop the UK satellite sector and create innovative business models which will support the growing small-satellite industry for the next 40 years. We therefore call upon:

UK Space Agency to:

- Fully revise the 30-year-old Outer Space Act to provide more flexible and simplified launch and operations licences for small-satellite operators. Additionally, support SMEs and TRL 3-6 satellite operators through a dedicated advisory team for small satellite license applicants.
- Align with other nations and end the third-party liability for small satellite operators.
- Continue to take a pro-active stance on future EU directives on EO data, by working with DEFRA to clearly define the UK position. Work to control access to data through the Export Controls Organisation and the Department for Business, Innovation & Skills, and amend the export licencing regulations to include dissemination of data.
- Develop a programme of public engagement and dialogue on satellite EO and data usage with emphasis on personal security and privacy. Provide more access to satellite imagery and data through web-based portals, social media channels and improved engagement with the press. An increase in funding and broadening the scope of the 'Space for All' community programme would support this initiative.

Satellite Applications Catapult to:

- Work with universities, industry and Innovate UK to enlarge the existing SpIN programme to include year-long funded placements for undergraduates, graduates, post-doctorates and professional engineers. The programme should look to increase its numbers to 1,000 a year over the next five years and to sustain this level until 2030.
- Continue its involvement in the Satellite Finance Network with an aim to increase the money available to SMEs from £20m to £70m over the next five years. Engage with the venture capital and other finance and investment companies outside the satellite sector to create a joint programme of competition funding with Innovate UK.

Ofcom to:

- Work with the UK Spectrum Policy Forum to address Spectrum licencing for all small satellite operators. Ofcom and industry must find mutually acceptable solutions to the limited spectrum bands and look to Licenced Shared Access (LSA) as a means of relieving the pressure on spectrum use.

Research Councils to:

- Work with HEFCE to create a long-term strategy to attract young people into the space sector. This could be achieved by incentivising universities to create more sandwich degree programmes in space-related subjects as well as providing space options on existing degree courses such as mechanical, electronic and IT degrees.
- Engage with the satellite industry to develop a focused strategy for space technology research; moving away from space being an enabler of other technologies, to being a funded stream in its own right.

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Terminology

- **Spatial resolution** – number of pixels utilised in construction of a digital image
- **Swath width** – the strip of Earth's surface from which geographic data is collected by a satellite

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