LLOYD'S

Emerging Risks Report 2019

Understanding Risk

NewSpace
Bringing the new frontier closer to home

LE London Economics

Lloyd's disclaimer

About Lloyd's

Lloyd's is the world's specialist insurance and reinsurance market. Under our globally trusted name, we act as the market's custodian. Backed by diverse global capital and excellent financial ratings, Lloyd's works with a global network to grow the insured world –building resilience of local communities and strengthening global economic growth.

With expertise earned over centuries, Lloyd's is the foundation of the insurance industry and the future of it. Led by expert underwriters and brokers who cover more than 200 territories, the Lloyd's market develops the essential, complex and critical insurance needed to underwrite human progress.

About London Economics

London Economics (LE) is a leading independent economic consultancy, with a dedicated team of professional economists specialised in the space sector. As a firm, our reputation for independent analysis and client-driven, world-class and academically robust economic research has been built up over 30 years. From our headquarters in London, and associate offices in five other European capitals, we advise an international client base.

As a team, we have been pioneering innovative analytical techniques to provide trusted economic advice to decision-makers across the space industry, space agencies and international governments since 2008. Drawing on our solid understanding of the economics of space, expertise in economic analysis and industry knowledge, we use our expertise to reduce uncertainty and guide decision-makers in this most challenging operating environment. Our consultants are highly-qualified economists with extensive experience in applying a wide variety of best practice analytical techniques to the space sector.

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Images

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- Cover: RADARSAT Mission (SpaceX)
- 1. Introduction: DIWATA-1 satellite (NASA)
- 2. What's different?: Dragon Prepares to Resupply Station (NASA/Kim Shiflett)
- 3. NewSpace trajectory: Antares Rocket With Cygnus Spacecraft Launches (NASA/Bill Ingalls)
- 3.1 Smallsats: the rise of constellations: CubeSats and Station Solar Array Panels (NASA)
- 3.2 Launch vehicles: New Shepard rollout (Blue Origin)
- 3.3 Space as a resource: Curiosity Self-Portrait at 'Mojave' Site on Mount Sharp (NASA/JPL-Caltech/MSSS)
- 3.4 Innovative mission concepts: Dragon interior view (SpaceX)
- p19. Panel A: RADARSAT Mission (SpaceX); Panel B: EDSN flight units (NASA Ames Research Center); Panel C: Dragon to Mars (SpaceX); Panel D: Dragon interior view (SpaceX).
- p20. NanoRacks CubeSats Deployed From Space Station (NASA)
- p.31. NASA and FEMA Conduct Asteroid Impact Emergency Planning Exercise (NASA)
- p. 33. Propellant Depot Evolution (Figure 17, NASA)

Contents

Executive summary

When people think of the space industry, what often comes to mind are things unconnected to daily lives such as rocket ships and resupplying the space station. However, there is another side to the space industry – one that enables people to carry out their daily lives – such as putting satellites into orbit that support our car navigation systems. The upstream part of the sector is undergoing a rapid transformation. As it does so, it is building new capabilities and unlocking new opportunities, as well as opening itself up to new risks.

This new Lloyd's report, published in association with London Economics, provides an overview of current and future developments in the space sector. It provides comprehensive analysis of the upstream sector so that risk managers in companies that are or will be involved in the industry, and all Lloyd's market stakeholders, can begin to understand the potential impacts on their businesses and how to benefit from new opportunities.

To build understanding we have also produced a guide to NewSpace insurance for customers to raise awareness about the complementary role of insurance to mission assurance.

Although the global space market is already worth an estimated $300bn (SIA, 2018), innovation in space looks to continue, further pushing the bounds of technology. Increasing interest in the sector and what the upstream sector has to offer have led to estimates that the value of the global space industry could be worth $1tn by 2040 (Morgan Stanley, 2019).

NewSpace lifts off

A wave of innovation – known as NewSpace – has attracted private investors seeking to take advantage of technological advancements in other terrestrial sectors. As a result, an alternative approach to overcoming the challenges of spaceflight has emerged, with focus moving towards low-cost, easy access routes to space.

This space sector is rapidly opening up to private enterprise, wealthy entrepreneurs, innovative start-ups, and even school projects and amateur hobbyists.

Space connectivity

Everything from watching the financial markets open on the other side of the world, checking the arrival of a customer's flight on your laptop, booking a taxi pick-up because a weather app showed it was going to rain to paying for the taxi using your smart phone, is satellite-enabled. As an example:

- Farmers are increasingly using satellite data to help them with crop management and determine the best time to harvest. News services transmit their coverage from field teams to your screen via space. Financial systems use global positioning satellite (GPS)-based timeclocks for their transactions. While financial markets have back-ups, many of these also depend on GPS.
- Planes receive signals for precise positioning and transmit the position via satellite, so aircraft controllers can safely direct traffic. Apps on smart phones also use this technology to allow people to track flights – and share documents while flying at 30,000 feet.
- Weather services around the world gather and share data derived from satellites, among other sources, that is used by national weather services, and commercial organisations that use and augment that data to provide additional services. Insurers also use this data to model weather events, so they are ready to give customers up- to-date knowledge, and where necessary investigate and pay claims.
- These days taxis are likely to use an app that relies on GPS data to find your exact location to pick you up and determine the best route to get you to your destination. It is estimated that approximately 7% of European GDP depends on satellite navigation applications, including aviation, maritime, rail, road, energy, telecommunications and financial services (The Royal Academy of Engineering, 2011). The US Department of Homeland Security has designated 16 sectors of infrastructure as "critical," and 14 of them depend on GPS (Tullis, 2018).
- When bank cards are used a satellite link is established between banks and the business to validate and initiate payment.

NewSpace trajectory

Changes in upstream space activities mean that satellite touch-points are going to expand and play and increasing role in people's lives. These capabilities are now a reality or within touching distance because of four main trends:

- Democratisation of space: New technologies are lowering barriers to entry and could be further coupled with automation allowing ease of access into what has long been the domain of governments. The segment has also come to the attention of outside investors. As a result, the frontier of space is fast becoming accessible to private enterprise, wealthy entrepreneurs, innovative start-ups, and even the amateur hobbyist.

  The characteristics of NewSpace are comparable with emerging sectors where rapid iterations, a strong focus on research and development, and private capital, mean that NewSpace entities are taking the risk on themselves. However, as the market matures, and traditional sources of finance are sought, these institutions are highly likely to require risk transfer to be part of the equation.

- Rise of constellations[a] and the need for greater and more varied launch capabilities. More numerous and varied launch capabilities, reusable launch vehicles, and commercial spaceports are increasing launch frequency and therefore the risks associated with launches.

  This raises new and interesting challenges around the aggregation of risks, as the collective value of hundreds of identical, interconnected constellations of satellites can now run to billions of dollars. Ridesharing[b] also brings up the question of who is next to who on the launcher and how stringent has each company's testing and risk management been?

- Development of space as a resource: this includes space tourism and the potential for manufacturing in space. There are also long-term options such as commercial space stations and asteroid mining that are being discussed and planned today to meet the needs of tomorrow.

  Launcher reusability is going to be paramount for lift costs to come down enough to allow space tourism to take off. When it does the insurance industry already has well developed products for high risk environments and the infrastructure that will be needed, and could use existing skills and thinking to support development.

- Innovative mission concepts: New innovative mission designs and concepts in areas such as in-orbit servicing. As scale increases, liabilities and resource-demand are likely to trigger new services that support the space sector.

  The ability to service and build satellites in space could allow for more proactive risk mitigation. For example, if a damaged satellite could be repaired or upgraded in space, it could remove collision risks and prevent further debris from aggregating.

Opportunities on the horizon

In the future businesses might:

- Decide to establish their own constellation of satellites, or use a satellite subscription service to buy bandwidth, so their network is secure and always online *(see Section 3.1 for details)*.

  There are plans for over 7,000 new satellites that are going to change market dynamics and open a new frontier for telecommunications companies. For example, SpaceX has started launching the first of its planned 12,000 constellation, and Amazon announced its version – project Kuiper – which look to use 3,000 satellites to provide high-speed Internet to up to four billion new customers.

  These ventures will increase interconnectivity, and provide huge amounts of data that will require artificial intelligence to analyse it. Both artificial intelligence and big data come with their own set of threats and opportunities *(see the reports from Lloyd's Digitalisation series to learn more)*.

- Offer new services to customers by connecting their Internet of Things (IoT) networks to company systems, to give customised, instant feedback *(see Section 3.1 for more details)*.

  Additional capacity will be needed to offer global connectivity, enable the Internet of Things, and provide the 5G backbone needed to support this development. Constellations of satellites are going to enable devices to be connected in regions that have remained unconnected by cables. Satellite Machine to Machine (M2M)/IoT[c] is expected to be a $11.6bn market over the next decade (NSR, 2019), with the strongest growth in industries with existing heavy machinery partnerships, such as agriculture and construction, and growth in the energy and maritime sectors.

[a] A constellation of satellites are a networked group of satellites working in concert. While constellations of satellites are not new, the scale is significantly larger under NewSpace, with potentiall constellations of thousands of satellites in a network to provide global coverage.

[b] Buying a seat on someone else's launcher that has spare space. Commercial entities are increasingly providing this as a service offering., and offering dedicated packages.

[c] The transmission of data between devices or a relatively closed network that can be considered part of the IoT. The development of M2M and IoT applications relies on connectivity, and s has created a specific demand for low-cost satellite communications to provide global connectivity (London Economics, 2017).

For example, DHI Global Seas is already allowing customers to reduce fuel consumption and to improve vessel performance by utilising satellite data enriched with ocean current, wave and wind data. SatCBRN is exploring the use of satellite services for surveillance and hazard management of incidents involving the release of chemical, biological, radiological or nuclear threat agents. New companies are lining up to provide new data, while traditional markets are increasingly offering new services that use their existing expertise to augment data.

- Launch a dedicated small satellite. Options for getting into space are becoming more varied and accessible through pooling resources with others, or booking a dedicated smallsat launcher for a mission *(see Section 3.2 for more details on how to achieve lift-off)*.

  The ability to service and build satellites in space is also on the horizon with the potential for services stations. This could allow the lifespans of assets to be increased, prevent breakdowns or recover damaged satellites *(see Section 3.4 for more details)*.

- Be able to develop new innovative products and services to meet customers' needs with access to new sources of materials and low gravity manufacturing environments.

  Scientific research that has occurred over decades has already been cataloguing potential asteroids and lunar excursions have revealed the presence of metals and minerals buried at or beneath the Moon's surface that could be used *(see Section 3.3 and 3.4 for more details)*.

- Take a suborbital flight to get to a meeting in record time or deliver essential components to where they are needed most just in time *((see Section 3.3 for more details)*.

  If suborbital point-to-point space liners can transport 5% of the passengers that currently take 10+ hour long-haul flights, UBS estimate this could be a $20bn a year market (Sheetz, 2019). To get to this point there are outstanding questions around regulations, profitability, infrastructure investments needed, and weather. Per kg lift costs, environmental impacts, and competing transport options may make commercial space tourism a more realistic growth segment over point-to-point in the short term.

- Travel to Mars *(see Section 3.3 to learn how this could be possible and which companies are involved)*.

  Some estimates put the date Mars travel will be possible to around 2037 (IDA, 2019), so there is still some way to go. However, plans are already underway and even if closer targets like the moon are first in line, companies operating in the space will require robust risk management frameworks and processes that adopt best practice and contain worst case scenarios, crisis response plans and full-scale exercises. There are many practical steps businesses can take to manage risks effectively, including investing in space technologies and transferring some of the risks to specialist insurers.

Risks and challenges

As these trends and opportunities become more widely adopted, risks and challenges are emerging. Insurers already offer products and services that meet these, and are developing new propositions to help customers manage these risks.

However, some challenges remain that will require all stakeholders to work together to ensure the sector develops in a responsible and considered way.

Traditional space risks include:

- Design/manufacturing defects and random failures: When multiple spacecraft feature the same or similar components, there is an inherent risk that previously unidentified issues can emerge that can cause loss of capability to multiple space missions, or even lead to the failure of satellites.
- Space weather events: Although we have evidence of space weather and solar storms existing for centuries, it poses a greater threat today because of the uncertainty of how NewSpace technology will respond to extreme events. An exponential increase in the number of satellites, identical designs and common components, mean any vulnerabilities could have severe consequences.
- Collisions and debris: Exponential rises in the number of forecasted satellites and stakeholders, alongside a patchwork of global systems, could see a rise in collisions. Some small satellites are being launched without propulsive systems, which means that they will be not be able to act on any warnings to avoid collisions. Space is big, but it is getting smaller. As the sector becomes further commercialised, a civil aviation style management model is going to become increasingly important to assess risks and establish mitigation efforts, standards, and monitor compliance.
- Cyber attacks: The exponential growth in satellite applications is creating a systemic risk. As a large, and increasing, number of globally interconnected services on the ground come to rely more extensively on satellite communications, certain signal disruptions or interruption to these services could have catastrophic consequences.

Lloyd's and space

The first space satellite insurance was placed with Lloyd's in 1965. Today, Lloyd's underwriters continue to play a crucial role in enabling satellite launches globally; each year, specialist space underwriters provide satellite owners and users – from national governments to telecommunications firms and research institutes – with protection worth more than US$7bn.

The Lloyd's market are developing innovative products to meet the needs of the NewSpace community with products such as Llift. The innovative product builds on the strong history of the Lloyd's market in supporting space endeavours, bringing together 18 syndicates to write NewSpace risks via a dedicated Lloyd's platform to meet the needs of the small satellite community. See the case study for more details.

Conclusions

NewSpace is growing rapidly, and will create an increasingly interconnected world. To grow safely and thoughtfully it needs to be underpinned by insurance, and all classes will need to collaborate to offer customers the products and services that will secure their futures.

NewSpace activities are going to enable affordable coverage to emerging markets where billions of people and internet of things devices are waiting to be connected where they are most wanted.

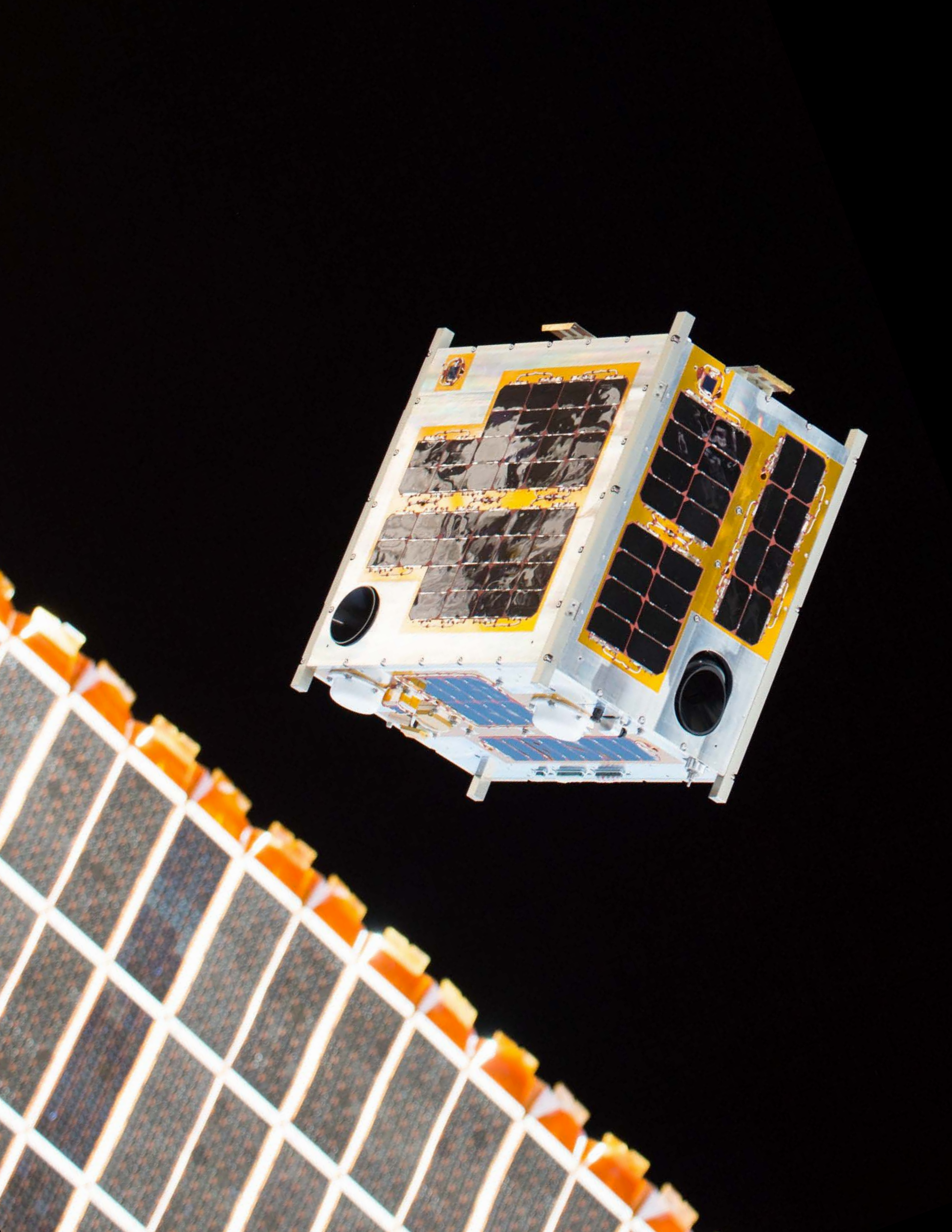
As increasingly ambitious concepts evolve, understanding the risks involved has never been more important. To take advantage of the opportunities on offer, insurers must:

- Talk to customers to establish where product gaps exist
- Ramp up innovation to increase product development for NewSpace
- Collaborate across classes to harness existing expertise to meet this growing sector

To build understanding we have also produced series of takeaways for risk managers and insurers, and a guide to NewSpace insurance for customers to raise awareness about the complementary role of insurance to mission assurance. For example, insurers are willing to be part of conversations from the beginning of ideation, and can help in the identification of coverage needs.

The Lloyd's insurance market has well developed tools such as scenarios, expert knowledge, and decades of experience at being at the front of the market helping customers to be brave. These skills will be needed to support the sustainable development of the new frontier.

1. Introduction



1. Introduction

While the concept of smaller spacecraft in lower orbits is not a new concept to the space industry, the size and scale of new developments displays an ambition beyond the initial thoughts and presents new opportunities for risk managers and insurance in a variety of sectors. 'NewSpace' is here, and it brings with it new challenges and opportunities, both for those well familiar with the space sector and those in sectors that will now be pulled into orbit.

This study looks to provide an overview of risks and innovations emerging from developments in the NewSpace economy to understand their future effects in terms of risks, threats and opportunities for insurers. Within the context of this report we shall consider any space related activities that have emerged within the last quarter of a century, focusing on commercial and start-up organisations, and traditional entities who are embracing the spirit of NewSpace.

A wave of innovation has attracted an inflow of private investors seeking to take advantage of technological advancements in other terrestrial sectors, and an alternative approach to the challenges associated with spaceflight has emerged.

As a result, the frontier of space is fast becoming accessible to private enterprise, wealthy entrepreneurs, innovative start-ups, and even school projects and amateur hobbyists. The new wave of entrants to the marketplace have led to a fundamental shift in attitudes and aspirations which has increasingly gained traction in recent years, with focus moving towards low-cost, easy-access routes to space.

Therefore, it is useful to see how NewSpace has developed to understand:

- Common definitions and characteristics
- What activities and developments fall into this sector, and how it differs from traditional space
- Why it is gaining increasing interest, and
- Why risk managers across all sectors should keep a watching brief as NewSpace brings new opportunities and risks into orbit

Common definitions

The term 'NewSpace' is an abstract concept that is difficult to pin down to one specific definition. Different stakeholders use alternate terms, such as Alt.space or entrepreneurial space.

The Space Frontier Foundation lays claim to its origins, but a slightly more nuanced view is given by NewSpace Global, who describe it as:

> *"A global industry of private companies and entrepreneurs who primarily target commercial customers, are backed by risk capital seeking a return, and seek to profit from innovative products or services developed in or for space"*
> (New Space Global, 2019)

Development of the space sector

To understand the current state of knowledge and applications, it is useful to know how this sector has developed, and where there is still large potential for change to occur.

Humankind first achieved spaceflight of a man-made object (the V-2 rocket) in 1944, followed by orbit of an artificial satellite (Sputnik-1) in 1957 – and we have been sending missions to space ever since. For much of the time since the Second World War era, space exploration has been solely the domain of governmental agencies, with the US and Russia dominating the space industry throughout the Cold War and beyond *(See Insight box: History of space, overleaf)*.

Whilst many governmental space activities managed, and ultimately accepted this risk, international governmental agencies operating satellites for communications services such as Inmarsat and Intelsat starting to purchase some insurance cover (initially just for the launch phase) to transfer some of their risk.

However, it was the 1980's, with the dawn of commercialisation, when commercial operators began to found business models predicated on space-enabled capabilities that the risk became unacceptable. Private investors sought to offset their risk with insurance – and space satellite insurance was born.

As commercialisation expanded, more satellites were launched, and the market continued to grow to what it is today. Over decades of underwriting space risks, market professionals at Lloyd's have developed a deep knowledge of the market.

For example, in 1965 the first satellite insurance policy was placed in Lloyd's to cover physical damages on pre-launch for the Intelsat I 'Early Bird' satellite - the first commercial communications satellite to be placed in geosynchronous orbit, enabling 'live via satellite' for the first time.

Between 1974-1982 the market went on to underwrite other policies for up to $100m each. Lloyd's continued to provide support for this innovative activity, and in 1984, Lloyd's launched a successful salvage mission to reclaim two rogue satellites, sending a shuttle and five astronauts into orbit.

This risk-sharing support has allowed the space industry to prosper, and to create a braver world.

$348bn–$360bn

Size of the global space economy (2018)[d]

$1trn

Estimated value of global space industry by 2040[e]

$76.2bn

Total global government space budgets (2017)[f]

8,714

No. of objects launched into space since 1957[g]

4,861

Number of orbital tracked objects[h]

2,062

Number of active satellites[i]

$450m

Global satellite insurance premiums (2018)[j]

d (SIA, 2018; Research and Markets, 2018)

e (Morgan Stanley, 2019)

f (Space Foundation, 2018)

g (Henry, 2018)

h (UNOOSA, 2019)

i (UCSUSA, 2019)

j (Foust, 2019)

Insight: History of space

The origins of space technology can be traced to the dawn of the Cold War era, a time when geopolitical rivalries drove national agendas. Whilst previousengagements had featured ballistic weapons, this battle would feature avery different projectile as its primary armament, the intercontinentalballistic missile, and at it's core – the space rocket.

The United States of America and the Soviet Union both raced to be the first to successfully land a man on the Moon. The first nation to do so would effectively position itself as the dominant super power. In order to achieve this, an unprecedented era of technological and scientific development began.

The two sides poured vast amounts of resources into their efforts as they strove to push the very limits of human ingenuity and endurance. Commencing in the post Second World War era, and relying on captured German rocket scientists and technology this race lasted nearly a quarter of a century, until eventually the US succeeded in their endeavours and landed a manned vehicle on the lunar surface in 1969.

Whilst the monumental achievement had yielded a phenomenal boon to humankind in terms of technological advancement and knowledge, it was unsustainable in both financial terms and with respect to the priorities of both nations. For space developments to progress markedly in the future there would have to be a way to address the shortfall, at which point the private sector entered as key partner.

Large scale developments in the post Apollo era such as the Space Transportation System (STS) necessitated the increasing involvement of private industry for space agencies such as NASA, in order to continue to advance in times of budgetary restrictions. Heavy industry took up the mantle of providing the tools and equipment needed by public space agencies, which expanded the circle of participants in space related activities slightly, but essentially the domain was one of restricted access.

The sector persisted for several decades as being the domain of governments, adopting a centralised model around large national/international space agencies with large-scale public funding, supported by sizable private manufacturing and commercial enterprises.

Commercial activities began to establish a foothold in the industry in the 1980's as independent enterprises emerged primarily offering the new service of satellite television, and grew further as the intergovernmental organisations were privatised and governments began to purchase satellite-based services from commercial operators.

The major turning point in this status quo between the public and private sectors arrived with the removal of the principal public sector access point to space for one of the leading space powers, with the retirement of the STS. NASA needed a new way to get to space and sought alternatives to tried and trusted procurement programmes, with companies such as Orbital Sciences and SpaceX.

Other developments, as the same time, such as the miniaturisation of electronics also allowed smaller, lower cost satellites to demonstrate their ever-increasing capabilities.

This was the herald of a new era, the era of NewSpace.

2. What's different?

2. What's different?

Where previously one large satellite could be used to fulfil a specific mission, or a small fleet of larger spacecraft used to provide global coverage, now thanks to the change in manufacturing economics enabled by a NewSpace approach and the increasing capabilities of micro-electronics, the same objective can be achieved by several smaller, cheaper satellites in low altitude orbits.

Table 1 *(below)*, attempts to summarise some of the differences in drivers and characteristics between traditional and NewSpace activities.

Table 1: Characteristics of Traditional Space vs. NewSpace

Trend	Traditional Space	NewSpace
Primary actors	– Governments – Military – Space agencies – Multinationals – Large national service providers	– Entrepreneurs – Start ups – Smaller spacefaring nations – Hobbyists
Innovation	– Tried and trusted methods – Gradual increments of new technology and features – Introduce new features with safeguards and iteratively	– Legacy methods useful, not essential – New design philosophies embraced – Spin in from other sectors – Disrupt existing technology markets
Procurement	– Space rated hardware from trusted suppliers – Heavily auditable quality processes	– Buy cheap, off the shelf technology – Aim for miniaturisation where possible
Development cycles	– Lengthy, must ensure quality of hardware and software	– Focus on rapid production – Mass production techniques utilised where possible
Capital base	– High procurement costs on quality specialist products requires significant CAPEX – Investment in larger vehicles – Funding from private equity and bond markets – High revenues from institutional customers	– Smaller, less complex vehicles – Funding from wealthy individuals, VC's, public sector grants, commercial investors
Durability	– Proven launchers costly and expendable – Spacecraft are built to last, as not easy to repair though typically heavily redundant systems	– Reduce launch costs to a minimum – Build cheap and fast – Disposable, technology moves quickly so replace frequently
Scale / scope	– Prefer larger, powerful spacecraft – Fleets of independent spacecraft for larger operators	– Smaller scale satellites – Can combine many satellites to deliver overall capability or global coverage – each constituent replaceable – New mission designs utilised

2.1 NewSpace in numbers

In comparison to normal space activities, NewSpace can be characterised by a step change in numbers, and has seen:

114
No. of attempted global launches (2018)[k]

83.8
Average annual global launches (2010-17)[l]

330
Number of smallsats (<500 kg) launched (2017)[m], a record annual high

Over 13,000
Number of future Low Earth Orbit (LEO) spacecraft approved by Federal Communications Commission (FCC) as of end of 2018

$3.25bn (2018)
VC annual investment in space[n]

Factors driving these numbers

The NewSpace movement has generated a lot of interest from entrepreneurs looking to use new technology to either deliver a new service or improve an existing one. This new approach is characterised by the many new companies and individuals with ambitious aims for development and progression. Various companies have focussed on different aspects of the space value chain, with each providing its contribution to the NewSpace economy.

SpaceX set about tearing up the blueprint established by decades of rocket design and manufacturing to develop new levels of mass production and scalability for launchers. Latterly these endeavours extended to the concept of reusability in launch operations, a demonstration of technology that is vital for future industry in terms of pushing through restrictive cost barriers.

Planet has launched a constellation of more than 150 four kilogram cubesats to be able to photograph the entire Earth's surface every day, bringing an unprecedented capability to watch our planet evolve. This was achieved with investment measured in the tens of millions of US dollars as opposed to the billions of dollars that would have prevailed using a traditional space approach.

What started as a few stakeholders has now developed into a market of over a thousand companies, from traditional players to new start-ups and students who are enabled by three core drivers, that are discussed throughout this study:

- Democratisation of space
- New mentality and ethos
- Differing manufacturing and procurement practices to traditional space

k (Kyle, 2018)
l (Kyle, 2018)
m (EuroConsult, 2018)
n (Seraphim Capital, 2018)

'Democratisation of space'

In response to high costs and reducing government budgets, the door was opened for commercial entities to enter the sector. This has allowed:

– Wider, more diverse participants
– Low cost, easy access to space
– More open to innovative/disruptive use of technology and mission types

What does this look like?

New technologies are lowering barriers to entry and could be further coupled with automation allowing ease of access into what has long been the domain of governments. The segment has also come to the attention of outside investors, who rather than associate space ventures with scepticism over risky technology and outlandish concepts, see the potential benefits on offer in an industry where in both a figurative and a literal sense, the sky is definitely not the limit.

With the level of annual investment as a proportion of the accumulated value of the global space industry to date currently around 10%, it seems clear that this is a sector undergoing substantive growth.

As a result, the frontier of space is fast becoming accessible to private enterprise, wealthy entrepreneurs, innovative start-ups, and even the amateur hobbyist.

Examples include:

– Entrepreneurs: such as Elon Musk through SpaceX, Richard Branson though Virgin Galactic, and Jeff Bezos with Blue Origin.
– Government backing: national space agencies and governments are also establishing commercial spaceports and encouraging partnerships to open new avenues to space for companies operating within their borders.
– Public private partnerships: the democratisation of space has been fuelled by the steady transition of power from the public sector to the private. Public sector knowhow and guidance still has an important role to play however in the development of the industry.
– Sharing economy: Interesting developments are taking place onboard orbital space stations as shared service models appear, and rideshare aggregators appear to help the smallsat community find space on launch vehicles.

Insight: Increasing lift-off

The limiting factor of access to space has been apparent since the early days of the space industry of the 1950's and 1960's, with colossal government budgets underpinning the efforts of the Cold War space race.

Budgetary constraints as a barrier to entry persisted throughout the era of hugely costly space vehicles, such as the US Space Transportation System (STS) – more commonly known as the Space Shuttle – which ultimately cost an estimated $209bn (Wall, 2011). A per-flight cost of nearly $1.6bn.

It was only following the retirement of the shuttle in 2011 that the door swung open to the commercial sector to address the challenge of lower cost access to space (Weinzierl, 2018).

Enabling factors, include:

– **National/International space agency support and knowledge transfer – NASA, ESA, UKSA etc:** Knowledge and know how flow down from public to private companies and combined with entrepreneurial activities increase success rates for start ups
– **Academic R&D:** Cutting edge research can be commercialised with innovative ventures often spun out of academia
– **Democratisation of space:** A wider pool of more diverse participants in the marketplace drives innovation and stimulates competition

New mentality and ethos

The new wave of entrants to the marketplace have led to a fundamental shift in attitudes and aspirations which has increasingly gained traction in recent years, with focus moving towards low-cost, easy-access routes to space. Characteristics include:

- Clean sheet design
- 'Spin-in' technology from other sectors
- Less durable, smaller satellites with shorter mission life
- Private funding primarily

What does this look like?

Democratisation and the manufacturing developments mean that you don't have to be an expert in space to bring concepts to market. Information, equipment, and skill levels required for entry are more accessible, and in an increasingly digital world, more and more applications are possible.

The quantum shifts in thinking currently at play in the space industry has not gone unnoticed by large-scale traditional industry players. Some traditional players are exploring these developments by engaging in various new smallsat endeavours, alongside maintaining their existing product lines to varying extents.

This allows the nascent NewSpace community to take advantage of technological advancement in other industries at a much faster pace than the slow, meticulous risk adverse style of traditional space technology development. Thus, the concept of 'spin-in' from other sectors boosts the dynamic, agile and progressive approach of the NewSpace generation.

Examples include:

- Start-ups with venture capital backing: commercial entities are also making increasing use of VC funding to bring ideas to life.
- Partnering: Traditional players are partnering with new entities to keep a watchful eye on developments.
- Mergers and acquisitions: in some cases, these companies are being fully acquired. This poses a risk for new entrants to the market, as expertise is increasingly consolidated within single firms instead of across a multiplicity of vendors and contractors.
- Accelerators: Private sector and philanthropic initiatives are helping spur unprecedented scopes for new space missions.

Insight: Quantum shifts

Driven by increasing competition, companies are looking to reduce production costs and speed up production lines by tightening up supply chains, tapping into robotics and digital printing technologies, and even producing key components in-house (Bockel, 2018).

Alongside this, smaller spacecraft and lower associated costs of manufacture, owing to increasing levels of mass manufacturing of clone satellites and increased adoption of commercial grade components, have driven down the average cost of a single satellite.

The potential exponential increase in the number of spacecraft populating sections of LEO increases the risk of collisions and raises the concern that there are many more orbital objects that will be susceptible to the effects of extreme space weather. Less durable, smaller satellites with shorter mission life would presumably have similar levels of tolerance to bombardments of solar heavy ions or galactic radiation, so a manufacturing defect or design error could have severe consequences.

Whilst the magnetic field of the Earth offers some protection for lower orbits, another implication of the use of COTS components could be less resistance to the harmful effects of solar and galactic radiation, which would be a particular concern for remote sensing spacecraft which by necessity must have their sensors exposed to the harsh space environment.

The World Economic Forum has the topic of space debris firmly on its agenda and has founded The Global Future Council on Space Technologies which will consider new global governance frameworks, new metrics for measuring the Space economy, as well as further discussions on Moon exploration.

It will also help steer the Space Sustainability Rating project and will reportedly look to establish a debris risk characterisation of different operators which could potentially be used to differentiate between operators with differing levels of responsibility within the space environment (World Economic Forum, 2019).

Differing manufacturing and procurement practices to 'traditional' space

Access to venture capital, a blank canvas, and the speed at which ideas can be developed and deployed, are allowing activity to happen quickly. They are also changing risk profiles.

- Reusable launchers
- Mass production of spacecraft
- Buy cheap, 'off the shelf' products
- Rapid development cycles

What does this look like?

The increasing democratisation of space has led to fresh perspectives upon some of the standard approaches to mission design. A more disposable view of satellites has taken hold in many quarters, where rather than focusing on robustness and 'building to last', a space mission is viewed as being a comparatively short-lived affair.

The rapid progression of technology makes some designs practically obsolete within a few short years, and thus satellites in practice naturally have a shorter 'shelf life'.

In such circumstances there is no need to invest large amounts of capital in over-engineering systems and subsystems; instead mass-produced consumer-grade components can be used (known as 'COTS' or 'Commercial-Off-The-Shelf' components) which are considerably lower cost than their bespoke 'space-rated' alternatives.

Examples include:

- Mass production and modular designs: GEO satellites and government earth observation spacecraft have traditionally been overengineered to cope with the stresses of launch and lifespans of up to 18 years. Operating at lower orbits and smaller scale is eroding this, and disposability and redundancy are changing risk profiles.
- Manufacturing in orbit: developments in 3D printing, falling launch costs, and the risk of launches are making people consider 'why not build and assemble in space?' This is being enabled by developments in new sources of materials and production techniques.

Insight: Rising numbers

The pace of miniaturisation of electrical components has meant that progressively the physical volume required for complex computational tasks has reduced over time. This means that whilst in years gone by it was necessary to design a satellite to be half the size of a jumbo jet, now it is possible for a computer the size of a smartphone to act as the 'brains' of a satellite, a concept actually demonstrated by NASA back in 2013 with the launch of a trio of 'PhoneSats' (NASA, 2013).

This trend towards miniaturisation means that the satellite communications industry is gradually shifting added focus towards constellation-based service models, as evidenced by the diversification by manufacturing primes venturing into new markets.

Of course, the reduction in size is not completely proportional; one modern smallsat does not have the equivalent capability as an older generation mobile GEO broadband spacecraft. Smallsats offer a new tool in the box, not necessarily a replacement for GEO systems.

Forecasts suggest that over 7,000 smallsats will be launched by 2027, of which 80% will be constellation spacecraft. The majority of these will form part of newly envisaged telecommunications systems and will be points of risk aggregation for any downstream sector reliant on space-based connectivity. With increasing numbers of satellites, risks around third-party liability, space weather, generic defects, and space debris are going to be increasingly important.

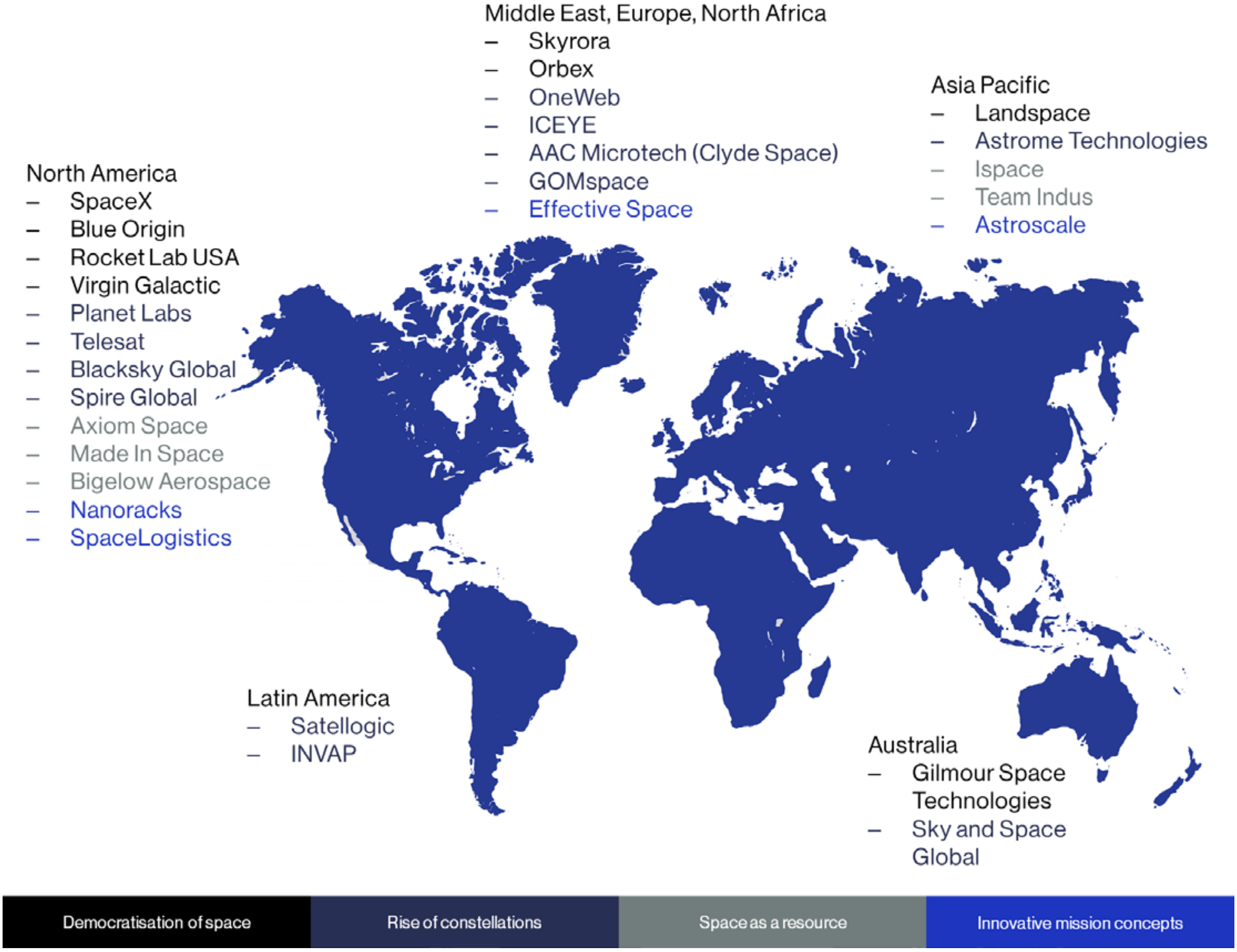
For example, when multiple spacecraft feature the same or similar components, there is an inherent risk that previously unidentified issues can emerge that can cause loss of capability to multiple space missions, or even lead to the failure of satellites. This risk can be mitigated by use of components with existing in-orbit heritage, as most common failure modes become apparent during the early stages of the life of a satellite.

This risk can potentially affect all spacecraft of a type or design which feature the same components and is considered to be heighted when multiple satellites are launched within a relatively short span of time, as could conceivably be the case for multi satellite constellations.

2.2 Stakeholders driving development

The map below presents a snapshot in time of service providers in each region unpinning NewSpace activities, the traditional space powerhouse of the USA is a major player within the sector, with high concentrations of industry around the historical launch sites on both the eastern 'space coast' and western test range. However, it should be noted that activity moves fast in this area, and these companies should not be considered a definitive list – new entities are emerging all the time.

Figure 1: Examples of NewSpace companies by region



Source: London Economics analysis

Western Europe also boasts a significant presence within the industry, and emerging suppliers in the Indian subcontinent presents a significant contribution with regards to the NewSpace manufacturing base.°

Russia and China also maintain a formidable level of space related manufacturing and launch capability; however, activity is predominantly still aligned with state activities and less correlated to free market commercial undertakings typically falling under the definition of NewSpace.

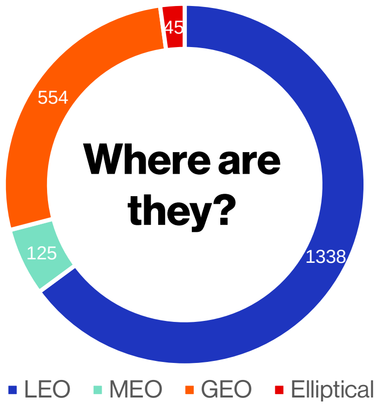
Elsewhere in Asia Pacific, Japan builds upon its space heritage and reputation as being a significant contributor to global technology markets by displaying considerable levels of activity related to NewSpace.

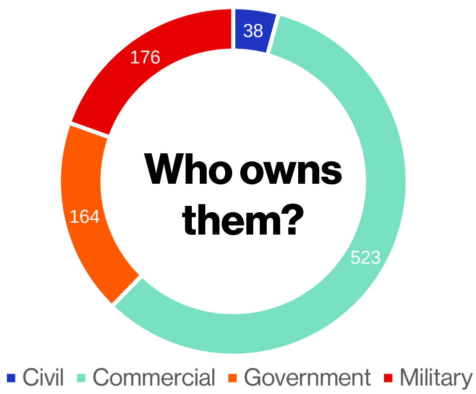
Australia is also looking to take advantage of its geographic location to establish itself as a key player in the Southern Hemisphere. For example, Australia's Space Activities Act received a major amendment, making it easier for small companies to launch satellites there (Australian Government, 2018).

° Supplier list available from satsearch.co/suppliers

2,062

Total number of operating satellites, of which...





Source: (UNOOSA, 2019)

Government backing

Industry research cites 86 countries currently investing in space programs (EuroConsult, 2019), although the number that will be viable are still in question.

In the short term, the US government continues to be the world's largest investor in space programs with a 2018 budget of $20.7bn. This is followed by China, Russia, France and Japan.

All these programs are looking to enable the connectivity required in the short-term by downstream activities such as in-flight Wi-Fi, connected vehicles, and VSAT-equipped marine vessels. Over the long term, these will enable capabilities such as globally available internet, autonomous vehicles, and autonomous shipping.

Where is this happening?

With the emergence of an increasing number of commercial spaceports, the needs of such establishments with regards to liability and prelaunch risks are likely to expand, and those in the property market should seek the insight of the insurance market to tap their speciality knowledge. There are known to be 11 prospective commercial spaceports in the US alone, with plans underway for a twelfth, plus developments occurring in Europe (Nanalyze, 2018)

Following on from the Mojave Air and Space Port in California, the Pacific Spaceport Complex-Alaska, and Spaceport America in New Mexico, the UK government announced in July 2018 plans to construct a dedicated commercial spaceport in the north of Scotland.

The government is providing funds to contribute to developing the site, alongside a grant to UK based start-up Orbex with the intention of developing a new smallsat launch vehicle to be operated from the site. These efforts will be in partnership with Lockheed Martin, which has also been provided with grant funding from the UK Space Agency (UKSA) to develop the vehicle (BBC, 2018).

UK based start-up (Skyrora) has plans to build upon the heritage of historic UK space technology and an existing industrial base in the Ukraine to develop their own suborbital launch vehicle. Whilst the company intends to launch also from a Scottish launch base, it is not clear as to whether this will complement or rival the Orbex offering, but in any case, demonstrates the vibrancy of the space sector in the UK (Adamowski, 2018).

Additionally, the UK government is not the only European nation looking to establish itself as a smallsat launch market; Sweden has outlined its aim to operate European launches for Virgin Galactic from its site at Kiruna Airport (Curry, 2011).

Entrepreneurs

A slew of commercial ventures has rushed to fill the void left open by reducing government budgets since the peak of the Cold War era *(see Insight: 'History of space' p11 and 'Increasing lift-off' p.14)*, with even start-ups entering the realm of credible players in this burgeoning market.

The principle figurehead for this was US start-up SpaceX, representing one of the first successful examples of a privately funded venture with both the means and willpower to take on the challenge.

Prime examples of this phenomenon occurred initially within the realm of commercial space launch, including the sub-orbit space tourism flights. Individuals such as Richard Branson via his Virgin Galactic and Virgin Orbit enterprises, and Jeff Bezos with the Blue Origin venture, aim to provide low-cost access to space for payloads and potentially people in the future

Start-ups with venture capital backing

Companies such as Rocket Lab, headquartered in the USA, have utilised Venture Capitalists (VC's) and private investment funds to finance their operations, receiving $288m as of November 2018 (Foust, 2018). The company has conducted first flights of its Electron launch vehicle for both commercial customers and as part of a NASA sponsored mission (Rocket Lab, 2018), and is intending to utilise its reported payload capability of 150 kg to Sun Synchronous Orbit (SSO) to loft further smallsat missions in the future.

Reputedly there are in the order of dozens of new launch ventures at various stages of development, with the endeavours not solely related to North America, with notably around ten private firms in China reportedly working on their own small launch systems (Moss, 2019).

Academia

As the most budget-constrained user group, academia has the most to gain from the falling cost of access to space.

A growing number of universities have students building NewSpace solutions and government organisations such as NASA and ESA are partnering with them. This is occurring through incubation centres looking to spin-up new solutions and by providing launch support.

Through using smallsats, fundamental capabilities of satellite design and engineering can be developed that can be translated up to larger projects. However, this pace of development also means that insurers are often left without confidence in launch schedule likelihood and that uncertainty can be reflected in the coverage.

Insight: Market evolution

Insurance can be a stakeholder voluntary process or a mandatory requirement coming from manufacturing and servicing contracts or coming from funding entities as banks, export credit agencies or venture capitalists.

For example, here are some of the stakeholders and their interests:

- Satellite operator: asset, revenues, expenses, liability
- Satellite manufacturer: manufacturing, transport, transit, incentives, liability
- User: revenues, expenses, investments
- Investor or lender: loss of investment or loan
- Launch services: relaunch guarantee, liability

Despite these points, at present only around 5% LEO satellites are insured (Serrano García, 2019), which raises interesting insights to the sector and how it is developing. However, products like Llift Space are emerging to meet demand *(See the Llift Space case study for more details).*

The characteristics of NewSpace are comparable with emerging sectors where rapid iterations, a strong focus on research and development, and private capital, mean that NewSpace entities are taking the risk on themselves.

The risks remain, and those without the ability to absorb those losses can find themselves out of business before they've hit commercialisation, especially where their devices don't survive launch.

However, as the market matures, and traditional sources of finance are sought, these institutions are highly likely to require risk transfer to be part of the equation. Therefore, it has never been more important for NewSpace entities to partner with insurers to explore their risks.

For example, with the increasing crowding of space – both in terms of vehicles and debris – it isn't a question of if, but when, for an extreme third-party liability event to take place.

Further details on how NewSpace entities can work with Lloyd's market stakeholders can be found in our NewSpace market guide.

3. NewSpace trajectory

3. NewSpace trajectory

Despite already being worth an estimated $300bn, innovation in space looks to continue its upward trajectory, further pushing the bounds of technology. The development of an affordable and reusable launch method into orbit is likely to continue to be key to reducing costs to commercially viable levels, something which SpaceX has already made significant progress towards. However, it remains to be seen whether true interplanetary exploration or commercial exploitation of asteroidal resources will become a reality in the coming years.

As NewSpace activities continue to develop, now is the time for insurers to think about expertise from existing classes, and how they can partner with existing expertise in the space market to create solutions that will allow customers to be brave.

For example, private firms such as Virgin Galactic and SpaceX have begun to change the landscape through facilitating advancements in rocket technology around reusability, that offer the potential to make private spaceflight affordable for commercial entities and even tourists. The Lloyd's market has already insured commercial launchers, including test flights and third-party liability cover for many of the launch service providers.

The timeline below presents an approximate timeframe of central developments to the NewSpace movement. This task is understandably challenging as the typical levels of optimism in the space industry may overlook slippages in mission schedules for example, due to budgetary restrictions or manufacturing issues, which is common to all space activities, an extreme example of which relates to the James Webb Space Telescope intended to replace the Hubble Space Telescope.

- Democratisation of space
- New mentality and ethos
- New manufacturing processes

- Smallsats and cubesats
- Constellations

- Asteroid mining
- Manufacturing in space
- Energy production
- Space tourism
- Sub-orbital spaceflight

- Fuelling and service stations
- Debris clearing
- Planetary habitation

3.1 Smallsats: the rise of constellations

3.1 Smallsats: the rise of constellations

A decrease in the cost to manufacture small-scale satellites and operate in Low Earth Orbit has opened the potential to have networked constellations of satellites.

Whilst the concept of smaller spacecraft in lower orbits is not new to the space industry the size and scale of the new developments displays an ambition beyond the rehashing of earlier concepts.

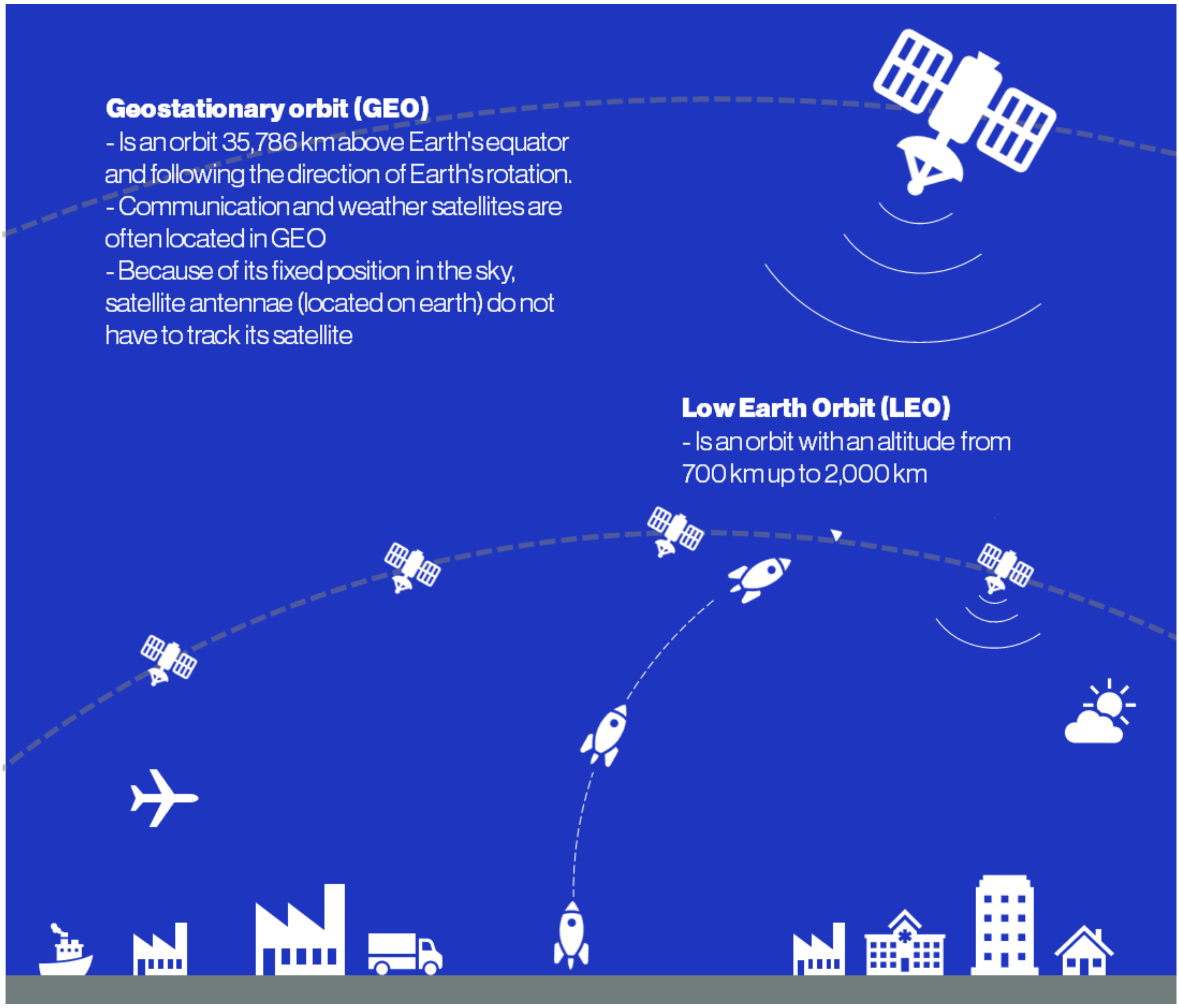
A pronounced shift away from the traditional large GEO telecommunications satellites has taken place in recent times, as market actors both old and new have shifted towards constellations of smaller, lower cost, mass produced spacecraft in LEO.

Depending on the specifications, a smallsat can be built and placed in orbit for $500,000. In comparison, the cost of a conventional satellite can be as high as $500m (Alen Space, 2019).

This raises new and interesting challenges around the aggregation of risks, as the collective value of hundreds of identical, interconnected constellations of satellites can now run to billions of dollars.

It also brings new dependencies on the resilience and reliability of the performance of constellations as a whole, and with increasing traffic in space, risks are growing.

Figure 2: The difference between satellites and smallsats



Constellations

Constellations are required to achieve global coverage. Thousands of smaller satellites are used to work together and operate as a single network. Since LEO is closer to earth they cover less territory due to the limited field of view from the cameras, antennas.

Large constellations can achieve constant 100% global coverage, which will be necessary for global internet access, imaging and surveillance with higher resolution.

Traditional commercial satellites have been GEO satellites with larger coverage, and LEO satellites are not able to compete on this factor. However, smallsats are lower cost and easier to develop, and these factors are driving interest.

As LEO and GEO become ever more crowded, operators are also giving fresh thought to alternative orbital locations, and there is currently focus around Mid Earth Orbit (MEO) to join the O3b constellation that already operates there. Despite space being so vast this expansion will continue to be an issue.

Examples include:

– Following on from its initial constellation of twelve communications satellites launched in 2013 & 2014, O3b have commenced expansion of their MEO fleet.
– OneWeb have also submitted a filing with the Federal Communications Commission (FCC) in addition to their LEO plans, and retain an option for a complementary constellation at higher altitude.
– Gapsat are another new entrant with ambitions to fill vacant orbital slots licensed by GEO operators by locating a smallsat as a placeholder for a future longer term, larger spacecraft.

  This is a potentially useful development as licensing requirements for specific operators tend to be based on first come, first served approach and loss of a vacant slot requires a lengthy and costly reapplication process.

Smallsats and CubeSats

A new era of the smallsat can be attributed to the reduced physical volume required for carrying out complex computational tasks, although one modern smallsat does not have the equivalent capability as an older generation mobile GEO broadband spacecraft.

The term 'smallsat' has a variety of meanings; for instance, NASA class any satellite below 300 kg as a smallsat, however other sources consider any spacecraft under 500 kg as a smallsat. In terms of size, small satellites are about the size of a large kitchen fridge.

Figure 1 *(below)*, illustrates a comparison between two GEO spacecraft – a High Throughput Satellite (HTS) which offers a phenomenal bandwidth capability for Broadcasting-Satellite Services (BSS), Fixed Satellite Services (FSS) and/or Mobile Satellite Services (MSS), and a proposed microsatellite platform for provision of broadband services from GEO.

Figure 1: Reducing size of communications spacecraft

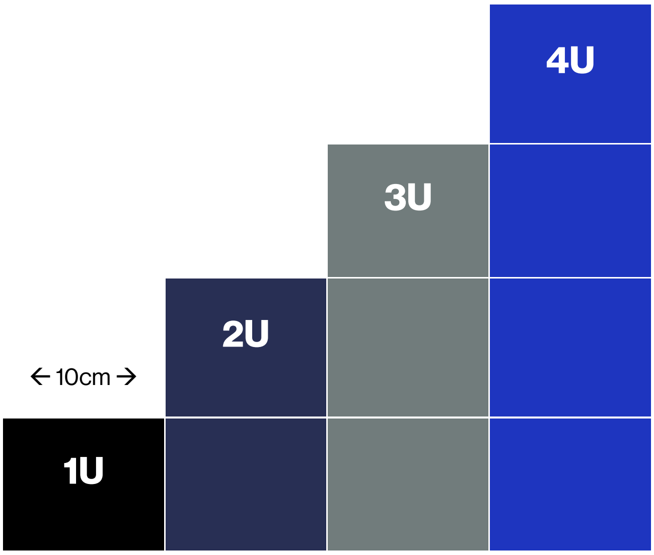
Note: Comparison for scale is the Intelsat EpicNG (26ft x 12ft x 11ft) and Astranis MicroGEO (3ft³): Whilst the exact payload capabilities of the Astranis spacecraft are unknown, it will reportedly feature the capability to provide up to 10 gigabits per second of capacity (Gbps), versus the Intelsat spacecraft which advertise 25 – 60 Gbps.

Source: Adapted from (Foust, 2018; IntelSat, 2019)

Even with small spacecraft, there is a large variety of size and mass that can be differentiated. Confusion can also arise when considering whether the mass includes propellant (wet mass), or purely refers to the mass of the satellite itself (dry mass). In addition, whilst 'small satellites' refers to all satellites in the sub-500 kg class, some smaller spacecraft have their own individual sub-classifications:

- Minisatellite, 100-500 kilograms
- Microsatellite, 10-100 kilograms
- Nanosatellite, 1-10 kilograms
- Picosatellite, 0.01-1 kilograms
- Femtosatellite, 0.001-0.01 kilograms

CubeSats are a class of nanosatellites that use a standard size and form factor. Standard industry terminology has been adopted that allows a base unit of measure for smallsats. This is specified as a 1U CubeSat, which is approximately a 10 cm cube with a mass of 1 – 1.33 kg each. Larger 'CubeSats' can then be expressed as multiples of a 1U CubeSat:



The rapid progression of technology means that mass-produced consumer-grade and lower cost components are increasingly being used (known as 'COTS' or 'Commercial-Off-The-Shelf' components). If a component fails on orbit, the disposable nature of the vehicle means it can be retired and replaced.

The 'CubeSat Standards' enable completed CubeSats to be easily interfaced with launch dispensers and allow mass production of parts to pre-defined international standards. Other innovative concepts such as modular design of spacecraft enhance the technological advancement in the NewSpace sector

These satellites require new types of products, and the Lloyd's market are responding to customers' needs:

Product: Llift Space

Llift Space builds on the strong history of the Lloyd's market in supporting space endeavors, bringing together 18 syndicates, led by Brit and Hiscox MGA, to write NewSpace risks via a dedicated Lloyd's platform to meet their specific needs.

Customers asked for scalable, modular coverage, in an easy to understand format, so policies were designed under one simple structure that could cover individual smallsats all the way up to entire constellations.

Policies can also cover multiple classes, which is done through a tailored set of easy to answer questions that are designed to cut through to the factors that matter. This ensures the conversation could be done in no more than an hour – an essential part of the design process that allows them to efficiently access the security that insurance offers, covering them from factory to orbit.

The result was the creation of a product that brought in the original efficiencies and scalable design and then combined it to a new modular approach that allowed the addition of an even wider range of client products to be added on.

Read the Llift Space case study for more details.

As well as commercial entities, there are also partnerships between government and academic groups that are supporting the development of CubeSat growth. For example, NASA's CubeSat Launch Initiative (CSLI), provides CubeSat developers with a low-cost pathway to conduct research in space that advances NASA's strategic goals in the areas of science, exploration, technology development, education and operations.

The initiative allows students, teachers and faculty to gain hands-on experience designing, building and operating these small research satellites. To date, NASA has selected 162 CubeSat missions, 69 of which have been launched into space with 38 scheduled for launch within the next 12 months (NASA, 2018).

Some industry forecasts suggest that over 7,000 smallsats will be launched by 2027, of which 80% will be constellation spacecraft (EuroConsult, 2018). The majority of these will form part of newly envisaged telecommunications systems, with Table 2 (below*)* illustrating the size and scale of the proposed proliferation of lower altitude orbits by mobile internet providers.

For example, OneWeb were one of the first to state their need for a minimum of 600 in-orbit spacecraft to achieve global coverage, although conceivably this figure could ultimately be higher. The original goal of the organisation was to utilise mass production techniques to reduce per spacecraft manufacturing costs to sub $500k, however recent reports suggest the costs have escalated to within the region of $500k - $1m per satellite (Henry, 2018).

In 2015 SpaceX announced its intention to venture into the smallsat market, with its own megaconstellation of small telecommunications satellites intended to orbit in LEO, providing mobile internet services. Known as 'Starlink', the constellation has received regulatory approval from the US Federal Communications Commission (FCC) to launch as many as 12,000 satellites (Coldewey, 2018).

Other LEO telecoms constellations have also been proposed by a mix of start-ups and established industry players, with one of the most credible prospects being that announced by established Canadian GEO operator Telesat. With FCC approval for a 117-satellite constellation (Henry, 2018), Telesat notably earned the distinction of being the first of the early movers to successfully launch a test satellite into orbit.

US operator Planet Labs was founded in 2010 and has operated a constellation of dozens of its Flock CubeSats from as early as 2014. Through a series of mergers and acquisitions it has increased its fleet of LEO Earth Observation (EO) spacecraft to take a leading position in the imaging marketplace, and as of 2017 it possessed the world's largest operational satellite constellation of over 150 spacecraft.

Other uses of LEO also account for a sizable portion of this total, such as the growing number of operators developing fleets of Earth Observation (EO) or enhancing existing constellations, leading examples of which are provided in Table 3 *(below)*. Whilst it is sensible to regard the scale of the proposals with a degree of scepticism, it is evident that a future where the aggregate population of LEO and MEO orbits is at least an order of magnitude higher than that currently occupying the GEO belt is imminent.

Table 2: Leading telecommunication constellations

Constellation owner/name	Orbital altitude (km)	Registered country	Approximate no. of satellites	Stage of development
OneWeb	1,200	USA/UK	~650	Prototypes launched and active
SpaceX (Starlink)	550	USA	Up to 12,000	Prototypes launched and active
Amazon (Kuiper)	590 – 630	USA	3,236	Seeking regulatory approval
Telesat	1,000 - 1,250	Canada	292, up to 512	Prototypes launched and active
LeoSat	1,432	USA	108	Licenced by FCC

Source: London Economics based on SpaceNews and original sources

Table 3: Selected proposed Earth Observation constellations

Constellation owner/name	Satellite size/mass	Registered country	Approximate no. of satellites	Stage of development
Planet (Labs)	Smallsat & CubeSat (3U)	USA	150 + 24	Constellations active, replenishing
Satellogic	NanoSat	Argentina	90	Constellation active, building
Spire (Lemur)	CubeSat (3U)	USA	150	Constellation active, building
Spaceflight Industries (BlackSky)	MicroSat (56 kg)	USA	20	Launch campaign underway
ICEYE	MicroSat (~70 kg)	Finland	18	Prototypes launched and active

Source: London Economics based on original sources

This next generation of satellites is supporting another area of business: monitoring. The UK Space Agency has awarded a $19m contract for a new satellite monitoring programme, which aims to protect 300 million hectares of tropical rainforests across the globe (UK Space Agency, 2017).

Earth observation services will enable activities such as, maritime and aircraft tracking, and weather prediction – a number of these are outlined overleaf to prompt ideas on space data's multiple touchpoints.

Advanced use of earth observation data from satellites, aerial surveys, ground sensors and other sources will support decisions and actions for disaster response and security. For example, SatCBRN is exploring the use of satellite services for surveillance and hazard management of incidents involving release of chemical, biological, radiological or nuclear threat agents.

How Lloyd's is looking at harnessing digitalisation

The global supply chain complexity is going to have new dependencies and open opportunities such as real-time service provision and insurance products. See the recent 'Triggering Innovation' series to find out more about how parametric insurance and smart contracts will use space observation data to act as oracles of truth that will allow the insurance sector to offer products around flooding, agriculture, flight delays, and shipping.

As part of the Future at Lloyd's, Lloyd's is rethinking the claims experience to build an efficient, dynamic service based on customers' needs. One example already in play in the Lloyd's market is the use of satellite imagery provided by McKenzie Intelligence Services, which is used to assess remotely damage to property days or even weeks before sites can be safely accessed by people on the ground.

Lloyd's used this technology to assess damage while the 2018 California wildfires were still burning, as well as in the aftermath of the 2016 Fort McMurray fire which caused devastation to homes and lives in this Canadian town (LMA, 2017).

Space as an enabler: the art of the possible

Exposure management
Detect land use changes and classify them in near real-time. Combined with other data sources such as IoT, this could enable a more accurate picture of exposures and the location of assets.

Modelling
New data sources for models. Abundant data helps models become richer, more sophisticated and constantly evolve with fresh input. For example, mapping physical hazard risks, and providing detection and monitoring services. This could allow wildfire risk forecasts based on multi-year historical data and near-real time data.

Capital reserving
A dynamic view of exposure means that capital reserves can fluctuate and be further optimized.

Claims
Access to real-time and abundant data makes it easier to identify fraud, prevent loss and validate claims immediately for faster settlement. For example, when were repairs completed, or did any further losses occur before the loss adjustor was able to get to site?

Business models and customer relationships
Insurers could partner with tech companies to integrate their data and support personalized and augmented service-based offers that will create a different value relationship with customers. Insurance solutions to become more bespoke, flexible and real-time. For example:

Supply chain risks
Monitor and track supply chain risk by tracking goods as they traverse the world. For example, Spire Global is already offering services to track ships and planes with automatic broadcast receivers.

New products
Build indexes for parametric and smart contract products using new sources of data. See our Triggering Innovation study for further details.

Catastrophe response
Monitor locations of multi-day catastrophe events, and to track the claims process. For example, customers could be alerted to claims before they know they have happened.

Partner with InsurTechs'
Third party providers are using other technologies such as machine learning, IoT, and artificial intelligence, to add value throughout the insurance chain. For example, when customers provide details during the sign-up process, forms are populated with data augmented from other sources to provide a richer view of assets.

Insurance All classes need to collaborate

As NewSpace activities continue to develop, now is the time for insurers to think about experience from existing classes, and how they can partner with existing expertise in the space market to create solutions that will allow customers to be brave.

The Lloyd's market has already insured commercial launchers, including test flights and third party liability cover for many of the launch service providers including the likes of Virgin Galactic and Space X. NewSpace activities are going to enable affordable coverage to emerging markets where billions of people and internet of things devices are waiting to be connected where they are most wanted. To take advantage of the opportunities on offer, insurers must:

- Talk to customers to establish where product gaps exist
- Ramp up innovation to increase product development for NewSpace
- Collaborate across classes to harness existing expertise to meet this growing sector

Knowledge	Things to think about
Cargo	Lessons can be taken from the transport industry on how to model and assess high value goods being stacked together on launch vehicles. Recent developments in the Internet of Things (IoT) to monitor the status of individual items and overall container statistics could also be used to create real-time assessments. Reports to prompt thinking, include: Steering the course A different approach to modelling marine risk for the changes in vessel size and the aggregation of risks., and Networked World for thoughts on the use of IoT.
Mining and extreme environments	Employees working in specialised environments, such as space based mining, manufacturing, or low gravity habitats will require specialised life insurance and workers compensation policies. Six years ago, our market developed a bespoke policy to cover one of the largest and most challenging polar expeditions ever undertaken. The 4,000km journey would take 273 days to complete, mostly in complete darkness, at temperatures as low as -90º. These kinds of extreme environments and conditions will also be faced by commercial astronauts. Reports to prompt thinking, include: Drilling in extreme environments, Arctic opening: opportunity and risk in the High North.
Aviation	Launches are currently insured on a flight by flight basis, but spaceplanes could be more suited to an annual policy style of insurance like that used in the aviation sector. Space ports are also expected to need their own cover. This would likely be an extension of that currently provided to airports but would need to take into account some new elements unique to spaceports, such as the storage of more exotic propellants. Reports to prompt thinking, include: Goods to Go, which analyses cargo insurance trends in the Lloyd's market, and uses past and present strategies for managing cargo risk accumulations to identify good practice.
Cyber	NewSpace is going to enable increasing connectivity, and bring online devices that have previously been unconnected, and may have been waiting there for years. Customers will have to deal with business interruption, financial penalties, regulatory scrutiny and reputational damage in increasingly complex ways, and at a scale they haven't done before. Report to prompt thinking, include: Business Blackout, Counting the Cost, Cloud Down, Networked World, Bashe Attack.

What can you do with space data?

These examples are already being used, a NewSpace has the potential to scale them up by enabling greater connectivity, and near real-time information.

Communication for emergency services

Emergency services require access to high speed communication tools to deal with emergency situations. Project HYDRA by Avanti is a high speed (60Mbps download and 20Mbps upload), secure 4G LTE mobile network backhauled through satellites for UK's emergency services. Terrestrial networks can get overloaded or may not have coverage, or can be installed permanently (e.g. as a network extension) for areas where additional capacity is frequently required. The network can be deployed immediately over a radius of 2 km, or an area of 12.5km^2 where needed.

Monitor air quality

EarthSense is a spinoff company from the University of Leicester. The Air Quality Hotspot Mapper is system that uses Copernicus MACC II and other data sources to deliver near real time pollution monitoring over urban areas (Public.io, 2019).

Carbon monitoring

Create reliable carbon stock baselines and improve land cover maps. For example, the UAE Space Agency and EXOLAUNCH are looking to launch MeznSat by the end of 2019. MeznSat will operate using a shortwave infrared spectrometer to measure the abundance and distribution of methane and carbon dioxide in UAE's atmosphere (Spacewatch Global, 2019).

Disaster event monitoring

Monitor refugee movements and infrastructure development in conflict areas to aid humanitarian efforts. Also, SatCBRN is exploring the use of satellite services for surveillance and hazard management of incidents involving the release of chemical, biological, radiological or nuclear threat agents.

Agriculture health monitoring

Monitor crop health and forecast crop yields with timely sub-meter imagery. This could also include identifying pest infestation and planning irrigation levels to augment precision agriculture techniques.

Ship performance

DHI Global Seas is already allowing customers to reduce fuel consumption and to improve vessel performance by utilising satellite data enriched with ocean current, wave and wind data.

National flood warning and mitigation

Ambiental and Telespazio VEGA UK Ltd developed a system that augments current national capabilities by providing unique real-time urban flood mapping and targeted risk identification. This was designed to improve the capability of local authorities through the lifecycle of flood events. The potential value of more efficient flood defence allocation has been estimated at benefits of £2.8m per annum (London Economics, 2018).

Fishing surveillance

Satellite imagery and AIS data can be used to monitor the whereabouts of fishing vessels and identify illegal activity that can be acted upon by coastguards and other surface vessels. The UK Satellite Applications Catapult have developed a prototype of the Information Analysis Platform designed to use freely available satellite data in combination with cross-country vessel datasets.

This allows the automation of fishery surveillance to detect Illegal, Unreported and Unregulated fishing (IUU) in real time, alerting nearby authorities and regulators to take action. A study of French authorities' use of Earth Observation satellite data to monitor its exclusive economic zones in the South Indian Ocean found that within one year, illegal fishing in that area was reduced by 90%, with none reported two years later. IUU fishing is a worldwide problem that depletes fish stocks and costs the global economy an estimated £15.2 billion every year.

Mobile medical screening

UK Space for Smarter Government Programme supported DEOS Consultancy to design and develop satellite-connected mobile breast screening vehicles to replace isolated screening vehicles that previously relied on resource intensive paper-based systems.

Carbon monitoring

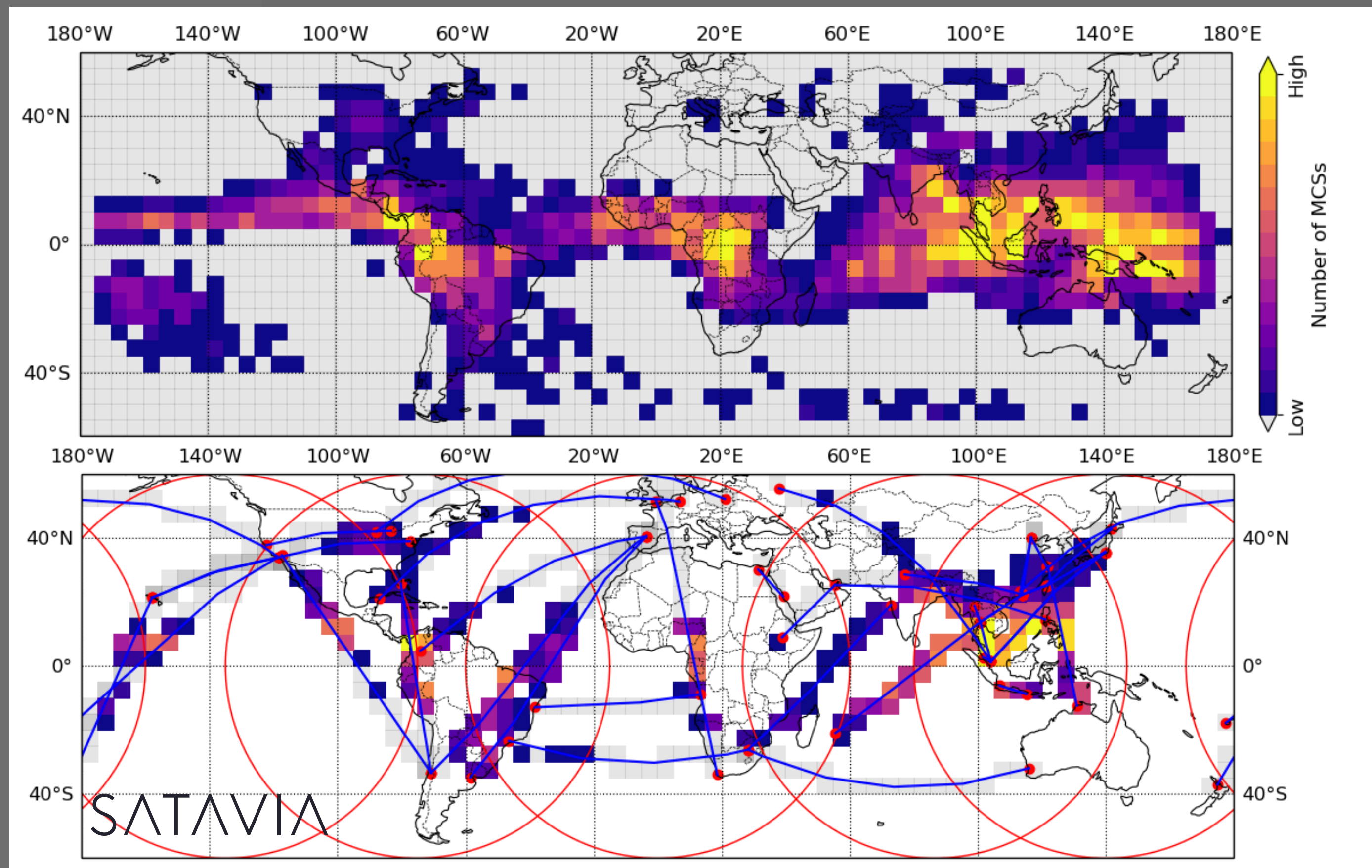
Create reliable carbon stock baselines and improve land cover maps. For example, the UAE Space Agency and EXOLAUNCH are looking to launch MeznSat by the end of 2019. MeznSat will operate using a shortwave infrared spectrometer to measure the abundance and distribution of methane and carbon dioxide in UAE's atmosphere (Spacewatch Global, 2019).

Proof-of-concept SATAVIA

Commercial jet engine aircraft occasionally experience uncontrolled power loss and turbine engine damage while flying at high altitudes in and around areas of deep convective clouds in the Tropics. Deep updraft cores reaching from the lower troposphere into the stratosphere can produce localised regions of High Ice Water Content (HIWC) at commercial aircraft cruise altitudes. This can lead to turbine blade damage in the engines caused by ice accretion and shedding following flight into high level ice crystal clouds.

For example, on 1st June 2099, Air France Flight 447 encountered a Mesoscale Convective System (MCS) and icing conditions over the Atlantic Ocean while at cruise altitude. The aircraft's pitot tubes which measure speed became obstructed by ice crystals, which eventually led to an aerodynamic stall. The aircraft did not recover.

As part of an Aerospace Technology Institute industry project, SATAVIA are building a global climatology of MCS using geostationary satellite data, and analysing city-pair routes to understand the likelihood of encountering an MSC. For example, 'hotspot' regions are located in Central and South America, Central Africa, and Southeast Asia *(top map)*. Flight routes can also be mapped and profiled for 'storminess' *(bottom map and table)*.



SATAVIA's proprietary software platform DECISIONX combines best-in-class technology from atmospheric science, software engineering, data science, and aerospace engineering. This capability is available now, and could be augmented using NewSpace cubesats offer the potential to provide near-real time Earth observation data, which could be used to improve weather forecasting and flight planning, and offer hazard alerting to in-flight aircraft.

Top 5 'stormiest' routes	Bottom 5 'stormiest' routes
Bangkok (Thailand) → Sainte-Marie (La Réunion)	Cairo (Egypt) → Jeddah (Saudi Arabia)
Singapore (Singapore) → Tokyo (Japan)	Dubai (UAE) → Addis Ababa (Ethiopia)
Moscow (Russia) → Singapore (Singapore)	Los Angeles (USA) → Honolulu (USA)
Dubai (UAE) → Manila (Philippines)	Perth (Australia) → Johannesburg (South Africa)
Darwin (Australia) → Shanghai (China)	Shanghai (China) → Beijing (China)

3.2 Launch vehicles

3.2 Launch vehicles

This bring us to the riskiest part of any space-based activities, the launch. Low-cost access to space is a key enabler and catalyst for NewSpace, and any developments are only going to be of use if they successfully get off the ground.

NewSpace activities are being enabled by:

- Heavy lift vehicles: Closer to familiar territory for insurance market. Examples include SpaceX's Falcon 9 and Falcon Heavy, Arianespace's Ariane V and Blue Origin's proposed 'New Glenn'. Heavy lift vehicles evolved from the need to loft a large payload mass on a single vehicle. The payload could be a single large satellite or multiple smaller NewSpace satellites. If the latter is insured, there is a potential for aggregation of risk on a single launch vehicle which may require several insurers to provide cover. See the NewSpace product case study on Llift Space for more details.
- Reusability: In an effort to reduce launch costs yet further, SpaceX has pioneered the concept of a reusable version of its Falcon 9 rocket. Unsurprisingly other companies have recognised the viability of the concept and begun to incorporate reusable elements to their launcher designs.
- Smallsat launchers: Over 40 new vehicles with payload capability under two tonnes to LEO in development globally. Launch costs are largely unknown at present. Rocket Labs Electron rocket reportedly priced around \$5m - \$6m per launch. The company has also announced plans to increase launch frequency by recovering and re-launching Electron's first stage (Rocket Labs, 2019).

Future developments in this class will also require centralising infrastructure, and commercial spaceports either existing or in development. The UK is pressing ahead with plans, with several spaceports established in the US. Kiruna in Sweden also attempting to establish foothold in market.

Alongside these developments, the global launch industry and its stakeholders should look to encourage, facilitate, and fund scientific research on environmental factors to ensure best practice around sustainability. This should include engaging with international regulators to discuss and model any knowledge gaps, such as atmospheric impacts, that could lead to uncertainty.

For example, different types of propulsion systems interact with the stratosphere in different ways and these should be understood before a conversation on policy takes place to have an informed discussion as space-based activity offers global monitoring of environmental conditions *(see p28-29 'Space as an enabler: the art of the possible' for examples of global data sets and use cases)*.

Heavy lift vehicles

At present the launch industry is dominated by a handful of commercial providers in the US, Russia, Europe and China. All these providers operate heavy/medium lift launch vehicles with the capability of lofting payloads of several tons to Geosynchronous Transfer Orbit (GTO), the pathway to GEO, with the potential for using the same launchers for dispensing payloads intended for other orbits.

Over the next five years, all the major launch vehicles will be replaced. While eventually this should lead to improved payload capabilities and efficiency savings, with any change there is always risk and uncertainty.

For reference, a selection of the most commonly utilised launch vehicles is provided in Table 4 *(overleaf)*.

Reusability

Traditional space launch concepts have involved the use of disposable rockets, with both lower and upper stages essentially discarded at the end of their useful phase. This has always been an economically inefficient process, which various initiatives such as the US Space Shuttle, and the Horizontal Take-Off and Landing (HOTOL) and successor Skylon and Virgin spaceplanes have attempted to address.

The Lloyd's market has experience of dealing with reusable rocket stages, as it has engaged with SpaceX regarding providing cover for missions featuring reusable Falcon 9 rockets. Should this trend continue within the space industry and be utilised in other launcher missions, then a potential opportunity exists for the insurance market to capitalise on this development as a means of launching a new product line. As the rocket stage itself has a value to the launch provider, it seems a logical step to start insuring the return of the rocket once this capability has matured.

Another potential benefit for insurers in supporting this area of development is with the learning opportunities this presents for launch operators. One of the difficulties associated with space is the lack of recovery in the event of mission failure. The return of spent rocket stages in a controlled manner allows launcher engineering teams to inspect the actual performance of a launch vehicle under real launch conditions. This has made it possible to detect anomalous behaviour not captured by sensor data relayed by telemetry at an early stage and correct it on subsequent flights.

Many launch failures have precursor symptoms in earlier flights which for whatever reason do not stray outside of mission parameters, but close inspection could head off some of these issues resulting in a lower failure rate and reducing claims frequency for insurers. Any resultant data could also be shared with insurers to allow detection of concerning trends, further lessening loss potential for insurers.

Table 4: Selected current launch service providers

Vehicle	Launching state	Launch reliability 2008-18	Launch reliability %	Year of First Launch	Payload to LEO (kg)	Payload to GTO (kg)	Approximate cost per launch
Antares 230	USA	4/4	100%	2016	7,000	2,700	$271.5m
Atlas V 401	USA	32/32	100%	2002	9,797	4,750	$132m - $164m
Atlas V 541	USA	6/6	100%	2011	17,410	8,290	$243
Delta IV Medium+ (5,4)	USA	7/7	100%	2009	14,140	6,337	$137m
Falcon 9 Upgrade (v1.2)	USA	47/47	100%	2015	22,800	8,300	$62m
Falcon Heavy	USA	1/1	100%	2018	63,800	26,700	$90m
Proton M Briz M	Russia	70/76	92%	2001	23,000	6,920	$105m
Rokot	Russia	20/21	95%	1994	2,140		$30m
Soyuz 2-1A	Russia	26/28	93%	2004	7,400	1,500	$46m
Soyuz 2-1B	Russia	25/27	93%	2006	8,250	1,800	$46m
Soyuz-FG	Russia	44/45	98%	2001	7,200		
Long March 2C	China	24/25	96%	1975	3,850	1,250	
Long March 2D	China	33/34	97%	1992	4,000		
Long March 3B	China	21/22	95%	1996	13,600	5,100	
Long March 3BE	China	21/22	95%	2007		5,500	
Long March 4B	China	20/21	95%	1999	2,230		
Long March 4C	China	22/23	96%	2006	2,950	1,500	
Ariane V ECA	Europe	55/56	98%	1996	21,000	10,000	$137m
Ariane V ES/ATV	Europe	8/8	100%	2008	20,000	8,000	$137m
Soyuz ST-A	Europe	6/6	100%	2011	4,340	2,760	$73m - $78m
Soyuz ST-B	Europe	13/14	93%	2011	4,900	3,150	$73m - $78m
Vega	Europe	12/12	100%	2012	1,500		$46m
GSLV Mk II	India	4/5	80%	2007	5,000	2,500	$40m
GSLV Mk III	India	2/2	100%	2017	3,000	4,000	$60m
PSLV XL	India	18/19	95%	2008	1,700	1,425	$22m
H-IIA 202	Japan	23/23	100%	2001	3,300	4,000	$82m
GSLV Mk II	India	4/5	80%	2007	7,000	2,700	$40m

Source: Space Foundation (2018), The Space Report 2018 and London Economics analysis

Smallsat launch

The key to cheap and affordable commercial spaceflight is, and is likely to continue to be, low-cost launch technology, either from the ground or from air-to-orbit launch aircraft.

Essentially at present, the only available option for owners of smallsats is to look to add their satellite onto the manifest of an existing launch, or to wait for a dedicated launch where several smallsats are combined to form the payload.

These options can be few and far between as launch operators tend to service the needs of large entities with repeat purchasing power firstly, unless a smallsat operator is intending to launch multiple spacecraft or their own constellation, in which case purchasing power increases and economies of scale become viable.

To service the needs of smallsat operators, intermediary companies offering to pair up satellites to take advantage of dedicated rideshare missions are emerging. This is also beneficial for reducing the number of launches from an environmental impact, and should be an area of research and development to provide a knowledge base for any regulatory uncertainty.

US based Spaceflight Industries, provides a range of services to the smallsat sector. Spaceflight's primary undertaking is in acquiring spare payload capability from launch service providers, and then essentially reselling the available payload capability to interested operators.

The company has also begun booking dedicated rideshare launches with providers, which allows an entire manifest of small spacecraft to be launched simultaneously. The first such launch occurred on 3 November 2018 with the 'SSO-A' mission via a dedicated Falcon 9 launcher, which successfully lofted 64 satellites for 34 customers to LEO.

As NewSpace becomes more mainstream it seems the shift from low-volume, high-value placements towards a higher volume marketplace for lower value propositions is inevitable.

New dedicated launchers

Despite some of these new undertakings to find new and innovative uses of the existing space launch capacity, it is clear that the existing launch infrastructure will be insufficient to meet the agility required by the nascent NewSpace commercial market. With numbers of satellites requiring launch per year forecasted to soar, a gap in the space launch market exists to cater to the needs of small and micro launch.

With the number of new vehicles in development globally reportedly exceeding 40 as of 2018 (Werner, 2019), not all of these concepts will ultimately prove viable – such as Firefly Space Systems and Vector Space Inc – less than ten launch vehicles were classed as operational.

Firefly suffered from legal and financing issues resulting in its collapse in 2017 and has since been reborn as a new entity. Vector Launch successfully won a launch contract from the US Air Force in August 2019 only to declare just two days later that the company was taking a "pause of operations" (Foust, 2019).

These two examples highlight the fragile nature of the smallsat launch industry, and the anticipated market shakedown over the next few years will likely see a very different field develop in response to challenging market conditions. A summary of the concepts currently considered as the most credible are provided in Table 5 *(below).*

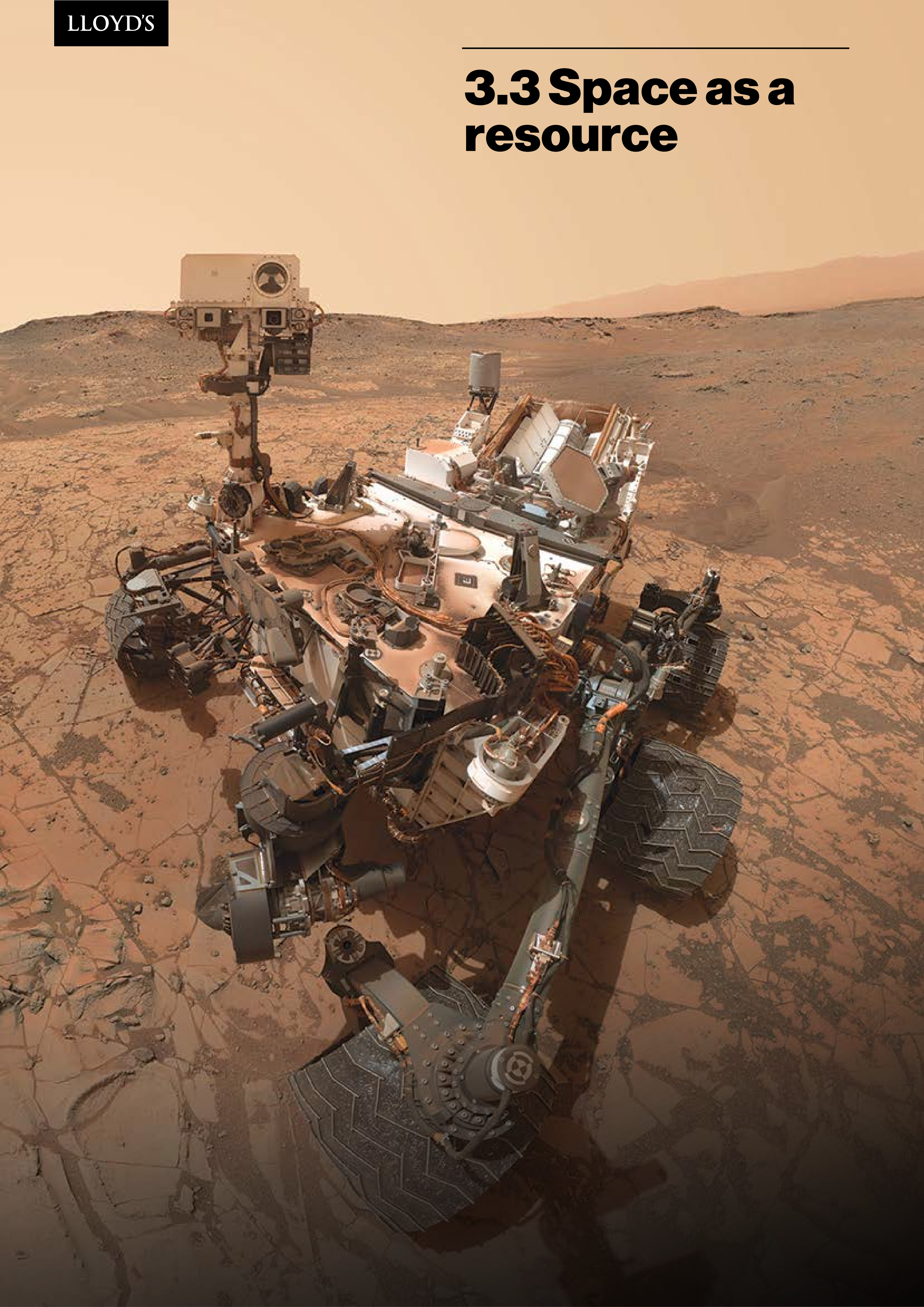
The Lloyd's market has a long tradition of collaboration and research with the space sector, and often produces insight that they share with the industry. This is especially important with the rise of new entities who may not have started in the space sector. For example, underwriters at Hiscox presented a paper at the '4S Symposium 2018', looking at risk and insurance implications from the first 750 cubesats that will be of interest to readers (Lecointe, et al., 2018).

Table 5: Selected proposed launch service providers

Operator	Vehicle	Launching state	Year of First Launch*	Payload to LEO (kg)	Payload to 500 km SSO (kg)	Approximate cost per launch ($m)
Rocket Labs	Electron	USA/NZ	2018	225		$5m - $6m
iSpace	Hyperbola-1	China	2019		200	
China Rocket Co. Ltd.	Smart Dragon-1	China	2019		200	$6m
ABL Space Systems	RS-1	USA	*2020*	1,200		$12m
Relativity Space	Terran-1	USA	*2020*	1,250	900	
Orbex	Prime	UK	*2021*		150	
Blue Origin	New Glenn	USA	*2021*	43,000		

Source: London Economics analysis * *Values in italics relate to estimates of year of first flight*

3.3 Space as a resource



3.3 Space as a resource

The new, less rigorous approach to pre-flight testing has opened the possibility to forgo the phase of preparing a spacecraft and its components for the extreme dynamic stresses of the launch environment.

Instead of utilising resources upon preparing a spacecraft and its components for the extreme dynamic stresses of the launch environment, why not forgo this phase entirely?

Manufacturing in orbit

The advent of 3D printing technology enables the manufacture of components in-orbit using pre-defined templates to be assembled in space. This removes budgetary constraints and potentially reduces the mass of components as high-density materials are no longer needed. This approach raises an obvious question – where do the materials required to construct space hardware come from?

The advent of 3D printing technology has made this a viable prospect, as components can instead be manufactured in-orbit using pre-defined templates and then assembled in space itself. Not only does this remove the constraint of finite launch budgets, but this also potentially reduces the mass of components as it is no longer necessary to construct them from such high-density materials, as the stresses and strains of orbital operations are magnitudes lower than those experienced in a typical atmospheric launch.

For example, Made In Space, are primarily concerned with how the unique traits of the space environment such as persistent microgravity and vacuum conditions can be harnessed to offer new commercial solutions. The company installed the first 3D printer in space, and have operations relating to Large Structure In-Space Manufacturing in partnership with Northrop Grumman. Ultimately Made In Space hope to supply space manufactured products to customers on earth.

Also, in this area, the Refabicator sponsored by NASA and developed by Thethers Unlimited Inc is an integrated recycler and printer that can recycle plastic waste into printable material (NASA, 2019). This feedstock material can be used to print medical and food safe items on demand, which will be necessary for long space missions.

In the future manufacturing in orbit could be extended to building or extending existing and new spacecraft. The Made in Space Archinaut program aims to do just that. The aim is to externally mount a robot to the ISS (Brigham & Kolodny, 2018). The robot has 3D printing functionality and is fitted with a robotic arm. The arm can be used to assemble components externally. This could in future be used to print large structures in space or repair external damage (Thompson , 2017).

By avoiding over engineered parts that must endure the stresses of launch, parts printed in space can be made 10 times lighter and 10 times cheaper. If this becomes an established technology, you could see an eventual reversal in satellite/spacecraft miniaturisation. This could be interesting from a risk management perspective as you could start with a low value launch, with an in-orbit asset increasing in value as it forms larger more complex structures (Wall, 2018).

One possible risk with manufacturing in space is an aggregation of vulnerabilities. If a mission is dependent on a 3D printer for repair and other products, a satellites lifespan could become vulnerable to 3D printing failure. Vulnerabilities could be exacerbated by perils such as space weather or cyber risks that could damage 3D printers. Other problems arise such as introducing a defective component. The defect could be introduced at several points: A defective design, a defective printer or defects in the printable material. This risk is mitigated by testing, which may not be possible for in-orbit manufacturing.

Of course, this approach raises an obvious question – where do the materials required to construct space hardware come from? One potential solution is to make use of the abundance of raw materials already available within the space environment.

Lunar excursions have revealed the presence of metals and minerals buried beneath the Moon's surface. In fact, the surface itself is rich with source materials that have been deposited there by millennia of natural space debris. Asteroids, comets and meteors are comprised of matter generated at the time of the birth of the universe and are a potential source of building blocks for future spacecraft, or indeed for transport back to Earth.

Despite large potential profits, the 2012 Keck Institute for Space Studies (KISS) study calculated that the cost for a future mission to identify and return a 500-tonne asteroid to low earth orbit would be US$2.6 bn (Messier, 2012).

Similar to traditional mining, materials, technical mining skills, a licence to operate and financing will play a crucial role in making commercial exploitation of asteroidal resources a reality in the coming years.

Deep Space Industries, another burgeoning mining firm, is targeting water as a potentially valuable space commodity (water comprises on average around 20% of an asteroid's mass). It is aiming to harvest and sell the liquid as the basis for future space propulsion systems.

Further along the development scale, asteroid mining presents another valuable proposition to the burgeoning space industry. Some asteroids contain within them vast amounts of precious metals. Planetary Resources, a leading space-mining company, estimates that a 30m long space rock could contain anywhere between $25–50bn of platinum, alongside other precious metals (Cofield, 2017). Supply and demand would mean that such abundance would bring down the price of said metals, but the amount of rare-earth material available could easily supply an on-orbit manufacturing economy, with no need to rocket materials into space.

Some may even be worth the trip back. For example, rare earth minerals are a key component to a number of low carbon technologies such as photovoltaic cells and batteries. See Lloyd's report 'Unearthing opportunity' for more information in this area.

Regarding regulations, the US and Luxembourg are at the forefront of developing the regulations for asteroid exploration and exploitation. In 2015 the Commercial Space Launch Competitiveness Act was approved in the US with the aim to "facilitate a pro-growth environment for the developing commercial space industry by encouraging private sector investment and creating more stable and predictable regulatory conditions, and for other purposes" (U.S. Government Publishing Office, 2015). It granted US citizens rights to own, use, transfer and sell mined space resources without granting exclusive ownership over the celestial bodies in compliance with international treaties such as the Outer Space Treaty (UNOOSA, 1966).

Since July 2017, Luxembourg has provided space law expertise and it is the first European country to adopt legislation regulating the ownership of resources acquired in space by commercial companies.

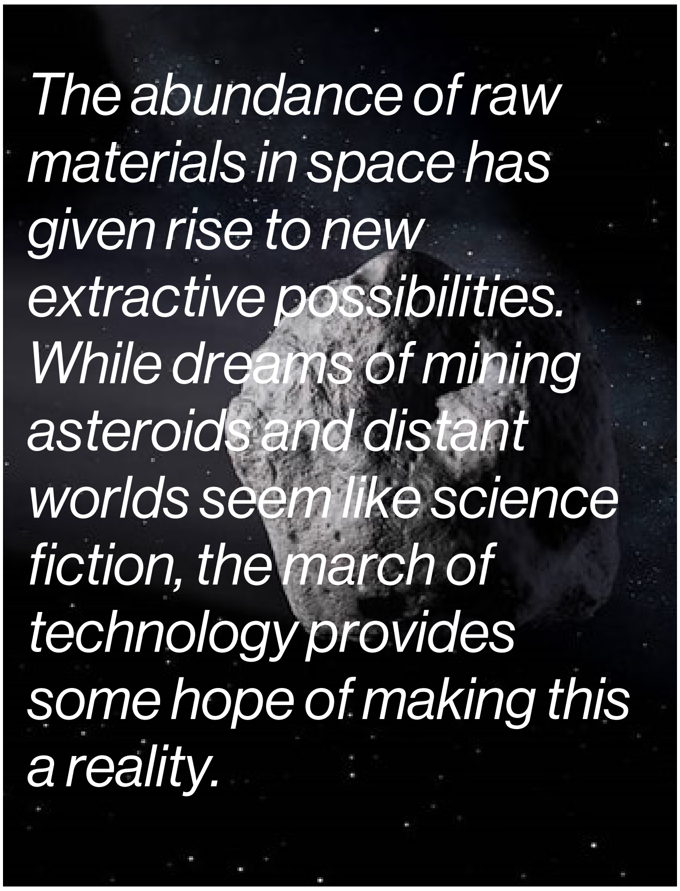
Private enterprises such as Planetary Resources, who have expressed intentions towards developing space exploration and resource extraction operations, are some of the most notable ventures to take advantage of Luxembourg's conducive environment. It has been cited that high initial capital expenditure costs for minimal early returns are limiting developments, despite the long-term prospects (Boyle, 2018). Commercial-scale development will be a longer-term option to watch but should not be ruled out.

Energy production

The transition to a low carbon economy makes harnessing the almost boundless energy of the sun appealing to solve global energy needs. Up in space there is no need to worry about cloud cover to reduce energy production.

Solar energy has been utilised as an energy source for virtually all of Earth's satellites for decades via solar voltaic technology. Proposals to harvest this energy for terrestrial applications via space-based solutions have been in the public domain for several years, with suggestions of beaming energy back down to Earth using spacecraft equipped with laser technology.

At present however there do not appear to be any commercial or public proposals that would make this a reality for terrestrial purposes within the next decade at least.



Space tourism

Commercial human spaceflight is a market set to undergo significant expansion in the coming years. This can be subdivided into two areas – suborbital flight and longer duration visits to space.

Closer to home is the potential to use suborbital point-to-point space-liners to reduce long-haul flights. If this can transport 5% of the passengers that currently take 10+ hour long-haul flights, UBS estimate that this could be a $20bn a year market (Sheetz, 2019). To get to this point there are outstanding questions around regulations, profitability, infrastructure investments needed, and weather. Lift costs and competing transport options may make commercial space tourism a more realistic growth sector in the short term.

The space age has seen a small number of high profile 'space tourists', largely due to the high costs of space launch. Launcher reusability is going to be paramount for space tourism to take off. As the cost per kilo into orbit goes down, so does the minimum wealth level required to make such journeys a reality for an increasing number of aspiring astronauts, and for the development of closer suborbital flights.

Several launch providers are working on suborbital shuttles (Virgin Galactic, Blue Origin, SpaceX). Virgin Galactic argues that sending private individuals into space is the logical next step in space technology, with Richard Branson and his family some of the first names on the list of potential future "space tourists".

While $250k for a single sub-orbital trip may sound expensive, it represents quite phenomenal value when compared to tourists of the past. Dennis Tito, the first-ever space tourist, bought a seat on a Russian Soyuz craft and spent eight days in space including a period aboard the International Space Station back in 2001 for $20m – some eighty times more than the fee quoted by Virgin Galactic.

Any space-based transport service will require ground-based infrastructure. For example, Virgin Galactic is in the process of moving to the world's first purpose-built commercial spaceport, which cost New Mexico taxpayers $220m to build. This will house their fleet of vehicles and over 100 staff by the end of 2019 (Davenport, 2019).

Other start-ups have ambitions to provide commercial space stations for customers (Axiom Space, Bigelow Aerospace) with a prototype module in-situ at the International Space Station (ISS) for the latter. Space tourism can be viewed as an extension to suborbital flight by offering longer duration visits to space aboard private space stations.

The most progressive of these firms to date, Bigelow Aerospace, received support from NASA to attach their BEAM expandable modules to the International Space Station (ISS), where they have been docked since 2016.

The modules are designed to be independent in the instance they are required to be removed from the ISS, and Bigelow plan to develop larger modules for future flights with the goal of eventually operating their own independent space station.

Another early innovator in this sector, Axiom Space, released the results of a commissioned study that suggested that:

> *The commercial space station market is worth a potential $37 billion between 2020 and 2030* (Davis, 2018)

This is presumably premised upon their reservation price of upwards of $50 million for their first paying guests, currently targeted for 2022 (Mamiit, 2018).

In the shorter term, SpaceX, is also looking to develop an Interplanetary Transport System designed to send a crewed mission to Mars by 2024. The completion of such a mission is likely to be preceded by further ventures into space tourism designed largely to raise capital for further research.

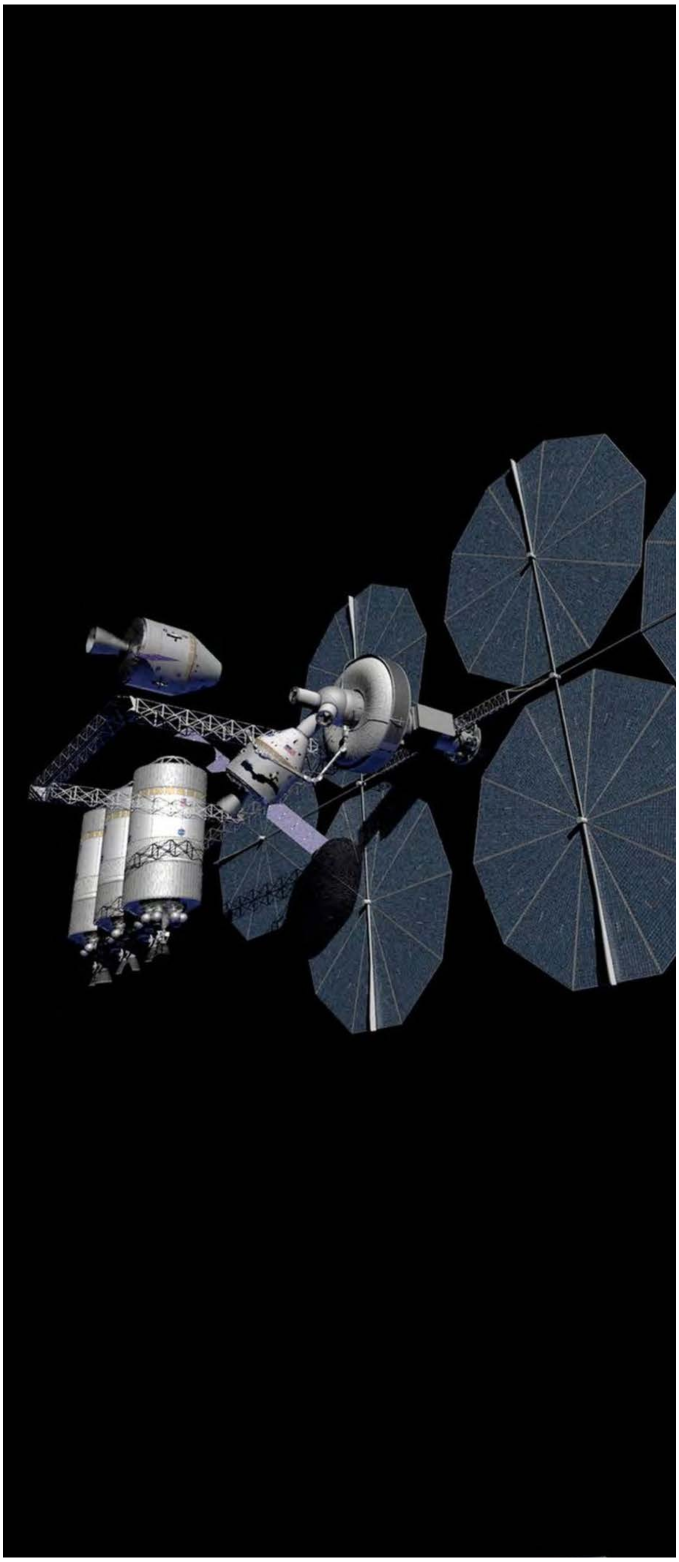
Insight: supporting innovation

Launcher reusability is going to be paramount for space tourism to take off. When it does this insurance industry already has well developed products for high risk environments and could use existing skills and thinking around:

- Travel insurance: Cancellation and patient repatriation (costs from the moon are likely to be higher than usual).
- Specialist personal accident for staff and passengers: Need for versions of life insurance, workers compensation insurance and protection for the business against the loss of highly and uniquely trained employees.
- Aviation hull and liability type insurance for spacecraft carrying passengers into, say, low orbit. Models of aircraft insurance and risk management should be explored to support the same reusability seen in that sector.
- Property: New ground infrastructure is going to be essential to support the development of all logistics seen in airports.

3.4 Innovative mission concepts

3.4 Innovative mission concepts



Another concept much discussed in space-focused circles for several years is in-orbit servicing of satellites. Recently the likelihood of this concept becoming a reality in the coming years has grown, as commercial enterprises that are looking to make a game-changing impact upon the global space economy have emerged.

Fuelling and service stations

Another approach to improving the economics of space is to extend the lifetimes of space missions that are limited by fuel reserves or anomalous performance. Technology development may now finally be ready to kickstart the in-orbit servicing industry.

The limiting life constraint for most satellites tends to be related to reserves of onboard fuel rather than any hardware failures. As such spacecraft are typically heavily engineered to meet the demands of multi-year operation in the harsh environment of space.

The option to refuel an existing asset or correct any anomalies or issues on orbit would appear to be economically a much more sensible option for most operators, assuming the levels of risk to the target spacecraft can be minimised to a level well below that of the launch and development risks of launching a new satellite into orbit.

Key drivers for the viability of such a concept include extending the operational lifespan of high value assets, as well as having the option to repair any defects in early phases. A key question is whether the pace of technological developments would render the satellites of today obsolete in a 15-18-year life cycle.

The market interest of in-orbit demonstration spacecraft makes this an interesting development in the future space economy. UK-based start-up Effective Space, with potential competition from US subsidiary SpaceLogistics of US Aerospace and Defence manufacturer Northrup Grumman, seeks to pioneer a servicing offering to commercial customers (Effective Space, 2019; Northrop Grumman, 2018). This would appeal predominantly to the community of GEO telecommunications operators, who invest significant levels of CAPEX in spacecraft designed to operate for at least fifteen years in-orbit.

Debris clearing

A building problem during the space age has been the by-product of space activities, namely space junk. Initiatives are underway to address this growing concern.

Many observers are already concerned regarding the increasing population of primarily man-made debris amassing in orbit. The debris ranges from larger objects trackable by ground-based systems, down to miniscule fragments such as a flake of paint, all travelling at high orbital velocities.

Efforts taken to minimise or mitigate the negative impacts of the increasing physical congestion in space and eliminate the creation of debris are known as Space Traffic Management (STM).

An important part of these activities is with regards to Space Situational Awareness (SSA), whereby ground- and space-based sensors are used to attempt to maintain awareness of the location of space objects with the aim of avoiding collisions.

Activities relating to STM are currently undertaken at a national level by certain nations, and while this is not an exact science as it features inherent error margins, it allows notification to be provided to satellite operators if a high probability of collision between two objects is calculated.

For example, the U.S. Space Surveillance Network regularly examines the trajectories of orbital debris to identify possible close encounters. If another object is projected to come within a few kilometres of the International Space Station (ISS), the ISS will normally manoeuvre away from the object if the chance of a collision exceeds 1 in 10,000. This occurs infrequently, about once a year on average (NASA, 2019).

By and large the system has been reasonably successful up until now, as major collisions between orbiting objects have been relatively few and far between, however this is likely to change. Firstly, with the increase in sheer numbers of objects in space (more objects have been given FCC approval for launch in 2017-18 than have previously been orbited in over half a century of space activities) and a corresponding increase in the number of space participants.

Secondly if many satellites at the level of nanosat and below are being launched without propulsive systems, then there will be no opportunity for operators of these spacecraft to act upon any warnings in any case.

Insight: Turning risk into opportunity

Increasing concerns about the existing – and likely increasing – population of high velocity fragments of debris currently afflicting sections of the Earth's orbits, has seen commercial and public entities explore solutions. There is a focus around lower altitude orbits below the threshold for atmospheric drag to naturally dispose of this 'space junk'.

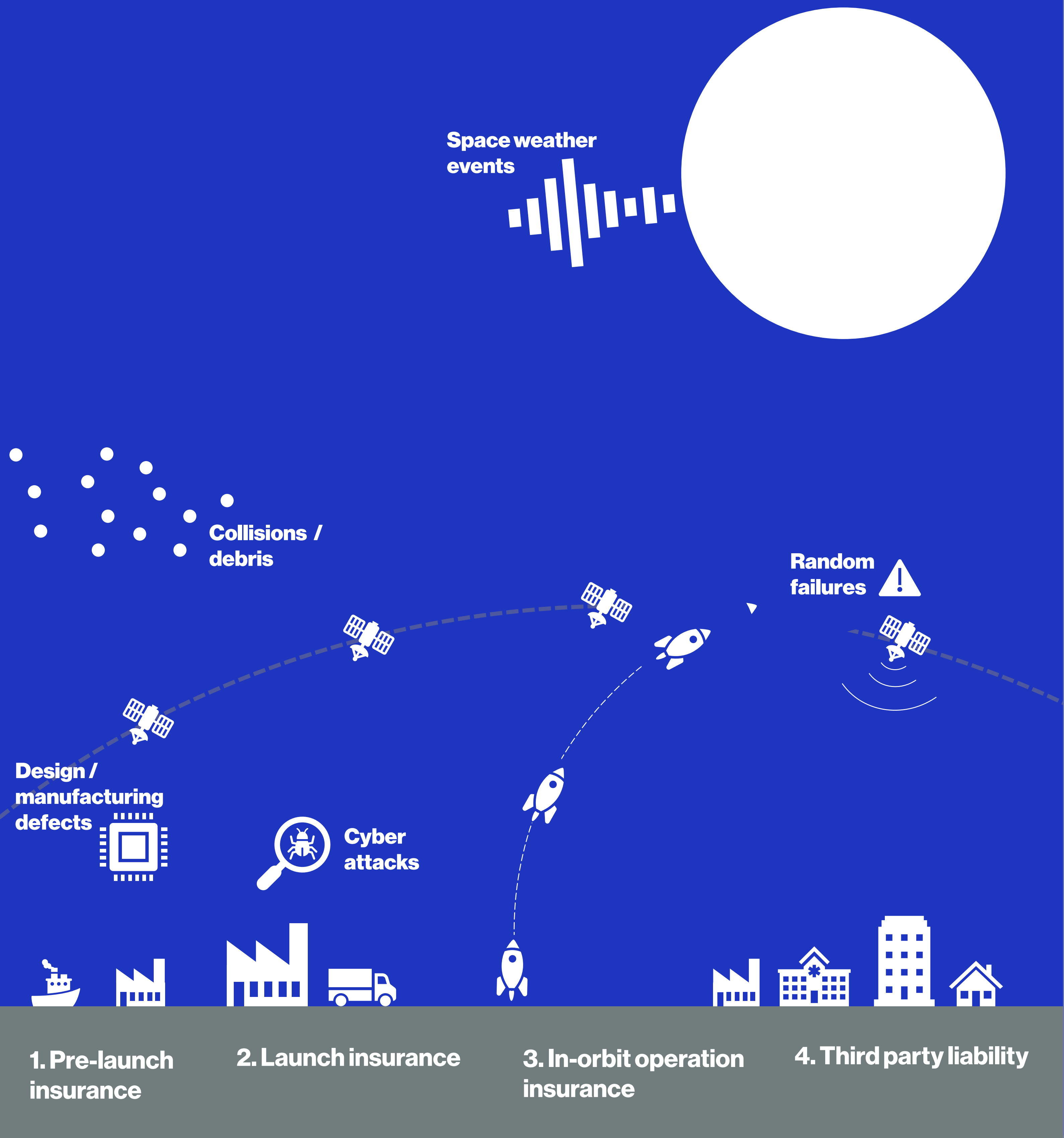
In September 2018 it was announced that the first in-orbit debris removal spacecraft had been successfully demonstrated. The 'RemoveDEBRIS' satellite was deployed in LEO and performed the capture of a target piece of 'junk' by ejecting a net to capture the object.

The project was co-funded by the European Commission and a consortium of industry and academic institutions and is potentially one of the first steps towards addressing a problem of key interest across the space world.

It should be noted however that these efforts are currently at a very early stage, with experiments consisting of pre-selected dummy targets. In practice removal of actual orbital debris may be a complicated affair, as the regulatory and legal frameworks for such endeavours are still currently in development, as debates such as to who can legally take possession of a space object regarded as 'junk' for disposal purposes are liable to continue for some time.

In the meantime, the international space community needs to follow the existing orbital debris mitigation guidelines to limit the generation of new and long-lived debris.

4. What other risks should you be aware of?



Whilst it is sensible to regard the composite of the proposals with a degree of scepticism, it is evident that a future where the aggregate population of LEO and MEO orbits is at least an order of magnitude higher than that currently occupying the GEO belt is imminent. This means that all stakeholders will need to think about how they will manage the risks. While many of these risks aren't new to the space sector, the increasing crowding of orbits and the trends at play will benefit from partnerships.

Looking to the future, there will be a need for an expanded version of a Civil Aviation Authority, directing and controlling routes, launches and landings on Earth, and between and on planetary bodies. Artificial intelligence might be needed to handle the high volume of manoeuvres in the future. All the safety and security considerations of air and sea travel will pertain to space travel at a vastly enhanced level, because the costs and risks are so much higher. There will have to be firm and well-understood protocols in the event of a spacecraft crashing, or two spacecraft colliding (Grady, 2017).

At the moment, the United Nations, through its Office for Outer Space Affairs, is responsible for promoting international cooperation in the peaceful uses of outer space. It also holds responsibilities to oversea the Outer Space Treaty (UNOOSA, 1966), which provides a governance framework for space-based activities for the 105 countries who have ratified the agreement. It has not been violated to date, however, like many innovation areas, policy has not tracked with the pace of change. For example, in 2018 the U.S Federal Communications Commission (FCC) levied a $900k fine on Swarm Technologies, who launched four picosatellites without regulatory approval (Henry, 2018).

Currently, if a private entity launches an object that subsequently causes damage in space, the State will be liable for the costs (Aon, 2016). Given the decentralisation and democratisation of space activities, new entities are being given access to space, it is therefore increasingly important that dialogue between all the stakeholders takes place, and that a solution is agreed before an incident happens to discuss where the liability will fall.

The trends are drivers also bring new implications to think about, and will need new solutions to existing risks:

Trend	Drivers	Implications
Entrepreneurial interest	– Wealthy individuals with the means at their disposal to overcome the costly barriers to space	– Opting for self-insurance – States will be liable for losses, not the commercial entity under the Space Liability Convention (UNOOSA, 1967)
Miniaturisation	– Rideshare options	– Increased number of satellites within a given space increases collision risks. – Collision with space debris shortly after release from the launch vehicle could cause a ripple effect
New approaches to manufacturing	– Use of Commercial-Off-The-Shelf (COTS) components – wider availability reducing manufacturing lead times	– Durability of materials to withstand high velocity impacts and harsh space weather – Unknown robustness of security systems to cyber attacks or resilience of batch components without overengineering
Democratisation of space	– A wider pool of diverse participants	– Increasing congestion in space – Claims process increases in complexity with multiple stakeholders – Increased need for tracking debris and Civil Aviation style association to manage flight plans and paths
Smaller spacecraft	– Lower costs of manufacture	– Lack of insurance
Shorter lifetimes of spacecraft	– Components do not need rigorous engineering – Disposable/commoditised view of satellites	– Less reliable performance, susceptibility to systemic failures for certain satellite batches – Opting for self-insurance

Design/manufacturing defects and random failures

When multiple spacecraft feature the same or similar components, there is an inherent risk that previously unidentified issues can emerge that can cause loss of capability to multiple space missions, or even lead to the failure of satellites. As a heightened pace of production could lead to a higher frequency of undetected generic defects in launched spacecraft.

This risk can potentially affect all spacecraft of a type or design which feature the same components and is considered to be heighted when multiple satellites are launched within a relatively short span of time, as could conceivably be the case for multi satellite constellations.

Any space system is only as strong as its weakest component, and so the potential for susceptibility to systemic failures for certain satellite batches may be heightened as a result.

This risk can be mitigated by use of components with existing in-orbit heritage, as most common failure modes become apparent during the early stages of the life of a satellite. If constellations are launched with a degree of risk aversion, i.e. a small initial batch of 'test' satellites, then presumably most major defects could be identified at an early stage.

The shorter design life of smaller spacecraft compared with their predecessors could encourage a shortening of intervals between launches however, which could potentially increase the number of susceptible satellites to a generic issue beyond the stated theoretical maximum of ten spacecraft assumed in current Lloyd's RDS. This approach could then be reviewed as and when policy structures are defined for constellation risks.

Space weather events

Although we have evidence of space weather existing for centuries, it poses a much greater threat today because of the emergence of vulnerable technologies. Electrical power, in particular, is vulnerable to space weather and is of course of critical importance to modern economies and societies.

The potential exponential increase in the number of spacecraft populating sections of LEO also raises the concern that there are many more orbital objects that will be susceptible to the effects of extreme space weather. Indeed, the numerous constellation satellites would presumably have similar levels of tolerance to bombardments of solar heavy ions or galactic radiation between their identical, or very similar spacecraft, so a manufacturing defect or design error could have severe consequences.

Whilst the magnetic field of the Earth offers some protection for lower orbits, another implication of the use of COTS (Commercial-Off-the-Shelf) components could be less resistance to the harmful effects of solar radiation, which would be a concern for remote sensing spacecraft which by necessity must have their sensors exposed to the harsh space environment.

Collisions/debris

The dangers of collisions and debris risks, while possible, was considered to be largely unlikely until the increase in orbiting objects following the Chinese experiment with an anti-satellite weapon on 11 January 2007, causing destruction of the Fengyun-1C (FY-1C) weather satellite.

This was further reinforced little more than two years later by the accidental collision between Cosmos 2251 and the operational Iridium 33 on 10 February 2009, which accounts for over 25% of catalogued on-orbit space objects. These two events represent examples of some of the worst satellite breakups in history.

Space activities involve high aggregations of risk and pose extreme potential liabilities. Articles II, III, and IV of the Space Liability Convention (UNOOSA, 1967), imposes absolute liability or fault-based liability in certain circumstances. These have yet to be tested, and as space gets increasingly busy these will need to be explored – especially for those looking to make themselves centres of activity.

- *Article II "...a launching State shall be absolutely liable to pay compensation for damage caused by its space object"*
- *Article VII "...each State Party to the Treaty (...) is internationally liable for damage to another State Party to the Treaty or to its natural or juridical persons by [its space object]"* (UNOOSA, 1967)

There are currently around 700,000 objects in LEO that can deliver a lethal blow are non-trackable because of their small size from 1cm to 10cm. There are likely thousands of other particles that are too small to track in rotation.

Two clear issues arise resulting from NewSpace activities however; first of all with the increase in sheer numbers of objects in space (more objects have been given FCC approval for launch in 2017-18 than have previously been orbited in over half a century of space activities) and a corresponding increase in the number of space participants, relying on a patchwork system dependent upon the auspices of a few leading nations such as the US seems ill-advised at best.

Secondly if many satellites at the level of nanosat and below are being launched without propulsive systems, then there will be no opportunity for operators of these spacecraft to act upon any warnings in any case.

Typically for modern spacecraft, special materials are used to mitigate the effects of debris collision, which are inevitable at some point in the life of longer duration space missions. A concern relating to the adoption of cheaper COTS (Commercial-Off-the-Shelf) components could be with regards to the durability of such materials to withstand high velocity impacts.

While attribution of losses has been difficult due to the size of debris and the challenges of de-orbiting satellites, the developments in NewSpace and the potential to develop in-orbit service stations could allow liability to be assigned.

As the sector becomes further commercialised, a civil aviation style management model is going to become increasingly important to assess risks and establish mitigation efforts, standards, and monitor compliance.

Cyber attacks

As cyber-attacks against satellites can carry higher catastrophic potential, the perpetrators of the attacks often view satellite hacking as 'trophy' attacks. Also, access to satellite cyber-attack enablers - such as hacking or jamming hardware and software - is becoming more accessible and affordable.

The exponential growth in satellite applications is creating a systemic risk. As a large, and increasing, number of globally interconnected services on the ground come to rely more extensively on satellite communications, certain signal disruptions or interruption to these services could have catastrophic consequences.

However, it should be noted that globally the number of malicious actors with the capacity and intention to attempt such an attack are low and risk management solutions are being devised and established, with both active and passive defence mechanisms being put in place. These solutions include risk transfer to insurers, along with improved satellite network resilience and robustness.

All risk managers should be asking questions about whether their supply chains and service providers include space-based activities, and how risks are being managed. Conveying likelihood and impact to the company Board or leadership structure should be a key part of that process to ensure effective governance.

5. Conclusion

5. Conclusions

The first space satellite insurance was placed with Lloyd's in 1965. Today, Lloyd's underwriters continue to play a crucial role in enabling satellite launches globally; each year, specialist space underwriters provide satellite owners and users – from national governments to telecommunications firms and research institutes – with protection worth more than US$7bn.

NewSpace will create an increasingly interconnected world, and all classes will need to collaborate to offer customers the products and services that will secure their futures. The Lloyd's market has already insured commercial launchers, including test flights and third-party liability cover for many of the launch service providers including the likes of Virgin Galactic and Space X.

NewSpace activities are going to enable affordable coverage to emerging markets where billions of people and internet of things devices are waiting to be connected where they are most wanted. Insurers should also be aware of these changes to understand the risks their customers are going to be facing, as well as how their existing expertise could pivot to a new sector.

As increasingly ambitious concepts evolve, understanding the risks involved has never been more important, and we hope this study stimulates thinking on the next frontier.

Takeaways for risk managers

The Lloyd's market are also developing innovative products to meet the needs of the NewSpace community with products such as Llift. The innovative product builds on the strong history of the Lloyd's market in supporting space endeavours, bringing together 18 syndicates to write NewSpace risks via a dedicated Lloyd's platform to meet the needs of the small satellite community. See the case study for more details.

Whether you are a NewSpace company or someone looking to take advantage of the services that will be offered, the Lloyd's market stands ready to respond. For example:

- The process of understanding the risks and exposures you might face, and deciding what can be managed, is a core process of any mature business. In the space sector it is complementary to mission assurance and can provide peace of mind in case something goes wrong.
- Depending on what stage your project is at, knowing that insurance will be available when the time comes will aid the financier's decision-making process. Insurance is there to provide certainty in the face of disaster and to help get customers back up on their feet. Working with insurers from the earliest phases of your project will help you understand what the high-risk items are, whether your project is insurable and allow you to allocate funds appropriately for your insurance needs.
- Did you know that insurers are willing to be part of conversations from the beginning of ideation, and can help in the identification of coverage needs? For example, the Lloyd's insurance market has well developed tools such as scenarios, expert knowledge, and decades of experience at being at the front of the market helping customers to be brave.

See our NewSpace insurance guide to learn more about how Lloyd's can support your endeavours.

Takeaways for insurers

The Lloyd's insurance market has well developed tools such as scenarios, expert knowledge, and decades of experience at being at the front of the market helping customers to be brave.

This study aims to bring the market up to date with changing dynamics in a growing sector. We hope all market stakeholders read the report and consider what NewSpace will mean for them.

To take advantage of the opportunities on offer, insurers must:

- Talk to customers to establish where product gaps exist
- Ramp up innovation to increase product development for NewSpace
- Collaborate across classes to harness existing expertise to meet this growing sector. For example:
  - Lessons can be taken from the transport industry on how to model and assess high value goods being stacked together on launch vehicles. Recent developments in the Internet of Things (IoT) to monitor the status of individual items and overall container statistics could also be used to create real-time assessments.
  - Employees working in specialised environments, such as space based mining, manufacturing, or low gravity habitats will require specialised life insurance and workers compensation policies.
  - Launches are currently insured on a flight by flight basis, but spaceplanes could be more suited to an annual policy style of insurance like that used in the aviation sector.
  - Space ports are also expected to need their own cover. This would likely be an extension of that currently provided to airports but would need to take into account some new elements unique to spaceports, such as the storage of more exotic propellants.
  - NewSpace is going to enable increasing connectivity, and bring online devices that have previously been unconnected, and may have been waiting there for years. Customers will have to deal with business interruption, financial penalties, regulatory scrutiny and reputational damage in increasingly complex ways, and at a scale they haven't done before.

These developments will also open new opportunities for insurers to establish new products and services, including the Future At Lloyd's vision of paying a claim before a customer realises they've experienced a loss.

One example already in play in the Lloyd's market is the use of satellite imagery provided by McKenzie Intelligence Services, which is used to assess remotely damage to property days or even weeks before sites can be safely accessed by people on the ground. Lloyd's used this technology to assess damage while the 2018 California wildfires were still burning, as well as in the aftermath of the 2016 Fort McMurray fire which caused devastation to homes and lives in this Canadian town (LMA, 2017).

The new frontier is here, and Lloyd's stands ready to help cutstomers be brave.

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Appendix

This study aims to provide an overview of risks and innovations emerging from developments in the NewSpace economy to understand their future effects in terms of risks, threats and opportunities for customers and insurers.

Approach

The report focuses on the upstream segment, and particularly considers developments occurring within the geography of Europe, North America (USA, Canada) and Australasia (Australia, New Zealand) plus the United Arab Emirates. Recognising the importance of developments in certain Asian markets (China, Japan) a commentary on developments in these areas will also be included where appropriate.

This report was developed through a structured research process, across two key stages:

- Desk-based research
- Consultations with insurance and space communities

Desk-based research

The initial phase of the project took the form of an extensive literature review to gain as comprehensive a view of the developments in the NewSpace sector as possible. The scope of this review was intended to incorporate information on the full gamut of public and private commercial enterprises engaged in this sector.

A wide range of sources have been investigated as part of the desk-based research phase. Types of sources utilised include space industry-focused research papers, space-specific and wider media, company and organisation websites, previous London Economics research papers, academic journal papers and a variety of online sources.

Consultations with insurance and space communities

Following completion of the desk-based research phase of the project, a workshop with underwriters took place to attempt to obtain an improved understanding of the demand side of the market dynamics.

LE and Lloyd's engaged with a panel of space industry experts during a focused session to attempt to obtain feedback regarding the proposed trends and themes highlighted for the report, and to gain valuable data insights to support the fundamental conclusions of the study.

Terminology

To help build understanding the following key terms and acronyms may be of use to build familiarity with the topic, as terms are interchangeable and the topic crosses fields.

Key terms

- Cislunar:Between the Earth and the Moon
- Cubesat: CubeSats are a class of nanosatellites that use a standard size and form factor. Standard industry terminology has been adopted that allows a base unit of measure for smallsats.
- Heritage: Typically a system or component that has demonstrated performance on a previous space mission(s)
- Loft:Launch, as in to place a satellite in orbit.
- Megaconstellation: An orbital fleet of spacecraft flown by the same operator, consisting of a large number of satellites in the same orbital plane, or potentially across multiple orbits
- NewSpace:A global industry of private companies and entrepreneurs who primarily target commercial customers, are backed by risk capital seeking a return, and seek to profit from innovative products or services developed in or for space.
- Prime: Short name for the prime contractor (usually a major space company) with ultimate responsibility for the design and assembly of complete spacecraft systems, and delivery to the governmental or commercial user.
- Spin-in: Adoption of technology from another related sector

Acronyms

- BI: Business Interruption
- BSS: Broadcasting-Satellite Service
- CDR: Critical Design Review
- DLT: Distributed Ledger Technology
- EO: Earth Observation
- EOL: End-of-Life, i.e. end of satellite mission
- FAA: US Federal Aviation Authority
- FCC: US Federal Communications Commission
- FSS: Fixed Satellite Services
- Gbps: Gigabits per second
- GEO: Geosynchronous Equatorial Orbit (AKA Geostationary orbit)
- HEO: Highly Elliptical Orbit
- HOTOL: Horizontal Take Off & Landing (launcher)
- HTS: High Throughput Satellite
- IADC: Inter-Agency Space Debris Coordination Committee
- IoT: Internet of Things
- ISS: International Space Station
- GTO: Geosynchronous Transfer Orbit
- LEO: Low Earth Orbit
- LOR: Loss of Revenue
- LRG: Launch Risk Guarantee
- LVFO: Launch Vehicle Flight Only
- MEO: Medium Earth Orbit
- MSS: Mobile Satellite Services
- SSA: Space Situational Awareness
- SEU: Single Event Upsets
- SSL: Space Systems Loral
- SSO: Sun Synchronous Orbit
- STM: Space Traffic Management
- STS: Space Transportation System AKA 'Space Shuttle'
- TL(O): Total Loss (Only)
- VTOL: Vertical Take Off & Landing (launcher)
- WPB: Warranty Pay Back


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