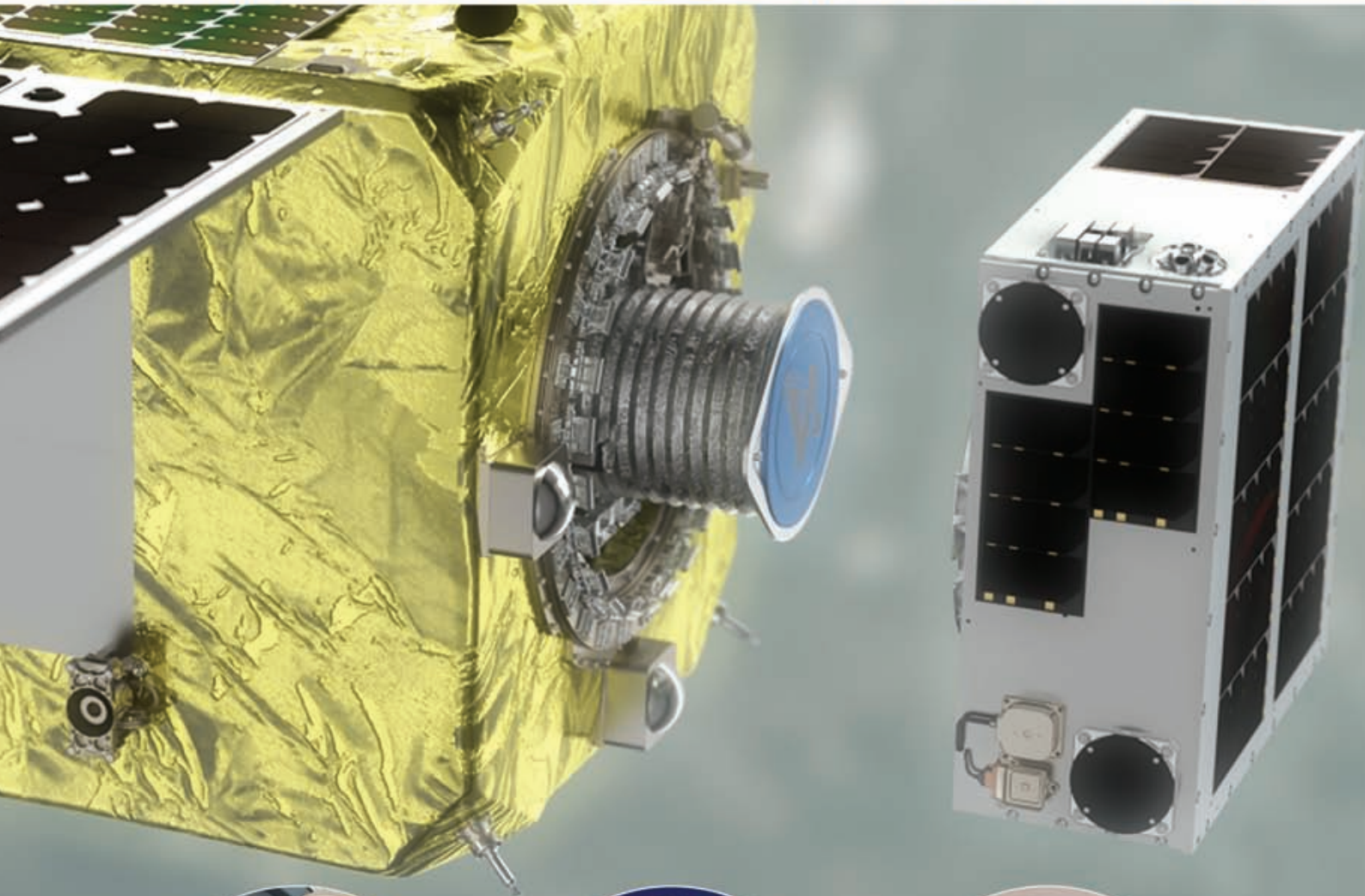
ISSN: 2516-4848

April 2020

Issue I / Volume 3

NewSpace INTERNATIONAL

In this issue: #SKYRORA #MANUFACTURING #NASA #SETTLEMENTS #ROBOTS #DEBRIS #QUADSAT #LEO #MEO



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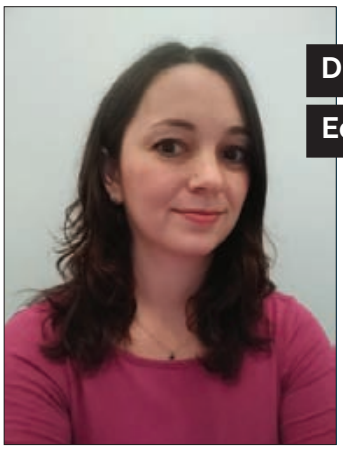

Dr Amy Saunders

Editor

Welcome to the April issue of NewSpace International, the first issue of the New Year! In this issue, we've focused on sustainable off-world settlements, covering areas from eco-habitats, water resources, robotics and manufacturing, all of which will be essential for humankind to find its second home in space.

While ambitious plans for off-world settlements remain in the eyes of many as science fiction, space sector professionals the world over are exploring ways to make it reality. In our overview of recent developments on page 16, we consider the sustainability factor and the importance of microorganisms, as well as eco-habitats such as the Seed of Life project.

Meanwhile, space-based robotics are advancing as fast as their terrestrial counterparts, with China successfully landing its Chang'e 4 lander and Yutu 2 rover on the far side of the Moon, with Chang'e 5 due for launch later this year. In other news, the European Space Agency (ESA) has issued a call for proposals for spelunking Moon robots in the hopes of finding water and a sustainable underground base. In this article on page 24, we also review how space-based robotics are helping extend the lifetime of satellites, with Northrop Grumman's MEV-1 nearing its first docking stage.

On a related subject, off-world manufacturing, an essential for supporting human life beyond Earth, is coming on in leaps and bounds with experiments with cement on board the International Space Station (ISS), and 3D printing prototypes such as Made In Space's Additive Manufacturing Facility (AMF) and Firmamentum's Refabricator project on the ISS. You can read about my personal favourite experiment in off-world manufacturing, the production of 3D printed meat on board the ISS, on page 8.

In this issue, we also discuss orbital sustainability with Astroscale on page 20. ■

Mars One

Sustaining life beyond Earth

Front cover: Photo courtesy of Astroscale

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ISSN: 2516-4848

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Singapore's Equatorial Space reveals 'Dorado' sounding rocket launch services

The Dorado, named after the swordfish constellation, will be Equatorial Space's second rocket after the Low Altitude Demonstrator, pending launch due to the COVID-19 work and travel restrictions.

The Dorado rocket will be the very first, commercial sounding rocket capable of exceeding the Karman Line, the conventional boundary of space, in Southeast Asia. The slender, 6.5m-long rocket will weigh approximately 370 kilograms once ready for its first mission in Quarter 4 this year.

The Dorado sounding rocket

"Unlike the SHARP vehicle which we are concurrently working on, the Dorado is not a technological demonstrator. It's meant to be simple, cost effective, and quick to launch and will not feature a Guidance, Navigation, and Control system," says Simon Gwozdz, the CEO of Equatorial Space.

"The Dorado will be made available in two versions - a single-stage vehicle designed to reach an apogee of 105 kilometres, and a two-stage version capable of reaching altitudes above 200 kilometres. This will provide our clients with approximately 3 and 6 minutes of weightlessness respectively."

The pricing of the Dorado missions, as well as the launch locations will be revealed at a later date.

Equatorial Space is a Singapore-based space tech startup developing innovative technologies for space launch and exploration activities. With its proprietary hybrid propulsion, its technology. ■

Arianespace to resume its launch campaigns at the Guiana Space Centre

Following the measures presented by the French government on April 28 as part of the gradual resumption of activity planned from May 11, and the announcement of a restart of operational activities at the Guiana Space Center, Arianespace confirms its following launch objectives:

- Flight VV16/SSMS – The first "rideshare" Vega launch, carrying approximately 50 small satellites, in mid-June;
- Flight VA253 – A dual-payload Ariane 5 mission for two customers, Intelsat and B-SAT, at the end of July.

All of these campaigns will be carried out in strict compliance with the health rules published by the Prefect of French Guiana, as well as the French CNES space agency and the Guiana Space Center. The objective is to preserve the health of launch site workers and those who are deployed to the space center, as well as the local population – all while ensuring the security and safety conditions required for preparation of the planned launches.

After the suspension of launch campaigns that was imposed on March 16, standby measures and security controls for launch vehicles and satellite payloads were handled by the teams of Arianespace, CNES and all the companies involved in the Guiana Space Center, and carried out in accordance with standard procedures.

The launch campaigns for two Soyuz missions – Flights VS24 and VS25 – will resume this summer. As of April 21, the measures to maintain the launch site in an operational configuration have been carried out with local teams based in French Guiana, applying social distancing measures. ■

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Off-world manufacturing

Off-world manufacturing is something of a conundrum – vital for the present day ultra-ambitious deep space exploration projects and planned otherworld settlements – the field remains in its infancy. Research is much needed should these grand dreams ever be realised, but there's a long way to go.

Amy Saunders, Editor, NewSpace International

Ever since man first entered the space domain, the topic of space-based manufacturing has been a very real and ongoing discussion. Back in 1969, Russian astronauts on the Soyuz 6 mission performed the first welding experiments in space, while the 1973 Skylab mission served as a manufacturing laboratory for 24 weeks; experiments included molten metal processing, crystal growth, electron beam welding, etc. In more recent years, NASA has been performing masses of research on board the International Space Station (ISS) across several distinct laboratories and disciplines.

The benefits of space-based manufacturing are well-established; potentially hazardous industrial processes can be performed in space with minimal risk to humankind or our environment; the unique space environment enables some processes which are not easily produced on Earth; the cost savings and increased practicalities that come with utilising resources – such as mined materials or extracted gases – in situ. All are extremely attractive to researchers looking to expand humankind's manufacturing capabilities into space, however, the unique space environment poses something of challenge for would-be manufacturers. The microgravity environment, the hard vacuum, the temperature extremes, the severe limits of materials, technology and equipment, not to mention the differing characteristics of materials in space, must all be considered.

Cementing an off-world future

One notable recent step forward in off-world manufacturing saw the creation of cement on board the International Space Station (ISS) in April 2019. Producing the common building material in microgravity for the first time, astronauts showed that the cement was able to harden and develop in space. Of course, anyone who knows anything about cement will understand that it can be made with local materials, opening up the door for the inclusion of Moon, Mars or other regolith.

"On missions to the Moon and Mars, humans and equipment will need to be protected from extreme temperatures and radiation, and the only way to do that is by building infrastructures on these extra-terrestrial environments," said Study Principal Investigator Aleksandra Radlinska, an Assistant Professor of Civil Engineering at Penn State. "One idea is building with a concrete-like material in space. Concrete is very sturdy and provides better protection than many materials."

The Microgravity Investigation of Cement Solidification project saw water mixed with tricalcium silicate, the main mineral ingredient in some of the most commonly used commercial cements here on Earth. When researchers compared the cement samples made on Earth with the cement samples made in space,

European Space Agency astronaut Alexander Gerst works on the MICS experiment aboard the International Space Station. Credit NASA

they found that the cement created on the ISS had very different microstructures, including increased porosity, than the cement made on Earth. However, the researchers think the way the experiments were conducted may have influenced the results of the study; cement on Earth is not processed in sealed, plastic pouches like it is aboard the controlled environment on board the ISS. Notably, although the space-made cement came out looking a little different from the Earth-made cement, it still developed and hardened.

3D printing

One of the most ground-breaking new technologies in recent years that must be highlighted when considering space-based manufacturing is 3D printing/additive manufacturing. The technology has gone from science fiction to science fact in the blink of an eye. The process is a sophisticated system in which material is joined or solidified under control of a computer to create a 3D object. The possibilities are almost endless, with the end product controlled via a 3D model or Additive Manufacturing File (AMF).

There are a number of interesting recycling projects around right now, including a 3D printer utilising waste plastic pellets to make new 3D printed objects by re:3D, which are proving exciting for eco-scientists the world over. Meanwhile, consumers are really getting in on the action with affordable printers utilising their own custom designs – anecdotally, I have one friend producing 3D printed light fittings as a hobby.

3D printing is also being utilised by a number of companies in the space sector; Blue Origin's BE-4 engine features a number of 3D printed parts, including the Ox Boost Pump (OBP) and the turbine nozzle and rotors; CRP Group has 3D printed a complete CubeSat, which doubles up as a dispensing system for two smaller TubeSats, made from its proprietary Windform material, a carbon fibre reinforced composite; Relativity Space is currently working on an entirely 3D printed launch vehicle, having recently raised US$140 million in funding which will fully finance its Stargate factory, a semi-autonomous full-scale production facility to house massive 3D printers and produce its first rocket, Terran 1.

Moving beyond Earth, there are endless possibilities when it comes to 3D printing in space. There are significant cost savings to be made by not having to launch tools and equipment into orbit, not to mention the time saved by simply printing whatever is needed, in space. Providing astronauts with the ability to print the things they need, when they need them, makes long-duration space travel, such as missions to the Moon, Mars and beyond, much more viable, not to mention much safer. Research has shown time and time again that self-sufficiency is vital as we move forwards into a space-faring era.

Despite all these advancements and the endless possibilities, 3D printing has a long way to go until we're seeing true space-based factories. There are very few off-world 3D printing initiatives under way, although we do expect to see more in the years to come.

Made in Space advances NASA Archinaut programme

Until recently, Made in Space (MIS) was the only commercial company currently working with additive manufacturing in space. The company leverages the unique properties of the space environment such as microgravity and vacuum conditions to develop solutions to commercial, industrial, research and defence challenges. According to MIS, by manufacturing and assembling structures in orbit, incredible design possibilities for extending the life of current on-orbit assets or entirely new structures can be unlocked. The MIS Additive Manufacturing Facility (AMF) was launched to the ISS in 2014, having been specifically developed to operate in a microgravity environment. Since it is installation, the AMF has been utilised by NASA, the US National Laboratory and commercial partners to carry out repairs, upgrades and installations, as well as complete novel experiments.

MIS has also been collaborating with NASA for its Archinaut Technology Development Project, an in-space additive manufacturing and robotic assembly platform, for several years, during which time the core technology, Archinaut's Extended Structure Additive Manufacturing Machine (ESAMM), and the Ground-Based Manufacturing and Assembly System Hardware (GBMASH), have been developed and ground tested.

In March 2019, MIS successfully demonstrated its additive manufacturing and robotic assembly

capabilities in a space-like environment. The Archinaut system underwent thermal vacuum (TVAC) testing at Northrop Grumman's Space Park facility; the TVAC testing simulated the thermal and pressure environment of a satellite in LEO to validate the technology readiness for the space environment. During TVAC testing, MIS successfully demonstrated manufacturing and robotic assembly of a variety of structures. While inside the vacuum, operations were monitored and inspected by an internally developed camera system to validate proper printing and assembly operations. MIS demonstrated autonomous reversible connection and joining techniques of 3D printed parts and other prefabricated components such as nodes and trusses via a robotic arm system and end effector designed for in-space assembly operations. Furthermore, the robotics system is also capable of carrying out repair operations and can be integrated into small satellites for payload retrievals and installations. With the completion of this ground-based testing, core Archinaut technologies are now prepared to operate in space.

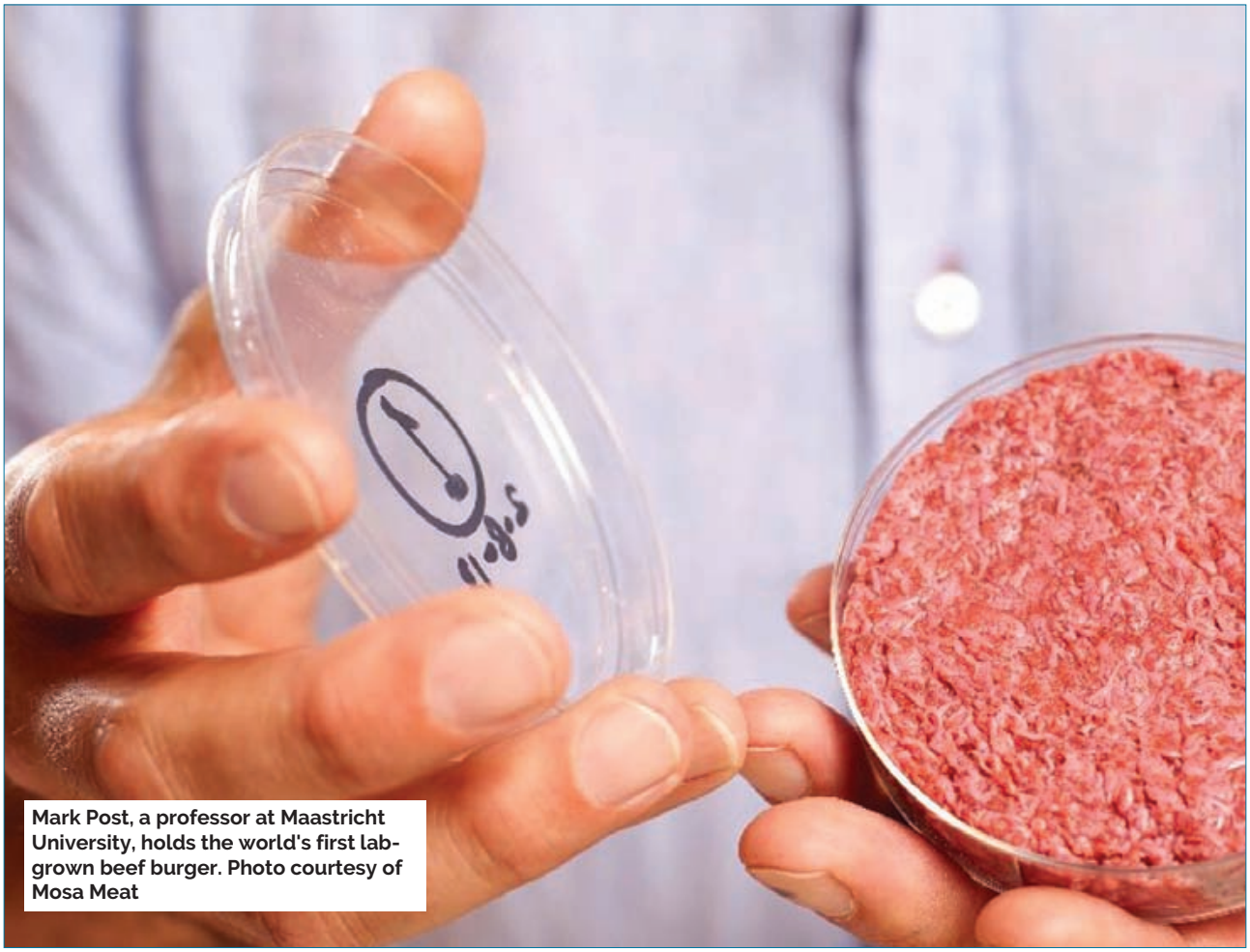
Most recently, in July 2019, NASA awarded MIS a contract to demonstrate the company's autonomous robotic manufacturing and assembly platform, Archinaut, on a flight mission. The objective of the mission, dubbed Archinaut One, is to construct two ten metre solar arrays, on orbit, to power an ESPA-class satellite. Once on orbit, Archinaut One will employ its extended structure additive manufacturing capabilities and advanced robotics to manufacture and assemble the satellite's power system. The Archinaut-created solar arrays will yield nearly 5x the power currently available to ESPA-class satellites.

In other news, MIS is also working with NASA to develop a next-generation metal space manufacturing system dubbed VULCAN. The system will fabricate precision parts made from more than 30 aerospace-grade metals and high-grade polymers, and hybrid components that combine multiple materials. VULCAN will be able to manufacture parts that require the strength and durability of aerospace-grade materials, such as housings for life support systems, that can't be made with current systems. The technology is being developed for a demonstration on the ISS to demonstrate its usefulness in future human spaceflight operations, such as on board the Lunar Orbiting Platform Gateway.

VULCAN will be the first of its kind to bring machined parts to space, enabling more critical parts to be manufactured off-world. The system's hybrid technique utilizes both additive manufacturing to create the desired near net-shaped part, and traditional manufacturing methods to machine down and create the finished product. The unique system manufactures, refines, and performs quality checks in a streamlined, automated process, eliminating the need for a human in the loop during manufacturing. VULCAN is expected to be ready for launch in the mid-2020s.

Whatever happened to the Refabricator?

Mankind's second space-based 3D printing achievement is the Refabricator experiment. Developed by TUI subsidiary Firmamentum under a NASA Phase III Small Business Innovation Research (SBIR) contract, the



Mark Post, a professor at Maastricht University, holds the world's first lab-grown beef burger. Photo courtesy of Mosa Meat

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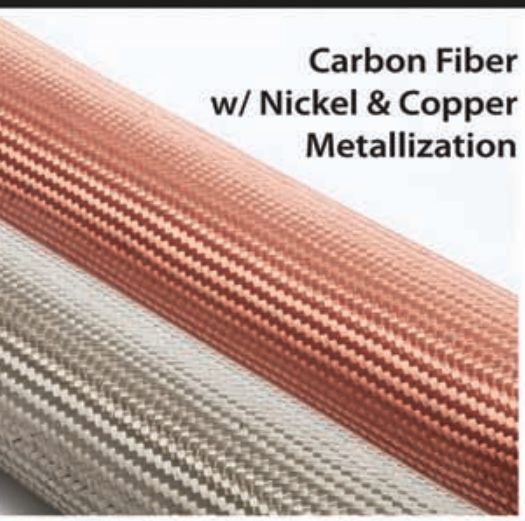

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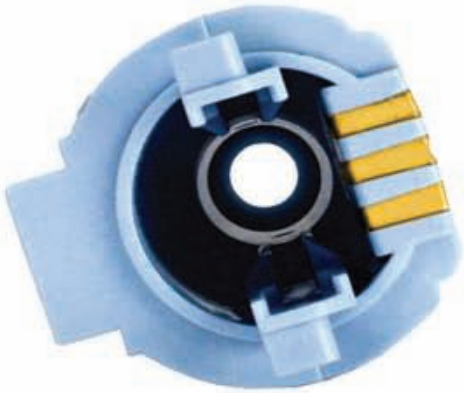

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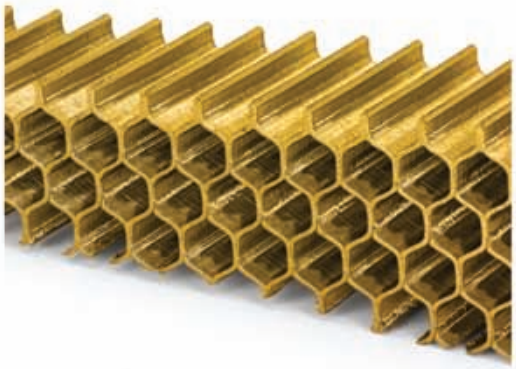

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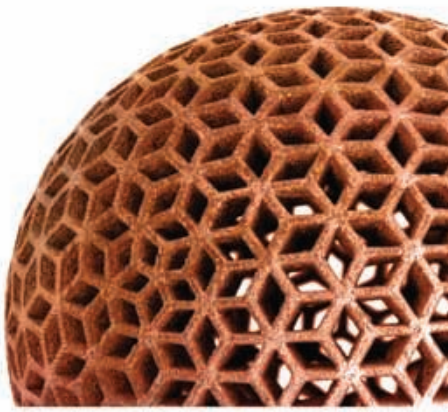

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experiment combines a 3D printer with a recycling system to produce a closed-cycle space-based manufacturing process. Around the size of an under-counter fridge, the Refabricator accepts plastic materials of various shapes and size, transforming them into feedstock for 3D printing.

"When we begin launching humans to destinations beyond low Earth orbit, space will be at a premium," said Niki Werkheiser, Manager of In-Space Manufacturing at NASA's Marshall Space Flight Center in Huntsville, Alabama. "It simply won't be feasible to send along replacement parts or tools for everything on the spacecraft, and resupplying from Earth is cost and time prohibitive. The Refabricator will be key in demonstrating a sustainable logistics model to fabricate, recycle, and reuse parts and waste materials."

"The Refabricator demonstration is a key advance toward our vision of implementing a truly sustainable, in-space manufacturing ecosystem," said Rob Hoyt, TUI CEO. "Astronauts could use this technology to manufacture and recycle food-safe utensils and turn what is now inconvenient waste into feedstock to help build the next generation of space systems. We believe re-using the waste could reduce the cost and risks for NASA and private space exploration missions."

According to the project, almost all the Refabricator operations are remotely commanded and controlled from Marshall's Payload Operations Integration Center and TUI. The Refabricator will be the first integrated recycler-manufacturer in orbit and may eventually be able to recycle and print, using metal as well as plastic, with very little monitoring from the station crew members.

The Refabricator was launched to the ISS in November 2018 on board Northrop Grumman's Cygnus spacecraft's 10th commercial resupply services mission and was duly installed on board the space station in February 2019.

Little news has been released on this project, until January 2020, when NASA reported that ground teams had successfully initiated and completed the first of five tensile sample prints using material that was once recycled on the ground. This hardware represents a key component of NASA's In-Space Manufacturing (ISM) technology development roadmap.

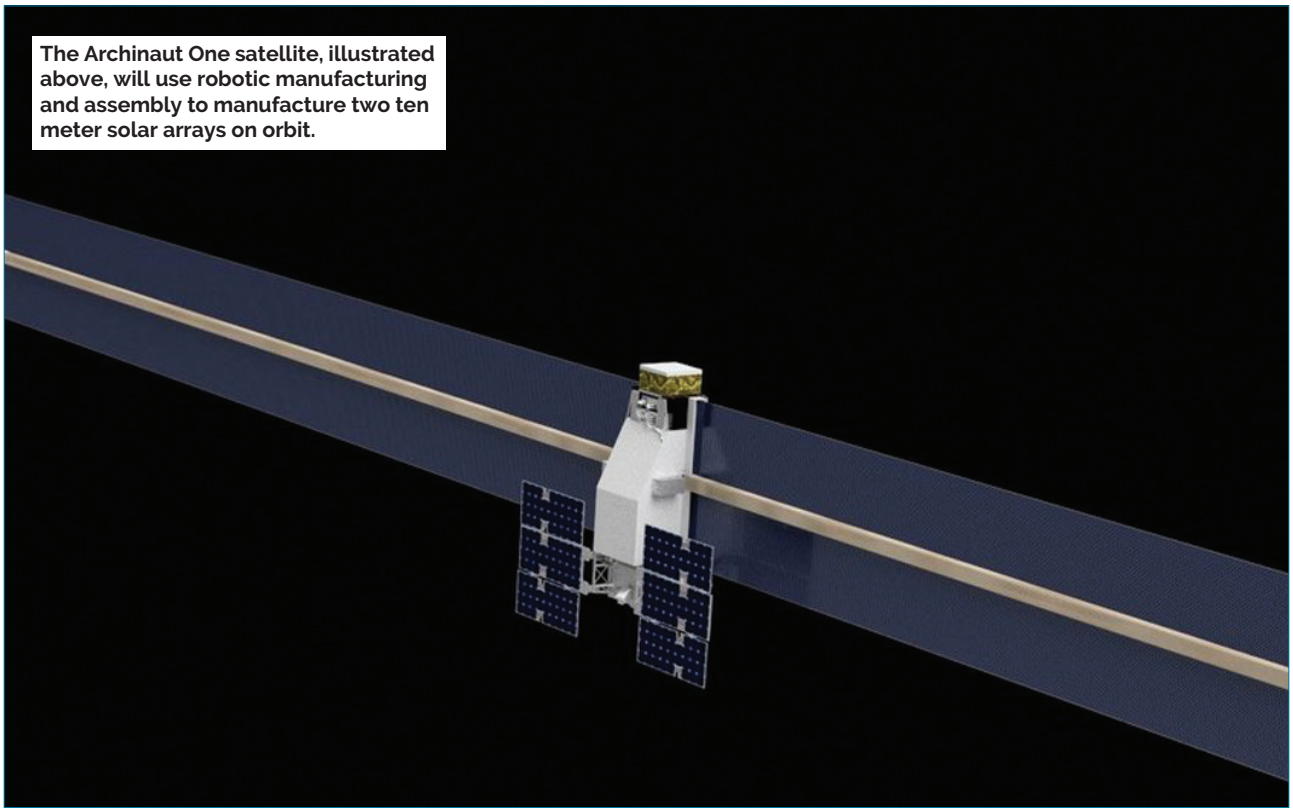
One giant bite for mankind

Space-based manufacturing promises to be a lucrative yet still futuristic endeavour requiring vast amounts of research before the process can truly be of use in off-world missions. While most projects are exploring the nitty gritty of building materials, tools, and other necessities for the future of space travel, one recent story tells of an altogether more human project.

Indeed, towards the end of 2019, a bioprinter on board the ISS successfully 3D printed meat for the very first time. The beef, rabbit and fish cells were created under a Russian-Israeli partnership, partly funded by Roscosmos, as the first example of artificial meat created in microgravity.

"It's one small nibble for man, one giant bite for mankind," said Yusef Khesuani of 3D Bioprinting Solutions, the Russian laboratory that created the bioprinter.

While today's astronauts do enjoy meat on board the ISS, that meat is vacuum-packed or dried on Earth for transport, and for longer journeys, such as the planned missions to Mars and other deep space exploration missions, transporting meat supplies from Earth doesn't work practically or economically. And while other experiments on board the ISS are currently exploring in-orbit crop growth for fruits and vegetables, farming live animals on board the ISS is beyond present possibilities. As such, this experiment may mark the first step towards sustainable lab-grown meat for the astronauts of the future.



The Archinaut One satellite, illustrated above, will use robotic manufacturing and assembly to manufacture two ten meter solar arrays on orbit.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The 50th anniversary of the Black Arrow: UK space experts reflect on the past as the future beckons

At the Farnborough Air Sciences Trust museum, Skyrora and the UK Space Agency celebrated the anniversary of the first successful launch of the Black Arrow rocket with a selection of esteemed speakers. Industry leaders reminisced over the UK's pioneering efforts in the final frontier and shared insights about the industry's bright future in the NewSpace era before an intersectional community of engineers, students, and journalists.

Laurence Russell, News and Social Media Editor, NewSpace International

The 4th of March 2020 marked the 50th anniversary of the first successful launch of the Black Arrow rocket, which would later become the first and currently only British rocket to carry a British satellite into space when it placed the Prospero science satellite into orbit.

The anniversary was celebrated at Farnborough Air Sciences Trust (FAST) Museum, supported by premiere NewSpace company Skyrora in partnership with the UK Space Agency (UKSA).

Speakers at the anniversary event included Richard Gardner, Chairman of the FAST Museum; Alan Thompson, Skyrora's Head of Government Affairs; Emma Floyd, Director of Commercial Spaceflight at the UK Space Agency; and most prestigiously, Terry Brooke, a veteran spaceflight engineer currently employed at Skyrora who is the last surviving specialist to have worked on the Black Arrow rocket.

The speakers addressed a crowd of UK Space Industry insiders alongside a collection of engineering students from Farnborough College of Technology, in front of the second stage fuel canister of the Black Arrow itself, which survived miraculously intact after re-entry following its successful mission to land in the middle of the Australian outback, and was only recently returned to the UK in 2017.

Richard Gardner expressed his enthusiasm for the remarkable artefact, stating: "This significant addition to our display of space satellites, systems and innovations that all came from the former RAE at Farnborough, should attract much interest, especially from young people, as we encourage the next generation to participate in the exciting NewSpace era that Skyrora is helping to re-establish in the UK." He was no doubt in part referring to the following of young engineers who attended the event to celebrate the anniversary, eager for a sense of where the UK's NewSpace industry is headed.

Richard welcomed Alan Thompson, who spoke to how the anniversary inspires the UK's path on the next steps toward space. He explained that: "The engineers who worked on this spectacular rocket, and past UK projects like it are our inspiration. They're what we're celebrating, and their achievements are precisely what Skyrora wishes to recreate, as we realise the UK's Space ambition."

European space business

Skyrora is one the biggest names in the world of European Space business, both as a swiftly growing rocket developer, and as the company that has trailblazed Ecosene fuel, a kind of Kerosene suitable for rockets and aviation, developed from conventionally unrecyclable plastics, which currently only possesses a one percent loss in thrust compared to conventionally produced Kerosene.

Skyrora recently successfully conducted an engine test using Ecosene in Scotland on the morning of the 24th of January, championing the possibility of a green rocket revolution with a fuel which is both cheaper to develop and possesses the incredible potential to introduce unprecedented profit to the recycling industry.

Skyrora hopes to bring together everything they've achieved on their journey to launch their flagship rocket, the 22m tall Skyrora XL, from a Scottish spaceport by 2022 using a series of disruptive technologies such as Ecosene fuel and 3D printed parts, to place smallsat platforms into polar orbit. The launch could catapult the

Alan Thompson, Skyrora's Head of Government Affairs Speaking

UK's space industry forward by field testing a series of emerging technologies and proving the UK's latent launch capability.

Alan closed out his remarks by saying: "Whilst we make progress and open up new opportunities in the NewSpace economy, we at Skyrora believe it is vitally important to see our past successes, to nurture inspiration and drive us forward into the future."

Emma Floyd was warmly welcomed to provide a more overhead view of the UK space sector. She began by introducing UKSA's efforts: "We are committed to growing our space sector, which has been a great success story over the last decade. Since we were established in 2010, the sector has grown by 60 percent to now generate £15 billion per year and employs more than 40,000 people."

She went on the explain the group's next steps: "The UK is world-renowned for building small satellites. Developers like SSTL and Clyde Space are cutting out a healthy slice of the satellite market, but the key to the industry is launch. That is what we are trying to build with the help of Skyrora. Industry and government have invested £40 million in grants to bring both vertical and horizontal launch back to the UK by supporting our spaceports. A healthy launch sector will act as a catalyst for growth in a wide range of UK commercial sectors."

Integrity of fuel systems

Terry Brooke closed out the event by recounting his role in ensuring the integrity of the fuel systems of the first and second stage chambers of the rocket when he was dispatched to Saunders-Roe on the Isle of Wight to aid in the development of the Black Arrow rocket's first and second stage systems.

He shared the reasoning behind the Prospero satellite's name which came from the unfortunate nature of the cancellation of its funding. Just like the Shakespearean sorcerer of theatrical legend, the satellite lost its powers, after a fashion, when the Black Arrow project was cut from the UK defence budget.

The satellite was originally named Puck, after the winsome sprite from A Midsummer Night's Dream, another key Shakespeare character, but was renamed to commemorate the satellite's fall from grace. Like Prospero himself, the development team continued without the powers they'd taken for granted and launched the satellite with what resources they had remaining, successfully orbiting the platform onboard the Black Arrow and making British history despite the Ministry of Defence's then lack of enthusiasm.

The story feels like a testament to the ingenuity of British engineering, that even in a time when the space race boom was dying out, space tech developers refused to give up, and achieved what they'd set out to do on a wing and a prayer. It would appear that the innovative spirit of the UK has survived the UK Government's decades-long disinterest in the space industry, which has seen us fall so far behind our neighbours, to be reinvigorated in time for the NewSpace era.

Terry dedicated his speech to the members of the team behind Black Arrow who are no longer with us and echoed the remarks of his fellow speakers in expressing his enthusiasm to see a new generation of space tech developers pick up where he and his team left off.

At the time of the late 1960s, the UK was still a leading scientific pioneer in the space industry, a reputation we have since lost, though as investment in the NewSpace sector soars and a new era of space travel dawns, British space technology is rising to the challenge with disruptive, collaborative technologies which are rocketing the UK back into a prominent position in the sector. While we may no longer be leading the charge, it looks like the UK will enjoy a valuable place at the table.

Black Arrow Anniversary Speakers

Off-world settlements

Living off-world has for hundreds of years been the starry-eyed dreams of those with massive imaginations, but little hope. Today, we edge closer to off-world settlements, perhaps on the Moon, Mars, or beyond, although perhaps not as fast as some would have us believe.

Amy Saunders, Editor, NewSpace International

The year is 2020, a lovely well-rounded series of numbers to type, and the beginning of a fresh new decade. Sure, climate change is a more pressing threat than ever before, with activists such as Ed Hawkins (of the #ShowYourStripes initiative) and Swedish teenager Greta Thungberg passionately campaigning to save the world; fish stocks the world over are at risk of collapse thanks to overfishing, with North Sea Cod expected to disappear from UK supermarkets imminently; and the Greenland ice sheet is melting at an alarming rate, losing 12.5 billion tonnes of ice in just one day in 2019.

Things might seem a little glum, but there's good news on the horizon. That is, should the human race hold off from bringing ourselves to extinction through war, antibiotic resistance or anti-vaxxers in the near future, we could soon start over with a brand-new shiny planet somewhere in space! While it's unlikely to be the new 'habitable planet' discovered in Autumn 2019 – which, while having liquid water, is likely to have an atmosphere closer to Neptune than Earth thanks to its huge mass – a true off-world settlement is certainly on the horizon, if not in our lifetimes, then in our children's'.

Off-world ambitions

Naturally, there have been more than a handful of ambitious off-world settlement plans and programmes announced in the last decade or so, some of which have been canned – like the Mars One company, which planned to colonise Mars by 2023, but went into liquidation last year – and some of which continue to make steps forward.

Elon Musk (SpaceX) and Jeff Bezos (Blue Origin) both have some very lofty plans for off-world settlements, and both are actively working towards the goals with the development of re-usable launch vehicles – which will make off-world trips more affordable, sustainable and accessible – and crew capsules to ferry astronauts on their interstellar travels. The European Space Agency (ESA) and NASA are both embarked on the first steps of other-worldly homes, while the UAE plans to establish the first human settlement on Mars by 2117 and is focusing on preparing specialised national cadres and developing capabilities in the fields of space science, research, artificial intelligence, robotics and advanced space technologies. And then there is the Space Kingdom of Asgardia, humankind's first space nation -

Mars One

boasting more than one million members already - which plans to establish habitable platforms in space and settlements on the moon.

A sustainable settlement

Of course, a sustainable off-world settlement requires so much more than just the ability to transport humans to Mars. Projects all round the world are currently exploring everything from food production, water supplies through to animal husbandry and suitable habitats. While there are many arguments for the usefulness of incredible synthetic materials and the capabilities of 3D printing in helping bring humankind's first off-world settlement into existence, there are a surprising number of people calling for a more holistic and natural approach.

Terraforming is, naturally, the easy answer, in so far as it is simple to decide to just terraform a whole planet, rather than adapt ourselves to it. Easier said than done, of course. The magnetosphere, atmosphere and temperature would all require major adjustments to enable human life, with possible solutions including importing hydrocarbons or ammonia, the use of orbital mirrors, fluorine compounds, moon dust or algae. There have been a few calls to terraform Mars over the years, notably from Elon Musk, who wishes to detonate nuclear bombs over the planet's poles in order to melt and vaporise the ice caps, liberating water and carbon dioxide, warming the planet. He likes the idea so much that you can buy a 'Nuke Mars' slogan t-shirt... Scientists remain uncertain whether terraforming an entire planet is actually possible, with a 2018 study from Nature Astronomy concluding that Mars doesn't have enough carbon dioxide for complete terraforming. Others have gone on record saying that instead of terraforming other planets, perhaps we should work on re-wilding our own to address the climate damage so many are trying to escape.

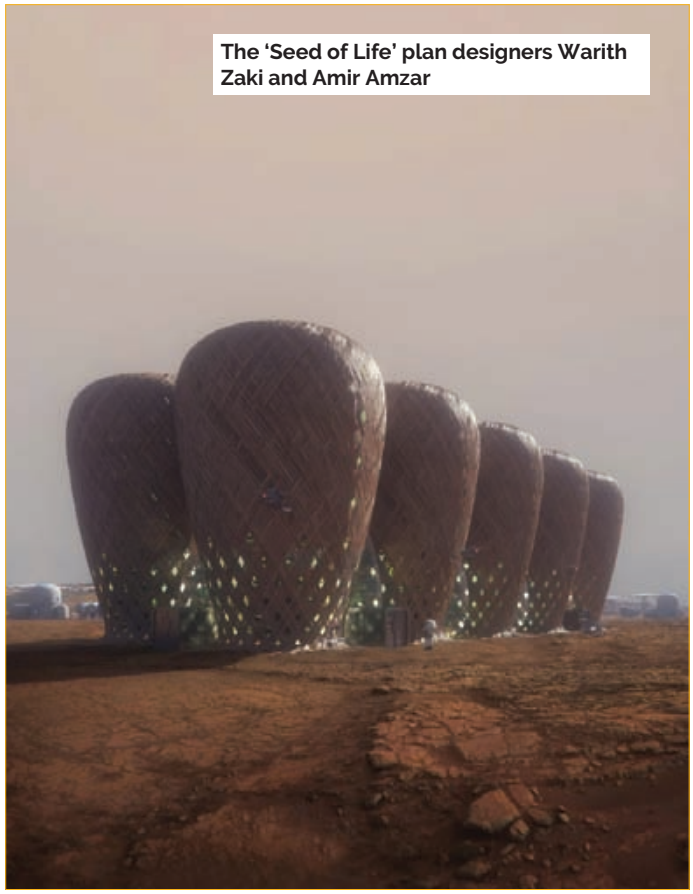
There's also been a great deal of discussion within scientific communities about the role of microorganisms in off-world settlements. A recent paper out of FEMS Microbiology Ecology 'Space Colonization Beyond Earth with Microbes First' claims that microbes would be the ideal immediate investment to jump-start a settlement on Mars.

"Life as we know it cannot exist without beneficial microorganisms," said Jose Lopez, Ph.D., a Professor at Nova Southeastern University's (NSU) Halmos College of Natural Sciences and Oceanography. "They are here on our planet and help define symbiotic associations - the living together of multiple organisms to create a greater whole. To survive on a barren (and as far as all voyages to date tell us) sterile planets, we will have to take beneficial microbes with us. This will take time to prepare, discern and we are not advocating a rush to inoculate, but only after rigorous, systematic research on Earth."

The paper has asserted that microbes should in fact be the first landing party for any future off-world settlements, as they can condition and even terraform (but not the huge-scale changes imagined by Musk et al) areas ahead of human arrival. The idea would see a lot of money saved, as well as improving quality of life in off-world settlements. However, much more Earth-based research would be required first, including the screening of potential hardy microbial candidates, toxic or lethal genes, and describing mechanisms for the most productive symbiosis.

In other news, when it comes to habitats, there are some fascinating ideas being opined. Whether they are realistic visions of the future or not, they make some imaginative solutions to real challenges with settling on Mars. One Malaysian design team has proposed that bamboo harvested and grown in situ could be used to build the first colony on Mars. The 'Seed of Life' plan designers Warith Zaki and Amir Amzar have proposed that a landing zone be scouted in close proximity to water, after which a self-deploying ETFE habitat containing bamboo shoots would be sent to Mars; a drill would release the subterranean water to support the bamboo growth. Once fully grown, the bamboo would be harvested from the growth chamber and woven by autonomous robots, and then used to build modular pods to form a complete colony. Each pod, having taken six years to build, would be filled with water which would freeze in the Martian climate, to provide additional protection from the elements. The fast-growing bamboo would dramatically reduce the amount of building materials required to be transported for an off-world settlement; humans have been using it for millennia here on Earth.

The Seed of Life project is not the only proposal to incorporate natural building materials. Architect Stefano Boeri has suggested that a 'new Shanghai' comprising 'vertical forests' could be built on Mars, utilising plant-covered towers built under sealed space-proof domes. The domes could be delivered via the International Space Station. The work comes off the back of an invitation to imagine what Shanghai might look like in 2117 for Shanghai Urban Space and Art Season (SUSAS) 2017, in collaboration with Tongji University's Future City



The 'Seed of Life' plan designers Warith Zaki and Amir Amzar

Lab and the Chinese Space Agency. Boeri's vertical forests are already in place in Milan, Paris will be getting its own, 'Foret Blanche' soon, and an entire city of vertical forests is planned for China. The domes, too, are very real, with NASA funding a project in Hawaii in 2019 which saw six scientists sealed inside a dome on a remote volcano.

An off-world future?

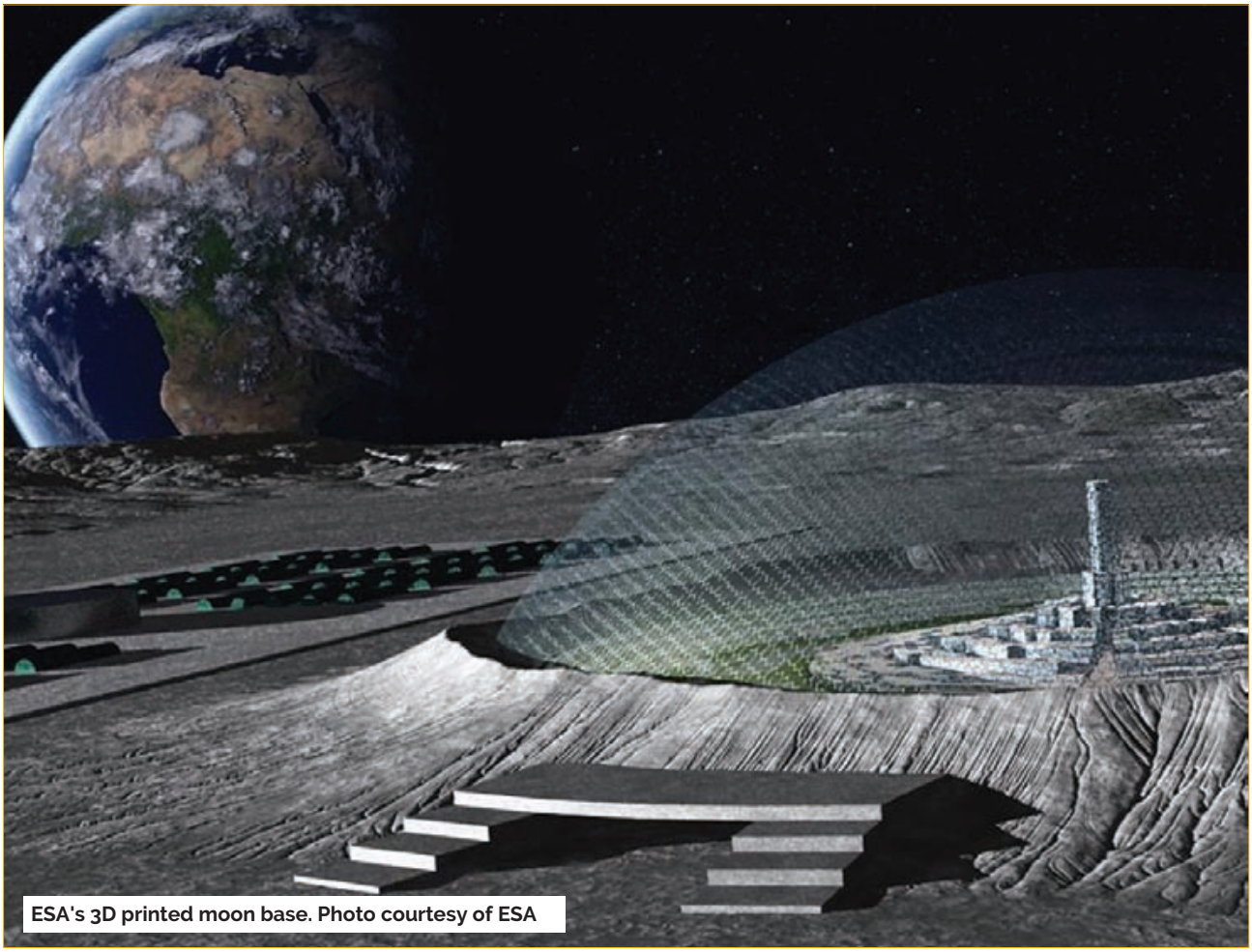
Some have argued that it is the height of human arrogance that we believe we even have the right to settle on other planets. We have made such a mess of our own planet – pollution, overcrowding, climate change, depleted resources, etc. – do we really have the right to do the same to another planet? Moreover, humankind has some pretty dangerous ideas, with horrific human rights abuses, extreme violence towards the vulnerable, and inequality that sees millions of starving people spread across the globe; are these really qualities we want to spread?

We have not even traversed beyond the Moon yet, and already there are arguments between space-faring nations. In 2019, President Donald Trump launched the new Space Command, designed to combat a growing threat to the USA's extra-terrestrial national interests. At the time, he stated: "Space Command will ensure that America's dominance in space is never questioned and never threatened." In response, the Space Kingdom of Asgardia has voiced concerns of the escalation of superpowers increasing their influence on space: "Asgardia cannot condone this move, which they judge to undermine the neutrality of space. Humankind has made tremendous advancements through the global co-operation of the International Space Station and it is surely in this spirit that space exploration, colonisation should surely continue."

"At Asgardia we hugely oppose this continued rhetoric that nations on Earth need to have a dominant military presence in space. The expansionist rhetoric of Trump is a continuation of this worrying trend of world powers seeking to look after their own self-interests by laying claim to space whilst showing no regard for their fellow human beings," said Lena De Winne, Minister of Communications for space nation Asgardia. "One of the key missions of Asgardia is to provide a home in space for humans, to safeguard the human race in a peaceful environment – far away from the weapons on Earth that have the potential to destroy our species. This announcement from President Trump undermines all notions of space being a peaceful environment. Instead, it transitions the battleground of the global superpowers from Earth to space."

All arguments aside, technically-speaking, we have a long way to go before humans successfully settle on a second planet. Despite the outlandish claims of settling humans on Mars or the Moon by 2022 – has anyone else noticed these dates keep getting pushed back? – realistically, we can expect it to take a few more generations yet.

That is not to say that we will never get there, but with so many complicating factors, and we delicate humans having so many precise requirements to thrive, it is going to take time and technology that we just don't have yet.



ESA's 3D printed moon base. Photo courtesy of ESA

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Confronting the issue of space debris

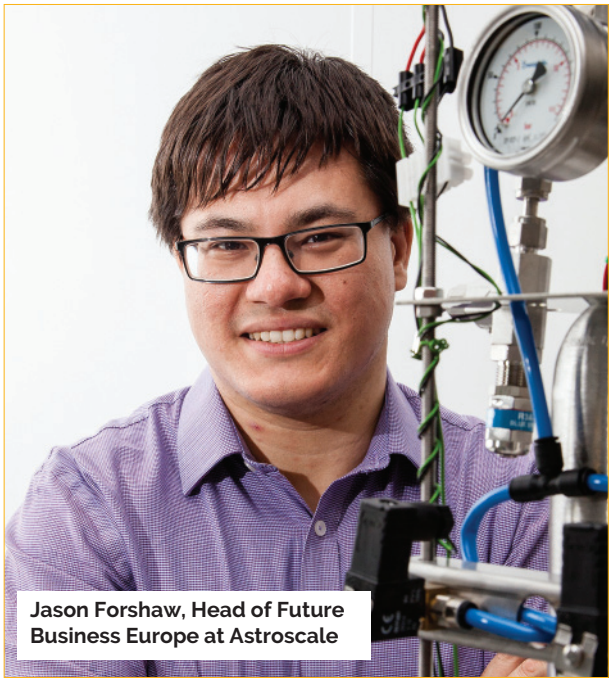
Astroscale is a global company headquartered in Japan which has more than 115 people developing innovations to promote orbital sustainability by confronting the issue of space debris. Their most recent project is ELSA-d, a demonstration that plans to show how spacecraft can be docked with and removed from orbit, showcasing technologies with a myriad of potential applications. Jason Forshaw, Head of Future Business Europe at Astroscale, and Ron Lopez, President and Managing Director, Astroscale US Inc, elaborate further.

Laurence Russell, News and Social Media Editor, NewSpace International

Question: Could you introduce us to Astroscale and how you fit into the NewSpace economy?

Jason Forshaw: Astroscale is a company tackling the propagation of space debris, an issue that's been discussed since the beginning of the space age decades ago. Debris is largely formed by collision events, some of which are due to spacecraft failure. Approximately 9,600 satellites have been launched in our history, of which only about 2,300 are currently functioning. There is no guarantee that a defunct satellite will be effectively de-orbited, so the broken satellites usually stay orbiting around our planet, not always in one piece. It's been estimated that we have about 8,800 tonnes of debris orbiting our planet at a variety of speeds.

Space debris is a clear and present threat to space infrastructure. Not a lot of people realise how many services related to satellites they closely rely upon daily. The infrastructure that underpins our way of life is sent and received in orbit. If the issue of space debris continues to grow as it has been, we are inviting a future, unsustainable space environment.



Jason Forshaw, Head of Future Business Europe at Astroscale

Ron Lopez, President and Managing Director, Astroscale US Inc

Astroscale's vision is to work towards global space sustainability. We do that in two ways: Launching satellites to remove existing debris; and to ensure satellites yet to be launched are equipped with the kinds of features that make them easier to de-orbit, such as Docking Plates (DP) that our removal platforms can connect to.

Our business started in 2013, when our Founder and CEO Nobu Okada sought to address the issue of debris by applying a start-up mentality. We have raised £108 million in capital and have more than 115 personnel across our offices in the UK, Japan, the US and Singapore.

Question: Which technology trends in the industry have particularly affected Astroscale?

Jason Forshaw: There is a general trend towards smaller satellites these days. As technology improves, you find components get lighter and more efficient, allowing for smaller devices, which we have certainly seen in electronics over recent decades. In the past, focus might have been on the construction of single, very large satellites. Today, many companies are working towards smaller, cheaper constellations of satellites that can perform the same functions. In the near future, thousands of satellites will be launched, which will form these larger constellations.

With these smaller satellites, many 'NewSpace' developers take a leaner approach to the design. They are built simpler and faster - methods manufacturers and operators are keen to capitalise upon, achieved in part with Commercial off the Shelf (COTS) components instead of custom-built assemblies. The reduced weight of these models makes them cheaper to launch.

Artificial Intelligence, a big buzzword in the world today, with algorithms capable of processing complex equations and self-learning to differing environments, is having an impact on space as well. Computer vision is

another domain where machines can view and interpret objects and plan a course to approach and orient to these objects.

We are also very interested in space sensors which can track debris with greater acuity, called Space Situational Awareness, which is of course highly conducive to our mission statement. As an innovative company with such considerable goals as ours, staying ahead of trends in the NewSpace sector is essential.

Question: Could you explain your spacecraft ELSA-d (End-of-Life Service by Astroscale demonstration), and what technologies have made it possible?

Jason Forshaw: The ELSA-d mission launching this year will be the world's first commercial demonstration of active debris removal (ADR). The concept we are demonstrating is to launch our platform, rendezvous with a selected orbital client, couple with it, and de-orbit where it will burn up in the Earth's atmosphere.

In the case of ELSA-d, we plan to launch the servicer vehicle and the client together before executing a series of docking procedures, including an instance in which we deliberately lose the client vehicle with the intention of finding it, completing a full inspection, and finally docking with it.

It cannot be overstated how complicated procedures like this can be. To remotely orient an orbital platform to be exactly aligned with another object and dock them together is far, far easier said than done; let alone finding one in the depths of space after you have lost sight of it! The size of the Earth's orbital environment is a massive area that is very difficult to conceive.

Question: You're making use of some impressive robotics for this program; could you outline that technology?

Jason Forshaw: There are a few technologies we are using in this project that we are keen to talk about! Perhaps the most obvious is the guidance, navigation, control (GNC) and propulsion systems capable of executing the complex manoeuvres I just mentioned. It is a common misconception that all satellites have some form of propulsion. This is untrue. Many do not, and those that do feature propulsion normally have only a single thruster. Because of the complex rendezvous requirements on our mission, ELSA-d has to have a series of thrusters pointing in a range of directions, to allow precise thrusting and positioning.

The agility we require for a docking and de-orbiting process is at the upper end of solutions currently available, so a lot of our expertise has gone into perfecting them.

Another technology is the all-important magnetic docking system. This is a two-part mechanism made up of the DP itself, and the docking robotics which extend and engage a magnet to dock onto the associated DP as well as allowing separation from the plate too.

This technology has proved interesting enough to attract the attention of large constellation providers. OneWeb recently announced at the NASA First International Orbital Debris Conference (IOC) that every satellite they manufacture henceforth would be constructed with a DP, to effectively 'future proof' them. The plates they intend to implement are of course compliant with our magnetic docking capabilities.

Question: In the wake of growing private interest for satellite and spacecraft launch, we have seen worldwide concern beginning to grow for the conservation of clean orbital space around the Earth. Do you share those concerns?

Jason Forshaw: Astroscale absolutely shares these concerns and we do believe very strongly in space sustainability. We are committed to doing whatever we can to deal with this problem. Of course, we are a commercial company interested in sustaining ourselves and our mission for as long as possible, but I can assure you that we make all efforts to accommodate sustainability.

Central to the debris debate is the oncoming rollout of large constellations. Our Astroscale US President, Ron

Photo courtesy of Astroscale

Photo courtesy of Astroscale

Lopez, has routinely compared the LEO environment to early development of the Western US. Under the US Homesteading Act, the early pioneers came and staked their claims. Later, as law and order prevailed, big investors entered the market, and the economy exploded. Following the recent near collisions in space, many can now see that this as a great analogy. We need more law and order globally to continue to see the space economy grow.

SpaceX has roughly 20 launches scheduled in 2020 comprising 60 satellites each; OneWeb has several launches of 34 platforms each time. Across all groups launching in 2020, we are anticipating up to 1,000 new satellites. These will be added to the 5,500 satellites that are already up there, expanding the number of satellites at a rate we have never seen before, and this trend is only accelerating!

Of these large numbers of satellites, it's almost a certainty that at least one will fail. No satellite, no matter how robust, is impervious to failure. Even if industry were not rushing to fill deadlines and taking advantage of regulatory grey areas, this picture is not exactly rosy.

Unfortunately, although there are recommended guidelines for satellite operators today, there are no international laws to hold companies liable in case their satellite fails before end-of-life. When a satellite goes dead, it simply keeps drifting, decaying and veering out of orbit little by little as hundreds already are.

Astroscale believes in championing a better standard, and we aim to provide a lifeline to the companies responsible for dead satellites so they can do something about them. We are actually contributing to the progress of the regulation itself. I was recently at the UN World Space Forum discussing global space sustainability. While I was there, I was pleased to discover how many member states were intimately aware of the dangers present, together with threats of climate change so fresh in their minds. We should well understand the danger of irresponsible exponential industrial growth in our day and age.

Space is part of the global environment, and if we do not take steps to sustain it, we are encouraging serious problems, potentially a Kessler syndrome type event, which would have negative implications on the space environment.

Question: Can we expect more cutting-edge missions like this from Astroscale?

Jason Forshaw: Firstly, I can mention that in Europe we are working together with OneWeb on the European Space Agency (ESA) Sunrise programme towards maturing technologies necessary for future active debris removal.

In February, we announced that we were selected as the commercial partner for Phase I of the Japan Aerospace Exploration Agency's (JAXA) first debris removal project, a ground-breaking step by Japan to commercialize space debris removal. Phase I will focus on data acquisition on an upper stage Japanese rocket body and we will be responsible for the manufacturing, launch and operations of the satellite that will characterize the rocket body, acquiring and delivering movement observational data to better understand the debris environment. Astroscale UK will update the National In-Orbit Servicing control centre at the Satellite Applications Catapult to provide the ground control system for this mission.

Both JAXA and ESA are funding missions to remove their own broken assets, which is a fantastic development that we cannot praise enough. We are working closely with both groups to help them make those plans a reality in the near future.

Finally, we are investigating in-orbit services such as satellite repair, re-location, and refuel. This is an immature market with no specific guarantee of widespread commercial adoption, but if the sector takes off as so many industrialists have assured us it will, we are extremely well placed to capitalise upon it.

Again, the ability to reliably rendezvous and dock with a satellite cannot be understated. We are very excited to reveal news on these topics as soon as we are able to, but the work we are attempting has been very promising.

Question: Based on Astroscale's global footprint, can you explain the direction that your US team has been taking with government users?

Ron Lopez: As the US Department of Defense (DoD) starts to disaggregate and distribute GEO capabilities to enhance resiliency in space, Astroscale believes capabilities will slowly migrate down to LEO, which will extend and enhance — not replace — the capabilities of the DoD's assets at GEO. Our US team anticipates a growing need for On Orbit Services (OOS) at LEO as well, such as the ability to refuel, manoeuvre, and raise or lower orbits to enhance mission performance or achieve other operational objectives. All of these on-orbit servicing technologies will be force multipliers for DoD while helping save valuable budget dollars. We are seeing increased interest in these services through the US Air Force's Research Lab and AFWERX organizations.

Question: In the US, innovative companies are harnessing new technology for space applications, including On-Orbit Services (OOS). Can you explain Astroscale US' use of innovative technologies to create future capabilities to support the space market?

Ron Lopez: Many recent technology advancements are impacting the space industry as noted earlier, and these will support many new applications. Specifically related to Artificial Intelligence, when you put the advanced computing elements we discussed together with novel applications enabled by AI technologies, you create a very powerful combination that translates into many more lower cost services that can be provided from orbit. This on-orbit digital transformation is also enabling new industries and services like on-orbit refuelling, manoeuvre and orbit change services, repairs, etc. - which in turn enable owner/operators to extend the life of their satellites, address obsolescence issues, and enhance their service offerings. Based on this, Astroscale US sees a virtuous cycle emerging - new technologies give rise to new services giving rise to new capabilities and so forth.

In addition to OOS, we are talking to governments and commercial entities about helping them better understand the space environment so they can build out capabilities with as much space situational awareness as possible. We can offer this service as we are refining our own situational awareness techniques to support our ELSA-d mission and future debris removal and OOS missions.

Question: As emergent technology becomes more available and affordable, how does Astroscale plan to innovate?

Jason Forshaw: This type of industry is not one where anyone can sit still in terms of technical trends. You cannot really wait for things to happen, or breakthroughs to materialise. The global space industry is growing rapidly, and you can see there is a general transition for many governments and state space entities to pass developments off to private companies.

SpaceX is perhaps the best example of this. They are a group that revolutionised the launch market by considerably bringing down the cost. Attempts to innovate in the direction of emerging trends must be made. We are internally researching new prospects and partnering with a number of industries and agencies to remain visible to any and all-important developments which would let us perform more effectively.

Again, space debris is not only a problem today, it is a problem that is getting worse in real time. The multitudes of potential client satellites orbiting around our planet in need of removal is growing every month. To ensure the future sustainability of our planetary environment, businesses like Astroscale exist to secure long-term sustainability for the future benefit of the public.

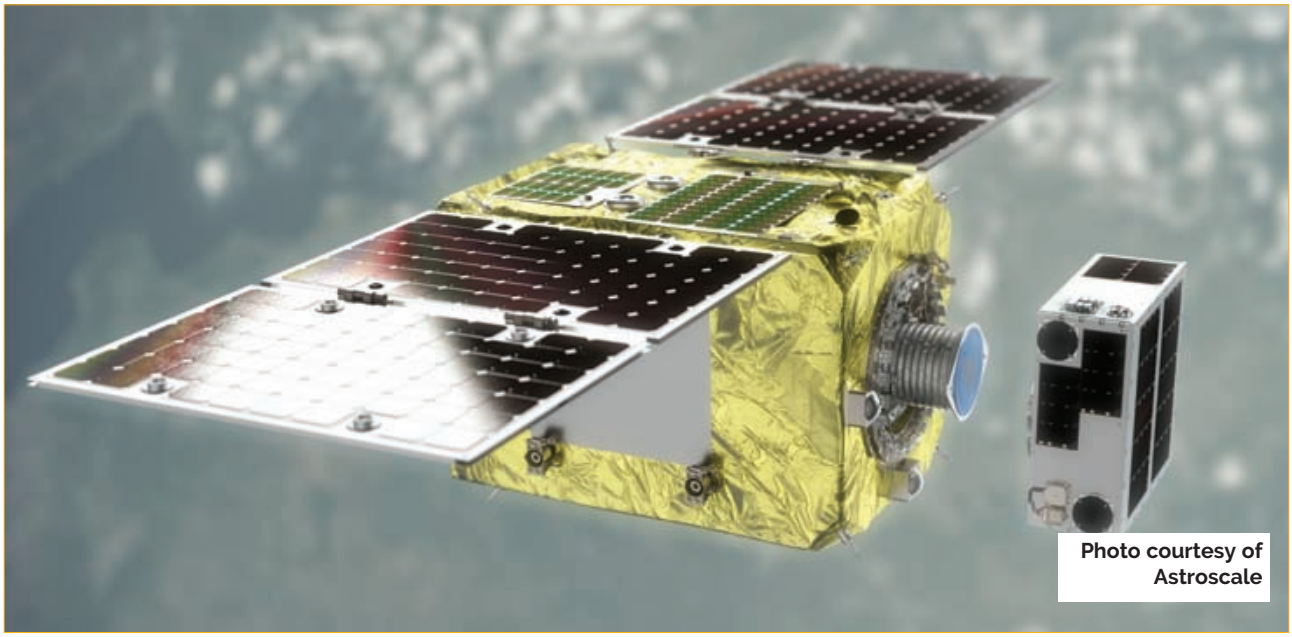
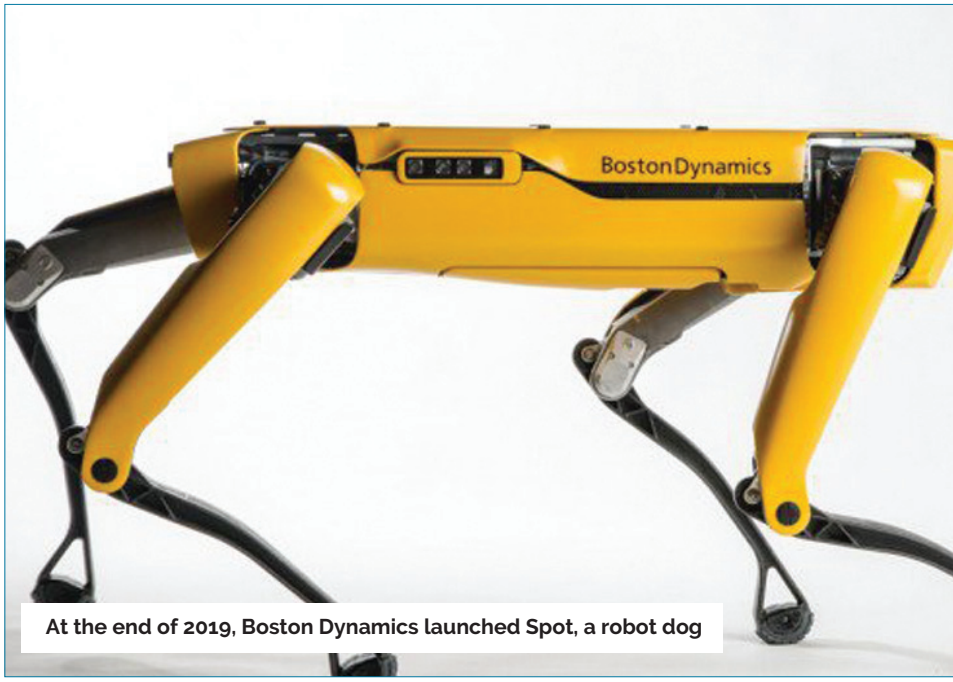


Photo courtesy of Astroscale

Robots in Space

The robotics sector has come along in leaps and bounds in recent years, with new prototypes and applications grabbing the headlines of major media outlets. With a significant history of off-world exploration, robots play a major role in the space sector, surveying new planets and moons, and soon, providing on-orbit services for satellites.

Amy Saunders, Editor, NewSpace International



At the end of 2019, Boston Dynamics launched Spot, a robot dog

Despite the numerous films warning of the dangers – note 'I, Robot,' 'The Terminator,' 'Minority Report' – of allowing robots and artificial intelligence (AI) access to our everyday lives, progress marches onwards, and robots are becoming increasingly commonplace across the globe.

Collaborative robots, or cobots, are popping up in workplaces everywhere, according to the latest World Robotics Report published by the International Federation of Robotics. The federation tracked a 23 percent increase in cobot installations from 2017-2018, with almost 14,000 new installations in 2018. That number is expected to double by 2021. The entire robotics sector also showed impressive growth, with some 422,000 units shipped in 2018, six percent more than in 2017.

"We saw a dynamic performance in 2018 with a new sales record, even as the main customers for robots – the automotive and electrical-electronics industry – had a difficult year," said Junji Tsuda, President of the International Federation of Robotics. "The US-China trade conflict imposes uncertainty to the global economy – customers tend to postpone investments. But it is exciting, that the mark of 400,000 robot installations per year has been passed for the first time. The IFR's longer term outlook shows that the ongoing automation trend and continued technical improvements will result in double digit growth, with an estimate of about 584,000 units in 2022."

Growth is expanding into new sectors, where automation has previously been unusual, particularly mining, construction and healthcare. China continues as the world leader in the industrial robot segment, accounting for 36 percent of installed units. Meanwhile, in the USA, the number of robot installations grew for an eighth consecutive year by 22 percent to 40,300 units in 2018.

The latest developments in robotics

So, the global robotics industry is thriving – that much is clear. One of the great things about this sector is that, like many other high-tech fields, technological advances in one area are quickly adopted by others. For instance, a major leap forward in robotic nimbleness in the medical sector can also be applied in the manufacturing or space sectors. A win for one is a win for all! Indeed, there are some fantastic developments in the world of robotics taking place right now, with future potential applications in a huge range of industries.

At the end of 2019, Boston Dynamics launched Spot, a robot dog a little too reminiscent of anthology series Black Mirror's Metalhead killer robotic dogs (Series 4, Episode 5). Spot the robotic dog was designed for autonomous sensing and remote operation needs, capable of climbing stairs and traversing rough terrains. The rugged and customisable robot can run at 1.6m/s, is equipped with 360° cameras, is water and dust-proof, and operates at -20 to 45°C. Boston Dynamics has released Spot to a specific group of customers, namely those in the oil and gas (for remote facility inspection and to improve awareness of plant operations), construction (to inspect site progress, create a digital twin, and compare as built to building information modelling) and public safety (to provide awareness of dangerous situations remotely) sectors. Spot's agility and impressive capabilities has huge potential in so many fields – interestingly, Cirque du Soleil (which does not feature any real animals in its performances) is reportedly in talks with Boston Dynamics for their show.

Meanwhile, Medtronic launched its new robot-assisted surgery platform in September 2019, promising it to be the most flexible and cost-effective system on the market to date. The Hugo system will be launched early this year to undisclosed locations. Only two percent of surgeries around the world are robot-assisted today, a number that could be easily boosted with the right tools and lower cost per use, according to Medtronic.

CEO Omar Ishrak expects robots to 'change the face of surgery' within the next ten years. A great many other companies are also investing in healthcare robots, evidencing a large opportunity, and potentially, a major change for future surgical patients.

In other news, scientists from the University of Virginia's School of Engineering have created the first robotic fish proven to mimic the speed and movements of yellowfin tuna. The work is expected to produce better understanding of fish propulsion, which could ultimately aid development of next generation subsea vehicles in defence, marine, infrastructure inspection and recreation applications. The Tunabot tests, taking place in a flow tank, saw the robot fish tethered with a fishing line, and a green laser cutting across the middle of the body, measuring fluid motion shed by the robot. As the tank current speeds up, the Tunabot's tail and whole body move in a rapid bending pattern, similar to the way a live yellowfin tuna swims. The big question, according to Project Leader Professor Hilary Bart-Smith, is: "How can we build something that looks like biology but swims faster than anything you see out there in the ocean?"

Robots in space

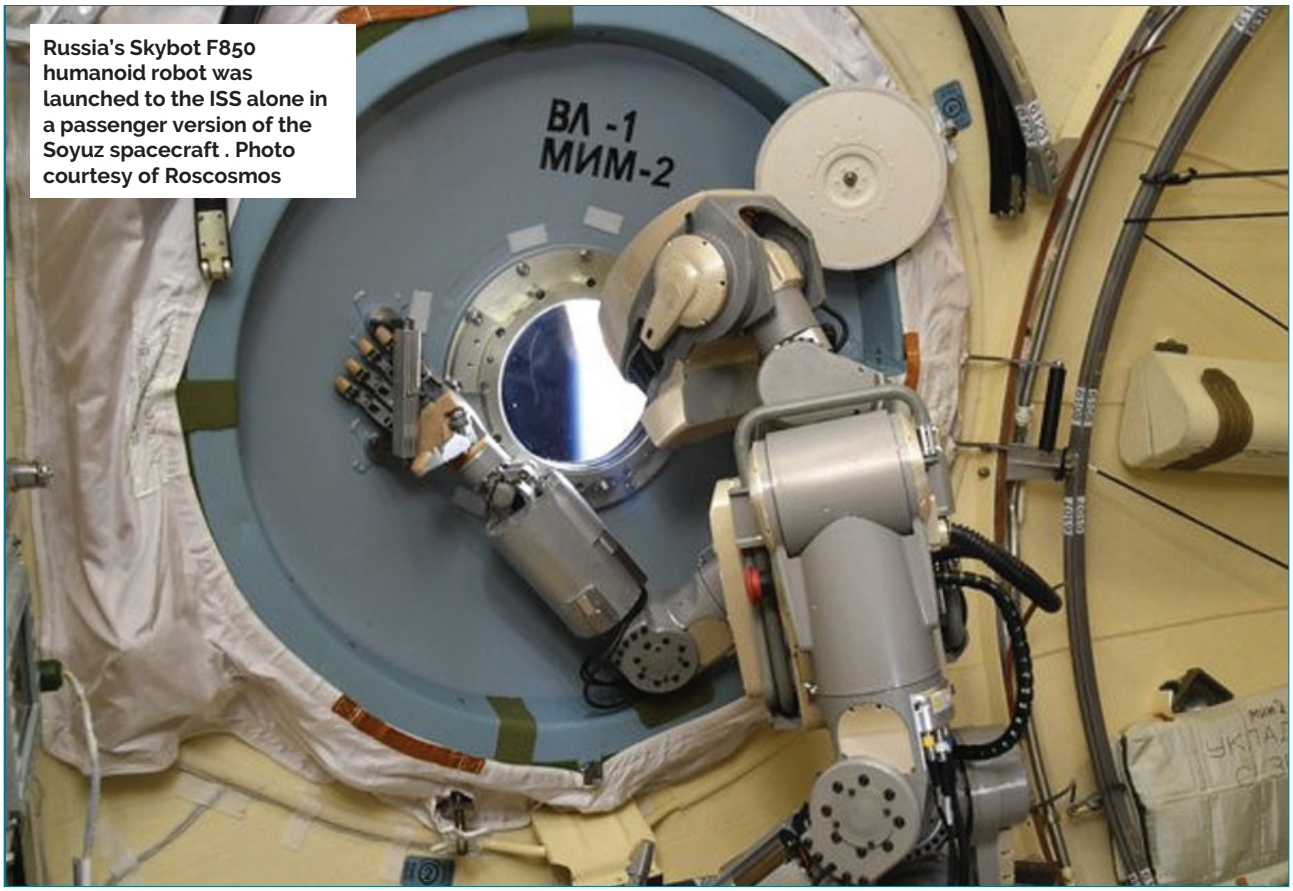
Robots have long held a valuable position in the space sector, which makes sense when you consider the environment. Space as a whole, lacks most of the elements vital for human life – air, water, ambient temperatures and pressures – and is in fact quite hostile, with cosmic radiation a huge problem for space exploration. Accordingly, major space agencies have utilised robots for off-world exploration for decades now. Such robots have to be pretty hardy to survive the rigours of the space environment; they must be strong enough to survive the sudden acceleration of lift-off; parts have to be flight qualified both on their own and when combined; they must also be able to operate in a huge range of temperatures.

The Soviet Union successfully landed the first roving remote-controlled robot to land on any celestial body, Lunokhod 1, on the Moon in 1970. Since then, a handful of rovers have been landed on the Moon and Mars, by the Soviet Union, NASA and China. India and ESA also have rovers planned for launch. Sending these roving robots, some of which are now semi-autonomous, off-world, is vital for future space exploration projects, allowing new areas to be mapped and explored in detail, and samples to be collected and sent back home.

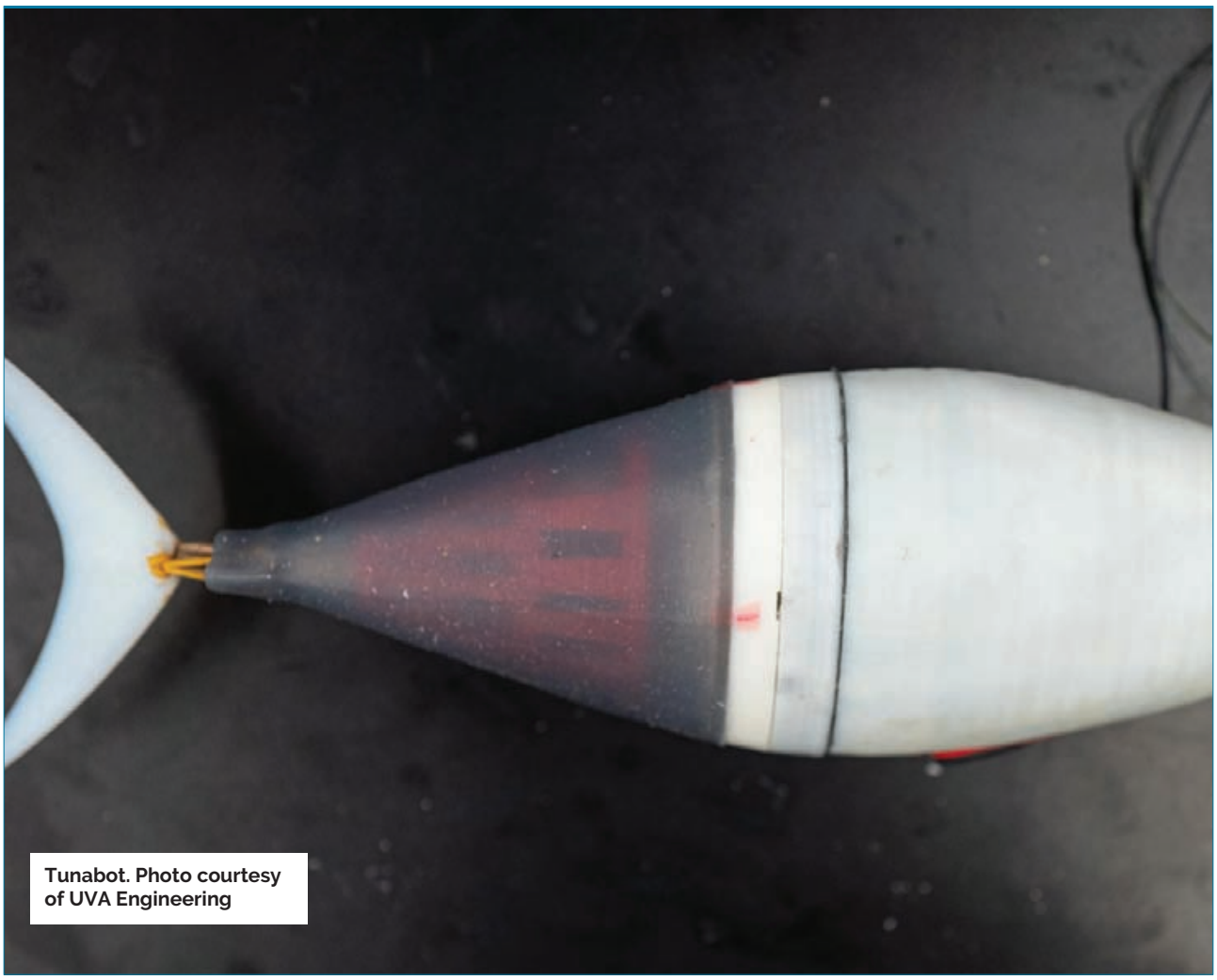
China is making great strides right now as the first country to land a spacecraft on the far side of the Moon (the Chang'e 4 lander and Yutu 2 rover), and with another four rovers planned, including a sample collection mission with Chang'e 5 this year. Russia, too, has big ambitions, of a 2024 orbiter, a 2028 sample collection and return mission and human flights in 2029-2030, and is teaming up with China for future robotic lunar missions. The two countries plan to build a shared data centre with one outpost in each country, for lunar and deep-space research, and China's future Chang'e 7 lander will work together with Russia's Luna 26 orbiter.

In other news, ESA has released a call for proposals for spelunking Moon robots. The agency is looking for creative solutions for a robotic mission to explore the caves beneath the Moon's surface, which could be the remnants of underground lava tubes. Intact, open tube segments of lava tubes could be suitable for housing a permanent lunar base, providing potential access to several resources, including volatiles and possibly water ice trapped in cave regolith.

"Exploring and mapping these tubes could provide



Russia's Skybot F850 humanoid robot was launched to the ISS alone in a passenger version of the Soyuz spacecraft . Photo courtesy of Roscosmos



Tunabot. Photo courtesy of UVA Engineering

new information about the Moon's geology, but they could also be an interesting option as long-term shelter for future human visitors to the Moon," Franceso Sauro, Director of ESA's Pangaea planetary geology astronaut training. "They would shield astronauts from cosmic radiation and micrometeorites and possibly provide access to icy water and other resources trapped underground."

ESA's robotic mission campaign therefore seeks to address the following points:

- Accessing and exploring lunar caves using robotic systems;
- Navigating and mapping lunar caves;
- Communication/power network from surface/orbit toward the lunar cave's interior; and
- Science payload to explore lunar caves.

One particularly interesting story from 2019 was Skybot's two-week stay on board the International Space Station (ISS). Russia's Skybot F850 humanoid robot was launched to the ISS alone in a passenger version of the Soyuz spacecraft on board a new 2.1a rocket – Russia plans to use the system to launch human crews to the ISS in the near future – which, after some difficulties, did successfully dock to the ISS. Skybot's mission was to see if time could be freed up for humans on board the ISS to focus on more complicated tasks; during the stay, it attempted standard cosmonaut chores including connecting hardware and working with tools. The robot also maintained a Twitter account documenting its exploits (apparently, its gears were in 'good shape' upon arrival). This application of robots to fulfil basic tasks in space is set to be a game-changer once fully refined; with robots performing the monotonous, repetitive tasks, a huge amount of astronaut man-hours can be freed up for more important tasks, including scientific research and wider space exploration.

On-orbit satellite servicing

This unique application of robotics in space has grabbed the headlines in recent years as it edges closer to reality; servicing satellites in space to provide life-extension solutions will soon be a genuine service on offer by a select few players. The lifespan of a satellite is currently dependent upon the amount of fuel on board, and, of course, on no errors or damage occurring; the ability to re-fuel or carry out minor repairs, perhaps replacing parts here or there, could drastically change the economics of today's satellite sector.

Northrop Grumman is making headway with its Mission Extension Vehicle (MEV), a cooperative on-orbit satellite life extension and manoeuvring services vehicle for geostationary satellites that will deliver flexible, scalable, capital-efficient and low-risk solutions. Northrop Grumman's MEV docks with up to 80 percent of existing satellites, providing the propulsion and attitude control needed to extend their lifetimes. Once the customer no longer requires the life extension

service, the MEV, which has an expected 15-year lifetime, can undock and move away to serve its next customer. Intelsat placed the first order for MEV-1, in 2016, to add an additional five years of life onto an existing satellite asset – MEV-1 successfully docked to the client satellite in February 2020 - followed by a second order, for a second MEV (MEV-2), in January 2018.

Next stage

Northrop Grumman also has plans for the next stage of its satellite servicing business, namely a new robotic servicing system consisting of Mission Robotic Vehicles (MRVs) and Mission Extension Pods (MEPs), which will provide customers with more flexibility to extend the life and effect repairs to satellites in-orbit. The MEP is an external propulsion module that attaches to and provides up to five years of orbital life extension for satellites which are running low on fuel. While the primary application of the MRV is to transport and install 10-12 identical MEPs or other payloads on customer satellites, it will also offer on-orbit robotic capabilities for in-orbit repairs and similar functions. One of the new features of the MRV is the ability it brings to capture those remaining 20 percent of satellites for servicing that cannot be targeted by the MEV, utilizing robotic arms. Northrop Grumman expects to launch the first MRV and MEPs in 2021.

The US Government's Defense Advanced Research Projects Agency (DARPA) also has a Robotic Servicing of Geosynchronous Satellites (RSGS) programme to develop technologies that would enable cooperative inspection and servicing in geostationary orbit. The initial plan was for DARPA to develop a robotic module and provide technical expertise and a government-funded launch, while partner SSL would provide a spacecraft, integrate the robotic module onto the spacecraft to create a robotic servicing vehicle (RSV), install the RSV onto the launch vehicle, and provide a mission operation centre and staff. After a successful on-orbit demonstration of the RSV, SSL will operate the vehicle and make cooperative servicing available to both military and commercial satellite operators on a fee-for-service basis. However, SSL's parent company Maxar Technologies has pulled out, and now DARPA is seeking a new partner, reportedly with multiple interested parties.

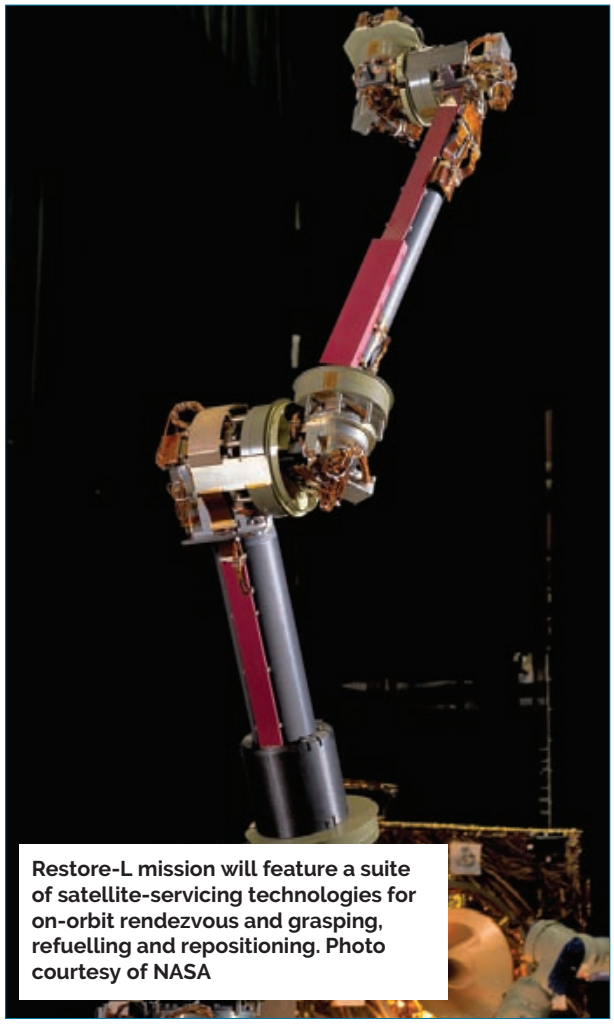
NASA is another major organisation working on its own robotic satellite servicing plan, with a focus on low Earth orbit (LEO). Its Restore-L mission will feature a suite of satellite-servicing technologies for on-orbit rendezvous and grasping, refuelling and repositioning, and includes an autonomous navigation system with supporting avionics, dextrous robotic arms and software. Future candidate applications for individual Restore-L technologies include on-orbit manufacturing and assembly, propellant depots, observatory servicing, and orbital debris management. In 2019, Maxar Technologies completed a Critical Design Review for Restore-L and reported that it is on track to ship the bus to NASA this year for integration with its payload and scheduled launch in 2022.

Effective Space Solutions Ltd is currently developing the SPACE DRONE, a satellite servicing spacecraft that docks to a host satellite with a patent-pending universal non-intrusive docking system in order to provide station-keeping and attitude control capabilities to extend the lifetime of a satellite by several years. The company's initial focus for the SPACE DRONE is on station-keeping and attitude control, relocation, deorbiting, orbit and inclination correction and 'bringing into use' (BIU), however, the spacecraft could be deployed in the future for active debris removal, the support of low or medium Earth orbit constellations and in-space explorations, mining and manufacturing logistics. There's been little news in 2019 on the SPACE DRONE project – updates eagerly awaited!

The future of robotics

Robotics as a field has huge potential to change the world, automating processes, cutting costs, and making life easier for the masses. In space, the potential is massive; from deep space exploration to satellite servicing, a wide variety of robotic architectures have a fundamental role to play going forwards.

One particularly noteworthy challenge in the future of robotics is that humans as a group tend to not like robots, particularly those with any form of AI. We do not trust them, and most of us without advanced engineering qualifications do not understand how they work. When it comes to off-world rovers and on-obit satellite servicing, this isn't a problem, as there is little human-robot interaction. But when we are looking at humanoid robots on the ISS and other future spacecraft, or robots operating in our day-to-day lives down here on Earth, acceptance is going to be a problem that only time will help mitigate.



Restore-L mission will feature a suite of satellite-servicing technologies for on-orbit rendezvous and grasping, refuelling and repositioning. Photo courtesy of NASA

Keeping up with orbit: Industry 4.0's solution for the ground segment

Industry 4.0 is set to revolutionise the world, with all aspects of everyday life being touched. Satellite naturally has a major role to play, but further innovation on the ground segment is required to keep innovation moving in the right direction.

Joakim Espeland, CEO, QuadSAT

The space industry is going through a dramatic overhaul; new players are stepping into the sector and we're seeing a vast number of changes in how it is being used. Ambitious new stakeholders are delivering sophisticated technologies, many of which boast smart technologies such as autonomy and AI. The projected numbers alone in low Earth orbit reflect how technology is enabling unprecedented use of space.

With this huge acceleration of innovation within space, the industry is now beginning to turn its attention to the ground segment. The main communications source between orbit and the ground is RF spectrum, and the industry is realising the need to rethink the ground segment in order to maintain high-quality connections with new orbit tech. The need is clear: Current methods available are not adequate for the changing demands being introduced by the latest technologies in-orbit. How can teleport operators transform existing systems to guarantee that they are capable of coping with shifting demands from the newest ventures within space? Is Industry 4.0 tech the answer?

Getting equipment right

Equipment is at the centre of RF infrastructures. To make sure RF is managed correctly, teleport operators must know that they are utilising equipment of a high enough standard to send and receive signals without loss in order to prevent it from causing transmission incidents. Globally, sourcing and managing the right equipment has been difficult; varying factors can result in poor quality equipment being produced, including cost focused approaches and a lack of standards and testing at the point of manufacture. Transmission incidents are often a result of poor and ill-suited equipment or mismanagement of terminals by personnel. Radio Frequency Interference (RFI) disrupts signals and can directly impact upon end user services. Additionally, we know that an RF incident can impact other terminals. With increasing numbers in orbit, the ground segment is set to become much busier in order to cope with the demand and the resulting stakes will be high: One transmission incident could disrupt multiple services.

Without the correct technology available, it is challenging and costly to identify high-quality equipment. Teleport operators do not intentionally purchase equipment that is insufficient for the job, however, sourcing the right equipment is difficult - especially for smaller terminal users because accessing the correct testing facilities can be costly. As with all businesses, cost factors hugely into decision making and it is important that systems are established to ensure that all teleport operators (including VSAT operators) are able to either test at sourcing, or at least access industry approved type approvals.

QuadSAT system

Knowing the importance of the ground segment, key GEO satellite operators have already created the SOMAP protocol which antenna manufacturers can follow in order to meet compliance of SOMAP specifications. The SOMAP framework consists of minimum antenna testing and performance requirements and aims to allow manufacturers to differentiate their products and help assure quality services. Up until the introduction of SOMAP in 2017, there was very little guidance available for antenna manufacturers and poor quality equipment was making its way through to the market. This guidance is providing manufacturers with a set of structured and clear standards which are improving the situation, however there is still a need for antenna manufacturers to have access to financially accessible testing methods in order to deliver reassurance to potential customers.

How Industry 4.0 drone tech is delivering on teleport quality

As Industry 4.0 arrives at the ground, there is a new technology which is delivering solutions at the teleport to respond to the high demands of the new in-orbit ecosystem. Drone technology is providing ground segment operators (both users of established teleports and VSATs) as well as antenna manufacturers with an innovative method to ensure that equipment is of a suitable quality at sourcing and during use in-field. The drone's simulated satellite payload is able to test, calibrate and measure the performance of satellite and VSAT antennas by mimicking an orbital satellite. Drone technology is perfectly suited to re-enacting the testing environment as it has been developed to transmit and receive RF signals whilst in the air above the ground

station. Not having to access satellite services for testing saves teleport operators both money and time allowing for testing to be performed whenever required.

The lower costs associated with drone testing methods are important when striving to increase accessibility to testing services for those working at the ground segment. This promotes both antenna manufacturers as well as buyers of teleport systems to deliver and procure products which are able to work at the required accuracy. Not only does it assist operators in antenna verification at sourcing, but it promotes regular testing within the field, allowing users to track antenna performance and adjust accordingly at a far lower cost than associated with hiring a satellite engineer. Beyond the current landscape, LEO satellites will introduce specific requirements when delivering services to antennas; redundancy and switching will be key. Drone technology will improve both the cost and operational efficiencies of the ground segment throughout the LEO ground ecosystem.

Transforming service delivery with new methods of in-field testing

VSATs have always faced challenges with RF interference issues; the small apertures and wide beam points need highly accurate setup and maintenance which can be challenging when being utilised in remote places or in comms-on-the-move. As with all terminals, VSATs need regular testing and calibration to ensure that they are working effectively and aren't negatively impacting on other satellite and RF services. Historically this testing has been at a huge expense to operators; for comms-on-the-move it has meant either laying on dedicated flights or trips within the aviation and cruise/maritime industries or sending satellite engineers to ships in order to complete testing in a realistic environment. In addition to the cost of testing itself, many operators are then impacted by the cost of operational downtime whilst testing.

Overhauling the in-field testing system is the only way to increase its uptake and in turn improve the robustness and accessibility of satcom services. Drone technology

Photo courtesy of QuadSAT

Photo courtesy of QuadSAT

can be utilised to offer a cost-effective solution for comms-on-the move as it performs testing and calibration to static vessels whilst replicating its movement. Cost and operational efficiency is imperative in ensuring that these terminals can be, and are, tested regularly to maintain quality services, allowing infrastructures (such as IoT) to be built around the robust connectivity enabled by new drone testing technologies.

How the ground segment can keep up with space

Undeniably, space and satellite communications are being revolutionised; emerging in-orbit technology is pushing the boundaries of satcom and promising to deliver pioneering services to end users. Therefore, turning our attention to the ground and acknowledging the crucial part it has to play within the communications system is hugely important. We know that sourcing high-quality equipment prevents RF transmission incidents and improves the quality of services to end users.

Emerging drone tech at the ground segment is offering an accurate and cheaper solution which can enable both antenna manufacturers and teleport operators to test the capabilities of antennas. We know that spectrum is going to become increasingly busy, with LEO and 5G creating fresh challenges and demanding highly accurate management of RF signals. For satellite communications to demonstrate its value, there is a monumental need for highly accurate and robust systems at the ground segment. Drone technology is set to revolutionise the collection of measurements and data, driving efficiencies and increasing new opportunities in-orbit through providing agility and dependability at the ground segment.

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