FINAL REPORT

The Case for Space 2015

The impact of space on the UK economy

CASE STUDIES

A study for the Satellite Applications Catapult, Innovate UK, UKspace and the UK Space Agency

LE London Economics

July 2015

About London Economics

London Economics (LE) is a leading independent economic consultancy, headquartered in London, with a dedicated team of professional economists specialised in the application of best practice economic and financial analysis to the space sector. As a firm, our reputation for independent analysis and client-driven, world-class and academically robust economic research has been built up over 25 years.

Drawing on our solid understanding of the economics of space, expertise in economic analysis and best practice industry knowledge, our space team has extensive experience of providing independent analysis and innovative solutions to advise clients in the public, private and third sectors on the economic fundamentals, commercial potential of existing, developing and speculative market opportunities to reduce uncertainty and guide decision-makers in this most challenging of operating environments.

All consultants of our space team are highly-qualified economists with extensive experience in applying a wide variety of analytical techniques to the space sector, including:

- Insightful and accurate market analysis and demand forecasting;
- Analysis of industrial structure, strategy and competitive forces;
- New technology adoption modelling;
- Estimation of public utility benefits;
- Opportunity prioritisation and targeting to maximise exploitation of investment;
- Sophisticated statistical analysis (econometrics, regression);
- Economic and financial modelling, including: Cost-Benefit Analysis (CBA), cost effectiveness analysis, Value for Money (VfM), impact assessment, policy evaluation, business case development, cash flow and sustainability modelling.

Head Office: Somerset House, New Wing, Strand, London WC2R 1LA, United Kingdom.
w: londoneconomics.co.uk/aerospace **e:** space@londoneconomics.co.uk
t: +44 (0)20 3701 7700 **:** @LE_Aerospace

Acknowledgements

We would like to acknowledge the useful guidance and feedback provided by the Satellite Applications Catapult, Innovate UK, UKspace and the UK Space Agency throughout this research. We would also like to thank all of the stakeholders consulted for their time and informative responses. Responsibility for the contents of this report remains with London Economics.

Authors

Greg Sadlier, Associate Director, +44 (0)20 3701 7707, gsadlier@londoneconomics.co.uk
Rasmus Flytkjær, Senior Economic Consultant, +44 (0)20 3701 7717, rflytkjaer@londoneconomics.co.uk
Maike Halterbeck, Economic Consultant, +44 (0)20 3701 7724, mhalterbeck@londoneconomics.co.uk
Viktoriya Peycheva, Economic Consultant, +44 (0)20 3701 7719, vpeycheva@londoneconomics.co.uk
Laura Koch, Economic Analyst, +44 (0)20 3701 7718, lkoch@londoneconomics.co.uk

Table of Contents

1 Case studies of R&D demonstrators

Box 1 TechDemoSat-1 – a collaborative satellite to demonstrate innovative UK space technologies for scientific and commercial applications

TechDemoSat-1 (TDS-1), produced by the UK's Surrey Satellite Technology Ltd (SSTL), is a compact, satellite test-bed for in-orbit technologies, and represents collaboration between industry and academia from across the UK.

TDS-1 was based on one of SSTL's existing satellite designs (the SSTL-150) and was contracted by InnovateUK and part-funded by SEEDA[1], which was involved at the early stage. SSTL claims to control a 40% share of the global small satellite export market and to have 21 satellites currently being manufactured.[2]

TechDemoSat-1 in orbit, artists' illustration

At a size of roughly 1 cubic metre, and a mass of 150 kg, TechDemoSat-1 had a total production cost of less than £10m.[3] TDS-1 was financed in part through a £3.0m funding injection by the Technology Strategy Board (now Innovate UK) and £0.5m from the South East England Development Agency (SEEDA), whilst SSTL provided additional investment of their own for research purposes. The satellite carries 8 external payloads, self-funded through the respective payload providers, an all-British collection of universities and commercial organisations which answered SSTL's invitation to participate in 2009.

Launched in July 2014 on a Russian Soyuz rocket (brokered by Commercial Space Technologies - CST), TDS-1 has been continuously returning payload data since having successfully passed its designated in-orbit Launch and Early Operations Phase (LEOP) and will continue to do so for the rest of its projected 3 year lifespan. Some of the results from payloads on board TDS-1 are now being announced[4], marking the first point at which each of these payloads start to deliver downstream benefits.

Many of the benefits can be directly derived from the performance of the satellite payloads, for example:

- The Highly Miniaturised Radiation Monitor (HMRM), built by Rutherford Appleton Laboratory, will be commercialised after being tested[5], and has been developed for future use on ESA missions.
- The De-Orbit Sail, by Cranfield University, attempts to provide proof-of-concept for a de-orbit system for small satellites.
- CubeSAT ACS, supplied by Satellite Services Ltd, attempts to improve on attitude determination and control subsystems for CubeSats.

Further, SSTL claim TDS-1 will "Inspire, Train and Retain", with these more intangible benefits coming in the form of scientific *inspiration* for schools across the UK, the *training* of students in academia and engineers in industry with data from TDS-1 payloads, and British engineers being *retained* to continue working on new developments.[6]

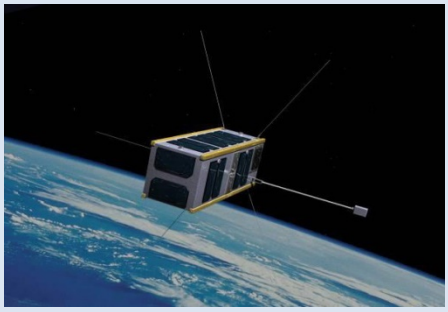
Finally, the very fact that this mission is a technology demonstrator opens up the possibility for further, follow-up projects, either demonstrating other technologies, or continuing the legacy that TDS-1 has started to create.

Source: London Economics based on secondary research and stakeholder consultations

[1] South East England Development Agency.
[2] "Changing the Economics of Space" SSTL, found here: http://www.sstl.co.uk/getdoc/79ada3f1-76c0-49f0-8f21-ade2c262677c
[3] "How they were funded" – SSTL presentation http://digitalcommons.usu.edu/smallsat/2013/all2013/4/
[4] The National Oceanography Centre hosted a one-day workshop in March 2015 to present the first results for ocean surface wind and waves monitoring with GNSS Reflectrometry on TechDemoSat-1. http://www.satnews.com/story.php?number=102772070
[5] HMRM Future Work, Slide 38, Presentation delivered May 2012 - https://indico.esa.int/indico/event/14/contribution/9/material/slides/0.pdf
[6] Slide 7, TechDemoSat-1 - https://www.stfc.ac.uk/RALSpace/resources/PDF/ASC_Presentation_13.pdf

Box 2 UKube-1, the UK Space Agency's first mission – a technology demonstration 'CubeSat' nanosatellite jointly funded by Clyde Space

UKube-1 was the first mission commissioned by the UK Space Agency after its formation in 2010, and is a CubeSat – a satellite comprising one or more 10x10x10 cm blocks (1U). UKube-1 has dimensions of 30x10x10 cm (3U) and will showcase new technologies for UK industry and academia. The mission was co-funded by InnovateUK.



UKube-1 in orbit, artists impression

Designed and built by Clyde Space of Scotland – themselves a CubeSat success story with over 40% of CubeSat missions using hardware developed by Clyde Space[7] – UKube-1 is envisaged to be the pioneer mission for the UK Space Agency's CubeSat programme. The aim for future missions is to establish a development and launch frequency of one CubeSat every 18 months, thus establishing a constant stream of CubeSat production and enabling British engineers to benefit from "hands-on, real-time training".[8]

UKube-1 was successfully launched in July 2014 on a Russian Soyuz rocket brokered by London-based Commercial Space Technologies (CST), and along with the engineering benefits mentioned above, it will increase capabilities for education and commercial activities, with payloads including[9,10]:

- TOPCAT – A University of Bath experiment that will use GPS signals to measure weather conditions in space.
- Janus – Airbus Defence and Space designed this experiment to test space-based random number generation for use in satellites.
- FUNcube-2 – This radio frequency transmitter will be used for students across the UK to receive data from UKube-1, enabling it to also act as an educational resource.

In developing UKube-1, Clyde Space have benefitted from treating it as an internal R&D project. Clyde Space improved their methods of integrating and testing their own products, assessing risk during the project, and simultaneously developing the payload and the platform at the same time[11], thus ensuring that UKube-1 has provided upstream improvements as well as the original downstream applications that were predicted.

Source: London Economics based on secondary research

[7] Clyde Space CubeSat Lab, http://www.clyde-space.com/cubesat_shop.
[8] UK Space Agency (2014) *Case study – UKube-1,* https://www.gov.uk/government/case-studies/ukube-1.
[9] UK Space Agency (9 July 2014) *Successful launch for UK Space Agency's first cubesat mission*, https://www.gov.uk/government/news/successful-launch-for-uk-space-agencys-first-cubesat-mission.
[10] Clyde Space (22 March 2011) *UK's first CubeSat mission starts to take shape* http://www.clyde-space.com/news/311_uk-s-first-cubesat-mission-starts-to-take-shape.
[11] Clyde Space *UKube-1*, http://www.clyde-space.com/ukube-1.

2 Case studies of end-user benefits

2.1 Introduction

This Section presents a range of the Case Studies that illustrate the wider effects (i.e. benefits[12]) of space-enabled technologies, services and applications for consumer, commercial and institutional end-users.

These Case Studies were researched using a mix of desk-based research of existing literature and information sources, supplemented by a short programme of qualitative research involving semi-structured interviews with selected key stakeholders.

These Case Studies provide a qualitative and quantitative evidence base that was used to inform Section 7 of the Full Report entitled 'End-user benefits'. As with the Section of the report, the Case Study presentation is structured using the *Space Action Growth Plan* market analysis (below).

Figure 1 *Space Action Growth Plan* high growth markets

Note: Priority markets identified in red.

Source: Space Innovation and Growth Strategy 2014-2030 – Space Action Growth Plan

[12] No negative externalities have been identified.

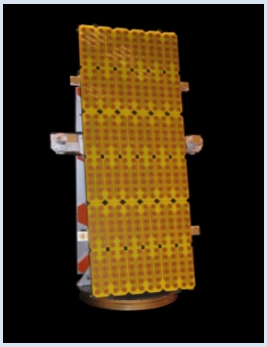
2.2 Security, safety & resilience

Box 3 NovaSAR, a demonstrator of Maritime Wide Area Search (MWAS) potential

NovaSAR is a constellation of four state-of-the-art Synthetic Aperture Radar (SAR) satellites which, once fully developed, will be able to operate in all weather conditions, day and night. Earth observation data provided by the NovaSAR satellites can be used to enhance the accuracy and capabilities of Maritime Wide Area Search (MWAS) applications.

The imaging frequency and the flexibility of their orbits allow the NovaSAR satellite to revisit the same Earth location, anywhere on the globe, as often as twice a week, observing in all weather conditions and at night. These instruments can therefore be used for regular monitoring of specific areas. This makes NovaSAR a preferred satellite data source in a number of Maritime Wide Area Search (MWAS) applications, including:

- maritime surveillance of drug trafficking;
- IUU fishing and piracy;
- oil spills management;
- deforestation detection;
- flood monitoring; and
- glacial melts.



Credit: Wikimedia Commons (Rama)

The NovaSAR system uses commercial off-the-shelf technologies, and its design builds on UK expertise in small satellites as well as SAR technology from ERS-1, ERS-2 and Envisat. The first NovaSAR demonstration satellite will be built by Surrey Satellite Technology Limited, a UK-based company, and is supported by Airbus Defence and Space UK.

Economic benefits from NovaSAR to the UK will result not only from jobs in the industry building the space infrastructure, but also from the creation of business opportunities across the wider economy. Once the satellite constellation is functioning, the Earth observation data it produces will be available to businesses which develop Earth observation services and applications, such as Maritime Wide Area Search application suppliers. An example of such applications is the Information Analysis Platform (AIP) for fishing vessels currently built by the Satellite Applications Catapult, which aims to detect fishing vessels practicing IUU fishing.

The Government has allocated £21 million to assist the development and launch of the first satellite of the constellation. It is expected that the success of the system will attract over £150 million of inward investment into the UK.[13]

Source: London Economics based on secondary research and https://www.gov.uk/government/case-studies/novasar

[13] UK Space Agency (2014) *Case study – NovaSAR*, https://www.gov.uk/government/case-studies/novasar.

Box 4 Maritime surveillance to develop a global monitoring system to combat Illegal, Unreported and Unregulated (IUU) Fishing

Credit: US Navy via Wikimedia Commons

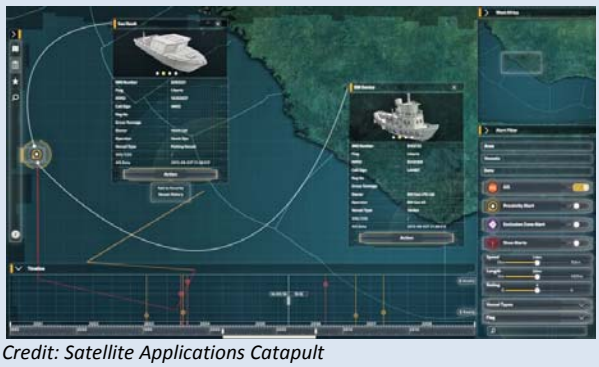
Wild-caught fish is the primary source of protein for 3 billion people around the world. In the UK alone, fish consumption by adults in 2012 was estimated at c. 416,000 tonnes and growing, which accounts for around 0.5% of world's fish consumption.

As 1 in 5 fish are taken illegally from the world's oceans, illegal, unreported and unregulated (IUU) fishing is a worldwide problem which depletes fish stocks and costs the global economy an estimated £15.2 billion every year. IUU has a wide range of negative implications:

- It is environmentally harmful and unsustainable;
- It is often accompanied by other illegal activities such as drug, weapon and human trafficking; and
- It is economically harmful to the legal and sustainable domestic fish markets.

DEFRA and the UK Fisheries Departments have already recognised the need for a fishing vessel tracking solution through their pilot Environmentally Responsible Fishing project. They would therefore directly benefit from a global, more effective and efficient system which provides fisheries departments worldwide with access to real-time, credible information, and prevents illegal fisheries from avoiding national legislation. The Satellite Applications Catapult has developed a prototype of the Information Analysis Platform (AIP), a tool which analyses the behaviour of fishing vessels. The application is envisaged to use freely available satellite data in combination with cross-country vessel datasets, to automate the fisheries surveillance process, detect IUU in real time and alert nearby authorities and regulators.

The Catapult and their partners who developed the application would be supplied national fisheries data, e.g. data provided to DEFRA through Applied Satellite Technologies, who manage the Vessel Monitoring System in the UK. The AIP can potentially utilise freely available satellite data from providers such as NovaSAR, Sentinel-1 and CubeSats, as well as from crowd-sourcing and unmanned vehicles. The application can be improved by Artificial Intelligence algorithms to identify even unregistered vessels, with higher speed and accuracy. The data which the AIP produces can then in turn be used by DEFRA, the Fisheries Departments and other authorities, to inform of any illegal fishing in UK waters.



Credit: Satellite Applications Catapult

IUU is a highly lucrative activity, as wholesale prices of one hold full of high-value species (such as skipjack tuna) soar above £0.7 million, far exceeding the risks faced by illegal fisheries. Since the rewards are high and the risk is low due to enforcement inefficiencies, IUU is widely practiced. For instance in 2007 alone, 500,000 tonnes of IUU fisheries products worth £800 million were imported in the EU.

Therefore, UK producers who practice legal, sustainable fishing would be more competitive if IUU fish imports in the UK were successfully eliminated, as fish prices would not be undermined. Moreover, UK fisheries would benefit from UK fish stocks not being depleted by illegal vessels. Additionally, data from the AIP would help assure UK consumers of the origin of fish they purchase. The global AIP would improve the environmental sustainability of fishing and aid the combat of accompanying illegal activities. Last but not least, the application can have spillover effects on technological companies and scientific research providers of data analysis, Artificial Intelligence and other analytical services.

Source: London Economics based on Satellite Applications Catapult' 'Ending Illegal Fishing' Case Study, secondary research and stakeholder consultations

Box 5 Galileo, a large scale European space infrastructure project promising significant benefits

The European Global Navigation Satellite System (GNSS), Galileo was set up to fulfil distinct policy goals namely:

1) eliminate or reduce reliance on foreign systems and augment Europe's strategic autonomy;
2) protect European infrastructures relying on GNSS by increasing redundancy; and
3) maximise socio-economic benefits for Europe by promoting commercialisation and/or monetisation of Europe's GNSS.

Credit: European Commission

UK companies have played a key role in the development and evolution of Galileo with SSTL building the first satellites and supplying payloads on the next order, Airbus Defence and Space designing and delivering the ground control segment and CGI developing the security systems. At the user equipment level, Cambridge Silicon Radio (CSR), Raymarine, and Nottingham Scientific Limited (NSL) are examples of UK players. In addition, US heavyweights Qualcomm, Broadcom, Garmin, and Trimble all have subsidiaries in the UK. Veripos also sells user equipment, but its primary activity is in the sale of value added services in the form of Differential GNSS signals. Inmarsat's satellites carry payload for Veripos and for the European Geostationary Navigation Overlay Service (EGNOS). Even further down the value chain application designers such as Hailo and Bounts provide location-enabled services for consumer end-users.

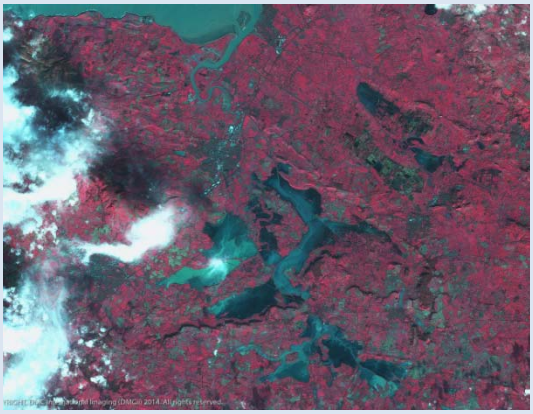
Based on the installed base presented in the European GNSS Agency's (GSA) *GNSS Market Report Issue 4* and assuming the UK's share of European devices is proportional to the UK's share of EU GDP, yields an estimated 93 million GNSS devices in the UK in 2015, consisting of primarily smartphones and road navigation devices.

Benefits from Galileo in addition to the benefits derived from US, Russian or Chinese GNSSs are difficult to measure, but some European allies may choose Galileo-compatible equipment to reduce reliance on other countries' military systems for political or commercial risk reasons. The European Commission have previously communicated benefits for the EU in the range of €60bn-€90bn over 15 years of Galileo service. Again assuming the UK's share of EU GDP accurately reflects benefits in the UK, this would imply UK benefits of between €9bn and €13bn over the first 15 years of Galileo service provision.

Source: London Economics based on secondary research and stakeholder consultations

Box 6 Flood disaster response informed by satellite imagery, including activations of the 'Space and Major Disasters' International Charter

In winter 2013/14, the UK was hit by a series of storms and heavy rainfall events that caused flooding across the country. On 05 and 06 December, Scotland, north Wales and the east coast of England experienced the most serious tidal surge in over 60 years. The Somerset levels became flooded in the middle of December 2013 and remained so until March 2014. In both January and February, a number of major rivers were flooding, among them the Thames, Severn, and Stour rivers. Overall, more than 8,342 households and 4,859 commercial properties were flooded, with a further 7,000 properties losing access to essential services or being cut off by flood water. The Environment Agency (EA), the UK Government agency responsible for issuing flood warnings and operating part of the nation's flood defence infrastructure, issued over 160,000 warnings to homes and businesses for the December floods and a further 200 flood alerts as of 06 January, and relied on satellite imagery to target recovery measures on flooded areas.



Flooding around Bridgwater, Somerset, UK (11 February 2014). *Credit: UK-DMC2 image @ DMCii 2014.*

Earth Observation is extremely useful for flood monitoring because it delivers timely mapping of areas affected by disasters and provides emergency response units with the opportunity to see the overall picture, which is usually difficult in disaster situations. Synthetic Aperture Radar (SAR) data is especially helpful because it can deliver images through cloud, which often occurs in flood risk areas.

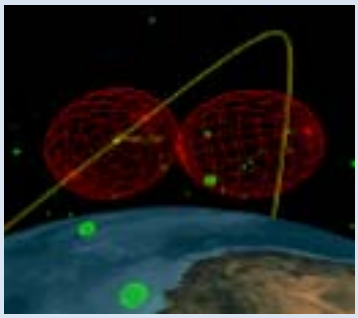
Access to satellite imagery is therefore critical for targeting disaster relief and cleanup operations and directing efforts on the ground to the areas most in need. While nationally owned assets can allow imaging requests of emergency response teams to be prioritised, the *International Charter on Space and Major Disaster* provides a unified system of space data delivery to national civil protection authorities in areas at risk. When the Charter is activated, the member space agencies around the world use their resources to supply satellite data with a range of resolutions and swath widths to those affected by natural or man-made disasters. The UK Space Agency is a key player within the international Charter and board representative of the UK Disaster Monitoring Constellation (UK-DMC), the UK space resource used for global disaster monitoring within the International Charter. DMC is a satellite constellation of low cost small satellites delivering daily 650km wide multispectral imagery with a resolution of 22 metres. DMC satellites are designed and manufactured by Surrey Satellite Technology Ltd (SSTL) and coordinated by its subsidiary, UK imaging company DMC International Imaging Ltd (DMCii).

The 2013/14 winter floods in the UK activated the International Charter three times, on 04 December 2013, 06 January 2014 and 06 February 2014. As a result, a dozen spacecraft acquired pictures of various locations in the UK at a range of resolutions and in a spread of wavelengths, among them UK-DMC, SPOT-5 (France), TerraSAR-X (Germany), Landsat-8 (United States) and RADARSAT-2 (Canada). The satellite data was used by the Environment Agency and Cobra, the UK government's emergency committee, for information on the extent of the flooding, creation of flood maps for future mitigation and damage calculations.

Source: London Economics based on secondary research (listed in 'References').

Box 7 Space Traffic Control, avoiding the space debris apocalypse

Given the increasing international reliance on space systems for communications, navigation, timing and surveillance; and the increasing threats to spacecraft in form of natural hazards and man-made threats, an international approach to Space Traffic Control (STC) will soon be necessary. An effective STC system could provide:



Credit: Airbus Defence and Space.

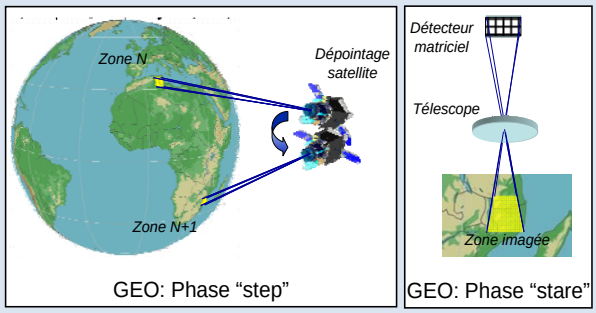
- Conjunction predictions/warnings for both active and inactive objects
- Forecasting and modelling of space weather, to allow for effective mitigation of adverse space weather effects
- Debris mitigation through targeting and tracking de-orbit operations
- Prediction of debris re-entry events
- Notification of fragmentation events
- Notification of station-keeping manoeuvres

In order to achieve the functions specified above, it will be necessary to enhance space tracking resolution, reliability and frequency as well as space weather monitoring and forecasting. On the one hand, this requires certain enhancements to both satellites and launch vehicles. For example, the deployment of sensors, laser reflectors, proximity warning systems or all-sky cameras on-board could provide real-time information on satellite/debris location and space weather thus helping overcome the limitations on earth-based tracking that are imposed by the day-night cycle and cloud cover. On the other hand, improvements to existing tracking technologies are also necessary. Using simultaneous observations from more than one optical site could increase the accuracy of satellite orbit determination. Inverse synthetic aperture radar (INSAR), a technique for imaging a satellite from the ground, can be used to provide additional information on both the mission and operational status of a satellite. A satellite's own downlink signals, can also be used to determine its orbit. and hence satellites might be required to comply with regulations requiring them to periodically communicate their positions to a global network of receivers. In extremes, 'no- orbit-zones' might have to be introduced, but this is the pessimistic future which STC seeks to avoid.

Source: Eves, S. (undated). 'Space Traffic Control: Avoiding the Space Debris Apocalypse', presentation (Airbus Defence and Space).

2.3 Game-changing services

Box 8 Geostationary Orbit Space Surveillance System, a continuous, always-on Earth Observation service



Credit: Airbus Defence and Space.

Geostationary Orbit Space Surveillance System (GO3S) is a project currently under development by Airbus Defence and Space, with the potential to revolutionise the satellite imaging market. As of today, most earth observation data is provided by satellites operating in Low Earth Orbit (LEO), at altitudes between 160km and 2,000km). While these satellites are able to provide precise imagery of any place on Earth, since they operate at lower altitudes, users have to wait for them to overfly both the point of interest and subsequently a reception antenna before images can be received. The GO3S project aspires to put an optical observation satellite into geostationary orbit (GEO), at around 36,000km. At this altitude, a single satellite could access a quarter of the globe, an area roughly the size of Asia or Africa, and instantaneously image a footprint of 100 x 100 km within that access region.

Credit: Airbus Defence and Space (then Astrium).

Imagery acquisition in GEO is different from that in LEO, requiring a matrix detector and operation in step and stare mode, with multiple optical sensors imaging the ground. The camera could be pointed within 2-5min, for virtually immediate video imaging at 1 frame per second of the target zone at a resolution of 2.5-3 metres in the system's baseline mode. The system could also provide up to 10 frames per second if the imagery is processed on-board and only changes are transmitted.

The real-time Earth Observation enabled by GO3S will open up unprecedented prospects in the fields of security and defence, disaster management and infrastructure, where rapid reaction and decision-making is required. For example, GO3S could provide real-time imagery of military operations and information about moving troops or approaching ships or aircraft, or track population movements in the aftermath of a humanitarian disaster.

Source: London Economics based on secondary research (listed in 'References').

Box 9 The UK leads the development of driverless car technology

The development of the driverless car and other automated vehicles is already a reality. This cutting-edge technology is expected to offer major benefits and to profoundly change people's day-to-day lives[14].

Credit: Transport Systems Catapult

A core feature of the driverless car is its capability to self-navigate to a given destination. This requires a reliable satellite navigation system which can communicate with the car's built-in computer. Connectivity with other vehicles, users and traffic control systems could develop the potential of the technology further. A smartphone app is already being developed in the Lutz Pathfinder pod[15], which would allow people to hail the pods when needed. In future when the technology has penetrated remote areas with unreliable mobile network connections, satellite internet networks, such as Inmarsat's 3G network and its M2M service, could be the obvious connectivity solution.

The rapid advances of this ground-breaking technology call for adequate policy response. With the ambition of the UK becoming a world-leading driverless automotive country and to boost high-skilled jobs, the UK government is reviewing legislation and launching trials in Milton Keynes, Greenwich, Bristol and Coventry.

Driverless cars have been forecasted to create a £900 billion industry by 2025[16] and directly benefit scientific research, developers, the automotive manufacturing sector as well as car users. Positive spill-over effects on both turnover and employment in other sectors as service and repair businesses will need to meet the higher skills demands of this new technology. Moreover, driverless car technology is expected not only to increase the comfort of current drivers, with cellular and/or satellite connectivity enabling vehicles to become infotainment hubs – a potential growth driver for satcoms growth – but also to include people who are otherwise unable to drive. Driverless vehicles would also create a positive externality by decreasing CO_2 emissions and traffic congestions, and improving road safety by minimising the risk of accidents.

Source: London Economics based on secondary research and stakeholder consultations

[14] Department for Transport (2015). 'The Pathway to Driverless Cars. Summary report and action plan'.
[15] Wakefield, J. (11 Feb 2015) 'Driverless car review launched by UK government', http://www.bbc.co.uk/news/technology-31364441.
[16] Topham, G. (11 Feb 2015) "Driverless cars set to roll out for trials on UK roads", *The Guardian*. Available at: http://www.theguardian.com/technology/2015/feb/11/driverless-cars-roll-out-trials-uk-roads

2.4 Climate and environmental services

Box 10 Investment and Insurance risk assessment using satellite data

Satellite imagery offers near-real time information about geographically referenced activities on earth, and, analysed and interpreted correctly, provides invaluable insights into what is happening around the globe. Whilst this sort of geospatial intelligence has been exploited by military units for many years, it often remains inaccessible to commercial users.

Credit: RS Metrics

Geospatial Insight, a Leicester-based business intelligence enterprise launched in 2012, seeks to address this need by converting geospatial intelligence into commercially relevant products to support business operations and investment strategies. The company partners with over 100 satellite and aerial imagery providers across the globe. Relationships with Kongsberg Satellite Services (KSAT), a Norwegian ground station operator for major global satellite owners, Blom and other partners ensure global reach and remove any resolution limitations. In addition, Geospatial Insight is the exclusive reseller in Europe for data on consumer traffic to retail and restaurant chains produced by the US proprietary data provider RS Metrics.

Through expert analysis and interpretation of satellite imagery and data, other geospatial information and government and client data, the company delivers timely and evidence-based intelligence to inform a variety of commercial decision-making processes, ranging from investment evaluations to the impact of catastrophic events on business continuity.

Geospatial Insight's services are used by a wide range of clients. For the financial services sector, the company provides assessments of revenue potential and investment risks from real-world observations of infrastructure, progress and output. A good example is the mining industry, where satellite imagery captures the extraction and processing infrastructure, transport access and tailings of a remote mine. Event impact assessments delivered during and immediately after catastrophic events, allow insurers to identify their liability arising from an event and to verify claims.

Other commercial users include retailers, who are provided with stock and customer traffic measurements for both their own and competitor's sales locations to better understand company performance and market share. In addition, Geospatial Insight offers asset monitoring and tracking services to clients who require precise information on the location of cargo assets or quantities of stored commodities.

Source: London Economics based on secondary research (listed in 'References').

Box 11 Agriculture benefits enhanced by space technology applications

With the global population expected to rise to 9.6 billion by 2050, managing the increasing demand for food in an environmentally sustainable and cost-effective manner is critical. Agriculture science and technology (agri-tech) provides important solutions to this issue. Agri-tech driven by a range of satellite-enabled services that assist in geo-positioning and generating geo-reference information (also known as precision farming) is one of the world's fastest growing industries. The global precision farming market is growing at an estimated 13% per annum, and is expected to be worth US$3.7 billion by 2018, with North America as the market leader.


Credit: John Deere

UK companies like SOYL Precision Farming, Frontier Agriculture, SoilEssentials, etc. are just some examples of successful suppliers of precision farming tools and equipment.

There are four main types of agri-tech applications – yield monitors, variable-rate technology (VRT), guidance systems, and GNSS maps – and all of them rely heavily on space technology to maximise benefits.

GNSS is used in guidance systems to carry out accurate ploughing, fertilising and harvesting. This saves input costs in terms of labour and chemicals. Auto-steer systems rely on GNSS and reduce human fatigue and error, while improving the working conditions and safety of farmers. VRT allows farmers to optimise the use of herbicides, pesticides, nutrients, water, and land, to not only save costs but also improve yield and quality. VRT can be map-based (GNSS) or sensor-based (EO or remote sensing). In the UK, auto-steering or guidance and soil mapping are used by 22% and 20% of farms, respectively and VRT is used by 16% of farms. The top three reasons cited for using precision farming are improved accuracy (76%), reduced input costs (63%) and improved soil conditions (48%).[17]

Controlled Traffic Farming (CTF), confining machinery loads to the least possible area in permanent 'traffic lanes', is the most successful example of precision farming on arable land and is able to reduce machinery and input costs up to 75% in some cases.[18] In the UK, GNSS guidance systems offer net economic benefits of at least £2/ha on a 500ha farm, and the net benefit from the whole system of GNSS guidance and variable-rate fertiliser application is around £19/ha for a 750ha farm.[19] Variable-rate application of Nitrogen fertilisers resulted in a yield benefit of around £5,000 per year and quality benefit of £5,000 per year for a 440ha farm.[20] For a 300ha farm, yield monitoring and variable-rate application of fertilisers resulted in financial benefits of around £6,000 per year.[21] Input costs can also be reduced as less fertiliser needs to be applied, with net savings of £14.22/ha.[22] On another UK farm, auto-steer improved accuracy and saved time and cultivation passes, resulting in benefits of around £15/ha per year[23] or about 2-5% additional savings on farmers' chemical costs.[24] In addition to these economic benefits to farm businesses, precision farming can also generate positive environmental benefits. Variable-rate fertiliser application can reduce excess chemicals from entering rivers. Catchment Sensitive Farming (CSF) is an ongoing project run by Natural England in partnership with the Environment Agency and DEFRA that reduces pollution of rivers from agricultural sources. A number of farms in catchment areas under this project have adopted precision farming techniques to reduce chemical run-off into waterways. As an example, variable-rate application at a farm in the River Eye catchment shows reducing levels of phosphate in the river.[25]

On the whole, the vast array of direct monetary and indirect environmental benefits from precision farming is a testament to how agricultural benefits have been enhanced by space technology applications.

Source: London Economics based on secondary research (listed in 'References')

[17] Department for Environment Food and Rural Affairs (DEFRA), (2013), *Farm Practices Survey Autumn 2012 – England*. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/181719%20/defra-stats-foodfarm-environ-fps-statsrelease-autumn2012edition-130328.pdf

[18] Joint Research Centre (JRC) of the European Commission (2014), *'Precision Agriculture: An Opportunity for EU Farmers - Potential Support with the CAP 2014-2020'*. Available at: http://www.europarl.europa.eu/RegData/etudes/note/join/2014/529049/IPOL-AGRI_NT%282014%29529049_EN.pdf

[19] Knight, S.; Miller, P.; Orson, J., (2009) "An up-to-date cost/benefit analysis of precision farming techniques to guide growers of cereals and oilseeds". *HGCA Research Review* 2009 No. 71, pp. 115. Available at: http://www.hgca.com/publications/2009/may/20/an-up-to-date-costbenefit-analysis-of-precision-farming-techniques-to-guide-growers-of-cereals-and-oilseeds.aspx

[20] HGCA (2009a), 'Case study 9: Precision Farming Solution: N-Sensor to Vary Nitrogen Rate'. Available at: http://www.hgca.com/media/183400/pf_cs9-be_precise_case_study_9_-_james_price.pdf

[21] HGCA (2009b), 'Case study 4: Precision Farming Solution: Yield mapping'. Available at: http://www.hgca.com/media/183365/pf_cs4-be_precise_case_study_4_-_j_and_t_clark.pdf

[22] HGCA (2009c), 'Case study 2: Precision Farming Solution: Variable Rate Application'. Available at: http://www.hgca.com/media/183359/pf_cs2-be_precise_case_study_2_-_tony_reynolds.pdf

[23] HGCA (2009d), 'Case study 5: Precision Farming Solution: Autosteer'. Available at: http://www.hgca.com/media/183368/pf_cs5-be_precise_case_study_5_-_w_bradshaw_and_son.pdf

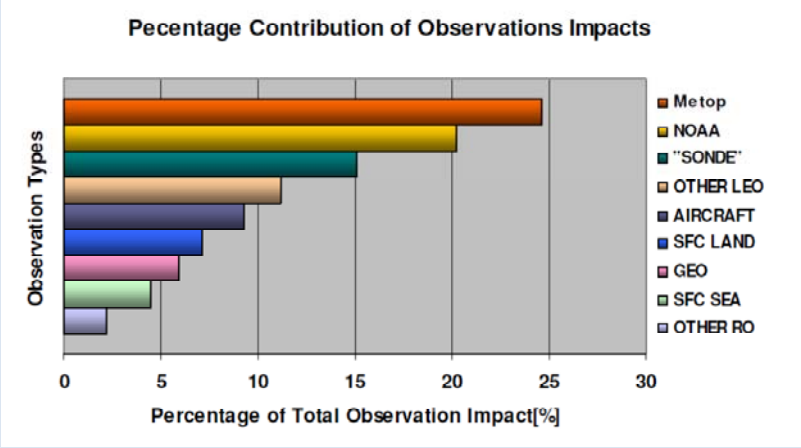
[24] Allen-Stevens, Tom (2011), 'Reaping benefits of auto guidance'. Farmers Weekly (14 March 2011), Available at: http://www.fwi.co.uk/machinery/reaping-benefits-of-auto-guidance.htm

[25] HGCA (undated). 'Environmental Benefits from Precision Farming'. Available at: http://archive.hgca.com/publications/documents/events/Environmental_Drivers.pdf

Box 12 The importance of earth observations for weather forecasting

Satellites generate substantial value to the UK economy through their application in weather forecasting. The Met Office, the UK's National Weather Service, considers satellites to be an integral part of their current forecast provision that directly impacts on the quality of the forecasts they produce. The Met Office is recognised internationally as delivering world-class weather and climate research, and recent work undertaken by London Economics suggests that the direct benefits of the Met Office's weather services alone exceed £2.5bn per year. With an estimated 32% contribution of satellite data to the overall value of weather forecasts, this yields an annual wider benefit of space infrastructure of £858m per year.

A Met Office analysis of observation impacts on forecast accuracy showed that satellite data account for 64% of short-range global forecast error reduction (out of all observations). In a cost-benefit analysis of EUMETSAT's current EPS/Metop programme, it was further assumed that observations and numerical weather prediction models each contribute around 50% to the accuracy of forecasts, thus suggesting that satellite data accounts for 32% of the value of Met Office weather forecast information. Combining this satellite attribution with the overall value of the Met Office weather services of £2.5bn, we obtained the above estimate of £858m, consistent with the estimate of £400-£1000m provided in *The Case for Space 2009*.



Source: Joo et al. (2012).

The current Metop satellite had no UK involvement, but Airbus Defence and Space UK have been selected to contribute microwave sounder instruments for the second generation.

Weather forecasts yield benefits for a variety of private, governmental, commercial and scientific users. They enable individuals to plan private activities and governments and emergency responders to better prepare for and react to severe weather events. UK academia and scientists around the world benefit from the Met Office's science outputs. In addition**, about one third of European GDP is considered to be weather dependent**, with value-add of the aviation, land transport, retail (see the Case Study that follows), agriculture and construction industries being particularly weather-sensitive. Two of the many end-users of weather-forecast products, government agencies/emergency respondents and the retail industry, are discussed in separate Case Studies.

Source: London Economics based on secondary research (listed in 'References')

Box 13 DemandMet – a tailored forecasting tool for retailers, using Met Office forecasts, to better predict consumer demand

The previous Case Study discusses the benefits of Earth Observation applications in weather forecasting from an upstream perspective. The focus of this case study is on the **downstream** part of the value chain of satellite imagery-enhanced weather forecasting, using the retail industry as a specific example of an end-user of weather forecast products.

Retailers use weather forecasts in conjunction with customer demand forecasting and stock planning. Surveys show that weather has a huge impact on end-consumer demand, affecting both what consumers buy and their propensity to buy. The adjoined figure shows a few examples.

Source: Met Office Barometer Online (26 August 2014).

DemandMet™, a tailored forecasting tool for retailers developed by the Met Office, helps UK retailers such as Sainsbury's predict end-consumer demand created and affected by weather conditions. The product range includes 14 day regional forecasts, national forecasts, executive summaries, forecaster advice and weather warnings and alerts. The application describes the weather in context instead of providing mere temperature forecasts, accounting for the fact that warm temperature impacts differently on consumer demand on sunny days compared to rainy days, or weekends compared to weekdays.

By including DemandMet predictions in their ordering system and targeting product availability accordingly, retailers can increase sales, reduce waste and capital tied up in stock, and improve use of storage. In addition, the severe weather warnings provided as part of DemandMet help predict reductions in the overall number of shopping trips during bad weather days, and ensure business continuity and availability of supply prior to severe weather events that might lead to panic shopping.

The benefits to retailers of incorporating weather forecasts into business decision making are substantial. Sainsbury's quoted that the Met Office helped it record its 'best-ever week of seasonal barbecue sales, with a '600% increase year-on-year'. The Met Office estimated that by increasing retailers' product availability from currently 92-95% to 100%, the retail industry would grow by £1.1bn a year.

An externality of retailer's use of DemandMet, and to a lesser extent of weather forecasts in general, is a reduction in food waste. In the UK, around £4.2bn of food is wasted every year, entailing severe environmental consequences. It is estimated that food waste is associated with 4% of the UK's total water footprint. With accurate demand forecasting, retailers can not only avoid the direct costs of wasting food but also improve resource efficiency and reduce the carbon and wider environmental impact of the grocery sector.

Source: London Economics based on secondary research of Met Office sources (listed in 'References')

2.5 More efficient public sector services

Box 14 Geo-tagged Plain Line Pattern Recognition (PLPR) maintenance scanning to reduce rail infrastructure costs

The UK's railway operator Network Rail might not be considered an obvious user of space technology – and GNSS (satellite positioning) in particular, but its 17,000 employees in the Route element of the Asset Management function derive productivity benefits from the use of GNSS. Network Rail's budget for track management in 2014/15 is £384.2m.

Credit: Network Rail

Network Rail uses a geo-tagged Plain Line Pattern Recognition system to improve efficiency of track maintenance operations. Four train rigs with seven HD cameras cover 80% of the network over a two-week period (at speeds up to 125mph) and take up to 70,000 HD pictures of the track per second, 3D and thermal images are also created. Advanced computer algorithms identify images showing sections of track that could be cause for current or future concern. The output of the computer algorithm is sent to track workers with GNSS-derived coordinates of problem areas to allow targeted work. The traditional approach had crew walking along the network in order to identify problems and record findings in notebooks before uploading findings to internal systems for crew to access.

A key supplier to PLPR is York-based Omnicom Engineering whose OmniVision system won the Institute of Engineering and Technology Innovation Award for asset management in 2013. The optical equipment and computer algorithm play key roles, but the system would not work without OmniRTPS, which uses GNSS and inertial measurements systems to geo-tag the images taken by the cameras. Geo-tagged images are crucial for dispatch of crew to the correct location, and add the ability to accurately monitor track decay over time and thus remedy issues before they become problems.

With the railway operating close to capacity, passenger services increased by 400,000 trains per year over the last 5 years, and 4 million train passengers per day, timely resolution of track issues is crucial for the operation of the UK's railway. The train operating companies all rely on Network Rail to be able to provide the service passengers demand and pay for.

The benefits of geo-tagged PLPR affect multiple groups:

- Network Rail reduces costs associated with traditional systems and its employees are relieved of many trackside duties, which reduces the risk of accidents. Network Rail's ambition is to reduce the number of trackside workers by 80%.
- Train operating companies that rely on Network Rail to maintain the track benefit through reduced reputational damage from cancellations and delayed services. The Office for Rail Regulation imposes fines on Network Rail when it has been found to be responsible for delays, but passengers may not fully understand the dynamic of the sector and instead blame the train operator. Punctual, running trains are also likely to increase passenger demand compared with a poorer service.
- With 1.5 billion passengers every year, any avoided delay carries a huge social benefit. Assuming for example that PLPR can save each passenger a minute on average (i.e. including savings from avoided cancellations), average hourly wage of £12 and value of leisure time relative to working time of 1:3, we derive aggregate benefits to passengers of £100 million.
- Benefits not only accrue to users of railways as improved performance of the system is likely to increase demand for passenger transport and thus reduce travelling in private cars. Other road users benefit from reduced congestion while the environmental impact of fewer passenger car journeys could be substantial as emissions per passenger km travelled is about 3 times higher for private cars than trains.

Source: London Economics based on secondary research of Network Rail (2013) A better railway for a better Britain

Box 15 Role of space in air traffic management

Air traffic management relies on satellite services to operate efficiently and effectively. Satellite communications, for example play a key role in air traffic management as a backup voice communication platform when the aircraft is out of VHF radio range thus enabling continuous communication between aircraft and ground. Inmarsat is a leading provider of communication infrastructure for aircraft.[26]

In addition, both general types of aviation, instrument flight rules (IFR) and general flight rules (VFR) use satellite navigation. IFR requires avionics equipment to be certified and the pilot relies on instruments to fly and land the aircraft. VFR requires the pilot to be able to use visual clues to operate the aircraft, but GNSS navigation is used to assist the pilot's planning and help plot the best course. The European GNSS Agency estimates 90% GNSS penetration worldwide in 2015 across both types of devices.[27]

Credit: Ken Ashton/NATS and Eurisy

The European Geostationary Navigation Overlay Service (EGNOS), which provides an additional layer of functionality of GNSS by improving accuracy and adding an integrity signal, was originally devised for aviation use. Compared with traditional GPS-based approached, EGNOS adds an important vertical element, which enables the pilot to position the aircraft more accurately and therefore improved efficiency in the landing.

In 2011, Alderney Airport became the first airfield in Europe to use EGNOS to support landing of scheduled passenger services. Alderney Airport has no costly infrastructure for traditional instrument approaches, meaning passenger flights were only able to operate under VFR. This implied that the service would be suspended in the case of fog or heavy rain. With the EGNOS landing procedure in place, aircraft can now serve the island in adverse weather conditions.

UK companies have played and continue to play a key role in the construction and operation of EGNOS. CGI, Airbus Defence and Space UK, and Serco were all involved in the ground system and Inmarsat currently hosts EGNOS transponders on its satellites. Garmin (whose European headquarters are in Southampton) is the leading provider of VFR devices and a key player in IFR. NATS lead the consortium that implemented and certified the EGNOS landing procedure, funded by the European Union and Eurocontrol.

Alderney's 2,000 inhabitants benefit from EGNOS-enabled landing procedures as the island relies on air transport for routine supply of goods and for evacuations in case of medical emergencies, which now occurs at night time about once a month. The airline serving the island, Aurigny, benefit from the ability to serve more of the flights it sells compared with a situation without EGNOS. Alderney Airport benefits from space services by avoiding investment in costly infrastructure to solve the same problems as EGNOS now does. Finally, pilots and passengers benefit from improved situational awareness on the part of the pilot and reduced risk of Controlled-Flight Into Terrain (CFIT).

In addition to passenger flights to Alderney, EGNOS procedures and certification of the general aviation segment could vastly improve the operations of general and business aircraft and pilots flying under VFR.

Source: London Economics based on secondary research and stakeholder consultations

[26] Nisner, P. (2014) *The role of space in air traffic management*, http://nats.aero/blog/2014/08/role-space-air-traffic-management/.
[27] European GNSS Agency, GSA (2015) *GNSS Market Report Issue 4*, http://www.gsa.europa.eu/system/files/reports/GNSS-Market-Report-2015-issue4_0.pdf.

Box 16 ICAO's commitment to urgent implementation of live flight tracking

Credit: ESA-P. Carril

The disappearance of Malaysia Airlines MH370 in March 2014 led the International Civil Aviation Organization (ICAO) to recommend adoption of a new 15-minute aircraft tracking.

London-based satellite communications giant, Inmarsat, has already offered its support and expertise for the design of the tracking system. Inmarsat already provides the tracking infrastructure for sea-going vessels and would be able to extend the same technology to aircraft. The avionics of 90% of transatlantic aircraft already support Automatic Dependent Surveillance – Contract (ADS-C),[28] which transmits the aircraft's current position and the next two planned positions, allowing air traffic control to track the aircraft's progress. The lateral position of the aircraft is obtained using GNSS, but the vertical position can only be obtained through barometers as overlay services such as EGNOS would be needed to achieve the necessary precision of satellite-based sources.

ADS-B (Automatic Dependent Surveillance – Broadcast) is a related service, which is key to achieving the Single European Sky. Once fully implemented, the system will enable air traffic control and aircraft in the sky to identify all planes in the vicinity and manage the Europe's crowded airspace more efficiently. The system relies on all aircraft broadcasting their position (based on GNSS and instruments) and with improved accuracy of the vertical and lateral position (thanks to EGNOS) it is possible to utilise the airspace better.

Both systems would have reduced the search cost associated (expected to ultimately cost hundreds of millions of dollars)[29] with the disappearance of MH370 as ADS-C would ensure that air traffic control knew the position of the airliner fifteen minutes before the crash (at most) while ADS-B would be an improvement if the aircraft flew near any other plane on its final flight.

Source: London Economics based on secondary research

[28] Inmarsat (6 Feb 2015) *Inmarsat supports ICAO's commitment to urgent implementation of live flight tracking* – Press Release,

[29] Wardell, J. (8 Apr 2014) "Search for MH370 to be most expensive in aviation history", *Reuters*, http://www.reuters.com/article/2014/04/08/us-malaysia-airlines-costs-idUSBREA3709520140408.

Box 17 Smart city planning and local authorities

Cities Unlocked[30] is a project designed to ease the most vulnerable citizens in their movement through cities. So far, the project has developed a prototype device which provides visually impaired people with a 3D soundscape to enrich their information of their surrounding environment. The device has the potential to change the day-to-day lives of the hundreds of thousands of visually impaired people living in the UK.

The device uses information fed by beacons scattered around the city. When the beacons network is sufficiently large, the application is planned to openly provide information via Bluetooth and Wi-Fi, which would make the extra information accessible by all vulnerable citizens via their smartphone. Satellite positioning improves the accuracy of positioning, and adds a vertical aspect that could be difficult to cover through terrestrial beacons alone.

Credit: Wikimedia Commons

The project is being developed by the Future Cities Catapult in partnership with Microsoft, Guide Dogs and The Bartlett Centre for Advanced Spatial Analysis at UCL. They are also working to engage large public and private organisations, such as Barclays, Tesco, Network Rail and First Great Western, to expand the networks of beacons.

The research group has conducted real-world trials on journeys between Reading and London, which have shown that visually impaired users feel more confident in their urban surroundings. If the network of beacons spreads sufficiently, it can help the over 2 million people who live with sight loss in the UK feel comfortable in urban surroundings, too. Of those, over 200,000 are particularly vulnerable as they live with severe sight loss or blindness[31], and the number of people living with a sight threatening eye condition has been predicted to increase over the next decade.

A fully networked application with open information access has the potential to improve the lives not only of visually impaired people, but also those of all citizens who feel vulnerable in cities. Additionally, the information on people's behaviours in urban surroundings can help decrease public costs of local government management and can create spill-over opportunities for scientific research based on the data available, and for innovative businesses to provide further efficiency-improving applications.

Source: London Economics based on the 'Cities Unlocked' (2014) report, secondary research and stakeholder consultations

[30] https://futurecities.catapult.org.uk/project-full-view/-/asset_publisher/oDS9tiXrD0wi/content/project-cities-unlocked/
[31] UK Vision Strategy (2014). 'Eye health data summary'. [Last accessed: 20/02/2015]. Available online at http://www.rnib.org.uk/sites/default/files/Eye_health_data_summary_report_2014.pdf

2.6 e-connectivity

Box 18 Live broadcast TV to subscribers

Satellite Television (Europe's first satellite channel) was launched in 1982 following OFCOM's authorisation the previous year. British Sky Broadcasting (BSKYB) was the result of a merger in 1990* and in 1991 started broadcasting encrypted live sports events via satellite.

BSKYB is the largest provider of Direct to Home TV, but in 2008 Freesat, a joint-venture between BBC and ITV, was set up to challenge BSKYB's dominance of satellite-based broadcasting. In 2014, BSKYB had 11.5 million customers turning over £6.3 billion[32] from retail subscribers and employing 25,000 employees,[33] whereas Freesat had 2.1 million subscribers.[34]

Credit: David Sillitoe/Guardian

UK companies play key roles throughout the value chain of satellite broadcasting with satellites and subsystems manufactured by Airbus Defence and Space, Qioptiq and Com Dev, ground systems and components manufactured by iSat, CGI and iDirect UK, ground systems operated by Arqiva and SIS Live. SES and Intelsat (both with UK subsidiaries in London) operate satellites and lease capacity to broadcasters while SIS Live operate a large fleet of outside broadcasting vehicles for live transmissions. Triax UK produce satellite dishes for people's homes, Invacom make LNBs converting signals from space data that Pace Microsystem's set top boxes finally convert to TV images and sound.

At the user level, broadcasting to subscribers is used by pub landlords to generate business. As a Sky subscription for a pub costs about £15,000 per year, the benefit to pub landlords is likely to be greater. In addition multiple other venues where access to news or sports is desired use subscription-based services (e.g. private members clubs, offices, retail and commercial premises).

Consumer end-users of satellite broadcasting benefit from a service that can be provided all over the country with no geographical restrictions or requirements on population density for the service to be provided. Consumers in towns and cities choose BSKYB as their provider to gain access to specific sports or movies packages that are difficult to access on other platforms.

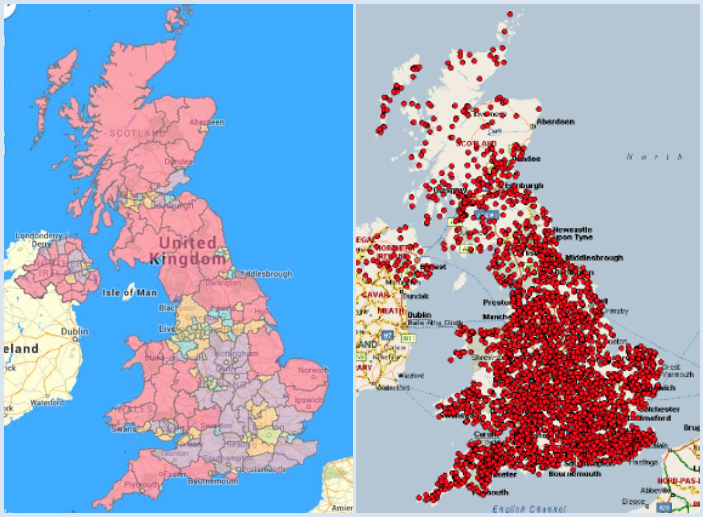
An additional effect of satellite broadcasting and BSKYB in particular is the increased value of contracts for screening the Premier League football matches. With the latest contract amounting to £5.1 billion, the Premier League football clubs have access to unprecedented broadcasting funds enabling them competitive in the market for star players and therefore able to compete with Europe's best improving the mood of (at least some) supporters.

Note: *: Satellite Television was one of the merging parties.
Source: London Economics based on secondary research and OFCOM and SKY websites.

[32] London Economics analysis of British Sky Broadcasting Group plc (2014) Annual Report 2014, https://corporate.sky.com/documents/annual-report-2014/annual-report-2014.pdf
[33] British Sky Broadcasting Group plc (2014) Annual Report 2014, https://corporate.sky.com/documents/annual-report-2014/annual-report-2014.pdf
[34] Ofcom / BARB Establishment survey (2014) http://stakeholders.ofcom.org.uk/binaries/research/cmr/cmr14/UK_2.pdf

Box 19 Fixed satellite broadband connectivity – Through femtocell and satellite backhaul solutions, Northern Ireland gets high speed connections for its rural dwellers

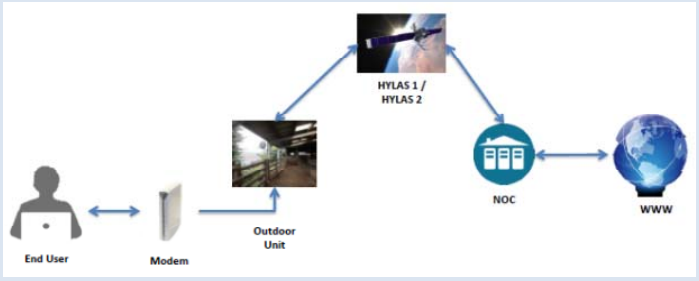
Rural areas with low population density and a rugged countryside are often not considered to be a commercially viable target by terrestrial network operators. The coverage of Fibre and ADSL networks is therefore often limited to urban regions, with broadband in remote locations unavailable or lacking reliability. In such cases, satellite broadband can offer a valid alternative, allowing for rapid deployment of communications services to any location within the satellite fleet's footprint.



Left: The percentage of geographic area over which all operators have 3G coverage. Green: 90-100&; Blue: 70%-89.9%; Orange: 50% - 69.9%; Purple: 25% - 49.9%; Red: less than 25%. *Credit: 2015 GeoBasis-DE/BKG (Ofcom website)*; **Right:** Avonline broadband Ka satellite coverage. *Credit: Avonline Broadband.*

There are currently three Ka satellite operators offering their services in the UK, Avanti Communications (UK), Eutelsat (France) and SES Astra (Luxembourg). Satellite broadband is able to provide up to 22 Mbps download and 6Mbps upload speeds everywhere in the UK, with end users not experiencing any difference between terrestrial/mobile broadband and satellite broadband.[35]

The three satellite operators provide wholesale capacity to intermediary telecoms service providers, helping them to extend their networks beyond the physical boundaries of traditional ground infrastructure. Avonline Broadband, the largest satellite broadband distributor in the UK, so far connected 11,000 UK customers to Ka services. End-users include customers in rural area 'not-spots' as well as consumers in high-usage areas who can benefit from quality and speed improvements through satellite backhaul. In addition, Ka satellite operators sometimes provide satellite connectivity directly to private, commercial or public end-consumers. Under a scheme of the *Northern Ireland Broadband Fund*, created in 2008, Avanti proposed and later implemented solutions for Ballintoy and Ballinamallard, two communities in Northern Ireland without internet coverage. In particular, Avanti provided rural businesses in these areas with reliable broadband coverage through satellite backhaul and small cell solutions. For example, Avanti provided a hotel in Ballintoy with larger femtocell alongside a base station, allowing the hotel to start ordering goods via the internet for the first time, and take reliable email bookings.



Credit: Avanti Communications Group Plc.

Source: London Economics based on secondary research (listed in 'References')

[35] Wynn, M. (2015) 'Ka Satellite Broadband'. Available at: https://sa.catapult.org.uk/documents/10625/0/Mark+Wynn+-+Avonline.pdf/8ef587fe-30ef-46ef-b2bd-e840631129f6

Box 20 Connecting isolated commercial merchant/fleet users and leisure consumers

Credit: Inmarsat

The United Nation's Conference on Trade and Development estimates that 1,233 vessels in the world's merchant fleet were owned by UK companies as of the 1st of January 2014.[36] The shipping industry is an important user group of satellite communications with Inmarsat reporting that 57% of mobile satellite service revenue came from maritime users in 2013.

Satellites enable communication between the captain of a ship and the ship owner or operator and in the event of emergencies (technical or medical), specialists are able to guide the crew or take over IT systems to ensure fast resolution and reduced time in port.

The ability to report on any change in the estimated time of arrival to the next port makes it possible for head office to negotiate a different docking time thus reducing down time. Maritime broadband also improves the flexibility of the operation by enabling ship operators to divert vessels and use ports that were not planned when the journey started and access to the internet means up-to-date weather forecasts are available around the clock, enabling the captain to change course and avoid adverse weather conditions. Finally, allowing the crew to use satellite telephones or accessing their email makes the crew able to maintain contact with friends and family at home and bolsters morale on-board.

In addition to merchant shipping, the UK's more than 300,000 sailboats and inboard motor boats are a potential user group for maritime broadband. As for merchant vessels, access to accurate weather data and keeping in touch with friends and family are key selling points to the boating population.[37]

UK companies play a very large role in the satellite communications value chain. Satellites and payload are manufactured by Airbus Defence and Space UK, Com Dev, Qioptiq and Printech Circuit Laboratories. The ground segment and components are manufactured by iSat, CGI, Hughes Network Systems. Ground systems and satellites are operated by Inmarsat and Harris CapRock. User equipment is manufactured by Cobham, Raymarine, KVH Industries and Inmarsat, who also retail the service to commercial and leisure users.

Improving the efficiency of merchant shipping naturally benefits the ship owner and operators, but reducing the time at ports and giving accurate ETAs to port operators enables a higher throughput using the same facilities thus reducing the need for extensions. In terms of monetised value, the lower bound on the worldwide utility benefit to ship operators is 57% of Inmarsat's MSS revenues, about $216 million.[38] As the UK owns 3.2% of the world's fleet,[39] a lower bound estimate of the benefit to UK owners and operators of fleet broadband is $7 million. Additional benefits derived by port operators and through crew satisfaction and leisure maritime are not possible to quantify.

Improving the efficiency of shipping could ensure that more products are shipped (i.e. containers that cannot be shipped profitably without satellite communications, being shipped anyway). The reduced costs of shipping could also be passed on to consumers.

Finally, responsible for 4% of the EU total greenhouse gas emissions,[40] any efficiency gains that can be made to the shipping industry will have a lasting effect on the environment.

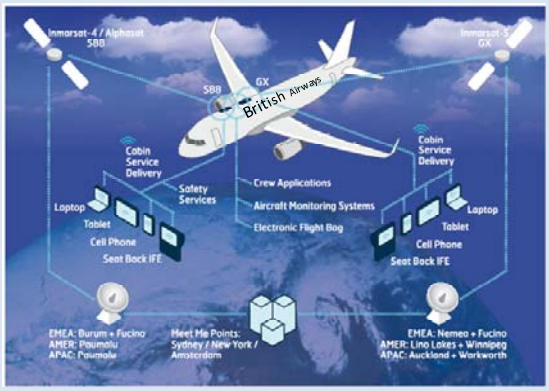
Source: London Economics based on secondary research and stakeholder consultations

[36] United Nations Conference on Trade and Development (2014) Review of Maritime Transport 2014, available at: http://unctad.org/en/PublicationsLibrary/rmt2014_en.pdf
[37] International Council of Marine Industry Associations (ICOMIA) (2014) Recreational Boating Industry Statistics 2013, available at: http://www.icomia.com/library/Default.aspx?LibraryDocumentId=1582
[38] Inmarsat Group Limited (2014) Annual Financial Information Disclosure for the year ended 31 December 2013, available at: http://www.inmarsat.com/wp-content/uploads/2014/04/2013-Inmarsat-Group-Limited-Bank-Reporting-document-FINAL.pdf
[39] United Nations Conference on Trade and Development (2014) Review of Maritime Transport 2014, available at: http://unctad.org/en/PublicationsLibrary/rmt2014_en.pdf
[40] Please see:http://ec.europa.eu/clima/policies/transport/shipping/index_en.htm [accessed 19th June 2015]

Box 21 British Airways in talks to offer the first pan-European high-speed air-to-ground Internet service

British Airways is the flagship airline of the UK. It carries 40 million passengers each year on its fleet of more than 280 passenger aircraft. The company employs 40,000 staff of which 15,000 are cabin crew and 3,600 are pilots. In 2013 the company turned over £11.4 billion.[41]

As an additional service offering to its passengers, British Airways announced in June 2014 that they have joined forces with London-based leading satellite communications company, Inmarsat, to offer high-speed broadband to passengers and thus becoming the launch customer of Inmarsat's GX Aviation service.



Credit: Inmarsat

The three satellites in the Global eXpress (GX) constellation use 89 fixed narrow spot beams and 6 flexible beams that can be focused on areas of high demand. The constellation operates in the high-throughput Ka-band. The third satellite is due for launch in 2015 and the service is expected to commence in the autumn of 2015.

Aircraft equipment will be manufactured by Thales UK and British Airways will roll-out the service starting with domestic UK flights. The service is expected to offer bandwidth of 50Mbps to the aircraft.

In 2011, 94% of all airline passengers brought at least one mobile device (phone, tablet or laptop) on board the aircraft.[42] In combination with the statistic that average smartphone user carries out 221 tasks on the device per day, the likely uptake of fast broadband onboard aircraft is great. The service is strong enough to offer passengers access to video telephony, streaming of movies alongside email, social media and voice calls over IP, currently offered by European airlines.

Benefits from broadband to aircraft accrue to airlines and passengers. Airline crew can receive information and instructions from headquarters at a higher rate than can be transmitted via radio. It is also conceivable that broadband to aircraft could assist in treatment of medical emergencies thus provided appropriate and timely health care to passengers in distress without needing to perform emergency landings. In 1999 British Airways had 1 incident per 11,000 passengers with the vast majority handled by crew and medical professionals on board.[43]

Benefits to passengers are derived from the ability to access all the services of the internet. The ability to keep up with one's favourite TV show or watch the particular movie desired increases customer satisfaction. Passengers aiming to work on the aircraft will be able to communicate with the office and receive materials and instructions and could also improve productivity by accessing more information.

Source: London Economics based on secondary research and stakeholder consultations

[41] British Airways Plc (2014) Annual Report and Accounts Year ended 31 December 2013, available at: http://phx.corporate-ir.net/External.File?item=UGFyZW50SUQ9NTYzNTg2fENoaWxkSUQ9MjYzNjgxfFR5cGU9MQ==&t=1; fleet information from: http://www.britishairways.com/en-gb/information/about-ba/fleet-facts; staff information from: http://www.britishairways.com/en-gb/bamediacentre/newsarticles?articleID=20140901111046&articleType=FactSheets#.VYQ46_lVikp

[42] Inmarsat (2014) A Universal Force, available at: http://www.inmarsat.com/wp-content/uploads/2014/09/Inmarsat-Corporate-Brochure.pdf

[43] Dowdall, Nigel (2000) "Is there a doctor on the aircraft?" Top 10 in-flight medical emergencies, British Medical Journal, 2000 Nov 25; 321 (7272); 1336-1337.

Box 22 Future Cities Catapult – Milton Keynes' Internet of Things

Milton Keynes' Internet of Things is the UK's first city-wide, open-access Internet of Things (IoT) network. Its purpose is to explore how the IoT can boost new and innovative services in cities around the world. Currently the application is under development by the Future Cities Catapult in collaboration with Milton Keynes Council, BT, Open University and the Connected Digital Economy Catapult.

Milton Keynes' IoT currently uses analogue TV whitespace which is no longer in use, to connect devices - citizens' smartphones and household hardware, parking spaces and recycling bins. This ubiquitous connectivity is possible via a public network. The exploitation of information relies on application of satellite navigation, for example, which is of key importance in the navigation to an empty parking space or when the waste disposal company needs to identify and empty full bins.

The public network of Milton Keynes' IoT via which all devices are connected has been installed by BT. They have collaborated with the Cambridge-based start-up Neul in the ground installation of 15 base stations which serve as communication hubs. If Internet-of-Things is to catch on in a wider context and outside of cities, Inmarsat M2M, for example, will allow the sending and receipt of data from any device, to any location, in real time, via Inmarsat's global 3G service which uses one single satellite network.

One service which has resulted from the IoT so far is the embedded recycle bins censors to inform the Council of bin collection needs. Recycle bin censors are expected to improve the efficiency of the Council's waste management system. Another IoT application is the digitalisation of parking spaces which can signal their availability. Further ideas to be developed in future and to improve the Council's service to its residents are a pest control censor system and a cycle traffic and footfall monitor system. Water metres, fire alarms, central heating systems and even soap dispensers are also being linked to the network, to create intelligent buildings. The technology might also be capable of tracking people with Alzheimer's, children, and even lost pets around the city.

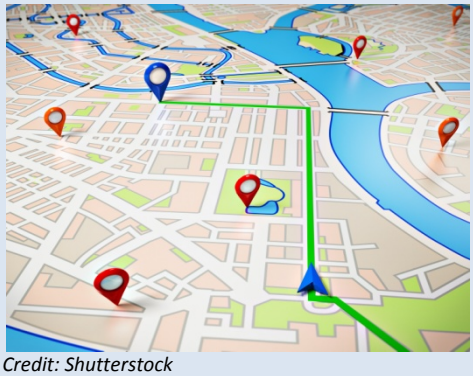
Credit: Wikimedia Commons (Wilgengebroed)

Citizens and the Council will use end-applications enabled by the IoT, which can be developed by various businesses. For instance, the company producing the parking spaces studs are developed by Deteq; and the information fed into the IoT network is overlaid on Google maps and made publicly available. The option of feeding this data to satellite navigation systems and smartphones would allow citizens to find a parking space in their surroundings much faster and therefore reducing traffic congestions. The IoT therefore provides multiple and diverse opportunities for businesses to create innovative applications which benefit either local governments, or consumers directly, and which can have positive externalities on society.

Source: London Economics based on secondary research (Future Cities Catapult https://futurecities.catapult.org.uk/project-full-view/-/asset_publisher/oDS9tiXrD0wi/content/project-milton-keynes-internet-of-things/) and stakeholder consultations

Box 23 Google Maps, enabling Smartphone users to efficiently navigate on foot and on the road

One aspect of modern life that has cemented the applicability of space to daily challenges is the rising use of smartphones for the purpose of navigation. Navigation applications in smartphones rely on assisted-GNSS, to find and track the user's position, and it is through this technology that navigation has fundamentally changed from looking at a map wondering "how to get from A to B" to looking at a screen and speculating "how to get from *me* (the blue dot) to B". It has been forecasted that 37.8 million individuals use smartphones in the UK in 2015,[44] corresponding to 60% of the total population.



Credit: Shutterstock

At present, UK companies have played a limited role in the provision of smartphone navigation with the space infrastructure all manufactured and operated from the United States or Russia and user equipment designed and manufactured in the US or Asia. The UK's involvement in the European GNSS, Galileo, through manufacture and operations support for space and ground infrastructure means that UK users – at least to some extent – will rely on outputs of UK infrastructure in the future. One element of the value chain, however, already has a UK fingerprint with the main application provider, Google, having a strong geo-spatial presence in their London offices amounting to about 2% of global staff. Google Maps is the most used smartphone application in the world as more than half of smartphone users open the application each month.[45]

The benefits from smartphone navigation accrue to both users and non-users. Users benefit through ability to navigate more efficiently (on foot or in a car) thus avoiding getting lost and reducing travel time, wear and tear of shoes or petrol consumption. Non-users primarily benefit through reduced congestion from the more efficient in-car navigation of users, which reduces their travel time and enables more efficient use of roads. Google Maps also offers the user the ability to identify relevant public transport options for the journey and reduce road congestion through this channel. Reduced exhaust fumes and noise pollution improves the health of dwellers and environmental impacts on climate change from fuel consumption are reduced.

Source: London Economics based on secondary research and stakeholder consultations

[44] Statista (2015) http://www.statista.com/statistics/270821/smartphone-user-in-the-united-kingdom-uk/.
[45] Statista (2015) http://www.statista.com/chart/1345/top-10-smartphone-apps-in-q2-2013/ for Q2 2013.

Box 24 G2way – geo-tagged Low Level Earth Observation (LLEO) aerial imagery using programmable unmanned aerial vehicles

G2Way is an alumnus of ESA's Business Incubation Centre in Harwell, Oxford, assisting farmers in precision agriculture by providing key inputs. The company users Unmanned Aerial Vehicles (UAVs) to photograph fields with a view of assessing crop health.

Credit: Low Level Earth Observation

UAVs are a complementary solution to Earth Observation satellites as they allow monitoring of fields even when it is cloudy. G2Way's UAVs fly 20-30 minutes per flight and generate 8GB of data during this time. The routes of the UAVs are programmed and using GNSS to ensure the device covers the desired area of cropland. The geo-tagged data are then processed remotely to assist farmers in planning fertiliser and pesticide use on the field and vary application by location on the field when combining with sophisticated RTK-enabled precision agriculture solutions. Geo-tagged data also enable tracking of the developments of each section of field, which allows the farmer to identify anomalies anywhere in the field.

Using UAVs for monitoring of fields enables reduces the amount of time necessary to inspect the field, which can be used for other tasks and being able to vary the application of fertiliser and pesticides presents the using farmer with large potential savings of inputs.

A different user group that could be imagined is civil engineering surveyors who may benefit from seeing the construction site from above and assess geographic features, which would improve the efficiency of surveys and could improve efficiency of construction.

Source: London Economics based on secondary research and stakeholder consultations

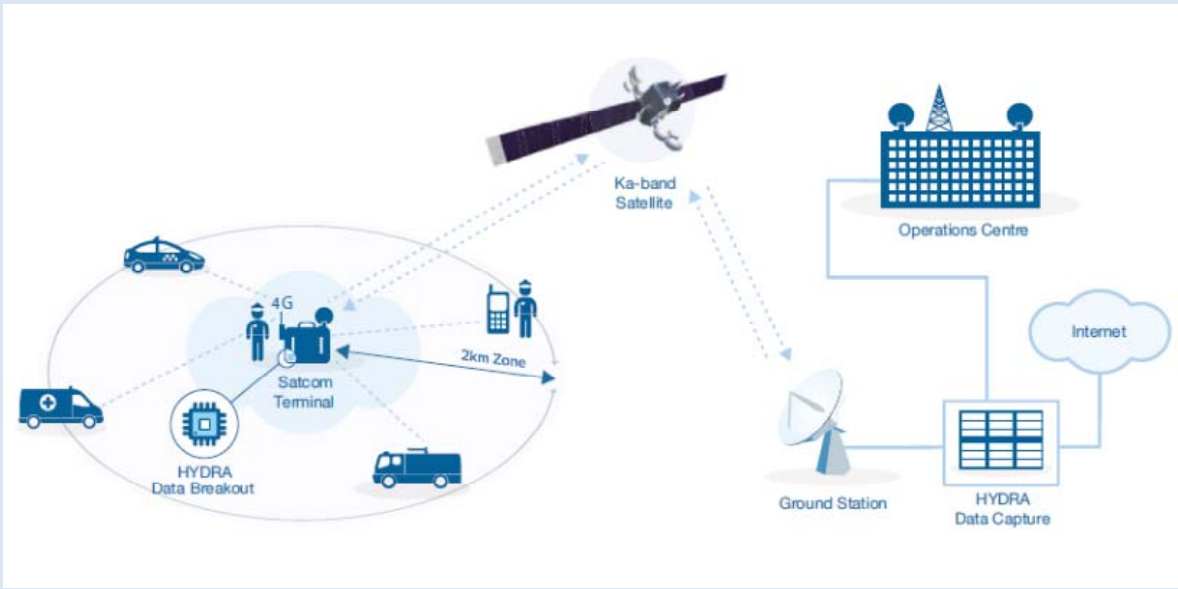
Box 25 Project Hydra – allowing UK emergency services to communicate on 4G LTE networks through satellite backhaul

Credit: SA Catapult.

Project HYDRA is a high speed, secure 4G LTE mobile network backhauled through satellites for UK's emergency services. It provides a private overlay cell network over a radius of 2 km, or an area of 12.5 square kilometres, anywhere in the UK, and can operate in both private (completely separate from the general public telecommunications network) or interconnected (roaming) modes. The portable platform enables 4G networks to be deployed immediately where they are needed (when terrestrial networks are overloaded or non-existent), and can also be installed permanently (e.g. as a network extension) for areas where additional capacity is frequently required.

Project HYDRA integrates satellite broadband services to become part of the mobile network operator infrastructure, thus using the ubiquitous coverage of Ka-band satellites to provide universal access to 4G. The programme is co-funded by the Technology Strategy Board, the British Association of Public Safety Communications Officials (BAPCO), satellite operator Avanti Communications Group plc (Avanti) and software company Quortus Ltd, and brings together the latest innovations in satellite broadband and small cell technology. The value chain involves Avanti, providing high speed (60Mbps download and 20Mbps upload) Ka-band data from its satellite network, and Quortus, whose software provides the core mobile network.

Emergency services critically require access to high speed communication tools to deal with emergency situations. Project HYDRA enables 4G devices used in the field by operational teams to access the full capability of 4G through addressing the challenges posed by coverage and capacity limitations of 4G networks. Operational benefits for emergency services and disaster victims include the opportunity for emergency services to securely transmit data, to make calls without interference and to locate injured people using the signal from their mobile phones.



Credit: Avanti Plc.

Source: London Economics based on secondary research (listed in 'References')

2.7 Space solutions for smart government

Box 26 Space for Smarter Government Programme

- **Wall to Wall Soil Water Alerts for UK** (Lead Supplier: Ecometrica; Core Customer: Defra, DECC, EA, local authorities) This project will test the feasibility of providing near real-time, high resolution, wall to wall soil moisture alerts for the UK to use in flood warnings.
- **Coastal Sentry and Roof Watch** (Lead Supplier: Stevenson Astrosat; Core Customer: Local Authorities) Coastal Sentry and RoofWatch will prototype and demonstrate benefits of satellites in the detection of damage caused by severe weather events, including erosion and damage to buildings. Coastal Sentry will focus on pre-identified areas of risk and will task orbital satellites to examine these areas after severe weather events to look for erosion, landslides or significant cracking and report this to the appropriate department. RoofWatch will focus on monitoring damage to roofs and building motion after severe weather events at the behest of insurance companies or local authorities.
- **Sea Level Spacewatch** (Lead Supplier: SatOC; Core Customer: Environment Agency) The aim of Sea Level Spacewatch is to provide regularly updated sea level advice around the UK, using data from space-borne altimeters and tide gauges. This project is the feasibility study developed specifically for the agencies with the responsibility for advising the Government on flood defence planning and climate monitoring.
- **Local Authority Air Quality Hotspot Mapper** (Lead Supplier: University of Leicester; Core Customer: Leicester and Northampton City Councils) This project is 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.
- **Flooding Information for Hampshire** (Lead Supplier: RSAC Ltd; Core Customer: Hampshire Hub Partners) This project aims to demonstrate to local Government the potential of a portfolio of EO-based flood information products. It will investigate, through example-led consultation, the interest amongst Hampshire Hub partners in EO-derived products such as rapid response flood maps, with the potential to enhance flood risk management in the county.
- **Digital Technologies to Help Keep Exeter a Clean, Safe and Well Managed City** (Lead Supplier: Bartec Auto ID; Core Customer: Exeter City Council) The aim of this project is to identify the viability of location-based technology that will allow citizens to quickly report safety and compliance issues within urban areas, allowing local authorities to supply faster, more efficient maintenance services. The tree management project, being trialled with Exeter City Council, is being run in two stages, the first stage using a small number of mobile devices and the second stage being the creation of self service on the Council website for public use.
- **Design Creation for New Concept Always Connected Mobile Medical Screening Vehicle** (Lead Supplier: RedFoot Technologies Ltd; Core Customer: University Hospitals of Coventry and Warwickshire NHS Trust Local Health Authority) The aim of this project is to research and design a breast screening vehicle that will exploit all of the benefits brought by satellite connectivity such as decreased cost with increased capacity and elimination of data entry errors. If built and adopted, the screening vehicle would allow NHS trusts to save money through reduced costs of screening and would provide more effective coverage and greater reach, resulting in more women being screened, more cancers detected earlier and better clinical outcomes.
- **An Assessment of the Utility of Latest Generation InSAR for the Regulation of Shale Gas Exploitation** (Lead Supplier: Earth Metrics Ltd; Core Customer: DECC) This project will explore the effectiveness of the Interferometric Synthetic Aperture Radar (InSAR) to provide data that could serve to aid the Department of Energy and Climate Change in the regulation of shale gas exploitation. InSAR will monitor any land change that occurs during shale gas extraction.
- **Hub and Spoke Data/Mapping Service** (Lead Supplier: Airbus Defence and Space; Core Customer: Defra) The Hub and Spoke Data/Mapping Service will explore options to create sustainable, operational services from satellite data and products to enable smarter, more efficient operations, reduce risk, and

enhance policy making. The project will benefit Defra and all its agencies and networks by providing a lower cost and sustainable evidence based system to inform and manage its agricultural and environmental remits.

- **Use of EO for Greening the CAP and Compliance Checking** (Lead Supplier: Environment Systems Ltd; Core Customer: Rural Payments Agency (RPA)) The EU Common Agricultural Policy reforms are introducing a new subsidy scheme in 2015. To meet the needs of the scheme it is expected that more geographic information will need to be captured, maintained and validated on an on-going basis by the Rural Payments Agency. This project will examine the usefulness of EO data for the new regulations that will soon be introduced and provide a sustainable and lower cost method of meeting EU requirements.
- **Developing an Operational Service, Using SAR Data, for Routine Monitoring of Land Management in the Uplands** (Lead Supplier: Environment Systems Ltd; Core Customer: Natural England) The aim of this project is to look at the practicalities for using SAR data in an operational monitoring programme to track environmental impacts of land management. It would help Natural England to protect the natural environment and ensure that contributions to GHG emissions are controlled. The reality of using satellite data operationally will be shared more widely by the SSGP programme.
- **Business Case Development for a Centre of Excellence for the Defra Network** (Lead Supplier: Assimila Ltd; Core Customer: Defra) In partnership with Defra, the Environment Agency and the wider Defra Network, this project will explore how a 'centre of expertise' within the Defra Network might provide opportunities to promote satellite use in a more integrated and cost-effective approach. The focus of the study will be on satellite EO technology but will also take into account other platforms including airborne, unmanned autonomous vehicles (UAVs) and high altitude balloons (HABs). The final report will demonstrate how current work practices may be successfully translated into a centre of excellence model that could benefit UK through better, lower cost administration.
- **Use of Space Applications for Catchment Sensitive Farming** (Lead Supplier: ADAS UK Ltd; Core Customer: Defra) Catchment Sensitive Farming (CSF) delivers practical solutions and targeted support to enable farmers and land managers to take voluntary action to reduce water pollution from agriculture and protect water bodies and the environment. The project will examine how space applications can be applied by the CSF user community and will make recommendations on overcoming any barriers to the uptake of relevant EO datasets.
- **Co-funding with Defra for: Enhancing the Business Case for Operational Use of EO for Biodiversity** (Lead Supplier: Environment Systems Ltd; Core Customer: Defra and JNCC) This project will enhance the business case for the operational use of EO data in the monitoring and managing of biodiversity. It has been demonstrated through the 'Making Earth Observation Work' project that EO techniques together with the development of geo-informatics have the potential to make a significant contribution towards quantifying habitat extent, composition and condition as part of a suite of surveillance techniques. This will look at the costs and benefits of such a system. The first round of projects look to benefit services such as flood management, weather damage management, air pollution monitoring, city maintenance, medical screening, mapping, land management and biodiversity management.

Source: UK Government (2015). 'Boosting public services with satellites'; Space for Smarter Government and Satellite Applications Catapult

3 Case studies of education, exploration and space science

3.1 Introduction

This Section presents a range of the Case Studies that illustrate the wider effects of space on education, exploration and space science.

The Case Studies were researched using a mix of desk-based research of existing literature and information sources, supplemented by a short programme of qualitative research involving semi-structured interviews with selected key stakeholders.

They provide the qualitative and quantitative evidence base that was used to inform Section 9 of the Full Report entitled 'Education, exploration and space science', with three sub-sections:

- Science, Technology, Engineering and Maths (STEM) education and careers;
- Space exploration beyond earth orbit; and
- Space science.

3.2 Science, Technology, Engineering and Maths (STEM) education and careers

Box 27 *Astro Pi* – inspiring a new generation to undertake STEM careers as part of British astronaut Tim Peake's *Principia* mission to the International Space Station

Credit: Raspberry Pi.

The UK Space Agency in cooperation with the Raspberry Pi Foundation, SSTL, Airbus DS, CGI, the Space KTN, National Nuclear Laboratory, National Physical Laboratory, ESERO-UK, ESA and the PD Group launched a competition amongst UK students aiming at inspiring school students to study STEM subjects. The competition invites Primary and Secondary students to devise and programme their own experiments and applications to be run in space. The ideas will be coded on a new 'Astro Pi' pocket sized computer, a Raspberry Pi computer connected to a sensor packed add-on board.

British ESA Astronaut Tim Peake will then deploy two Astro Pi computers on board of the International Space Station as part of his mission commencing at the end of November 2015. He will load up the winning code whilst in orbit, run the experiments and distribute the data generated to the winning teams.

To help students develop their code, ESERO-UK and Raspberry Pi are developing a set of teaching resources to explain how to use and programme Astro Pi computers and to link the contest to teaching subjects.

Addressing the STEM issues in UK schools and universities is one of the key recommendations of the Government's Space Innovation and Growth Strategy 2014-2030. The government's ambitious expansion plans for the space industry will provide an estimated 100,000 new jobs in the UK, and training young people in STEM subjects is essential to meet this future demand. The Astro Pi competition is only one of many educational outreach activities around Tim's mission seeking to promote STEM subjects, with the UK Space Agency having been granted a £2m programme to this end. How effective such outreach activities are is currently being investigated by Science Education researchers at the University of York and space scientist Dr Maggie Aderin-Pocock, who are gathering views form pupils, teachers and space scientists on whether human spaceflight inspires students to study STEM subjects. The participation level in the Astro Pi competition looks rather promising in this regard.

Credit: Raspberry Pi.

Source: London Economics based on the Astro Pi website (http://astro-pi.org/)

3.3 Space exploration beyond earth orbit

Box 28 Prominent role for UK technology in ESA's successful *Rosetta* mission

The ground-breaking Rosetta mission succeeded, with the Rosetta orbiter landing its cometary lander module, Philae, on comet 67P/Churyumov–Gerasimenko on 12th November 2014. This first in planetary science was achieved after a transit period of more than 10 years, with the launch taking place in March 2004.

Rosetta and Philae, artists impression

As a project of the European Space Agency (ESA), of which the UK is a constituent member, British participation was already secured through the funding of a portion of the mission. However, increased involvement was present in the manufacturing and design process of this project. In fact, at least 12 British contractors (9 for the Rosetta orbiter[46] and 3 for the Philae lander[47]) were involved in building items ranging from batteries for the orbiter, antenna for communicating with Earth, landing gear, and the momentum wheel on Philae.

Significant academic contributions were also present, with UK scientists and institutions involved in 10 of Rosetta's 21 experiments[48]; with scientists from Oxford University, Queen Mary University of London and the University of Kent working on and analysing data from the VIRTIS, CONSERT and OSIRIS experiments respectively.

In addition, the Ptolemy experiment, a series of ovens on the Philae lander that would analyse the comet's material to investigate it's surface, and arguably one of the most important on-board payloads, was completely designed, built and led by the Open University in collaboration with STFC RAL Space of Oxfordshire.[49]

This combination of academic and engineering work on Rosetta ensured that British experts were always at the centre of the mission, with trickle down effects from knowledge and experience gained on the project seeming likely. ESA also produced a high budget, English language short film called Ambition, to act as an evocative and awe-inspiring promotion and companion to the mission. Ambition premiered at the British Film Institute, 2014.[50]

Source: London Economics based on secondary research

[46] Industrial involvement in the Rosetta Mission - ESA - http://sci.esa.int/rosetta/54180-industrial-involvement-in-the-rosetta-mission/
[47] Industrial involvement in the Philae lander - ESA - http://sci.esa.int/rosetta/54181-industrial-involvement-in-the-philae-lander/
[48] UK Involvement in Rosetta - https://www.gov.uk/government/case-studies/rosetta
[49] Lander Instruments - Ptolemy - ESA - http://sci.esa.int/rosetta/31445-instruments/?fbodylongid=896
[50] ESA – Ambition the Film, http://www.esa.int/spaceinvideos/Videos/2014/10/Ambition_the_film

Box 29 *ExoMars* programme 2018, with the UK taking overall leadership of the rover module

The ExoMars programme, announced in its original form by the European Space Agency in 2005, is a two part mission with the ultimate goal of searching for evidence that points towards the past or present existence of Martian life. ExoMars will be collaboratively operated by ESA and member nations, as well as Roscosmos, the Russian Federal Space Agency.

ExoMars rover prototype, 'Mars Yard', Stevenage

The first half of the mission consists of a Trace Gas Orbiter, due for launch in the January of 2016, and contains NOMAD, an instrument which "identifies components of the Martian atmosphere" with UK support in the form of research collaboration.[51]

However, it is the second half of the mission, the ExoMars Rover due to be launched in 2018, that the UK is securing a lead role in developing. The minister responsible for the UK Space Agency, Greg Clarke MP, announced on the 12th December 2014 that an extra £47.7m of government money will be poured into ExoMars to "retain leadership of the Mars rover development". This investment, on top of ESA payments already derived from the UK's contribution to the organisation, also ensure that the UK will "play a leading role" in the ExoMars programme as a whole.[52] This enables the development, building and testing of the rover, as well as some of the on-board instruments, to be entirely undertaken in the UK by Airbus Defence and Space, and makes the first non-American Martian rover a very British affair.

Benefits accrued from this extensive involvement in the ExoMars programme will come in the form of both permanent and transitory highly skilled jobs (from research and operating positions to physical development of the rover), capital investment and the development of a space infrastructure (a world-leading Mars Yard to simulate the Martian surface environment and an "advanced clean room" have been created in Stevenage, Hertfordshire, in order to enable rover production[53]), the utilisation of any R&D multipliers that arise through the duration of the programme and an active inspiration for the British public.

Source: London Economics based on secondary research

[51] Trace Gas Orbiter instrument list - ESA - http://exploration.esa.int/mars/48523-trace-gas-orbiter-instruments/

[52] £47.7 million to play a leading role in Europe's Mars mission and retain leadership of Mars rover development – for more information, please see: https://www.gov.uk/government/news/uk-space-industry-set-to-rocket-with-over-200-million-of-new-investment-for-europes-space-programme

[53] Airbus Defence and Space opens state-of-the-art Mars Yard - https://www.gov.uk/government/news/airbus-defence-and-space-opens-state-of-the-art-mars-yard

Box 30 Lunar Mission One – a successfully crowd-funded UK-led mission planned to the moon's South Pole

Aimed at being both a successful scientific study of the Moon's South Pole, as well as an educational outreach programme inspiring children and young people to become excited by STEM, and specifically Space[54], subjects, Lunar Mission One was announced at the 2014 Re-inventing Space Conference, held in London by the British Interplanetary Society.

Lunar Mission One

After being unveiled by Lunar Missions Ltd, a clear community engagement strategy was immediately apparent with the creation of a Kickstarter[55] campaign, proceeds from which would be used to fund the first development phase of the project. This fundraising campaign proved popular; over 7,000 people pledged money to the project, ranging from £3 to £5,000, and exceeding the project's initial goal of £600,000 to secure just under £675,000 (over USD$1m) in funding.[56] This level of support has proven that a project of such potential magnitude can capture the public's imagination and garner the support of a community willing to fund its development.

With a timeline that consists of instrument and engineering development in the late 2010s, and spacecraft assembly in the early 2020s, a launch is already forecast for 2024[57]. As well as the scientific instruments that will fly to the moon, Lunar Missions Ltd plan to deposit a billion year time capsule of life on Earth, and adding private messages (so contributors can place MP3 messages or even their own DNA) , in an attempt to maximise the level of public interest, involvement and funding.

In working with British educational establishments on this project (UCL, The Open University and many others) and having a constituent team of scientists based in the UK, the collection of scientific data has a large potential for knock on effects across the educational and scientific establishment. Further, to build upon the public involvement aspect already seen, the Lunar Missions Trust has been set up as a not-for-profit organisation to oversee the project for public good, including the creation of a long term funding legacy; full educational resources along with a public archive will be created.[58]

As a global project, most of the project's implementation (engineering, science, revenues, education) will be overseas. But the UK's origin and influence is reflected by the heavy initial Kickstarter backing from the UK – 70% by number of backers and 80% by value.

Source: London Economics based on secondary research

[54] Lunar Mission One has three main aims… - http://launch.lunarmissionone.com/index.php/lunar-mission-one/introduction
[55] Kickstarter.com is a crowd-funding website where interested parties can pledge a one-off payment to a development project, in return for perks. The sum of monies is only transferred to the project developers if their funding target is exceeded.
[56] Lunar Mission One: A new lunar mission for everyone. - Kickstarter - https://www.kickstarter.com/projects/lunarmissionone/lunar-mission-one-a-new-lunar-mission-for-everyone
[57] Lunar Mission One press pack - Media Area - http://launch.lunarmissionone.com/index.php/component/rsfiles/files
[58] Global engagement timings – Lunar Mission One press pack

3.4 Space science

Box 31 Biomedicine – using space as a vehicle for biomedical research to benefit terrestrial healthcare

With commercial spaceflight likely to become operational in the coming years, advances in space biomedicine to improve human's health and ability to live and work in space are crucial. Many physiological problems faced by humans during spaceflight are still not fully understood, examples of which are muscle wasting, bone loss, cardiovascular de-conditioning and loss of neuromuscular control.

Credit: UK Space LABS

As a spin-off effect, research concerned with resolving space-related biomedical conditions can result in Earth-based healthcare gains. The space and healthcare sectors both face biomedical challenges that are closely aligned, as the physiological conditions caused by weightlessness in space resemble those of ageing on earth. The examination of numerous biological and physical systems in the space environment, under the associated unique and unusual circumstances, can drive terrestrial research and particular healthcare innovation.

For example, the technology used for a 'skinsuit' currently being developed by researchers at King's College London, Massachusetts Institute of Technology (MIT) and the European Space Agency (ESA), mimicking the gravitational pull experienced on earth to avoid spinal lengthening and associated lower back pain occurring in space, might be suitable for support clothing for cerebral palsy sufferers.

In the absence of gravity, body-fluids shift head-ward, leading to heightened intracranial pressure that can result in visual impairment. In response to this, the University Hospital Southampton developed a non-invasive means to measure changes in pressure within the brain to enable better monitoring of astronauts. This non-invasive measuring system provides a valuable tool to hospitals for the treatment of patients with head injuries.

In the UK, the Space Life and Biomedical Sciences Association (UK Space LABS) provides a unified, national space biomedicine strategy and facilitates liaison in the field. The organisation aims to improve communication, cooperation and collaboration between UK based academic, industrial and government organisations involved in research, healthcare, outreach and educational activities related to space life and biomedical sciences and the human element of human spaceflight.

Source: London Economics based on secondary research (listed in 'References')

4 Case studies of future prospects

This Section presents Case Studies illustrating the future prospects of the UK space economy. The Case Studies were researched using a mix of proprietary research, desk-based research of existing literature and information sources.

4.1 Low-cost access to space

Box 32 Spaceport UK (future: 2018)

The Government's Space Innovation and Growth Strategy 2014-2030 and Space Growth Action Plan both include the Government's ambition to establish a spaceport in the UK by 2018. On the basis of an 18-months review of the operational requirements of the commercial spaceplane and spaceport industry, carried out by the UK Civil Aviation Authority (CAA), ministers revealed 8 potential airfields that could host a spaceport in July 2014. After further consultations, a number of options have been excluded, and the government issued an updated shortlist in March 2015 including: Campbeltown, Glasgow Prestwick, and Stornoway in Scotland; Newquay in England and Llanbedr in Wales. RAF Leuchars is also included as a potential temporary facility.

Credit: Department for Business, Innovation & Skills, Department for Transport, UK Space Agency, Civil Aviation Authority

One important consideration was location, with airfields required to be easily accessible for both employees and visitors, but located at a coastal location away from densely populated areas and normal air traffic routes for safety reasons. Further criteria were favourable meteorological conditions and the ability to comply with standard environmental regulations on noise, air quality and storage of hazardous materials. Finally, candidate airfields had to be established large sites with a runway that is, or is capable of being extended to, 3000 meters in length.

Currently, an overwhelming majority of space launches take place from the US, Russia or China. Centre Spatial Guyanais (CSG) Spaceport in French Guyana, is the European spaceport.[59] A UK spaceport would establish the UK as a European centre for space launch and a leader in the space market. Moreover, it would make the UK an attractive location for space plane operators and manufacturers, attract regional and international investment, and pave the way for commercial spaceflight.[60]

The economic case for a UK spaceport is supported by two economic studies. The first study, completed by London Economics proved the financial and economic viability of a UK spaceport, with positive cumulative net revenues from year 9 onwards and totalling in excess of £550m over 25 years. The study also completed a social cost-benefit analysis of costs and benefits accruing to society as a whole, not just the spaceport operator, finding a Net Present Value of £540-590m.[61] The second study by the Satellite Applications Catapult found that the spaceport has the potential to create about 2,000 new jobs and generate £320m of additional economic activity from suborbital human spaceflight, satellite launch, regional tourism and microgravity research by 2028.[62]

Sources: London Economics based on secondary research (listed in 'References')

[59] The only operating spaceport in Europe, Spaceport Sweden located within the Arctic Circle, is exclusively used for sounding rockets.
[60] Civil Aviation Authority (2014). 'UK Government Review of Commercial Spaceplane Certification and Operations. Technical Report'. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/329758/spaceplanes-tech.pdf
[61] London Economics (2013). 'Towards a UK launch infrastructure, Economic analysis work package'. Unpublished study, part of the Space Collaborative Innovation Team Initiative (Space CITI) programme.
[62] Satellite Applications Catapult, University of Oxford, SAID Business School and UK Space Agency (2014) 'SpaceportUK - Forging Ahead With Commercial Confidence'.

Box 33 SKYLON (future 2025+)

SKYLON is an unmanned, fully reusable spaceplane of 84m length that can take off from a conventional runway, fly directly to low earth orbit with cargo of up to 15 tonnes and return to earth for a runway landing, just like a normal aircraft. It is currently under development by Reaction Engines, based in the UK, and planned to become operational in the mid 2020s.

Credit: Reaction Engines Ltd.

In a 2011 report, the European Space Agency concluded that SKYLON can be realised given existing technologies and the successful development of the Synergetic Air-Breathing Rocket Engine (SABRE), which will be used by SKYLON in the early part of the flight before switching to full rocket mode.[63] SABRE extracts the oxygen it needs for low atmosphere flight from the air itself, using a combination of a pre-cooler heat exchanger to cool the hot atmospheric air entering it at high speeds and a compressor to raise the air pressure high enough to be used as the oxidiser. SKYLON is light at take-off because the fuel required to achieve speed of up to Mach 5 (five times the speed of sound) can be extracted from the air rather than stored on-board. This enables the spaceplane to make a single leap to orbit, instead of using and dumping propellant stages on the ascent as current non-reusable rockets do.

SKYLON can be used to launch satellites and carry cargo to the International Space Station (ISS) at about one-fifth of the cost of non-reusable launch vehicles, enabling frequent launches with little downtime. London Economics estimated that launch prices for SKYLON would range between €16.2m-€37.5m, compared to current launch prices of €49m per launch for US launcher Falcon 9 (SpaceX) and the expected €70m for Ariane 6. This would revolutionise the economics of satellite launch, opening up cheaper access to space and enabling the space launch supply market to be turned into a fully commercial activity. At a later stage, SKYLON might even be able to bring astronauts to the ISS or carry spaceflight experience participants.[64]

The SKYLON project is primarily funded by private investors, but a significant contribution has been made through the ESA technology development programme, and the UK Space Agency's 2013 investment of £60m in the construction of a prototype SABRE. From a UK perspective, SABRE could potentially create 21,000 high value engineering and manufacturing jobs and maximise the UK's access to a conservatively estimated £13.8bn launcher market over the next thirty years as well as provide economic benefits from spillovers. London Economics estimated the socio-economic impacts for Europe of a SKYLON-based European Launch Service Operator at €20-24bn in Net Present Value terms (2014 prices, nominally 30 years).[65] SABRE might also be used within the atmosphere to shorten journey times for long-distance flights. It is estimated that Brussels to Sydney could be done in four and a half hours by a Sabre-equipped airliner.

Source: London Economics based on primary and secondary research (listed in 'References')

[63] European Space Agency (2011) Skylon Assessment Report.
[64] London Economics (2014) "Feasibility Study of the Business Plan for a SKYLON-based European Launch Service Operator", a confidential report for ESA, but main findings published in: Hempsell, M., Aprea, J., Gallagher, B. and Sadlier, G. (forthcoming). "A Business Analysis of a SKYLON-based European Launch Service Operator".
[65] London Economics (2014).

References

Box 6

Amos, J. (2014). 'UK Floods Prompt Space Charter Activation', BBC News (07 January 2014). Available at: http://www.bbc.co.uk/news/science-environment-25638840

Department for Communities and Local Government (2014). 'Winter 2013/14 Severe Weather Recovery Progress Report'. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/380573/Winter_2013-14_severe_weather_recovery_progress_report.pdf

DMC International Imaging Ltd (undated). 'DMC Constellation'. Available at: http://www.dmcii.com/wordpress/?page_id=927

Eurisy (2014). 'The Environment Agency in England, UK, Uses Satellite Imagery to Target Recovery Measures on Flooded Areas'. Available at: http://www.eurisy.org/good-practice-cabinet-office--environment-agency-use-of-copernicus-emergency-service-and-charter-in-the-flooding-of-2014_128

International Charter: Space & Major Disasters (2013). 'Charter Activation of 04 December 2013'. Available at: https://www.disasterscharter.org/web/guest/-/flood-in-united-kingdom

International Charter: Space & Major Disasters (2014a). 'Charter Activation of 06 January 2014'. Available at: https://www.disasterscharter.org/web/guest/-/flood-in-england-uk

Space & Major Disasters (2014b).'Charter Activation of 06 February 2014'. Available at: https://www.disasterscharter.org/web/guest/-/flood-in-south-west-engla-1

Pixalytics (2014). 'Is the Southern UK Flooding a Disaster?'. Available at: http://www.pixalytics.com/is-the-southern-uk-flooding-a-disaster/

Space Blog (2014). 'New Satellite Image of Somerset Floods from UK-DMC2'. Available at: http://www.sstl.co.uk/Blog/February-2014/New-satellite-image-of-Somerset-floods-from-UK-DMC;

Surrey Satellite Technology Ltd (undated). 'Applications of Earth Observation'. Available at: http://www.sstl.co.uk/Divisions/Earth-Observation-Science/EO-Applications

Box 8

Alexandropoulus, M. (2013). 'It's happening, you're watching'. Available at: http://www.spaceairbusds.com/en/news2/real-time-video-from-space-go-3s-satellite.html

Littlehales, M. (2011). 'Geostationary Orbit Space Surveillance System', presentation (Airbus Defence and Space)

Thisdell, D. (2014). 'Europe readies video eye in the sky'. Available at: http://www.flightglobal.com/news/articles/europe-readies-video-eye-in-the-sky-404584/

Box 10

Geospatial Insight website. http://www.geospatial-insight.com/services-2/

Satellite Applications Catapult Ltd (undated). 'Case Study Geospatial Insight. Using Satellite Data to Help Clients Gain an 'Information Edge'. Available at: https://sa.catapult.org.uk/documents/10625/53165/Geospatial+Insight+case+study/57f1fd17-128e-4ff8-9d95-44ea33a15906

Box 11

Allen-Stevens, Tom (2011), 'Reaping benefits of auto guidance'. Farmers Weekly (14 March 2011), Available at: http://www.fwi.co.uk/machinery/reaping-benefits-of-auto-guidance.htm

Department for Environment Food and Rural Affairs (DEFRA), (2013), Farm Practices Survey Autumn 2012 – England. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/181719%20/defra-stats-foodfarm-environ-fps-statsrelease-autumn2012edition-130328.pdf

HGCA (2009a), 'Case study 9: Precision Farming Solution: N-Sensor to Vary Nitrogen Rate'. Available at: http://www.hgca.com/media/183400/pf_cs9-be_precise_case_study_9_-_james_price.pdf

HGCA (2009b), 'Case study 4: Precision Farming Solution: Yield mapping'. Available at: http://www.hgca.com/media/183365/pf_cs4-be_precise_case_study_4_-_j_and_t_clark.pdf

HGCA (2009c), 'Case study 2: Precision Farming Solution: Variable Rate Application'. Available at: http://www.hgca.com/media/183359/pf_cs2-be_precise_case_study_2_-_tony_reynolds.pdf

HGCA (2009d), 'Case study 5: Precision Farming Solution: Autosteer'. Available at: http://www.hgca.com/media/183368/pf_cs5-be_precise_case_study_5_-_w_bradshaw_and_son.pdf

HGCA (undated). 'Environmental Benefits from Precision Farming'. Available at: http://archive.hgca.com/publications/documents/events/Environmental_Drivers.pdf

Joint Research Centre (JRC) of the European Commission (2014), 'Precision Agriculture: An Opportunity for EU Farmers - Potential Support with the CAP 2014-2020'. Available at: http://www.europarl.europa.eu/RegData/etudes/note/join/2014/529049/IPOL-AGRI_NT%282014%29529049_EN.pdf

Knight, S.; Miller, P.; Orson, J., (2009), An up-to-date cost/benefit analysis of precision farming techniques to guide growers of cereals and oilseeds. HGCA Research Review 2009 No. 71, pp. 115. Available at: http://www.hgca.com/publications/2009/may/20/an-up-to-date-costbenefit-analysis-of-precision-farming-techniques-to-guide-growers-of-cereals-and-oilseeds.aspx

PR Newswire (2014). 'Precision Farming Market Review on Technology and Components with Forecasts & Global Analysis for 2013 – 2018', PR Newswire (17 September 2014). Available at: http://www.appy-geek.com/Web/ArticleWeb.aspx?regionid=4&articleid=29013738&m=d

The Economist (2014). 'Don't panic', The Economist (24 September 2014). Available at: http://www.economist.com/news/international/21619986-un-study-sparks-fears-population-explosion-alarm-misplaced-dont-panic

Box 12

EUMETSAT (2014). 'The Case for EPS/Metop Second Generation: Cost Benefit Analysis'. Available at: http://www.wmo.int/pages/prog/sat/meetings/documents/PSTG-3_Doc_11-04_MetOP-SG.pdf

Joo, S., Eyre, J. and Marriott, R. (2012). 'The Impact of Metop and other Satellite Data within the Met Office Global NWP System Using an Adjoint-Based Sensitivity Method', Forecasting Research, Technical Report, no. 562 (February). Available at: http://www.metoffice.gov.uk/media/pdf/9/m/FRTR562.pdf

Met Office (undated). 'Using Satellites to Help Create Weather Forecasts'. Available at: http://www.metoffice.gov.uk/learning/first-steps/observations/satellites

Box 13

IGD (2014). 'UK Grocery Retailing'. Available at: http://www.igd.com/Research/Retail/retail-outlook/3371/UK-Grocery-Retailing/

Love Food Hate Waste (2015). 'The Facts About Food Waste'. Available at: http://england.lovefoodhatewaste.com/node/2472

Met Office (2013). 'Forecasting demand', Barometer online. Available at: http://www.metoffice.gov.uk/barometer/news/2013-10/forecasting-demand

Met Office (2014a). 'Businesses Can Harness the Weather and Boost Profits' Says Met Office. Available at: http://www.metoffice.gov.uk/news/releases/archive/2014/Business-Weather

Met Office (2014b). 'Why Choose DemandMet?'. Available at: http://www.metoffice.gov.uk/services/industry/environment/retail/future

Met Office (2014c). 'More Sales on Demand', Barometer online. Available at: http://www.metoffice.gov.uk/barometer/features/2014-08/more-sales-on-demand

Box 19

Avanti Communications Group plc (2013a). 'Helping WI-FI Operators Grow Their Network'. Available at: http://www.avantiplc.com/sites/default/files/case_studies/WiFi_Web.pdf

Avanti Communications Group plc (2013b). 'Northern Ireland Gets High Speed Connections for its Rural Dwellers'. Available at: http://avantiplc.com/sites/default/files/case_studies/FemtoCell_Web.pdf

European Regional Development Fund (undated). 'Northern Ireland Broadband Fund'. Available at: http://www.detini.gov.uk/deti-telecoms-broadband-fund

Wynn, M. (2015) 'Ka Satellite Broadband'. Available at: https://sa.catapult.org.uk/documents/10625/0/Mark+Wynn+-+Avonline.pdf/8ef587fe-30ef-46ef-b2bd-e840631129f6

Box 25

Avanti Communications Group plc (2014a). 'Project HYDRA'. Available at: http://www.avantiplc.com/mno/images/hydra-case-study-web.pdf

Avanti Communications Group plc (2014b). 'Project HYDRA provides UK emergency services with secure, high-speed mobile networks'. Available at: http://www.avantiplc.com/news-media/trade/avanti-quortus-achieve-world-first-delivery-4g-over-satellite

Satellite Applications Catapult (2014). 'Project Hydra hails new 4G LTE satellite network for emergency services'. Available at: https://sa.catapult.org.uk/industry-news/-/asset_publisher/rfNOnfu0uCQV/content/project-hydra-hails-new-4g-lte-

Box 31

Evetts, S. N. & Whiteley, I. (2012). 'Space Biomedicine. UK Research for Health in Space'. Available at: http://www.aglobalvillage.org/journal/issue11/space-the-next-suburbia/simon-evett/

Qi3 (undated). 'UK Space Biomedicine Consortium'. Available at: http://www.qi3.co.uk/clients/case-studies/uk-space-biomedicine-consortium/

Robinson, T. (2012). 'UK Aims to Carve Space Biomedicine Niche'. Available at: http://aerosociety.com/News/Insight-Blog/1672/UK-aims-to-carve-space-biomedicine-niche

The British Interplanetary Society (2014). 'UK Space Life and Biomedical Sciences – A Launchpad for British Human Space Flight'. Available at: http://www.bis-space.com/2014/03/04/12501/uk-space-life-and-biomedical-sciences-a-launchpad-for-british-human-space-flight

Ward, P. (2015). 'UK Space LABS. Purpose'. Available at: http://www.ukspacelabs.co.uk/about/1-purpose

Box 32

Civil Aviation Authority (2014). 'UK Government Review of Commercial Spaceplane Certification and Operations. Summary and Conclusions'. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/329756/spaceplanes-summary.pdf

Department for Transport (2014). 'Supporting Commercial Spaceplane Operations in the UK. Consultation on Criteria to Determine the Location of a UK Spaceport'. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/360448/spaceport-consultation.pdf;

London Economics (2013). 'Towards a UK launch infrastructure, Economic analysis work package'. Unpublished study, part of the Space Collaborative Innovation Team Initiative (Space CITI) programme within the UK Space Agency's National Space Technology Programme (NSTP)

Satellite Applications Catapult, University of Oxford, SAID Business School and UK Space Agency (2014). 'SpaceportUK - Forging Ahead With Commercial Confidence'.

Space IGS (2010). 'Government's Space Innovation and Growth Strategy 2014-2030'. Available at: http://www.nottingham.ac.uk/grace/documents/resources/marketreports/spaceigsexecsumandrec.pdf;

Space IGS (2014). 'Space Growth Action Plan'. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/298362/igs-action-plan.pdf;

UK Space Agency, Civil Aviation Authority, Department for Business, Innovation & Skills, Department for Transport and Ministry of Defence (2014). 'Government Paves Way for UK Spaceport. Press Release'. Available at: https://www.gov.uk/government/news/government-paves-way-for-uk-spaceport

Box 33

Civil Aviation Authority (2014). 'UK Government Review of Commercial Spaceplane Certification and Operations. Technical Report'. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/329758/spaceplanes-tech.pdf

Hempsell, M., Aprea, J., Gallagher, B. and Sadlier, G. (forthcoming). 'A Business Analysis of a Skylon Based European Launch Service Operator' (presented at IAC 2014 in Toronto IAC-14.E6.3.8)

London Economics (2014). "Feasibility Study of the Business Plan for a SKYLON-based European Launch Service Operator", a confidential report for ESA, but main findings published in: Hempsell, M., Aprea, J., Gallagher, B. and Sadlier, G. (forthcoming). "A Business Analysis of a SKYLON-based European Launch Service Operator"

Reaction Engines (undated). 'Space Access: SKYLON'. Available at: http://www.reactionengines.co.uk/space_skylon.html

UK Space Agency (2013). 'Government to Invest £60m in World's First Air-Breathing Rocket Engine', Press release from 17 July 2013. Available at: http://www.reactionengines.co.uk/press_release/Press_Release_17July2013_SABRE.pdf

Index of Case Studies

LE London Economics

Somerset House, New Wing, Strand,
London, WC2R 1LA, United Kingdom
londoneconomics.co.uk/aerospace
space@londoneconomics.co.uk
+44 (0)20 3701 7700
@LE_Aerospace