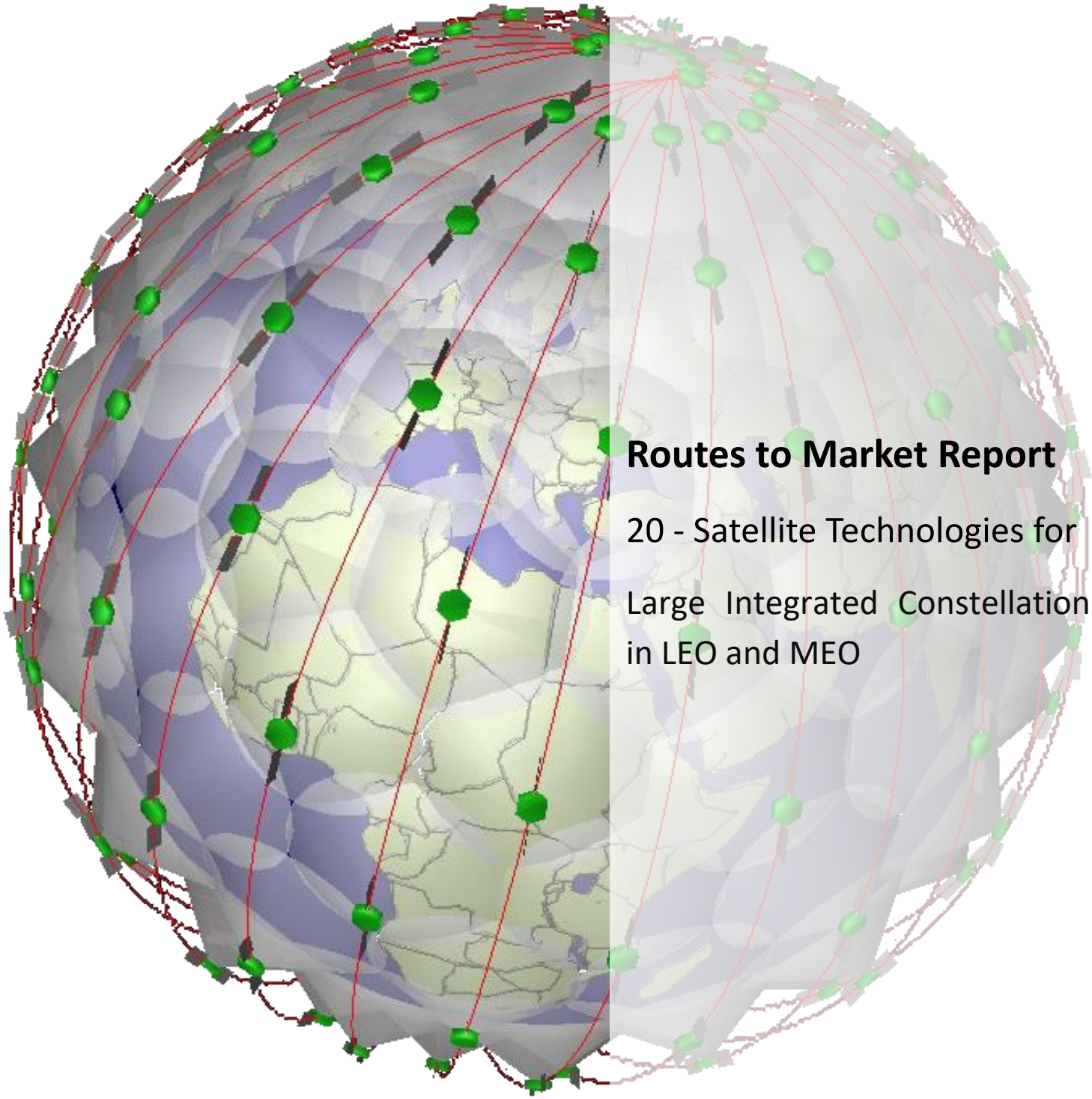

Routes to Market Report

20 - Satellite Technologies for Large Integrated Constellations in LEO and MEO

Innovate UK

FROST.COM

CATAPULT Satellite Applications

Contents

1. Introduction and Scope

Large, integrated constellations of satellites have multiple satellites flying in formation such that each location on Earth has access to the same number of satellites at any given time. Earth-observation and connectivity are transitioning toward a model of small-satellite operators managing large satellite constellations, with Earth-observation seeing a huge increase in the number of small-satellites. For the purposes of Earth-observation, operators are flying fleets from as small as 3 to over 100 small-satellites, whilst connectivity has larger constellations of 65-720 satellites. Connectivity missions have to deliver uninterrupted connectivity and when the mission objective covers global connectivity they tend to involve a large number of satellites placed around the Earth in symmetrical orbits.

Persistent surveillance is the key driver for Earth-observation constellations, whilst seamless connectivity over remote locations is the driver for communication constellations. Orbit wise, 250-500 km range covers Earth-observation missions and 600-900 km range covers communication constellations.

Small-satellite constellations, owing to their low manufacturing costs, provide affordable versions of existing and evolving satellite capabilities. This will enable the small-satellite operators to deliver products and services at relatively lower prices. While LEO and MEO constellations can include both small and large satellites, at present, multiple small-satellite based business models are gaining prominence and therefore they will dominate the trend in terms of numbers. Table 1 provides a brief description of different orbit segments.

Table 1: Orbital Classification

ORBIT CLASSIFICATION	DESCRIPTION
Low Earth Orbit (LEO)	Up to 1000 km altitude (+/- 500 km)
Medium Earth Orbit (MEO)	From 1000 km altitude up to GEO
Geostationary Earth Orbit (GEO)	About 35,780 km altitude

Table 2 displays the key aspects of the satellite constellation trend, its impacts, and expected industry outcomes. There is a clear distinction between the sensor and mission-level requirements needed for Earth-observation and connectivity missions. The connectivity missions aim to operate at higher Low Earth Orbit [650-800 km orbits] and they will need suitable measures to remove decommissioned satellites before replacing them with new ones. However, Earth-observation missions targeting orbital altitudes of 500 km and below will have self-decaying orbits which will enable suitably sustainable space operations. Frequent revisits and coverage over polar regions will be critical differentiating factors for such constellations.

Table 2: Constellation Trend: Aspects, Impacts, and Outcomes

OPPORTUNITIES	IMPACTS	ONGOING INDUSTRY EFFORTS	EXPECTED INDUSTRY OUTCOME
Small-satellites	Low-cost space assets	LEO constellation based business models	New low-cost satellite products and services
Need for persistent surveillance	Multi-satellite missions	Formation flying constellations	Products and services with frequent updates
Connectivity over remote locations (including polar regions)	Multi-satellite missions	Constellations with inter-satellite connectivity	Global services with seamless data-transfer capabilities
LEO Operations	Fast moving satellites with shorter mission times	Standardised manufacturing through serial production	Persistent demand for small-satellite hardware and launches
Earth-observation satellite missions	Smaller sensors and operations at 300-500 km altitude orbits	High-resolution sensors for standardised small-satellite formats	Sustainable space operations through self-cleansing satellite missions
Connectivity satellite missions	Smaller transponders and operations at 650-800 km altitude orbits	Antenna systems for enhanced throughput and coverage, de-orbiting capability	Demand for satellite de-orbiting services

2. Market Overview and Opportunities

2.1. Earth-Observation

Existing Global Information System (GIS) products and services are expensive owing to the upstream segment of the business model utilising large and expensive satellites. Some of those services also require extensive investment in IT infrastructure. This makes such GIS solutions unaffordable to a large segment of customers who are not large enterprises.

However, research indicates that diverse stakeholder groups across industries such as agriculture, forestry, mining and maritime etc., are interested in procuring GIS products and services, provided they are at affordable prices and are accessible on computers and smart devices through web-based platforms. The satellite data product being expensive is the key challenge and, in response, the small-satellite operators are looking to provide cheaper satellite imagery products and services. Utilising Commercial-Off-The-Shelf (COTS) hardware for relatively cheaper space assets, small-satellite operators are looking to field constellations of small-satellites.

2.2. Communications

Most of the existing satellite communications capability based out of geosynchronous orbits (including GEO) does not provide reliable coverage at latitudes closer to the poles. Unreliable connectivity scenarios over the polar regions have become a deterrent to multiple human endeavours in those regions which need the support of critical communication links.

While fibre-optic cable network serves as the backbone for global broadband connectivity, those regions which are not yet connected through the fibre-optic network do not have access to broadband connectivity. As a result, governments and commercial organizations are facing challenges promoting digital services to populations in remote locations. While telecom operators are expanding their networks, small-satellite operators are looking to field LEO constellations to deliver wireless broadband connectivity to remote locations that are not connected with the fibre-optic network.

3. Customer and Value Proposition to Customer and End-user

- Low-cost products and services: Earth-observation domain operators are looking to support existing GIS customers with low-cost satellite data and new customers with big-data-analytics based surveillance services that enable data-driven decision making. Connectivity operators are looking to work with administrations globally to deliver affordable broadband connectivity to remote locations which are not connected by fibre-optic network. Small-satellite operators such as Sky and Space Global are focused on narrowband services to remote locations.
- New customers: Regular consumers will be part of the customer group for both segments' constellation operators. While the connectivity domain will cover more consumers, Earth-observation will help governments and organizations support an equal number of consumers indirectly through data-driven decision making.
- Seamless connectivity and persistent surveillance: Frequent data updates, connectivity anywhere, and solutions accessible via Web-based platforms across diverse devices will be key selling points for the services that will utilise small-satellite constellations.

4. Value Chain and Competing Solutions

The following organisations are the leading competition for the United Kingdom.

4.1. OneWeb [Communication Services]

This business is a small-satellite operator aiming to deliver wireless broadband services to remote locations using a constellation of about 720 satellites. The operator raised an initial $500 million funding and recently secured another round of $1.2 billion as part of initial investment. Virgin Group, Airbus Group, Bharti Airtel, and Qualcomm are key partners of this joint venture. The business is aiming to deliver wireless connectivity services by 2019.

4.2. Planet [Earth-Observation Services]

Currently Planet manages over 100 nano-satellites in LEO, delivering Earth-observation products and services to commercial and government customers. The operator has developed serial production process such that satellites are manufactured in batches and are ready to replace the existing ones when they are nearing their end of mission life. The business, as of mid-2015, had raised $118 million of investment and was valued at $1.13 billion.

4.3. LeoSat Enterprises

LeoSat Enterprises is planning to field a 108-satellite constellation, with Ka-band connectivity payloads for an LEO based high-throughput communications solution that can enable businesses to realise seamless high-throughput connectivity across their global network. Their connectivity solution focuses on inter-satellite connectivity crucial for seamless data-transfer capabilities. Unlike other constellation businesses, LeoSat Enterprises aims at top 3000 corporation of the world. The business aims at starting operations in 2019.

4.4. Spire

Spire has launched 42 satellites of it's Lemur-2 nano-satellite constellation, and hopes to have 100 in orbit by the end of 2018. These satellites provide weather data and ship-tracking services across the globe, allowing Spire to win the first commercial weather data contract from the US National Oceanic and Atmospheric Adminstration. The company has raised $66.5 million of investment for building its constellation.

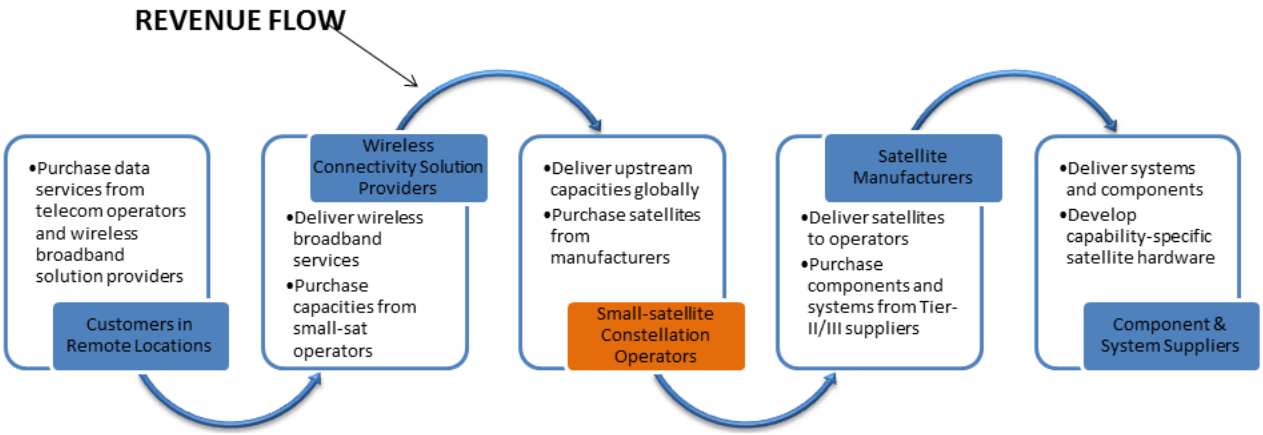

Figure 1: Small Satellite Constellation Value Chain and Revenue Flow

Figure 1 indicates the revenue flow along the connectivity value chain with respect to the small-satellite constellations. The value chain is similar for GEO satellite operators except the satellite operator role is taken by small-satellite operators fielding a constellation of small-satellites. The business models will have the telecom operators and solution providers deliver the connectivity services to the end-users while

investing in cheaper satellite capacities from small-satellite operators. The telecom operators will procure the upstream capacities for backhaul and solution providers will deliver customized wireless broadband services through their certified portable hardware. The small-satellite operators in turn are looking to field constellations to deliver the upstream capacities. They also invest in satellite manufacturing which is supported by satellite manufacturers who in turn invest in component and system suppliers. Overall, the key aspect of the value chain is that small-satellite constellation operators can deliver satellite capacities over polar and remote locations are relatively lower prices. The lower cost of manufacture and redundancy inherent in small-satellite constellations also reduces the risk associated with the business model. The loss of one satellite does not represent as significant an investment and will not have as large an impact on capability as it would for a traditional large, high-capability satellite.

5. Role of UK Companies

The United Kingdom should consider a LEO constellation for Earth-observation to support the military, civil government, and commercial segment users with low-cost options for reliable and frequently updated surveillance data. Civil government stakeholders, for example DEFRA and the Coastguard, would benefit from next-gen satellite-based surveillance capabilities to identify and control Illegal, Unregulated and Unreported (IUU) fishing, piracy, illegal transshipment, illegal immigration and human-trafficking, and other fast growing maritime risks. Such efforts can benefit from cheaper satellite imagery products and services.

6. Revenue Projections

Figure 2 provides the revenue forecast for the 2018-2027 timeline. This forecast covers service revenues accounting for new subscribers from remote locations and the subsequent drop in prices for connectivity services. The revenues here do not include the existing telecom market revenues. The growth to 2023 indicates the expansion of the constellation and its services across the globe. The leveling trend afterwards indicates the standardized availability of small-satellite constellation-based services to users globally, including those in remote locations.

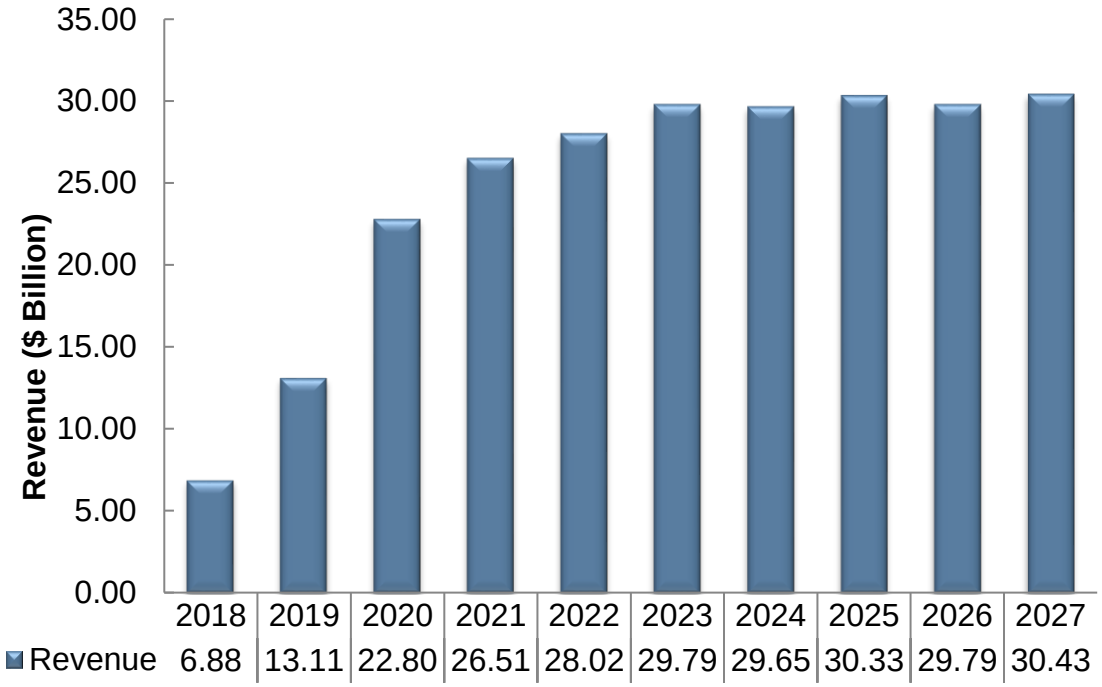

Figure 2: Revenue Forecast: Small-satellite based connectivity services (Source: Frost & Sullivan)

7. Market Blockers and Enablers

7.1. Key Market Enablers

- Web-based GIS Platforms: New web-based platforms delivering customised services will help small-satellite constellation businesses reach out to existing customer base with lower cost products.
- New business models: Small-satellite operators are aiming to field pay-per-image pricing options so that individual customers can purchase products of their choice (image of area of choice on date and time of choice) at relatively low cost. These services being developed for Web-based applications will be accessible to customers on computers and smart devices.
- Standalone wireless broadband services: Solution providers are offering wireless broadband solutions to users in remote locations. These participants will become channel partners with small-satellite constellation operators. The solution providers will control the downstream hardware and service delivery while the constellation operators will control the upstream capacities.
- Launch vehicles: The growth of small-launch vehicles offering tailored launches to small-satellite operators will allow constellations to be put into preferable orbits that are currently harder to access for these satellites, whilst also allowing the launches to happen at the small-satellite operator's own schedule.

Export Opportunity

From a communications perspective, the United Kingdom should consider the development of a global LEO constellation or invest in a suitable business to deliver affordable satellite capacities to remote locations both within the UK and globally. This effort will help millions of new users joining the Internet, which will benefit multiple industries directly and indirectly. While this effort will be relatively more expensive compared to an Earth-observation mission, this can directly impact everyday consumers in a very positive way by enabling them realise uninterrupted connectivity. The downstream impact will cover solution providers and telecom operators who will expand their portfolios and this will result in the creation of multiple sustainable employment opportunities.

7.2. Challenges and Steps to be Taken

LEO constellation growth will be significant over the next decade and this will require more space situational awareness, the Catapult's forecast for the next four years alone is around 1,300 new small-satellites. However, from a commercial standpoint, such constellations will be able to deliver services comparable to that of GEO systems at affordable prices. Their low-cost nature will be the main driver behind the price differentiator. This in turn will enable multiple customer groups to utilise satellite capabilities who otherwise could not afford a GEO satellite capability.

Key challenges for constellation based business models:

- Lack of regulatory framework to include small-satellite constellations through dedicated spectrum/channel allocations such that the existing and new market participants do not face any interference issues. Similar regulatory framework is required to accommodate all satellite operators in a fair and consistent way such that the LEO/MEO space is shared in a fair manner among the market participants.
- Lack of funding for start-up companies.
- Lack of affordable access to space through dedicated launch services.

Key steps to be taken:

- Promoting the evolution of regulatory framework to enable small-satellite constellation businesses (spectrum and orbital slot wise) will help establish a new space market segment with new customers and revenue opportunities.
- Enabling public-private partnerships to support space start-up companies will help the industry realise a new value chain which will create sustainable employment opportunities in the countries the businesses operate.
- Enabling the spaceport based LEO launch services business models will help small-satellite constellations procure affordable access to space which in turn will translate into lower price end-user services. The caveat in this area is the increased cost per kilogram for small launch vehicles, which can be as high as $30,000/kg compared to $2,800/kg for the Falcon 9. The advantage lies in the priority which small payloads will be able to get when they no-longer have to piggy-back on larger launches. This will enable them to launch on their own schedule to their preferred orbit.

8. Market Dynamics

The constellation operators have raised interference concerns (transmitting in the same frequencies/channels at various power levels) among existing GEO satellite operators. However, research indicates that the space regulatory frameworks are evolving to accommodate small-satellite operators and GEO satellite operators amiably without disturbing existing and evolving operations. International Telecommunication Union (ITU) is also evolving its regulatory framework to accommodate small-satellite operators such that LEO and MEO constellations co-exist with GEO satellite systems without interference issues.

8.1. The UK Perspective

The United Kingdom already has leading small-satellite platform developers and operators who have been helping satellite businesses globally for decades. However, they are few in number and the diversity of applications is fairly limited. Establishing a small-satellite business ecosystem focused on affordable services for remote locations is a potential opportunity for the UK space industry. Small-satellite constellation based business models look to bring new customers into the Earth-observation and connectivity domain through delivering cheaper services, these small-satellite constellations are not only going to bring in new revenue, but also are going to support the evolving launch services market. These constellations will also add value to existing areas that utilise space capabilities such as air-traffic management, air-to-ground (aeronautical) communications, machine-to-machine communications etc. Thus, supporting the establishment and growth of small-satellite constellation based business models will help the UK support and hold a significant amount of the evolving global small-satellite market.

Table 3 gives examples of key industry participants who are UK based businesses and are a part of the small-satellite constellation value chain.

Table 3: UK Constellation Value Chain Participants [Examples]

Satellite Constellation Operators	– Sky and Space Global – DMCii
Satellite Manufacturers	– Surrey Satellite Technology Limited (EADS/Astrium-Airbus Defence and Space) – Clyde Space
Satellite System Manufacturers	– Surrey Satellite Technology Limited (EADS/Astrium-Airbus Group) – Clyde Space – Satellite Services Limited
Satellite Component Manufacturers	– Clyde Space – Ford Aerospace Limited

9. Market Trends

The main market trends include:

- Low mass satellites: The majority of small-satellite launches in the past decade have been nano-satellites (satellites between 1-10kg). Again, this category is buoyed up by the Planet and Spire constellations.
- COTS products: Small-satellite, systems and components manufacturers have standardised their offerings to small-satellite customers and the market now has COTS opportunities that can support relatively small-budget space missions.
- Specialised small-satellite systems: Companies such as Surrey Satellite Technology Limited have developed high-resolution sensors for small-satellite applications. Small-satellite operators can now capture and deliver high-resolution imagery products.
- Comprehensive GIS Solutions: Solution providers such as esri are open towards including small-satellite data products and services in their ArcGIS platform so that their customers will have multiple data options to choose from. This will enable small-satellite constellations to reach the existing customer base through solution providers.
- Earth-observation satellites: These have constituted the majority of the small-satellite market for the last four years, whilst communications satellites have not seen as significant growth in the last decade. This trend is largely due to the high numbers of satellites launched by Planet and Spire.