Actuaries Institute

Research Note 5

An introduction to Space

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The Actuaries Institute is the peak professional body for Actuaries in Australia. The Institute provides expert comment on public policy issues where there is uncertainty of future financial outcomes. Actuaries have a reputation for a high level of technical, financial skills and integrity. They apply their risk management expertise to allocate capital efficiently, identify and mitigate emerging risks and to help maintain system integrity across multiple segments of the financial and other sectors. This unrivalled expertise enables the profession to comment on a wide range of issues, including life insurance, health insurance, general insurance, climate change, retirement income policy, enterprise risk and prudential regulation, the digital economy, finance and investment and health financing.

About the profession

Actuaries use data for good by harnessing the evidence to navigate into the future and make a positive impact. They think deeply about the issue at hand, whether it's advising on commercial strategy, influencing policy, or designing new products. Actuaries are adept at balancing the interests of stakeholders, clients, and communities. They're called upon to give insight on complex problems, by looking at the full picture. Actuaries analyse the data and model scenarios to form robust and outcome-centred advice.

About the authors

This Research Note has been prepared by the Young Actuaries Space Working Group.

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We thank the actuaries that guided this Working Group.

Acknowledgement of Country

The Actuaries Institute acknowledges the traditional custodians of the lands and waters where we live and work, travel and trade. We pay our respect to the members of those communities, Elders past and present, and recognise and celebrate their continuing custodianship and culture.

Contents

1. Space environment and economy

Key points

- The space economy is valued at about half a trillion US dollars and is much more than NASA, satellites and SpaceX.
- New technologies and the Australian government's commitment to Australia's space strategy mean that skilled workers with STEM skills will be needed to manage the space frontier.
- As space assets can fundamentally "see and hear" a population, added surveillance brings data ethics and governance into question.
- Commercial space activity will increase the number of items orbiting the earth, increasing the risk of space junk and the damage that can cause.
- While there are international legal agreements for key aspects of space, we anticipate substantial developments will occur. For example, is it time to shift laws around space junk from being punitive to preventative?

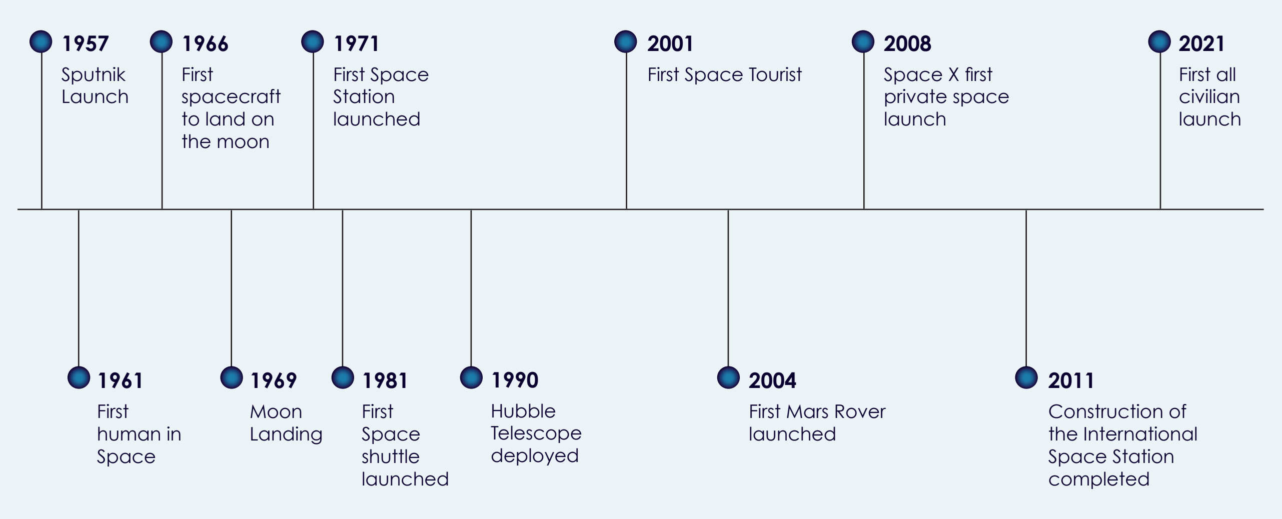
1.1 The space frontier

When we initially think about space, we think of galaxies far away from reality and environments like those we see in sci-fi movies. However, the development of commercial space activity over the past five years to enable communication and advanced technology mean that space is a reality that will need to be defined, explored and managed. As our world gets more complex and reliant on space technology, the risks of this business increase and must be managed, and therefore actuarial skills will be valuable.

Australia is not a major space player in 2022, however, the Commonwealth Government's Australian Civil Space Strategy means that understanding space, space risk, and space insurance is of importance. This Paper provides an introductory overview of space, current insurance arrangements and some likely implications as our reliance on space grows.

As the space industry matures, there are aspects of insurance that will require deep consideration and analysis. The importance of the space industry is vital to global economic growth given how many applications on earth are dependent on assets in space. Specific insurance examples include managing against the collision risk of space junk, and as the commercial space travel industry grows there will be a need for travel insurance and some form of workers' compensation insurance. In the long term, there may be implications for life insurance as increasing numbers of people travel to or temporarily live in space, recognising there is limited information on the specific impacts of time spent in space on the human body and implications for life expectancy and morbidity.

Figure 1: The space economy timeline[1]



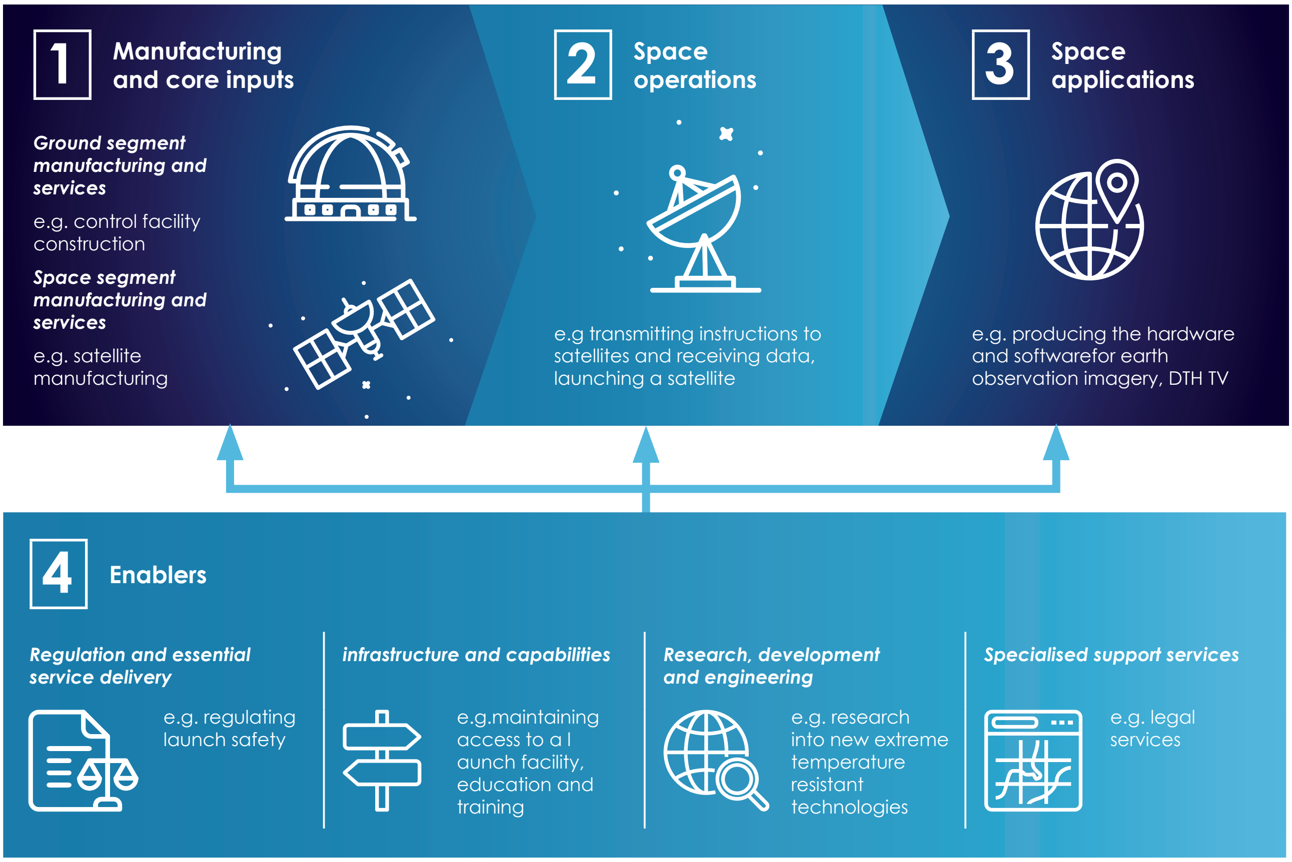
1 2008: first privately funded liquid fueled rocket to reach orbit - NASA

The space race was a product of the Cold War in a competition between The Soviet Union and the United States (Figure 1). The United States Government spent $US47.7 billion in 2020 ($US54.7 billion 2021)[2] on space and is the largest participant in space exploration. The space economy is much larger than just the well-known NASA and the US Government's contributions. The entire space economy was valued at $US414.8 billion in 2019 ($US447 billion in 2020)[3]. Other countries involved in space activities include Australia, Canada, the People's Republic of China, France, Germany, India, Italy, South Korea, Mexico, the Netherlands, New Zealand, Norway, Switzerland and the United Kingdom.

1.2 Australia as a Space Nation

Australian civil space sector revenue in 2019 was estimated at $4.8 billion[4] – equivalent to 0.25% of GDP and about 20% smaller than Canada's space sector by revenue. Most of Australia's space companies are concentrated in the enabler and applications segments which involve highly skilled, service-intensive jobs[5].

Figure 2: Value chain of the space sector



Source: Australian Government, Department of Industry, Science, Energy and Resources (Aus) – Activities included in the space sector

2 Statista – Government expenditure on space programs in 2020 and 2021, by major country

3 The Space Report Online – Economy

4 The economic contributions of Australia's space sector in 2018-19 – alphaBeta Australia

5 Defining the Australian space sector - activities included as "space enablers" include regulation, essential service delivery, infrastructure and capabilities, research, development and engineering and specialised support services.

There are considerable opportunities for Australian companies with suitable technical capabilities to enter the sector (Figure 2). This is especially in areas such as manufacturing, where Australia operates in reduced numbers compared to global averages but has a strong manufacturing capability and the required facilities to grow the industry[6].

The Australian Civil Space Strategy, released in 2019, outlines the Government's plan for Australia's space industry over ten years. The Government recognises that the space industry can benefit the broader economy and inspire Australians. The Australian space sector will need to continue to create relationships with global organisations involved in space, increase Australia's space capabilities, promote responsible use of space through regulation and risk management, and build a future workforce for Australians in the space industry. The future workforce opportunities extend beyond those sectors that already use space-based technology, including weather forecasting, emergency management, internet access, online banking, global positioning systems (GPS), crop monitoring and the use of autonomous vehicles in mining.

1.3 Robotics and Automation on Earth and in Space Roadmap 2021-2030

The Australian Space Agency's Robotics and Automation on Earth and in Space Roadmap outlines a 10-year vision to grow this space segment for Australia (Figure 3). Australia has developed expertise in remote operation capabilities which will have significant potential for the future of space exploration. Australia is already a leader in remote asset management in the resources sector using space technology. This can be extended beyond resources to transport and agriculture as lower costs make these systems more accessible.

Figure 3: What is robotics and automation?

Source: Australian Government, Department of Industry, Science, Energy and Resources (Aus) – Robotics and Automation on Earth and in Space Roadmap 2021-2030

6 The economic contributions of Australia's space sector in 2018-19 – alphaBeta Australia

1.4 Who is participating in space?

There are two types of participants in space: Government (State) funded space activities and commercial space operations. Government investment can be further broken down into two separate groups: Military and Civilian.

Military activities include satellite imagery and communications, and civilian activities include television and broadband/mobile communications.

Commercial space activity is loosely defined as goods or services that have a reasonable portion of risk or investment from a commercial entity. Commercial activities largely consist of the satellite industry and the data extracted from those satellites and make up 79% of the entire space economy[7]. Commercial activity has doubled in the last decade and includes satellite launching, space equipment maintenance, telecommunications, internet networks, insurance and the on-selling of data from space exploration. Global tech giants including Meta and Alphabet rely on the space industry for satellites to entertain, communicate and educate, relaying data from satellites and using other space related infrastructure.

The infrastructure and data collected from these satellites have provided greater opportunity for surveillance to be used in commercial activities. Tech company CGI uses satellite imaging to assess the quality of assets. General Insurers use satellites to verify whether the asset has been well maintained without the need for a loss adjuster to physically visit the site. These are basic examples where space has enabled technology to aid an existing industry with additional data.

Some tech companies are using data to influence customer behaviour (See **Text Box 1**). Given that these space assets can fundamentally "see and hear" a population, added surveillance brings data ethics into the question – and where professionals such as actuaries can use their skills and actuarial capabilities framework to manage data governance.

Text Box 1: Pokemon GO using satellite data[8]

The augmented reality game *Pokemon Go* uses the Google Maps engine (built from satellite data) for commercial success. John Hanke, CEO of Niantic, found one of the most surprising results was how much "the behaviour of the player changes". This changed the fundamentals of the game, whereby the game can direct players to certain local businesses to attract traffic for commercial gain of local establishments.

As organisations across various sectors, including commercial and government enterprises, demand data driven insights, the space economy has grown. Future growth is likely to escalate as technology advances and the increasing use of data mining and quantum computing.

Space tourism became a possibility during 2021 with SpaceX, Blue Origin and Virgin Galactic launching space flights with civilian passengers. Funding for individuals to access these space flights is limited to high-net-worth individuals, however, as the cost decreases, civilian space flights will become more popular, and insurance, such as "travel" and total and permanent disability insurance will be required.

The orbital ecosystem is complex with machinery, satellites, debris and an unpredictable environment. Space operators will require insurance to protect their business from incidents that may occur if space travel becomes more frequent. To mitigate these risks and to create genuine insurance products for space travel, the orbital ecosystem will need to be understood thoroughly by all parties, including regulators, governments, space operators, consumers and insurers.

Private investors have capitalised on the growth of the space economy, with widespread media coverage of space exploration from high-net-worth individuals. Individual space uses, such as space launches undertaken for in-space manufacturing of scalable habitats, radiation shielding, resource extraction and debris mitigation, deliver a limited payoff when undertaken separately. Low-cost multi launches improve the profitability of space activity[9].

7 Space Foundation 2019

8 Inverse – The secret history of 'Pokemon G0', as told by creator John Hanke

9 Multi launch or reusable launch systems that allow for multiple launches from the same launch vehicle

1.5 Who owns Space?

When determining property rights, legislation covers ownership and liability depending on the use of the assets.

There are five international treaties covering space law, which are managed by the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS)[10].

1. The Outer Space Treaty

"Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies"

The Treaty is the foundation of international space law for signatory nations (108 in 2019). The Treaty presents principles for space exploration and operation;

- Space activities are for the benefit of all nations, and any country is free to explore orbit and beyond
- There is no claim for sovereignty in space; no nation can "own" space, the Moon or any other celestial body
- Weapons of mass destruction are forbidden in orbit and beyond, and the Moon, the planets, and other celestial bodies can only be used for peaceful purposes
- Any astronaut from any nation is an "envoy of mankind" and signatory states must provide all possible help to astronauts when needed, including emergency landing in a foreign country or at sea
- Signatory states are each responsible for their space activities, including private commercial endeavours, and must provide authorisation and continuing supervision
- Nations are responsible for damage caused by their space objects and must avoid contaminating space and celestial bodies.

2. The Rescue Agreement

"The Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space"

3. The Moon Agreement

"The Agreement Governing the Activities of States on the Moon and Other Celestial Bodies"

The Agreement states that celestial bodies can only be used for peaceful purposes, that they should not be contaminated, that the UN should always be made aware of any station on a non-Earth body, and that if resource mining on the Moon becomes feasible, an international regime must be established to govern how those resources are obtained and used. The United States is not a signatory of the Moon Agreement.

4. The Liability Convention

"The Convention on International Liability for Damage Caused by Space Objects"
Signatories take full liability for any damage caused by their space objects and agree to standard procedures for adjudicating damage claims.

5. The Registration Convention

"The Convention on Registration of Objects Launched into Outer Space"

Expanding a space object register, the Convention empowers the UN Secretary-General to maintain a register of all space objects.

Source: Space Foundation - International Space Law

10 Space Foundation – Space Briefing Book

The Outer Space Treaty (1967) (OST) Article II states that outer space celestial bodies are "not subject to national appropriation by claims of sovereignty by means of use or occupation." Therefore, States have no right to own outer space.

However, the OST and the Moon Agreement (1979) (MA) allow commercial appropriation. The Commercial Space Launch Competitive Act (2015) (CSLCA) (US Congress) along with the Artemis Accord (2019) (AA) grants property rights in space to whoever "gets there first."

This leads to a contradiction between commercial property and sovereign property. For example, if both commercial entities A and B land on comet C to mine iron, how are the resource rights split? Does first arrival take all rights? These are essential questions to be answered before a traditional insurance framework is created.

The Permanent Court of Arbitration (PCA) is responsible for settling space disputes however there is no precedent for space property rights as yet, adding to the risk of space activities. However, that precedent may be close to being set as the Artemis Accord aims to have people return to the moon by 2024 and establish a crewed lunar base by 2030. The legality is complicated and needs to be established – and risk managers will be required for their expertise.

1.6 The problem of space junk

Space junk is those items that have been launched into space that are no longer useful and are now orbiting the earth. According to the United Nations Office for Outer Space Affairs, satellite activity has increased by 28% over the previous year. As of September 2021, there are now around 7,700 orbiting satellites in space. However, only about half of those are active[11].

Space junk is orbiting the earth at 11,000Km/h, posing a significant risk of collision. The European Space Agency estimates that there are roughly 130 million items of space debris smaller than one centimetre, one million items between the size of one and ten centimetres, and 34,000 items larger than ten centimetres. Current technology can only track the movements of larger items (larger than 10cm), so most space junk is untracked, and the risk of collision is unknown.

There are two main issues of having so much space junk. Firstly, space junk crashing back to earth is a risk and secondly, space junk colliding into working satellites increases. We now rely on technology and demand instant communication that relies on satellite networks. Facebook's recent launch to expand its operations to the metaverse signals an indication of the increasing reliance on the virtual world, deepening our dependence on satellites and increasing the number of items in space. More space junk means more risk and increases the threat of communication being cut off through the destruction of satellites. This greater dependence on technology creates greater vulnerability to technology.

Who is responsible for damage from space junk, and what can be done to ensure ownership of no-longer-used space assets and their safe removal from space? There is no formal law that prevents the actual creation of space junk (whilst there are standards, they are not international law. However, if this space junk was to damage other property, either in space or on earth, the State that launched that space asset is liable according to the OST and the Space Liability Convention (1972).

In 1978, Soviet nuclear-powered satellite Kosmos 954, crashed into Canadian territory. The Soviet Union was the launching state, making it liable for the clean-up or an amount for damages. In this instance, each State acted and settled without the need of the Permanent Court of Arbitration. There is still no precedent to determine how international courts will rule and uncertainty around the strength of any ruling.

Any proposed regulation is likely already outdated as it does not include guidance on how to treat complex matters such as joint partnerships and joint launch states, the balance of burden and liability ownership, ownership of past and future proliferation, and the rights of non-space entities (e.g. countries without any space presence at the mercy of entities with a space presence).

Restraint, and a commitment to protect the space environment, is needed. In November 2021, Russia tested its anti-satellite technology, shooting a missile at another satellite, causing an explosion. The debris from this exercise presents an enormous threat to operational satellites and is predicted to remain an issue for at least a decade, according to the Financial Times.

Space junk laws are punitive rather than preventative. It is likely we will see a worsening of conditions and a "business as usual" attitude regarding the space environment. Management of the space environment has not benefited from our mismanagement of earth and the resulting climate impacts. Polluters have not taken responsibility for the space junk they have created, and international space regulation needs to change to include preventive litter management to protect the space environment.

11 United Nations Office for Outer Space Affairs - Outer Space Objects Index

2. The different phases of space insurance

Key point

- Insuring space assets is complex with coverage dependant on the phase of space travel

While the Australian market for space insurance is limited but expected to grow, some international insurance companies have long established space insurance lines, including policies covering launch type, third-party liability, contract obligations, damage to property, business interruption and satellite contingency[12].

Space insurance provided by most insurers is designed to respond to the losses of space vehicles during various phases of space activity, including in pre-launch (preliminary to launch), launch (between the beginning of the launch phase and at the end of the positioning phase) and in orbit (life phase of satellite operation). Some insurers offer other extension insurances to cover further aspects of space activity, including business revenue and expenses, loss of incentives, cyber-attacks and third-party liabilities.

2.1 Pre-Launch Coverage

This insurance is used by the satellite manufacturer and is largely written by marine cargo or transit insurers[13]. Most leading insurers in Australia provide pre-launch coverage.

Pre-Launch coverage typically provides insurance for any physical damages to the satellite before it is launched. However, the coverage event determined by each insurer is not the same.

Many insurers cover the manufacturing and testing phase of the satellite. Other insurers limit the scope of insurance to cover any damages to the satellite and launch vehicle during its transportation to the launch site and integration with the launch vehicle. In addition to this, one leading insurer also provides launch cover.

Typical pre-launch insurances end when the launch can no longer be aborted or until intentional ignition. Some insurers cover the risks that the launch vehicle will fail to operate.

2.2 Launch stage

Launch insurance is arranged by either satellite buyers or manufacturers and is largely written by aviation insurers.

It typically covers the value of satellite and launch vehicles for material damage and malfunctions occurring at any time between the beginning of the launch phase and the end of the positioning phase, i.e., until in-orbit testing has been completed.

The scope and length of coverage provided by insurers vary significantly. Some insurers provide coverage for only launch systems and commissioning equipment, whereas others provide broader coverage of risks such as financial losses arising from loss of operational capabilities of satellite and future losses of fuel and power if the loss manifests itself during the coverage period. One insurer also provides a launch risk guarantee which provides a refund or credit towards a re-launch in case of damage caused due to launch vehicle failure.

The length of coverage period also differs between insurers, with some insurers providing a longer coverage period of 180 to 365 days after the launch thus combining the launch stage and in-orbit phase into one product.

Usually, insurance cover includes only one satellite. However, with improvements in technology, clusters of satellites are being launched from one launch vehicle. One insurer has innovated their product to provide insurance to all the satellites that make up a cluster, including losses arising from failure to meet the contractual obligation.

2.3 In-Orbit Phase

In-orbit insurance policies protect against the risk of physical loss, damage, or even failure of the insured satellite while in orbit or during orbit placement. Some insurers also cover the loss in revenue arising from partial or complete loss of the satellite. Insurance for the orbit phase of a space mission is arranged by the satellite owners. Typically, a communication satellite will require an insured period of around 15 years[14] and with more satellites being launched, many insurers are now excluding collision coverage and some satellites are launched with no insurance at all. There is no longer insurance coverage once the satellite reaches the end of its functional life, with some space machine manufacturers looking to materials that could burn up on re-entry or degrade after its functional life.

Insurers also provide unique products such as third-party coverage to insure against damage to persons or property on the ground from re-entering debris and incentive insurance which covers the loss of revenue or additional expenses and service interruption arising from non-performance of the satellite. With an increase in space debris, some insurers are also providing insurance against satellites being damaged by space debris.

12 Lloyds - Space

13 ESCL Summer Course on Space Law and Space Policy – Space Insurance

14 Brown University – Joukowsky Institute

3. Insuring Space

Key points

- Collision risk is a growing and potentially catastrophic risk which will need an insurance solution.
- Space modelling and pricing is a growing field of research and work.
- Efforts around climate risk, and sustainability more generally, will soon need to extend to Space because space activity will compound these challenges.

At the core of insurance are the actuarial functions of pricing, reserving, data analytics and risk management. Actuaries add value to an insurance company particularly in those situations where data is unreliable or interrupted. With insurers relying on space data to make informed pricing and reserving decisions, actuarial skills are needed to combat disruptions to data collections.

Pricing actuaries can use their predictive analytics skills to feed into managing risk exposure from space debris, reserving actuaries will be needed to start modelling long term developments of satellite diagnostics during their entire lifecycles, while data actuaries can leverage ethics frameworks to review the potential data and policy the industry will require.

3.1 Collision risk

The future for space risks is focused on increased low earth orbit (LEO) activity, coupled with the commercialisation of space ventures. As of September 2021, there were 7,700 satellites orbiting Earth - 42% of them were inactive with the number of active satellites having increased 28% from 2020, and 200% from 2016.

Collision risk is a material issue – the potential for catastrophic losses will increase with the inevitable growth in private space flight and the commercialisation of space activity. Excluding these risks from policies is only a temporary mitigation of loss for insurers – and better management of known risks lies with the collection and application of quality data and the modelling of collisions and other space risks. Insurers are aware of the increased risk of collision with many space insurers excluding collision coverage from their policies, and some insurers leaving the LEO insurance market altogether.

SpaceAble, a French start-up firm specialising in Space Situational Awareness[15] (SSA) services, expects that there will be a tenfold increase in LEO satellites over the next five years. SpaceAble's mission is "to enhance operational safety in LEO through collection and management of space-related data and modelling". Currently, they provide two solutions:

- ISSAN – a space data processing software that "is able to successfully address space needs related to space weather, the tracking of debris, and the management of space traffic"; and
- Orbiter – which services client satellites by providing reliable, secure, and certified data to prolong their lifetime.

Most of the data processed and collected by SpaceAble with the ISSAN program is done by sensors attached to satellites that capture information, including the angular drag on satellites, orbital risks and forces, and launch information. The impacts of space weather on earth can also be monitored with sensors – capturing climate events such as solar flares (that create radio blackout storms), solar energetic particles (that cause electrical failures in satellites), and geomagnetic storms (that can affect power grids).

AXA XL Insurance has established a global partnership with SpaceAble to enhance its insurance solutions for satellite operators.

3.2 Modelling Space

Looking at satellite collision risk shows the complexities of modelling space activity.

While the National Aeronautics and Space Administration (NASA) suggests that the probability of two large objects (>10cm in diameter) colliding accidentally is quite low[16] (and what it means by low is not defined), it also notes that cleaning up the debris in space remains a technical and economic challenge. Insurers already have exclusions in place for space collisions in the current "low" probability environment, however, is this a long-term solution? Insurers may be expected to eventually price for this risk – but what can they do about it now, and how difficult is it to track space debris?

With existing technology, space debris with a diameter of larger than 10cm can be tracked. However, this debris makes up 0.027% of total estimated space debris that can cause loss to a satellite via a collision[17]. Debris smaller than this can be seen through radar installations, allowing the amount of total space debris to be estimated. Yet, this debris cannot be tracked for long enough to determine its orbits.

15 Space Foundation - Space Situation Awareness – tracking objects in orbit and predicting their trajectory
16 NASA Education
17 The European Space Agency -Space Debris by the numbers

If technology improves the tracking of smaller space debris, this will lead to more data, a better understanding of debris risk and the ability to model and predict the future debris landscape.

An academic paper published in 2019 introduced the Space Objects Long-term Evolution Model (SOLEM) which is "expected to predict the evolution of space debris population and possible collision rates for a long period in future, usually decades"[18]. The model comprises of an orbital propagation model, collision probability estimation model, fragment generation model, future launch model, post mission disposal model, and active debris removal model (if the active debris removal measures are considered).

As a replacement for comprehensive debris tracking data, insurers can leverage this model to give a portfolio level prediction of collision rates, considering the size of the space asset and the geographic location of the launch. More sophisticated modelling is required to achieve a reasonable per-satellite or per-launch collision rate.

3.3 Risk Pricing or Reinsurance?

The lack of accurate data for debris tracking, the low probability of events occurring and the potential for catastrophic losses all lead to the likely scenario that reinsurance arrangements will be necessary.

Like catastrophe modelling of natural perils which has developed over time, it is easy to see space modelling becoming an increasingly important and accessible function of a space actuary. This is an exciting area, with some of the following problems to think about.

- Space debris and space traffic is dynamic – it is likely that using historical data and standard actuarial models to estimate the probability of collision will be insufficient.
- Orbital paths of some larger space debris can be tracked – including the altitude, direction and elliptical planes – but how will an actuary condense this information to give a singular view of risk?
- The actuary will also need to consider models that predict the future space environment: patterns of space weather, the rate of increase and impact of space debris.
- How will a loss be identified and quantified when the asset in space cannot be examined directly?

What does the industry do now? The Australian Government's Space (Launches and Returns) Act 2018 which regulates the insurance and financial responsibility of a space flight, uses many space models in its methodology for calculating the Maximum Probable Loss (MPL) of a space flight. These space models are well established in academia, with papers investigating the following phenomena: re-entry prediction, future space debris environment, hypervelocity impact damage assessment and operational collision avoidance.

At its core, the MPL methodology is the actuarial calculation of risk cost – frequencies are derived from underlying physics models, and the costs are estimated at a high-level by the users. As actuaries, several questions about this calculation naturally arise: how reliable and reflective are these physics models of real life? Do the models account for the correlation of risks? What is the uncertainty of the MPL when all costs are estimated inputs by the user? What is the distribution of all potential costs, including the MPL?

The MPL methodology is likely to be a reasonable approach given the current information set, however, moving forward, there are areas where additional actuarial perspectives would be valuable. As more data is collected from space, the precedent should be set that actuarial involvement is necessary.

3.4 Sustainability and the climate countdown

It is evident that harnessing the lessons from climate change should help manage and protect the space environment. With the amount of data and advanced tools at our disposal, it is our responsibility to drive improved space regulation and environmental sustainability.

Space insurers will inevitably play a large role in managing space climate risk. Initiatives are being instigated in the industry, noting AXA XL's partnership with SpaceAble and space insurers will continue to leverage space data and software from companies with space operations. Space insurers will face the common issues of the quality and consistency of the data across sources – and it is not guaranteed that these will improve as technology evolves in this new field. Insurers should take an active role in improving data collection and management. Data is at the core of insurers' and actuaries' ability to meaningfully contribute to space risk management.

As the world continues to manage the effects of the COVID-19 pandemic, we have all learned what will be an enduring lesson – our systems are not as resilient as we believed. As businesses struggled to stay afloat, governments worked to revive economies, and insurers grappled with lawsuits and business interruption claims, we were all left wondering: what will we do when a disaster of this scale happens again?

18 Wang and Liu, 2019

3.5 Applying climate lessons to space environmentalism

Much of this rhetoric has turned towards the climate crisis. As environmental conditions continue to worsen, so does the fear of more frequent and severe natural disasters that could one day bring our economies to a halt yet again. Actuaries have been dedicating substantial efforts to this challenge.[19] It is time to extend these efforts on sustainability to cover space, including how space travel impacts the environment.

The environmental effects of space travel begin long before passenger spacecraft leave the ground. In February 2020, SpaceX's SN1 prototype exploded during a nitrogen pressure test. In May 2020, the SN4 exploded a minute after an engine test, this time causing a massive fire and spreading debris around the test site. In December 2020, the SN8 was destroyed in a ball of flames, as were the SN9 in February 2021, the SN10 in March 2021, and the SN11 that same month. These explosive failures, as well as the fuel and fluid leakages from SpaceX and other companies, cause significant damage to launch sites and surrounding areas and mean that noxious gases and particulate matter are released very close to the ground.

Environmental activists have expressed concerns about how these tests will impact nearby habitats for wildlife, with the Federal Aviation Administration (FAA) (US) stating that even the sound emitted from launches was enough to disrupt wildlife within five miles of the launch area[20]. There is also concern for the communities that live near launch sites – falling debris could cause significant harm to human life in the short-term, and the long-term effects of launch-related pollution are yet to be uncovered.

As we count down to the take-off of commercial space travel, actuaries must consider the climate risks of this pre-travel period. How will we insure for the direct damage on launch sites during testing, take-off and landing? Who is responsible for the damage to surrounding wildlife and human communities, and how can we insure against this damage? What could be the long-term health and mortality effects for the people who live near test or launch sites, and how should this play into our models? While some of the answers to these questions may lie in revisiting data on analogous pollution catastrophes like oil spills and water contamination, much of it is likely to rely on more data emerging as test and commercial launches become more frequent. Until then, it is a waiting game.

Direct damage is not the only way that space travel affects our environment – greenhouse gas emissions associated with space travel are equally concerning. While a traditional long-haul plane flight would emit between 1 and 3 tonnes of carbon dioxide per passenger, a rocket launch would emit up to 75 tonnes per passenger[21]. These emissions would take place at a higher level in the atmosphere, meaning they also remain for a longer time and hence have an increased warming effect.

Environmental impacts are cumulative and long-term. How can actuaries work around these challenges? Will there be a reliance on environmental simulations to feed into actuarial models? How can the inherent riskiness/uncertainty of these simulations be handled? Whilst the answers to these questions are not immediately apparent, it is certain that we cannot ignore these issues that have so great an impact on our futures.

4. What's next

Just like solving for how to manage climate change is a multi-disciplinary and global effort, so too is solving for how we should conduct ourselves in matters involving space.

Public policy, private sector commitments, and individual choices will have to come together to ensure our systems are more resilient than they have been before. However, those with the technical ability to quantify our thoughts about the future, and those with the qualitative skills to draw insights from limited data, will have a key role to play.

Actuaries could be a valuable resource to governments as they form their space strategies. Actuaries are well equipped to influence the safeguards that must be put in place to ensure that extra-terrestrial ambitions do not jeopardise sustainability commitments closer to home.

19 Reflected in extensive publications such as the Actuaries Institute Climate Change – Information Note for Appointed Actuaries (2020), the series of papers by the Climate Risk Task Force of the International Actuarial Association (commencing 2020), and the IPCC's Climate Science: Summary for Actuaries (2022) and the Actuaries Institute Public Policy Statement on Climate Change (2020).

20 Wired - The FAA Weighs the SpaceX Launch Site's Environmental Effects

21 UCL Centre for Outer Space Studies

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