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# Small is beautiful

## A new paradigm for space

23 June 2020

**Small satellites, ie those weighing less than 500kg, are increasingly being deployed to provide internet connectivity to remote and rural areas, to provide environmental monitoring services and to track assets. Widespread deployment requires changing the paradigm from expensive, bespoke satellites to platforms and payloads that can be manufactured and launched in their thousands. This report explores the drivers behind this revolution and profiles several of the key-players.**

## Internet-in-the-sky/eye-in-the-sky

Satellites have been used for several decades to provide connectivity to remote parts of the earth's surface and for remote observation applications. Traditionally satellites have been launched into geo-stationary orbits (GEOs), where one large, complex satellite can cover almost one-third of the earth's surface. More recently, satellites have been launched into low-earth orbits (LEOs), which are much closer to the earth's surface. This removes latency issues when sending large amounts of internet data and makes it easier to capture detailed images of the earth's surface. However, many more LEO satellites are required than GEO ones to provide similar coverage of the earth's surface. This means that the cost of building and launching satellite platforms and their payloads needs to be substantially reduced for mega-constellations of LEO satellites to be economically viable.

## Emergence of mega-constellations

Frost & Sullivan predicts that nearly 10,000 small satellites will be launched during the decade commencing 2020. This market growth is predicated on the deployment of mega-constellations, ie networks of a hundred satellites or more. While SpaceX has been grabbing the headlines with 480 LEO satellites in orbit as of early June 2020, established space communications companies are building LEO constellations too. Telesat intends to supplement its fleet of 14 GEO satellites with a network of around 300 LEO satellites, which will commence operation in 2022. LEO constellations are also being deployed for collecting images of the earth's surface. For example, Planet Labs operates a fleet of over 100 imaging satellites.

## Profiling companies that epitomise the new approach

This report does not attempt to provide an exhaustive list of companies involved in the small satellite market. Instead it provides profiles on three companies that epitomise the new approach required for success in this sector. These are AAC Clyde Space, which provides nanosatellites, subsystems and satellite services; Mynaric, which provides part of the communications payload on satellites; and SpaceX, which provides launch services.

### From the street

'The fusion of terrestrial tech with space applications is changing and accelerating the economics of space. As satellites are getting smaller, smarter and less expensive to launch, our reliance on them is growing exponentially. These satellites and their vast data sets will ultimately underpin emerging new technologies that will transform industries over the forthcoming decades.'
Seraphim Capital

### Edison themes

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***AAC Clyde Space and Mynaric are research clients of Edison Investment Research Limited***

# Small satellite market

## Covering the entire globe

Satellites have been used for several decades to provide connectivity to remote parts of the earth's surface including the oceans and to areas where the density of population makes it uneconomic to deploy terrestrial fibre broadband networks, as well as in situations where other communications networks have been destroyed by a disaster such as a hurricane. Initially satellites were used for TV broadcasting. For example, in 1972 Canadian communications company Telesat launched Anik A1, the world's first domestic communications satellite, to transmit TV broadcasts to the northern parts of Canada. As technology developed and consumers' communications needs became more demanding, satellites started to be used to provide broadband, voice, data and video services as well. For example, Telesat launched Anik G1 in 2013 to provide direct-to-home TV in Canada, additional capacity for broadband, voice, data and video transmission in South America and to support government applications across the Americas and much of the Pacific Ocean, including Hawaii.

In addition, from the very beginning of space flight, satellites have been used for remote monitoring applications. Sputnik 1, which was launched in 1957 and was the world's first artificial satellite, transmitted data on the density of the upper layers of the atmosphere and the propagation of radio signals in the ionosphere. In April 2020 the Union of Concerned Scientists stated that there were 2,669 satellites in operation, 901 of which were being used for earth observation.

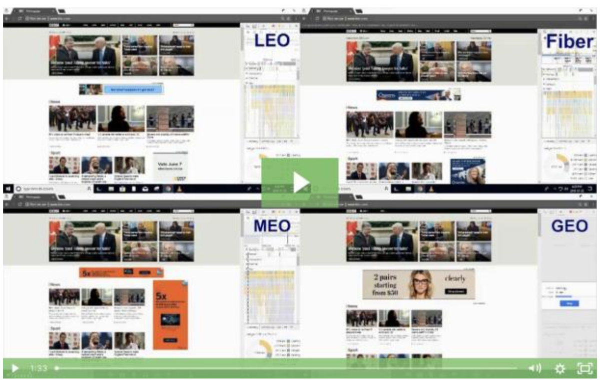
## LEO networks solve latency problem

Until recently most communications satellites were located in GEOs. The laws of physics mean that to stay in the same place above the earth as it travels through space, GEO satellites must be 36,000km from the planet's surface. At this height a single satellite is able to transmit signals to around one-third of the earth's surface so very few satellites are required for global coverage. However, signals take around 540msecs to go from a ground station to a GEO satellite and back. This high latency rate is not ideal for internet transmission, particularly online gaming or stock trading and other real-time applications.

**Exhibit 1: Using LEO satellites to expand 4G/5G network coverage**

Source: Telesat

**Exhibit 2: GEO/LEO latency comparison**




Source: Telesat

The solution to the latency problem is to locate satellites nearer the earth in either medium earth orbit (MEO), eg the GPS navigational satellites are at an altitude of 20,200km, or LEO, which is typically 400–1,400km above the earth's surface. The latency period for a satellite in LEO reduces to around 25msecs for a round trip, which is similar to cable or fibre systems. However, because of their low altitude, a LEO satellite can only transmit and receive signals from a small area (about

1,000km radius) as it passes overhead, completing an orbit in around 90 minutes. This means that many satellites, known as a satellite constellation, need to be in orbit simultaneously to provide global coverage in real time rather than having to wait until a single satellite has completed its orbit and is back overhead. Some of the satellite constellations being proposed (see below) will deploy over a thousand satellites in order to cope with the volume of data being transmitted.

Being closer to the earth's surface is also advantageous for satellites that are collecting images of the earth's surface, eg for environmental or threat monitoring. The on-board detector electronics do not need to be as complex because the signals being detected are stronger. Similarly, the signal transmitting collated data back to earth does not need to be as strong.

## Small satellites: A new paradigm for the space industry

Deploying so many satellites in a single constellation has transformed the way the space industry needs to work. The emphasis has shifted from designing and manufacturing individual large, expensive satellites to deploying smaller, less expensive satellites that are manufactured in volume. So although small satellite technology was originally developed as a cost-effective way of giving academic institutions a mechanism for conducting experiments in space, it has become the preferred solution for constellations of large numbers of satellites. The GPS III military satellites launched in 2015 weighed 3,680kg at launch, cost US$577m each to build and are designed to last up to 15 years. It takes two to three years to develop and launch a larger commercial satellite. A small satellite can weigh anything from less than 1kg for a picosatellite to up to 500kg for a minisatellite. A 10cm × 10cm × 10cm small satellite weighs around 1kg, typically costs around US$0.5m, is designed to last up to five years and can be developed and launched in less than a year. The transition to small satellite architectures substantially reduces the initial capital costs and enables network operators to start collecting revenue more quickly. While the relatively short satellite lifetime means that satellites must be replaced, this presents an opportunity for operators to upgrade functionality.

## 'Internet-in-the-sky' potentially connects half of the world's population

**Exhibit 3: Internet users as a percentage of regional population**

| Region | 2018 | 2023 |
|---|---|---|
| Global | 51% | 66% |
| Asia-Pacific | 52% | 72% |
| Central and Eastern Europe | 65% | 78% |
| Latin America | 60% | 70% |
| Middle East and Africa | 24% | 35% |
| North America | 90% | 92% |
| Western Europe | 82% | 87% |

Source: CISCO Annual Internet Report (2018-2023)

Around half of the world's population do not yet have internet access. CISCO's Annual Internet Report, which was updated in March 2020, predicts that the number of internet users globally will rise from 3.9bn, equivalent to 51% of the global population in 2018, to 5.3bn, or 66% percent of global population, by 2023. The fastest growth, 10% CAGR from 2018 to 2023, is expected to occur in the Middle East and Africa (see Exhibit 3). This growth cannot be achieved simply by installing more fibre optic backbone as this is uneconomic for areas of low population density or only a few connected devices and may not be feasible if the terrain is inhospitable because of natural causes such as mountain ranges or unhelpful human activity ranging from warfare to simple pilfering of the optical cable. Relaying communications signals via a constellation of satellites overcomes the problems associated with laying optical fibre.

## Asset tracking applications require global coverage

The CISCO report cited above notes that the number of connected devices globally is expected to grow faster than the world's population between 2018 and 2023 (10% CAGR vs 1% CAGR) and the number of internet users globally (6% CAGR). Growth is being driven by the development of new machine-to-machine (M2M) applications including smart meters, video surveillance, healthcare monitoring, transportation, package tracking and asset tracking. The report predicts that M2M connections will rise from 33% of all connections in 2018 to 50% by 2023 representing 14.7bn M2M connections by 2023 and a 19% CAGR during the period. This growth will contribute to demand for internet connectivity, some of which will be satisfied via satellite networks. Some of these applications, eg asset tracking, require global coverage. LEO solutions are ideal for these. Firstly, the satellite coverage is global, complementing terrestrial internet of things (IoT) networks. Secondly, because the satellites are relatively close to the earth's surface, the transmitters do not consume a significant amount more power or cost more than those for terrestrial networks.

**Exhibit 4: Monitoring crop growth using earth observation imagery**


Source: Planet Labs

## Coronavirus pandemic highlights need for reliable connectivity

During the COVID-19 pandemic, broadband connectivity became a lifeline for many people. Global communications giant Nokia reported that one week after lockdown it saw weekday peak traffic increases of over 45% and weekend evening peak traffic increases of over 20–40% compared with pre-lockdown levels. Video-conferencing usage increased by 350%, Netflix streaming by 58% and Facebook usage by 27%. As it seems likely that work patterns will change permanently in the wake of the pandemic, with employees spending more time working from home rather than in an office and taking fewer business trips, it is probable that video-conferencing usage will not go back to pre-pandemic levels. This topic is explored in a recent interview with SpaceX veteran Bulent Altan, who is a member of the management board of Mynaric, a specialist in free-space laser communications.

## Scaling the market

According to market research specialist Frost & Sullivan, 873 small satellites were launched in the three-year period between 2015 and 2018, out of which 499 were commercial. The firm estimates that the decade commencing 2020 will see nearly 10,000 small satellites launched, over 9,000 of which will be launched by entities that have already started launching. It forecasts the total number of satellites to be launched between 2019 and 2033 to be 20,425, This market growth is predicated on the deployment of mega-constellations, ie networks of a hundred satellites or more such as Amazon's Project Kuiper and SpaceX's Starlink. According to an analysis in a report published by Northern Sky Research in November 2019, communications applications will to account for the largest number of satellites launched between 2020 and 2028. The report expects earth observation satellites to be the second largest application.

## Small satellite constellations

The rapid growth in the number of small satellites in orbit described above is based on the successful launch of mega-constellations. Some of the most significant of these are described in this section. These include 'internet-in-the-sky' proposals from global giants Amazon and Facebook. We also profile some smaller, less well publicised and potentially lower-risk projects by established space communications and imaging companies. These constellations are summarised in Exhibit 6. Constellation operators must gain approval from the relevant organisation administering spectrum allocation. In the US this is the Federal Communications Commission (FCC) for non-governmental applications. For constellations with global coverage the FCC or its local equivalent, then obtains approval from the International Telecommunication Union (ITU) which provides the basic framework for the global coordination and management of the radio-frequency spectrum.

**Exhibit 5: Active and proposed LEO constellations**

| | Number of satellites | Satellite mass | Transmission frequency | Launch date | Application |
|---|---|---|---|---|---|
| Amazon's Project Kuiper | 3,236 | N/A | Ka uplink, K downlink | N/A | Internet |
| Eutelsat ELO | 25 | 12kg | Unspecified ISM bands* | 2020-2022 | IoT |
| Facebook Athena | N/A | 150kg | E-band | 2020 pilot | Internet |
| ORBCOMM | c 40 | 172kg | 137–138MHz downlink, 148–150MHz uplink | 2015-2016 | IoT |
| Planet Labs | 100+ | 5kg | 8.0–8.4GHz (X-band) downlink, 2.0–2.1GHz (S-band) uplink | 2013 onwards | Earth observation |
| SpaceX Starlink | 12,000+ | 227kg | Ku-band, Ka-band and V-band. Optical links between satellites | 2019 onwards | Internet |
| Spire Global | 80+ | 4kg | 8.0–8.4GHz (X-band) downlink, 2.0–2.1GHz (S-band) uplink | 2014 onwards | Earth observation |
| Telesat | 298 | c 750kg | Ka-band. Optical links between satellites | 2018-2023 | Internet |
| US Space Development Agency | <1,000 | 200kg+ | Optical links between satellites | 2020 onwards | Defence |

Source: Edison Investment Research. Note: *Industrial, Scientific and Medical – unregulated spectrum.

### Amazon's Project Kuiper (AMZN:US)

Project Kuiper is a long-term initiative to launch a constellation of 3,236 LEO satellites that will provide low-latency, high-speed broadband connectivity to unserved and underserved communities around the world. This includes 784 satellites at an altitude of 590km, 1,296 satellites at 610km and 1,156 satellites 630km above the earth. These will provide data coverage for latitudes from 56 degrees north to 56 degrees south, which addresses around 95% of the global population. In March 2019 Amazon lodged an application with the ITU for the Ka-band spectrum that the proposed satellites will use for transmitting data. In July 2019 Amazon advised the FCC that it plans to launch the satellites in five waves, with satellites designed to operate for seven years. Amazon has not said when it plans to launch its first satellites but it will need to launch at least one by early 2026 to retain full spectrum rights under ITU rules.

### Eutelsat Communications (ETL:FP)

Eutelsat Communications was founded in 1977 and currently operates a fleet of over 30 GEO satellites and associated ground infrastructure. It serves clients in the video, data, government, fixed and mobile broadband markets, for example broadcasting over 7,000 television channels to one billion viewers. In September 2019 the group announced plans for its ELO (Eutelsat LEO for objects) constellation, which targets the IoT market. The constellation will offer global IoT coverage enabling objects to transmit data, irrespective of their location. The project will begin with four small satellites, two from Loft Orbital, which will be launched in 2020 and two from AAC Clyde Space, each weighing 12kg, which will be launched in 2021. These four satellites will enter commercial service as soon as they are delivered into orbit. If this new initiative proves successful, other satellites will be added to the constellation, to reach a total of 25 satellites dedicated to IoT services in 2022. The cost associated with each satellite will not exceed €1m. Eutelsat's strategic goal is to use ELO to position itself as the partner of choice for IT integrators and terrestrial operators seeking to offer their customers worldwide coverage.

## Facebook (FB:US)

Facebook was scheduled to launch its first Athena satellite on 24 March 2020, sharing a lift into space on an Arianespace Vega rocket from French Guiana with around 50 other small satellites. The satellite was originally expected to launch in 2019 and will test the viability of E-band transmission (60–90 GHz), which potentially offers download speeds (to the receiver) of 10Gbps and uplink capacity of 30Gbps, but is blocked by rain and other particles in the air. The March 2020 launch was rescheduled to mid-June as activity at the site in French Guiana was suspended on 16 March because of the coronavirus pandemic. Facebook has also experimented with optical communications equipment from Mynaric (see below) carried on high altitude platform stations (HAPS). In 2018 the company decided to shelve development of its own Aquila unmanned solar-powered aircraft and to work with partners such as Airbus on HAPS connectivity instead.

## LeoSat

LeoSat had intended to operate a constellation of 78 to 108 cross-linked Ka-band satellites for high-speed internet costing around US$3.5bn. It shut down in November 2019 after Spanish satellite operator Hispasat and SKY Perfect JSAT of Japan failed to follow up their previous investments in LeoSat's US$50m Series A funding round. LeoSat had lined up US$2bn in soft commitments from customers wanting to use its network once deployed. Unlike other constellations, the target market was high-end government and corporate customers willing to pay a premium for large quantities of broadband at fibre-like latencies rather than consumers.

## OneWeb

OneWeb had intended to start delivering over 375Gbps of capacity to remote and under-connected locations later in 2020. By March 2020 it had launched 74 satellites out of a planned 648, begun development on a range of user terminals for a variety of customer markets, had half of its 44 ground stations completed or in development, and performed a successful demonstration of its systems with broadband speeds in excess of 400Mbps and latency of 32ms, It had also experienced significant early global demand for its services from governments and the automotive, maritime, enterprise and aviation industries. However, management was unable to complete a financing round intended to fully fund the company through its deployment and commercial launch. In March management filed for Chapter 11 protection while it pursued a sale of the business.

## ORBCOMM (ORBC:US)

ORBCOMM is a single source provider of dual-mode (satellite/cellular) industrial IoT devices, satellite and terrestrial network connectivity, smart applications and analytics. It has around 2.2m subscribers to its services in industries including transportation, warehousing and inventory, heavy equipment, natural resources, maritime and government. Its solutions enable businesses to maintain contact with their remote assets, thus achieving improved operational efficiency. Global coverage is provided via ORBCOMM's own LEO constellation and Inmarsat's GEO satellites. ORBCOMM's own LEO constellation is dedicated to M2M transmission. It includes 17 newer OG2 satellites (five of which are not operational), which offer up to six times the data access and up to twice the transmission rate of OG1 satellites, of which around 20 are still operational, and also have automatic identification system (AIS) capability.

## Planet Labs

**Exhibit 6: Planet's rapid revisit satellite platform**


Source: Planet Labs

Planet Labs is a privately held Earth imaging company based in California. It has over 100 satellites in orbits that enable it to line-scan the Earth's surface every day. The images collected, which typically cover areas of 24×7km, are stored and analysed to monitor changes and identify trends. This information is used in applications as wide ranging as checking on crop growth in fields, preventing deforestation, gaining early warning of pipeline failure, determining the extent of flood damage and detecting attempted insurance fraud. Planet designs and builds its satellites in-house. The satellites are small, only 10×10×30cm in size. Planet is able to modify the satellites to respond to customer needs and get these in orbit quickly because it typically launches new satellites every three or four months.

## SpaceX Starlink

SpaceX received approval from the FCC in March 2018 for a constellation of nearly 12,000 LEO satellites. The ITU was subsequently asked by the FCC to allocate spectrum for 30,000 more. As of early June 2020, 480 of these had been launched in seven separate batches, making SpaceX the largest satellite operator in the world. The satellites are 227kg each. From the end of 2020, SpaceX intends to launch satellites with optical inter-satellite links that will allow them to share data with each other, ensuring that customers will never lose service. On 22 October 2019 SpaceX founder Elon Musk successfully sent a Tweet via Starlink, with the initial 'Sending this tweet through space via Starlink satellite' being followed two minutes later by 'Whoa, it worked!!'. Less publicly, at the same time the service was being tested by the US Air Force on a C-12 transport plane, indicating that SpaceX hopes to take a share of the US military's US$14bn space budget. In February 2020 Bloomberg noted that SpaceX was considering spinning-off and pursuing a public offering for Starlink.

SpaceX has faced criticism regarding whether satellites that have reached the end of their life will become space junk, posing a collision danger for other satellites. It has addressed this by lowering the planned orbit of the satellites so that satellites will naturally fall out of orbit and burn-up as they enter the Earth's atmosphere within 25 years of launch because of atmospheric drag. It has also faced criticism about light pollution from satellites. It is addressing this with deployable visors to block sunlight from hitting the brightest spots of the spacecraft.

## Spire Global

Spire was formed in 2012 and is a data and analytics company headquartered in California that collects data from space using its constellation of over 80 operational Lemur nanosatellites. The satellites collect data using a range of on-board sensors and apply machine learning algorithms to predict what will happen in future. The information is used for global ship tracking for example checking on illegal fishing, supporting search and rescue endeavours, assisting insurance investigations and preventing piracy or smuggling, tracking flights in remote areas and for weather monitoring. The company has raised over US$160m in funding and in September 2019 indicated that it provisionally intends to list in 2021.

## Telesat

**Exhibit 7: Telesat's proposed LEO constellation**


Source: Telesat

Telesat is a Canadian satellite communications company that launched the world's first commercial domestic communications satellite, Anik A1, in 1972. It already has a fleet of 14 GEO satellites providing connectivity to airlines, broadcasters, governments, shipping lines and enterprises with sites in remote locations. It intends to supplement this with a network of 298 LEO satellites, which will commence polar launches in 2022 with full global services available in 2023. The system will use optical inter-satellite links to connect locations anywhere on earth via a single network. While this configuration will provide terabits of capacity, Telesat believes it will need to expand the constellation over time to satisfy demand and has submitted proposals to the FCC covering up to 1,671 satellites. The company's first LEO satellite was launched in January 2018 and has been used since then to support live demonstrations across a variety of markets and applications. At c 750kg the new LEO satellites will not fit into the small satellite category, which has an upper bound of 500kg, but we believe the constellation is of interest because it being developed by an established communications company in which Loral Space and Communications (LORL:US) has a 63% stake.

## US Space Development Agency

The US Space Development Agency (SDA) was formed in March 2019 to ensure US technological and military advantage in space by co-ordinating the development and deployment of the US Department of Defense's National Defense Space Architecture. This is a proposed network of nearly 1,000 LEO satellites that will locate targets on the ground and at sea and track advanced missiles and then rapidly convey that information to a missile interceptor. Other functionality, such as a navigation system for GPS-denied environments, will be added over time. The tracking and communications satellites will have optical links so they can talk to each other. The agency wants to launch its first satellites in 2020 ahead of the network commencing operations with 20 satellites in 2022 and is turning to commercial providers to help meet these ambitious timescales. Having secured US$125.3m funding from Congress for calendar 2020, in May the agency issued a Statement of Work, setting out details of the first phase of the constellation for contractors interested in tendering for the project. This document notes that one of the critical technologies that the first phase needs to prove is the optical intersatellite crosslinks, up to four per satellite (ie forwards and backwards and either right and left or up and down) that will enable satellites to communicate with their nearest neighbours. These will be supplemented with radio frequency crosslinks as a back-up. If a satellite cannot establish a contact with a ground-station it can pass data from one satellite to the next until it reaches a satellite with a connection to the ground.

# Enabling the space industry's new paradigm

The shift from small numbers of large, expensive GEO satellites to less expensive small LEO satellites has revolutionised the way in which satellites are manufactured. It has also transformed the approach to manufacturing the communications payload on satellites and the way in which satellites are launched. In this section we profile three companies that epitomise this approach: AAC Clyde Space, which, among other space related activities, designs and manufactures nano-satellites; Mynaric, which aims to be the first company to offer laser communications terminals in the volumes and at the price point required by communications systems described earlier in this note; and SpaceX, which deploys reusable launch platforms to cut the cost of space travel.

## AAC Clyde Space (AAC:SS): Full range of satellite solutions

AAC Clyde Space was formed when ÅAC Microtec, which is based in Uppsala in Sweden, acquired Glasgow-based Clyde Space for SEK376m (US$38m) in January 2018. It has been supplying the small satellite market since 2005. The group designs, manufactures and sells avionics, management and control subsystems such as on-board controllers, power systems, altitude and orbital determination and control systems and data management systems for satellites up to 150kg. It also builds, integrates and tests complete nanosatellite platforms up to c 25kg and offers a 'satellite-as-a-service' capability in which it designs missions, builds the satellites, arranges for them to be launched and then operates them on behalf of the customer. For example, it will own and operate two asset-tracking satellites for ORBCOMM (see above), allowing its customer to focus on business delivery. A summary of recent orders (Exhibit 8) illustrates the breadth of the group's offer. The group employs over 90 people.

Fundamental to the group's approach is the use of standardised subsystems and platforms to reduce the cost of manufacturing satellites, thus enhancing the economics of proposed constellations, with the goal of then supplying multiple identical satellites for these constellations. This includes replacements when satellites are retired after five years. The satellites are designed on the CubeSat principle. Standard 10cm$^3$ modules or units containing microelectronics and power systems are combined with solar panels to provide power to create 1U (1 unit), 3U, 6U or 12U satellite packages weighing from around 1kg up to around 20kg. The modules contain standardised control systems that are customised by enabling and disabling software functionality. The modular nature of CubeSat design gives a disproportionately favourable increase in payload capacity as more units are added because less than 2U of a configuration is typically used for mission subsystems. The group has the capacity to manufacture up to 120 satellites a year of the same model.

**Exhibit 8: Significant orders announced since April 2019**

| Customer | Order | Value (US$k) | Comment |
|---|---|---|---|
| Orbcomm | Construction and operation of two 4kg Cubesats | 5,900 | Satellite-as-a-service model |
| Kepler Communications | 6U satellite | N/A | Third satellite ordered by customer. Prototype for constellation delivering IoT connectivity. |
| Eutelsat | Delivery and launch of two 6U CubeSats | 2,140–5,350 | Scheduled for launch Q121. Potential expansion into full commercial constellation of 25 satellites by 2022 offering global coverage for IoT. |
| US Air Force Academy | Three small satellite solar panels and eight small satellite reaction wheels for FalconSAT programme | 655 | Delivery scheduled for Q320. Third order from US Air Force Academy. |
| Intuitive Machines | Power systems for Nova-C lunar lander mission | 575 | Project to provide transit to lunar orbit, payload delivery to the lunar surface, and data communications and power services to assets both in lunar orbit and on the surface. First robotic landing on the moon planned for 2021. |
| NSLComm | Manufacture, launch, commission and operate a 6U satellite. Includes delivery of ground segment software | 1,500 | Satellite NSLSat-2, scheduled for launch in Q321, will be the first of an intended commercial constellation of c 80 satellites monitoring assets in industries including oil, shipping and agriculture. AAC Clyde Space has been appointed 'preferred supplier' to this proposed constellation. Follow-on order from NSLSat-1, which was delivered in 2019. |
| Intuitive Machines | Battery systems for Nova-C lunar lander mission | 730 | Broadens scope of earlier order related to mission. |
| Orbital Microsystems | Construction and delivery of 6U Epic satellite platform plus associated services including launch and commissioning support | 642 | Satellite for delivery in April 2021. Part of Global Environmental Monitoring Satellite (GEMS) programme. Order follows on from in-orbit success of IOD-1 GEMS, a 3U satellite produced by AAC Clyde Space. |
| Loft Orbital | Power systems to manage power distribution to multiple payloads hosted on the YAM-3 and YAM-5 satellites | 250 | Order announced April 2020. Use of existing design for systems enables delivery by end 2020. |

Source: AAC Clyde Space press releases

It also builds, integrates and tests complete nanosatellite platforms up to c 25kg and offers a 'satellite-as-a-service' capability in which it designs missions, builds the satellites, arranges for them to be launched and then operates them on behalf of the customer. For example, it will own and operate two asset-tracking satellites for ORBCOMM (see above), allowing its customer to focus on business delivery. A summary of recent orders (Exhibit 8) illustrates the breadth of the group's offer. The group employs over 90 people.

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The group already has an exemplary track record in the small satellite industry. Management estimates that there were over 1,500 satellites weighing between one and 10 kilograms launched between 1998 and 2019 and that the group had provided components for around 30–40% of these. A large part of this was the provision of subsystems for the Spire constellation of earth observation satellites. Over the last year the group has delivered two satellites. It is currently ramping up for the start of manufacture of seven satellites in its Glasgow facilities.

For more information on AAC Clyde Space, please refer to Edison's research on the company.

## Mynaric (M0Y:GR): Fibreless optical links in the skies

Mynaric was founded in 2009 by former employees of the German Aerospace Centre (DLR) to commercialise wireless laser communications technology for space and aerospace applications. The company demonstrated the viability of this technology through a series of tests culminating in a 10Gbps air-to-ground transmission from a moving aircraft in 2017. It has commenced pre-production and is currently preparing for the serial production phase. The company's headquarters are close to Munich in Germany with a subsidiary in Los Angeles. It employs over 140 people and listed in 2017.

**Exhibit 9: Product portfolio**

| Product | Function | Status |
|---|---|---|
| HAWK AIR | Terminal for air operations | Unveiled at Paris Air Show in July 2019. Available now. |
| HAWK SPACE | Terminal for inter-satellite and satellite-to-ground operations | Details to be disclosed. Will be based on HAWK AIR platform, but tailored to needs of specific mega-constellations. Potentially available by end 2020. |
| CONDOR | Inter-satellite operations | Preliminary stages of production commenced. Available for launch on-satellite H220. |
| RHINO | Ground terminal for satellite operations | Available now. |
| ARMADILLO | Ground terminal for air operations | Available now. |

Source: Mynaric data

Earlier this year Mynaric completed the manufacture of the initial pre-series volumes of its airborne terminal. Initial volumes of its space terminals are going through the final test and qualification phase, with delivery of the first units to customers scheduled for H220. It currently has more optical communications terminals in its production schedule (over 30 units) than have ever been launched by all of its commercial competitors combined. The ability to supply terminals at the same time as potential customers are launching their initial pathfinder flights positions Mynaric as a key supplier to these proposed mega-constellations.

In October 2019, Mynaric announced that it was going to deliver multiple laser communication flight terminals under an initial contract valued at €1.7m for a product validation mission. This will be the first launch of its complete satellite terminal into space and is scheduled for H220. The name of the customer has not been disclosed. This was followed in January by a multi-million-euro contract from another, also undisclosed, space customer. This second contract is also for terminals for deployment as part of a product validation. If these product validation missions are successful, Mynaric could potentially generate substantially more business from these customers.

Mynaric's technology uses near infrared light waves (200THz, 1THz = 1,000GHz) to transmit data from one point to another in free space, ie without having to pass down optical fibre. This technology supports transmission rates similar to that achieved through optical cables in terrestrial applications. Experiments have demonstrated rates up to 320 times faster than the transmission rates achievable using advanced microwave (radio frequency) to link between satellites and the earth and for inter-satellite links. This speed is clearly advantageous for internet-in-the-sky applications. It is also beneficial for downlinks from earth observation satellites, which currently do not have the bandwidth to transmit all the data they collect. Since wireless laser beams do not spread out like microwave links, they are much more difficult to intercept illegally and are thus much more secure. The narrowness of the laser beam also means that wireless laser links from one network are very much less likely to cause interference with wireless laser links in another network, meaning that it is not necessary to obtain an operating licence from the ITU for a wireless laser network. The interference issue is particularly important when considering constellations of many hundreds of LEO satellites and their impact on transmissions from existing GEO satellites. Additionally, laser links are significantly more power efficient, which is an important advantage when transmitting from a solar powered satellite.

**Exhibit 10: Preparing for serial production**


Source: Mynaric

In February 2020 Northern Sky Research published the second edition of its Optical Satellite Communications report. This forecast a US$3.8bn cumulative revenue opportunity until 2029 for space-based laser communications, with a significant portion of the revenue flow going to lasercom terminal manufacturers. This growth is dependent on widespread deployment of the technology (nearly 11,000 units by 2029, with two to five terminals per satellite according to Northern Sky Research) in non-GEO constellations.

For more information on Mynaric, please refer to Edison's research on the company.

## SpaceX: Reusable rockets reduce cost of launch

SpaceX is a private company founded in 2002 by Elon Musk with the ultimate goal of enabling humans to live on other planets. In pursuit of this goal, it is designing, manufacturing and launching advanced rockets and spacecraft. These are designed to be reusable on the premise that this is the key breakthrough needed to reduce the cost of access to space and enable people to live on other planets. Whether or not Elon Musk will achieve his dream of putting humans on Mars remains to be seen, but the resultant reduction in satellite launch costs is an important factor underpinning the realisation of mega-constellations. The company currently employs around 6,000 employees across locations including its headquarters in California, launch facilities at Cape Canaveral Air Force Station in Florida, the Kennedy Space Center in Florida and the Vandenberg Air Force Base in California and a rocket development facility in McGregor, Texas.

SpaceX is one of the world's fastest growing providers of launch services using its Falcon 9 and Falcon Heavy rockets. Falcon 9 is a two-stage rocket designed and manufactured by SpaceX for the reliable and safe transport of satellites. It delivers payloads into space either inside a composite fairing designed to deliver multiple satellites into orbit or as cargo inside a free-flying Dragon spacecraft carried on the nose of the rocket. The Dragon spacecraft is also capable of carrying up to seven passengers to and from Earth orbit or beyond. The Falcon 9's simple two-stage configuration minimises the number of separation events, thus improving reliability and it has nine first-stage engines so it can safely complete its mission even in the event of two engines shutting down during flight.

**Exhibit 11: BulgariaSat1 drone ship landing footage**


Source: SpaceX

Crucially the Falcon 9 is partially reusable, with the first stage capable of re-entering the atmosphere and landing vertically on a drone ship or on land after separating from the second stage. The Falcon Heavy is a more powerful version of the Falcon 9, with three Falcon 9 nine-engine cores. The Falcon 9 can place a payload of up to 22,800kg in LEO, the Falcon Heavy up to 63,800kg, which is more than a 737 jetliner loaded with passengers, crew, luggage and fuel. The standard pricing for a launch is US$62m (2018 rates) for a Falcon 9 and US$90m for a Falcon Heavy. SpaceX claims that the Falcon Heavy can lift more than twice the payload of the next closest operational vehicle, the Delta IV Heavy, at one-third the cost. SpaceX is selling rideshares on Starlink launches to other companies, with launch prices for a rideshare payload of up to 200kg starting at US$1m.

The two rocket types have completed around 100 missions so far, representing contracts worth over US$12bn. These include batches of satellites for the Iridium NEXT and Starlink constellations as well as delivering equipment to the International Space Station for NASA and returning to Earth with cargo.

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