# Space Debris – The Tragedy Of The Commons

## Introduction

Space, in particular the satellites in low-Earth orbit, is a crucial component of 21st century society. From providing access to the internet for remote and war-torn corners of the globe (In 2022, during the Russian invasion, Ukraine requested SpaceX to activate their "Starlink" satellite internet service to replace internet and communication networks that were being degraded or destroyed[1]), to providing real time data to insurers and farmers on weather patterns, space based technologies have an essential role to play in providing the data that make markets function.

However, as the competition to provide space-based services hots up, orbits are becoming crowded, and a new menace is raising concerns – that of space junk. This supplement to GGFI 12 aims to explore this issue further and proposes a market-based solution to the problem that covers environmental, social and governance issues.

## The Beginning

On 4 October 1957, Sputnik 1 blasted off from what is now known as known as the Baikonur Cosmodrome in Kazakhstan. The satellite, travelling at a speed of 8 km/s (18,000 mph), took 96 minutes to orbit the earth, transmitting regular pulses on 20.005 and 40.002 MHz, which were monitored by radio operators around the world[2].

Sputnik maintained transmissions for 21 days, until its power failed, and the satellite continued to orbit the earth until 4 January 1958 when it burned up while re-entering Earth's atmosphere.

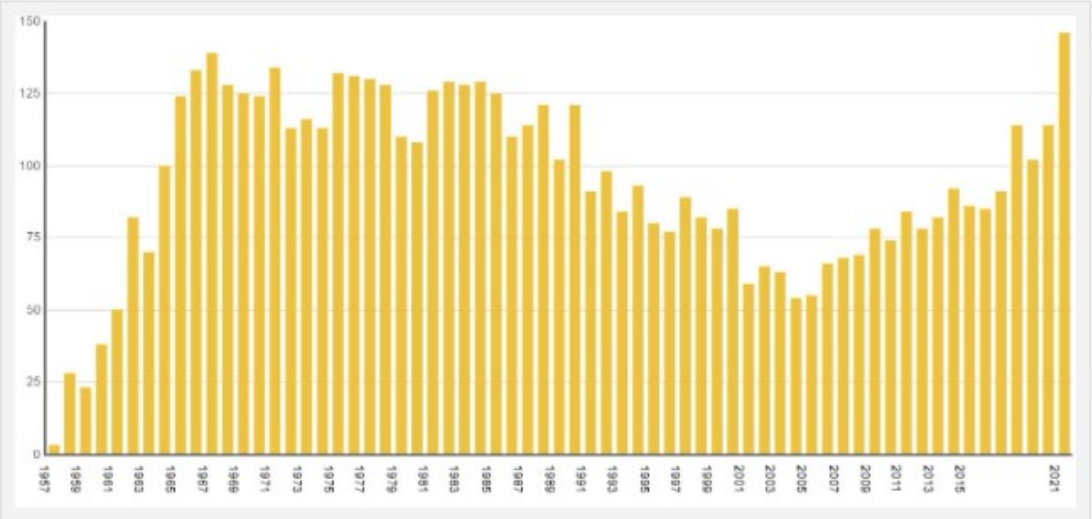
[1] The Economist Satellite2022 ***Internet is a hot new commodity in Ukraine***
https://www.economist.com/graphic-detail/2022/04/29/satellite-internet-is-a-hot-new-commodity-in-ukraine
[2] Nasa (retrieved 2023) https://history.nasa.gov/sputnik.html

Since 4 October 1957, there have been approximately 5,860 launches from 50 sites around the world, which have taken satellites, and people, into orbit[3]. Since 2008 when SpaceX became the first privately developed rocket to reach orbit, the number of launches per year has accelerated.

## The Space Race

Initially, the exploitation of space was an extension of the cold war, with the two late twentieth century superpowers, the US and the USSR vying for supremacy (hence the decline in launches from the late 1980's to the early 2000's (see figure 1)). However, the last two decades has seen a rapid expansion of commercial activity, particularly with respect to launch capability, which has seen the cost per kilo for payload launches drop from over $100,000 per kilo to under £2,000 (see figure 2). At the same time, advances in technologies such as robotics, remote sensing, and artificial intelligence have catalysed opportunities in digital mapping, enhanced communications, navigation, and resource and environmental management – particularly with respect to biodiversity and carbon emissions.

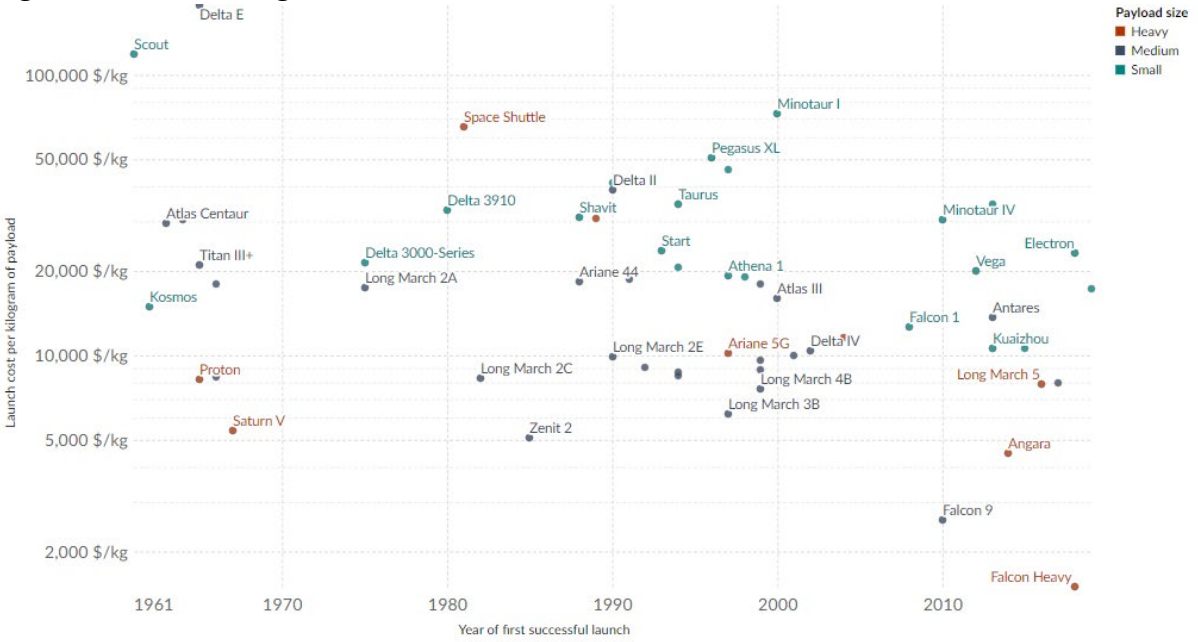
***Figure 1 Annual Orbital Launches***




*Source: Seradata[4]*

[3] Statista (Retrieved 2023) https://www.statista.com/statistics/1343344/orbital-space-launches-global/#:~:text=The%20number%20of%20orbital%20space,the%20Space%20Race%20in%201957.
[4] Seradata (retrieved 2023) https://www.seradata.com/2021-launch-year-a-new-record-for-both-orbital-rocket-and-satellite-launch-totals-in-a-year/

***Figure 2 Cost Per Kilogramme For Launches***




*Source: Our World In Data*[5]

In 2019, 95% of the estimated $366 billion in revenue earned in the space sector was from the space-for-earth economy: that is, goods or services produced in space for use on earth[6] – primarily data.

The earth-for-space economy involves the launch vehicles (or busses) and the hardware that is put into orbit. This includes telecommunications and internet infrastructure, earth observation capabilities, national security satellites, and more. This part of the space economy is also booming - as the number of commercial space launches has grown and new companies enter the market, there has been a marked decrease in costs for launch and space hardware.

## Crowded Orbits

In the early 1960's, the General Assembly requested space nations to voluntarily register their satellites with the Secretary-General to help the newly established Committee On The Peaceful Uses Of Outer Space (COPUOS) to develop laws governing activities in space. In 1975, UN member states adopted the Convention on Registration of Objects Launched into Outer Space, which entered into force in 1976.

[5] Our World In Data (retrieved 2023) https://ourworldindata.org/grapher/cost-space-launches-low-earth-orbit?time=earliest..2019

[6] Weinzeirl M & Sarang M 2021 ***The Commercial Space Age Is Here,*** Harvard Business Review https://hbr.org/2021/02/the-commercial-space-age-is-here#:~:text=The%20implications%20%E2%80%94%20for%20business%2C%20policy,space%20for%20use%20on%20earth.

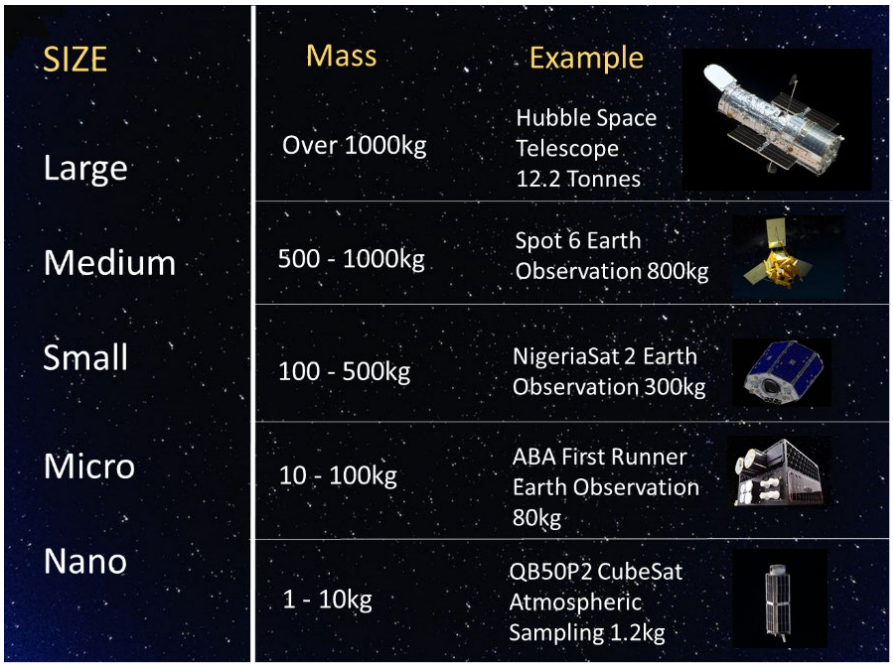
Today the United Nations Office for Outer Space Affairs (UNOOSA) keeps a register of objects launched into orbit and maintains a watchful eye on the exploration and use of outer space under the Outer Space Treaty[7].

Article IX of the Outer Space Treaty specifically states that "*Parties to the Treaty shall pursue studies of outer space, including the moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination*".

According to UNOOSA records, there were 8,261 satellites orbiting the Earth as of January 2022. Of these only 4,852 were active. However, just in the last year, this number has since been significantly augmented. Taking only SpaceX's Starlink programme as an example, as of August 2023, there were almost 5,000 Starlink small satellites in low Earth orbit (LEO)[8]. Nearly 12,000 satellites are planned to be deployed, with a possible later extension to 42,000. Other commercial space organisation and nations are also rushing to enhance their orbital capabilities. In particular, China is considering its own mega-constellation with a plan to launch 12,992 satellites under a project called "Guo Wang"[9].

There is no international body responsible for regulating who launches what into space, instead oversight is maintained by a patchwork of over 30 national regulatory frameworks[10].

***Figure 3 Satellite Sizes***




[7] UNPOSA (retrieved 2023) https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html
[8] Jonathan's Space Pages (retrieved 2023) https://planet4589.org/space/con/star/stats.html
[9] Suess J 2023 ***Guo Wang: China's Answer to Starlink?*** https://rusi.org/explore-our-research/publications/commentary/guo-wang-chinas-answer-starlink
[10] COPUOS 2023 ***Schematic Overview Of National Regulatory Frameworks For Space Activities*** https://www.unoosa.org/res/oosadoc/data/documents/2023/aac_105c_22023crp/aac_105c_22023crp_28_0_html/AC105_C2_2023_CRP28E.pdf

Satellites vary greatly in mass. Each launch can propel multiple satellites into orbit which weigh between 1 kilogramme and 15 tonnes (see Figure 3). Space is a very unforgiving environment and satellites face particular peril at the launch phase, when vehicular failure can destroy many millions of euros of equipment – The financial times recently reported that the space insurance sector has had a particularly torrid year "*When all the mishaps are added up, claims could total roughly $1 billion this year, say industry sources, against premium income of roughly $600 million*"[11].

Even if the launch is successful, the successful deployment of the satellite in the correct orbit is a major technical challenge. According to NASA the unsuccessful deployments of solar arrays, antennas and other spacecraft deployable appendages are one of the main causes of initial satellite failures[12].

Geostationary orbit (GEO) is the best place for telecommunications satellites, whilst low Earth Orbit (LEO), the most effective deployment for earth observation satellites. LEO is a particularly harsh environment as tenuous wisps of atmosphere act as a drag on satellites, causing them to lose speed and altitude. For micro and nano satellites this is factored into their life cycle and they generally de-orbit and burn up in the atmosphere within 5 years of deployment.

For small, medium, and large satellites in GEO, which represent a more substantial investment, the spacecraft generally has some form of propulsion module for apogee injection, attitude manoeuvre for transfer orbit, station keeping and orbit control, which can keep a satellite operational for decades. At the end of operational life, it can deorbit or transfer to a graveyard orbit. These propulsion systems contain highly reactive substances such as hydrazine.

## Space Junk

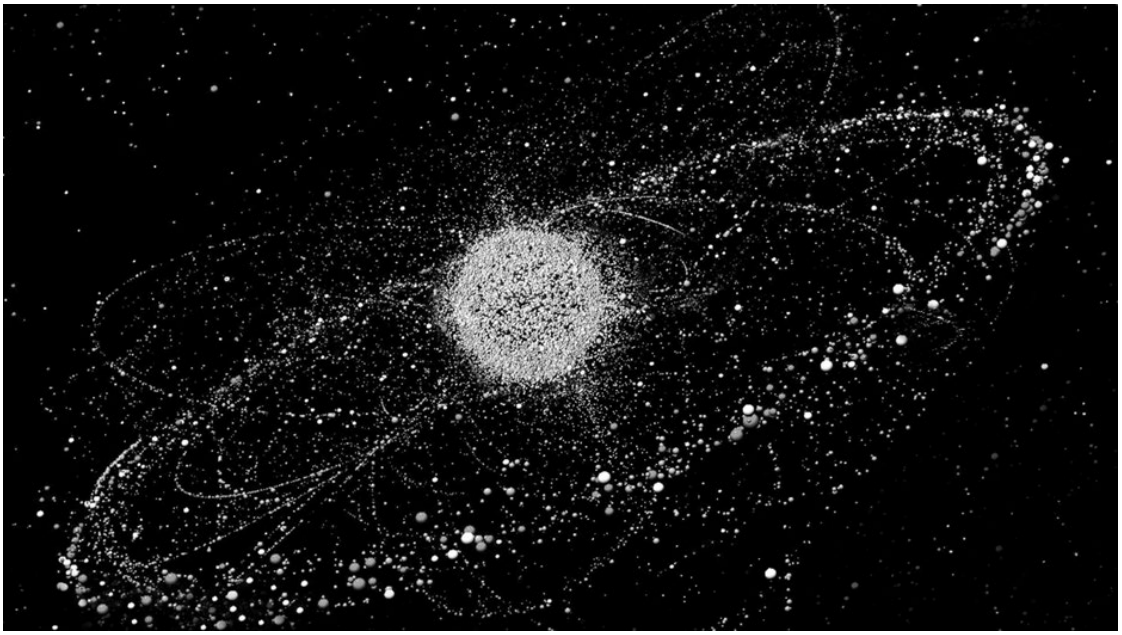
Space debris, also known as space junk, refers to the collection of defunct human-made objects in Earth's orbit. These objects range from dead satellites and spent rocket stages to smaller fragments resulting from explosions, collisions, or disintegration.

Scientists estimate the total number of space debris objects in orbit to be around 29,000 for sizes larger than 10 cm, 670,000 larger than 1 cm, and more than 170 million larger than 1 mm. About 65% of the catalogued objects originate from break-ups in orbit – more than 240 explosions, caused by uncontrolled hydrazine reactions – as well as collisions[13] (See Figure 4).

Among the larger objects, there are approximately 2,000 inactive satellites and spent rocket stages. These larger objects are tracked more accurately than smaller fragments.

[11] Hollinger P 2023 ***Space Needs A Sustainable Insurance Industry***, Financial Times 28/09/23
https://www.ft.com/content/d93f6044-73fd-41fe-a2e5-a57becc26eea
[12] Rivera A & Stewart A 2021 ***Study of Spacecraft Deployables Failures***, NASA
https://ntrs.nasa.gov/citations/20210020397
[13] European Space Agency, (retrieved 2023)
https://www.esa.int/ESA_Multimedia/Images/2018/09/Debris_around_Earth

***Figure 4 Composite Image of Space Junk Orbits***



*Source: European Space Agency*[14]

Most 'space junk' moves extremely fast (7.8 km/s is low-Earth orbital velocity) and due to the speed and volume of debris in LEO, this present a significant threat to current and future space-based services as LEO is, according to NASA "*the world's largest garbage dump*"[15].

Space debris is a rising global risk that needs to be addressed as the accumulation of space debris poses several significant challenges and risks:

1. **Threat To Operational Satellites**: Space debris poses a serious threat to operational satellites that provide essential services such as communication, weather monitoring, navigation, and scientific research. Collisions with debris can cause irreparable damage or complete destruction of satellites, leading to service disruptions and financial losses.
2. **Risk Of Collisions**: With thousands of active satellites and an estimated 128 million debris objects larger than 1 mm in orbit, the probability of collisions between space debris and operational satellites is increasing. Each collision creates more debris, setting off a chain reaction known as the Kessler Syndrome, where the density of debris in certain orbits becomes so high that it significantly impairs future space activities.
3. **Crewed Space Missions At Risk**: Human spaceflight missions, such as those conducted by the International Space Station (ISS) or future crewed missions to the Moon and Mars, face heightened risks due to space debris. Even small debris pieces can cause catastrophic damage to spacecraft, endangering the lives of astronauts and jeopardising space exploration efforts.

[14] European Space Agency (accessed 2023) https://www.esa.int/ESA_Multimedia/Videos/2019/02/Distribution_of_space_debris_in_orbit_around_Earth
[15] NASA (retrieved 2023) https://www.nasa.gov/centers/hq/library/find/bibliographies/space_debris

4. **Economic Impact**: The economic consequences of space debris are significant. Satellite operators and insurers bear the financial burden of insuring against potential losses from collisions with debris. Satellite operators may also incur additional costs for collision avoidance manoeuvres, satellite replacements, or the premature retirement of operational satellites due to increased risks.
5. **Long-term Space Sustainability**: The accumulation of space debris poses a threat to the long-term sustainability of space activities. If left unaddressed, the growth of debris could render certain orbital regions unusable, limiting the potential for future satellite launches and hindering space exploration and scientific research endeavours.
6. **Limited Regulatory Framework**: Currently, there is no comprehensive international regulatory framework governing space debris mitigation. Guidelines and best practices exist, but compliance is voluntary, leading to inconsistent adoption and implementation. Strengthening regulatory measures and promoting international cooperation is crucial to effectively address the space debris problem.

If access to space becomes problematic the world will suffer serious impairment to 38% of the Sustainable Development Goals (SDGs). *A 2018 study conducted by UNOOSA, in cooperation with the European GNSS Agency (GSA), indicates that "almost 40%, or 65 out of 169 targets, that are underpinning the 17 SDGs are directly taking advantage from the use of geo-location and earth observation satellites. With the inclusion of telecommunication satellites, this statistic rises considerably*"[16].

Despite this risk there are no international laws requiring companies to clean up debris in LEO, although national regulators are beginning to wake up to the risk. On 2 October 2023, the United States Federal Communications Commission (FCC) issued its first ever fine to a company for littering in space[17]. The FCC's investigation found that the company violated the Communications Act, and the terms of the company's license by relocating its direct broadcast satellite EchoStar-7 at the satellite's end-of-mission to a disposal orbit well below the elevation required by the terms of its license. At this lower altitude, it could pose orbital debris concerns. The settlement included an admission of liability from the company and an agreement to adhere to a compliance plan and pay a penalty of $150,000.

Although, the sum is negligible, this is a landmark decision, following on from a 2022 decision to adopt new rules requiring satellite operators in low-Earth orbit to dispose of their satellites within five years of completing their missions, significantly shortening the long-held 25-year guideline for "deorbiting" satellites post-mission.

Unfortunately, it stops short of plans floated to require satellite operators to indemnify the U.S. government against harm caused by their satellites, which could include the introduction of a performance bond (that could reach $100 million for megaconstellation operators)[18].

[16] , UNOOSA & European GNSS Agency 2018 https://sdgs.un.org/un-system-sdg-implementation/united-nations-office-outer-space-affairs-unoosa-24523
[17] FCC 2023 **FCC *Takes First Space Debris Enforcement Action*** https://docs.fcc.gov/public/attachments/DOC-397412A1.pdf
[18] Henry C 2023 ***FCC punts controversial space debris rules for extra study***, Space News https://spacenews.com/fcc-punts-controversial-space-debris-rules-for-extra-study/

## Market Based Solutions

There are several interlinked approaches which can be used to tackle the problems of space debris:

1. **Space Debris Tracking And Monitoring**: Enhance global tracking and monitoring capabilities to catalogue and predict the movements of space debris more precisely. This information is vital for collision avoidance manoeuvres and future planning.
2. **Debris Mitigation Measures**: Encourage satellite operators and manufacturers to adopt best practices for debris mitigation, including designing satellites with built-in deorbiting capabilities, minimizing the creation of debris during satellite deployments, and implementing end-of-life disposal plans.
3. **International Collaboration**: Foster international collaboration and cooperation among space agencies, private industry, and regulatory bodies to develop and enforce comprehensive space debris mitigation guidelines and standards. Establish mechanisms for information sharing, joint research, and coordinated efforts to address the global nature of the space debris problem.
4. **Research And Innovation**: Invest in research and development of advanced technologies and materials that can help mitigate the risks of space debris. This includes improved shielding technologies for spacecraft, better tracking and monitoring systems, and innovative propulsion methods for satellite deorbiting.
5. **Public Awareness And Education**: Raise public awareness about the challenges posed by space debris and the importance of responsible space operations. Educate the public, policymakers, and future space professionals about the potential consequences of unchecked space.
6. **Active Debris Removal (ADR)**: Develop and deploy technologies for actively removing larger debris objects from orbit. ADR initiatives, such as capturing and deorbiting defunct satellites or using robotic systems to clear debris, can significantly reduce the risks posed by existing large debris items.

***Figure 5 ADR Concept ClearSpace 1***

However, the most effective leverage could be applied through the insurance sector.

The Organization for Economic Cooperation and Development points out that: *"While not strictly a debris mitigation measure, in-orbit insurance, in particular third-party liability insurance could play an important in shaping operator behaviour and contribute to covering remediation costs"*[19].

Despite this, it is estimated that currently only six percent of satellites in low-Earth orbit have in-orbit insurance. A recent paper, published at the International Astronautical Congress in Baku[20], proposes the of performance bonds and P&I mutuals to reduce premiums by spreading exposure.

Performance bonds could be offered for satellite retirement and anti-collision insurance- these are financial instruments that guarantee the funding required for the safe deorbiting or retirement of satellites at the end of their operational life if the satellite does not safely deorbit or retire according to plan.

A requirement to obtain such a bond before getting permission to launch would ensure that satellite operators retire their satellites in a responsible manner and adhere to established guidelines for sustainable space operations.

Holding satellite operators accountable for disposal can significantly reduce the accumulation of space debris and promote long-term space sustainability. In the event of an operator not retiring their satellite responsibly, the bond can be used to cover the costs of doing so.

Features of performance bonds for satellite retirement could include:

- A tiered pricing structure based on satellite size, mission duration, and risk factors.
- A rigorous evaluation process for satellite retirement plans to ensure compliance with international guidelines.
- Close collaboration with satellite operators to monitor retirement plan execution and provide guidance if needed.
- Regular audits and inspections to verify compliance with retirement obligations.
- Clear indemnification terms in case of unexpected satellite failures or operator bankruptcy.

Fundamentally anti-collision insurance coverage should be mandated by the regulatory bodies responsible for overseeing the space sector in each jurisdiction. This would be taken by satellite operators, space agencies, and commercial space ventures. This insurance would protect against financial losses resulting from collisions with space debris or other operational satellites.

[19] OECD 2020 Space Sustainability: The Economics Of Space Debris In Perspective, page 35 https://read.oecd.org/10.1787/a339de43-en?format=pdf

[20] Mainelli M et al 2023 ***In-orbit servicing and insurance markets: a symbiotic approach*** International Astronautical Congress (IAC 2023), Baku https://www.longfinance.net/documents/3690/Astroscale_-_Insurance_-_Draft_v10.0_Final_Copy_Edited.pdf/

Incentivizing operators to adopt collision avoidance measures would mitigate the risks of catastrophic collisions and minimize the creation of additional debris. However, providing appropriate cover economically may require a collaborative effort between public and private entities -an existing example of which can be found in the UK's Pool Re for terrorism insurance.

Taking a combined public and private approach would provide:

- Access to government space debris databases, research, and technological advancements.
- Shared risk and financial burden between the public and private sectors.
- Leveraging the expertise of insurance and reinsurance professionals.
- Pooling of resources for enhanced risk modelling and analysis.
- Efficient regulatory compliance and coordination between relevant stakeholders.

## Conclusions

The current situation with respect to space debris and orbital crowding in LEO is "the tragedy of the commons" writ large. Without international cooperation and effective regulation, underpinned by effective insurance products, the possibility of a Kessler Syndrome event occurring within the next decade increases in probability – and the more debris there is in orbit, the higher the insurance premiums and the lower investors' appetite. To quote one senior practitioner involved in the sector- "*Why throw billions into orbit if it has a high risk of getting shredded?*"

Action is required to protect space, and the insurance industry and the nascent In-Orbit Servicing industry stand ready to facilitate that action. That action could come in the form of international agreement to leverage insurance for liability and removal of debris for satellite operators. That action will preserve the benefits of space for society today and put it on a sustainable footing for the future.

The satellite insurance market presents unique challenges for insurers, especially with potential high risk of exposure for individual incidents. It is time that operators, insurers, and government come together to consider alternative possibilities to provide effective coverage against the risks inherent in satellite operations, while taking the opportunity to promote best practices across the satellite industry.

It may be that financial centres may be in the best position to kickstart the debate by assessing interest and appetite, as well as identifying problems and pitfalls. The City of London will be hosting a series of discussions on the concept of SDRBs and associated products and initiatives provided by space protection insurers from November 2023 to November 2024: The 695th Lord Mayor's Space Protection Initiative.