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In-orbit servicing and insurance markets: a symbiotic approach

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Abstract

The space industry stands at the precipice of a new paradigm of in-orbit servicing (IOS). The emergence of IOS is underpinned by key technological trends and fueled by an influx of capital from private and public markets. These forces are bending cost curves, enabling new business models and technical architectures. Those same forces have dramatically reshaped our orbital environment. There are 8,500 active satellites operating alongside over 1 million pieces of debris over 1cm, each with the capacity to damage or destroy spacecraft [1]. The development of IOS is a direct response to this unsustainable path, aimed to secure the orbital environment and establish a circular space economy for the benefit of future generations.

As nations define their strategies for leadership in these nascent markets, some are exploring links to established industries and native capabilities. The United Kingdom has sought to pair its growing space ambition with the City of London's historic strength as a global hub for finance and insurance. This strategy of merging 'space and the City' has led to a partnership between Astroscale, the first private company devoted to space sustainability, and the City community. Together, we are investigating novel insurance products and structures to tackle the growing problem of space debris and foster the further development of IOS. This paper is the first in a series and an associated set of workshops investigating such ideas. The approaches described herein include a 'space' P&I Mutual and Space Debris Retrieval Bonds (SDRBs), with the latter recommended for further pursuit.

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.

Keywords: In-orbit services, space insurance, space sustainability, orbital congestion, space debris, protection and indemnity mutual, space P&I mutual, space debris retrieval bonds, insurance-linked securities, ISLs

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Acronyms/Abbreviations

ADR: Active Debris Removal
AMC: Advance Market Commitment
APAC: Asia-Pacific
ASAT: Anti-Satellite Weapons
EOL: End-of-Life
EPFL : Ecole Polytechnique Federale de Lausanne
ESA: European Space Agency
FCC: Federal Communications Commission
ILS: Insurance-Linked Securities
JAXA: Japanese Aerospace Exploration Agency
LEO: Low Earth Orbit
NASA: National Aeronautics and Space Administration
OECD: Organisation for Economic Cooperation and Development
OIG: Office of the Inspector General (NASA)
PMD: Post Mission Disposal
P&I: Protection and Indemnity
R&D: Research and Development
SDRB: Space Debris Retrieval Bond
UK: United Kingdom
UKSA: United Kingdom Space Agency
US: United States
VAT: Value Added Tax

1. Introduction

In January 2023, The UK Minister of Science, Research, and Innovation, George Freeman MP hosted a Space Insurance Roundtable at Lloyds of London [2]. This was the latest in a series of discussions aimed at merging the UK's ambition as a space leader with its historical strength as a global financial services hub through the City of London. This national strategy of coupling space and the city, and particularly the insurance industry, has long been viewed by proponents of In-Orbit-Servicing (IOS), as "a natural pairing."[3]

To this end, Astroscale, the first private company devoted to space sustainability and a global leader in IOS, has partnered with the incoming Lord Mayor of London, Professor Michael Mainelli. Together with colleagues from the space and insurance industries, we are examining initiatives that could prove strong synergies between the two sectors. The objective is to unearth products and structures that would both offer an attractive business proposition for the insurance industry, while fostering the development of IOS markets and tackling the growing problem of space debris.

This paper examines two such ideas under consideration, each leveraging a coordinated panel of interested insurers. The first is the opportunity to create financial incentives via a space analogue of a maritime protection and indemnity (P&I) mutual. The second is a space debris retrieval bond (SDRB), which would guarantee the funding required for the safe deorbiting or retirement of satellites at the end of their operational lives. The paper will take each of these proposals in turn, examining their core features along with strengths and limitations. Ultimately, based on consultation with experts in the insurance industry, it is our view that space debris retrieval bonds offer a more feasible near time option in addressing the challenge of space debris.

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2. The Challenge of Orbital Debris

Our use of space is already unsustainable. As of August 2023, there are 8,500 active satellites in orbit, 3,650 pieces of debris over 10cm, and over 1 million pieces of debris greater than 1cm [4]. The last 20 years have seen increasing deployments of CubeSats and constellations, as

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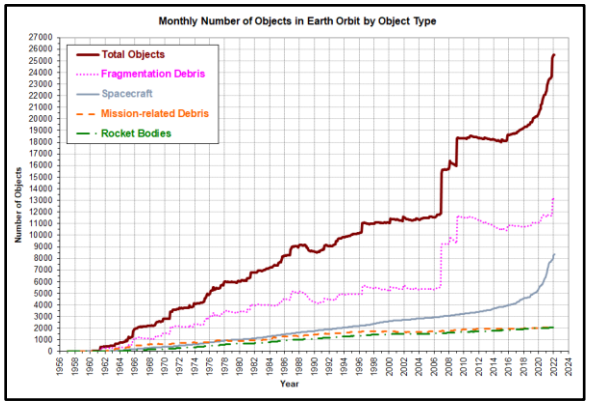
well as debris generating events such as the Fengyun-1C Anti Satellite Weapons (ASAT) test (2007), Iridium Cosmos Collision (2009), and more recently the Russian ASAT test destroying Cosmo 1408 (2021), which created around 1,300 pieces of debris larger than 10cm and thousands of smaller pieces [5]. One of the biggest global challenges facing the space sector is orbital congestion and an increasingly hazardous level of space debris. The deployment of an unprecedented number of satellites in the next 5-10 years will contribute to more crowded and dangerous orbits. (fig 1)



As such, there is a need for satellite operators to protect, manage, and optimize operational service in an increasingly congested environment. Space debris poses a persistent threat to governments, industry space assets, and downstream applications, as well as a growing risk to the sustainability of the entire orbital environment.

As space debris is a rising global risk that needs to be addressed, one way is financial incentives that could be created via coordinating a panel of interested insurers. A P&I mutual or space debris retrieval bonds (SDRB) could guarantee the funding required for the safe deorbiting or retirement of satellites at the end of their operational lives.

2.1 Challenges & Risks of Space Debris & potential actions

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 [6], the probability of collisions between space debris and operational satellites is increasing. Each collision creates more debris, potentially 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 jeopardizing space exploration efforts.
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 maneuvers, 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

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orbital regions unusable, limiting the potential for future satellite launches and hindering space exploration and scientific research endeavors.

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.

Perhaps most problematic is the impact the loss of satellites threatened by space debris would have on the world's most vulnerable populations, with a 2018 study by UNOOSA, with support from European GNSS Agency funding, that 40% of targets in the study are taking advantage of geo-location and Earth observation satellites in support of the United Nations Sustainable Development Goals [7].

2.2 Basic Levers of the space debris problem

To tackle the space debris problem, it is widely recognized by industry stakeholders that several measures are vital:

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 maneuvers 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.

This paper would add "use insurance" to the above list in the form of performance bonds and P&I mutuals. The OECD points out:

"While not strictly a debris mitigation measure, in-orbit insurance, in particular third-party liability insurance could play an important in shaping operator behavior and contribute to covering remediation costs."[8]

3. Market structure and limitations of current space insurance approaches with respect to IOS

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3.1 Satellite Insurance Market

The satellite insurance market is currently focused predominantly on launch, but around two-thirds of contracts cover launch plus oneyear of orbital activities [9]. With respect to on-orbit insurance, only 1% of LEO satellites are insured, and less than a 1/3 of satellites in geostationary orbit (GEO), medium Earth orbit (MEO), and other orbits are insured. [10]. Operators of large satellite constellations are less likely to insure their satellites due to the distribution of risk across a larger network of satellites, and the lack of debt covenants in their operations [11].

At the same time, insurers are competing for a relatively small number of operators, forcing underwriters to outbid the competition, yielding downward pressure that has considerably narrowed margins [12]. In the UK [13], and in certain other jurisdictions, it is compulsory to have third party liability (TPL) insurance up to a set value. Some jurisdictions, such as the UK, require this cover to be obtained for both launch and in-space operations, whilst countries such as the US [14] only require TPL insurance for launch.

At the beginning of 2023, the global satellite insurance outlook appeared strong for insurance, with insurers having enjoyed yet another profitable year in 2022 [15]. However, the notable Vega rocket explosion in 2022 represented the volatility and risk involved in the provision of insurance to the space sector, with the single accident that year representing two-thirds of the loss suffered by the underwriter AXA XL [16]. Historically, the market has been highly sensitive to individual incidents [17] and the future looks much the same.

This year, volatility is once again threatening to destabilise the satellite insurance market. Bloomberg reported that the recent failures of Viasat-3 and Viasat's Inmarsat I6 F2 satellites represent nearly $1 billion of potential liability, which could up-end the entire space insurance market [18]. A potential claim is liable to increase premiums and could significantly reduce capacity available for other satellite operators should underwriters and reinsurers withdraw from the market [19]. Indeed, available data demonstrates that, since 2016, the total premiums collected annually could not have covered claims on the largest policies in any of those years [20]. Our proposal, however, is to approach a different part of the insurance market, and therefore capacity should not be impaired by recent losses.

3.2 Challenges in Collaboration between IOS Operators and Insurers

A key challenge for on-orbit servicing has been in understanding how such activities may be financed and how parties will be incentivised to utilise them. Mitigation of risks and uncertainties play key roles in the economic value of in-orbit servicing [21]. Thus the insurance market and the IOS market have much reason for collaboration with each other, with Malinowska identifying a ‘natural pairing’ between the two [23].

Despite close opportunities for collaboration and the ability to reduce premiums, IOS operators themselves face more pronounced difficulties in obtaining insurance for their missions due to uncertainties in the operation of the liability, jurisdiction, and control regimes with respect to such activities [24]. The unknowns of such a novel technology present a significant challenge when it comes in appropriately pricing an insurance policy for such operations, with insurers lacking historical data and technical insight to evaluate the risk associated with such missions. Thus, insurers are likely to have to pursue individualised underwriting until the risks associated with IOS are better understood [25]. Additionally, future development of IOS operations necessitates the development of more advanced SSA capabilities [26], which will

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boost data available for more appropriately priced insurance policies.

An additional obstacle to insurer-funded IOS is the difficulty of attribution. Space debris is a third-party liability issue rather than a first-party loss. If the losses caused by space debris are borne by the injured party or by society at large, rather than by the operator which left the debris, then that operator and their insurers have little incentive to remove their debris.

On that basis, removing debris is currently a benefit for the whole space community rather than the specific operator which caused it. There is no mechanism currently for funding that benefit equitably — with the cost split between all operators.

That is compounded by low insurance penetration. If satellites were almost all insured, then the economics of debris removal could work for insurers. Insurers would also find it easier to collaborate on efforts to remove debris than operators. Given that 99% of LEO satellites are currently uninsured, cost sharing would have to take place between myriad operators across many jurisdictions.

3.3 Opportunities in Collaboration between IOS Operators and Insurers

The traditional insurance market offers property and liability insurance for satellites, with coverage out to 15 years available[50].

The market is well-placed to cover IOS triggered by a failure of the satellite, given its expertise in underwriting technical risk associated with satellites. It would also be technically possible to extend coverage within a traditional space insurance policy to cover those IOS costs. The main obstacles are the lack of a government mandate to remove failed satellites and the difficulty of attribution if elements of the failed satellite damage operational satellites.

4. Protection &Indemnity Mutuals

4.1 Defining the P&I Mutual

In the shipping industry, P&I clubs are associations of stakeholders which provide protection and indemnity cover to their members. Through the P&I club, the members are able to pool risk. The defining feature of a P&I club is its mutuality. Member shipowners are both the insurers and insured [28], contributing to a common fund from which any future claims can be paid [29]. When surplus contributions are at hand, they are invested to boost cash reserves for the payment of future claims [30]. However, the majority of the cover comes from the international reinsurance market, under the traditional reinsurance model. The mutuals themselves retain only the smallest everyday losses.

4.2 Benefits of P&I Mutuals

P&I clubs were born out of necessity and capture a high share of the maritime market. For instance, the twelve P&I clubs that comprise the International Group in London provide marine liability cover for around 90% of all ocean-going tonnage among them [31]. The model followed by these clubs enables individual competition to remain amongst the insurance providers, whilst sharing the substantial risks involved in the marine industry [32]. The ability to pool cash reserves is beneficial in an industry with a relatively low number of claims yet a relatively high potential cost to individual insurers.

Potential exposures to large liabilities as a result of one-off incidents in the satellite market have already led to several insurers pulling out entirely [33]. This suggests that the line of insurance is more volatile than others [34], particularly for individual insurers. It is already typical for multiple insurers to participate in one launch because of the large loss potential [35]. The participation of multiple insurers will be an important part of attaining the necessary limits.

P&I clubs in the marine industry have demonstrated a positive benefit on the

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environment by creating a mutual interest in risk minimisation [40]. The benefits for safety and the environment cannot necessarily be obtained by P&I clubs without the fulfilment of certain characteristics. Bennett suggests that the strongest impact may come from the exclusion of substandard would-be participants from P&I insurance, where membership is a requirement for participation in shipping [42]. However, this effect on safety and environment requires the Club to be small enough and with sufficient homogeneity for this sanction of excludability to be enforceable.

4.3 P&I Mutuals as Governance Tools

The general insurance industry can prove an effective tool for governance, filling voids more effectively than government regulation due to an ability to respond rapidly and fine tune requirements year-on-year [43]. Amongst the traditional applications of P&I mutuals in the marine insurance setting has been for collisions and compulsory wreck removal [44]. Thus it has a proven track record of facilitating marine operations that offer an analogy with active debris removal (ADR) missions. The study of the potential analogues between the application of P&I clubs in the marine context and their ability to boost compliance with space traffic management (STM) guidelines has been considered in recent academic literature [45]. Despite some criticism of their current operating frameworks in relation to competition, the history of P&I clubs in the marine sector demonstrate their potentially useful role in universalising best practices for STM and incentivise or require the use of ADR where necessary to achieve high post-mission disposal (PMD) rates.

4.4 Criticism of P&I Mutuals

Despite wide application in the field of marine insurance, it has not all been smooth sailing. The clubs have come under increasing scrutiny for their impact on competition amongst insurers, leading some scholars to go so far as to describe the International Group of P&I Groups, headquartered in London, as a cartel [36]. Indeed, this is not a new criticism faced by P&I clubs. In the late 1990s, the European Community's Competition Commissioner threatened to revoke the International Group of P&I Clubs' exemption from the then European Community's competition rules [37]. It's not only the reduction of competition between insurers that has led to the clubs drawing the ire of critics. Some critics have also cited potential difficulties faced by injured third parties seeking recovery from P&I clubs [38]. Most P&I club models incorporate a so-called "pay to be paid" clause, which requires the insured to actually pay out a claim, judgment, or settlement before being indemnified by the club. This might be acceptable in the shipping industry, but is perhaps less suitable for the satellite insurance market in which many companies have limited financial reserves [39].

Additionally, to form a mutual, satellite operators would all have to agree that this is the correct approach to transferring risk, They would then have to capitalise an entity with their own funds. Once this is in place, they would need to hire underwriters and a management team, and obtain authorisation from the relevant regulators. They would also need to seek the necessary licences to operate in the many different jurisdictions. All of this usually takes a great deal of time and money. If they do manage to get the venture up and running, the sums at risk will almost certainly force them to purchase an extensive reinsurance programme, which will further reduce any potential for profit. On top of this, if the premiums paid into the mutual are insufficient to pay for the losses, the operators will be liable for a cash call. These factors mean that mutuals are not usually used as a vehicle for transferring risk if there is a commercial solution available. In fact the origins of the P&I clubs was an unwillingness on marine underwriters' part to take on third party exposures.

Sufficient capacity is currently available via the open market route, and therefore all the other options will add unnecessary additional

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complexity and cost. However, this does not mean that satellite operators are precluded from exploring alternative structures in the future. However, as mentioned earlier, certain underwriters at Lloyd's have written pre-launch, launch, and in-orbit risk for over 50 years. We are yet to see any operators attempting to deviate from the open market approach to this risk.

5. Space Debris Retrieval Bonds (SDRBs)

5.1 Background on Insurers Interests for Performance Bonds

There is a wealth of experience about space-related risk in the world-wide insurance market. Underwriters at Lloyd's wrote their first satellite launch insurance policy in 1965. Underwriters hired the space shuttle *Discovery* in 1984 to recover two misaligned satellites, Palapa and Westar.

It is a fundamental principle of insurance that the premium of the many should pay the losses of the few. Underwriters who are not guided by this will soon find themselves out of a job. Without responsible management and mitigation, today's satellites are tomorrow's debris, with only the date of transition being uncertain. The insurance industry has plenty of ways to lose money already, and it does not need us to invent new ones.

Fortunately, the many types of insurance policies available in the world today can point towards possible solutions. Performance bonds for space debris offer a guarantee that something will happen, and therefore one of the most fruitful areas of investigation is existing performance bonds. Examples include completion bonds that guarantee a feature film will be finished and surety policies that pay up if the main contractor on a construction project becomes insolvent. In the US, there are also bail bonds, which are activated when a defendant fails to turn up for a court hearing, placing an onus on the bondsperson to apprehend the fugitive and return them to custody.

The insurance market usually deals with duration by insuring the entity rather than the activity. For instance, an architect will buy a policy covering all work for a 12 month period, rather than one for each project. This then gives rise to issues on what are called "nose" and "tail," coverages, which will be discussed later. There are many ways satellite operators could obtain SDRBs. They can access insurance via the open market, group purchasing schemes, and captives. They can also form a mutual and mitigate catastrophe risk via reinsurance. This may or may not have a state guarantor.

5.2 Definition of Performance Bond and Assessment for the Space Industry

A performance bond is a surety bond issued by an insurance company or a bank to guarantee satisfactory completion of a project by a contractor. The underwriter guarantees an amount equal to the decommissioning sum in return for an arrangement fee and premium. Performance bonds are used in other industries that operate under risk-laden conditions in extreme environments, such as offshore wind, maritime, and mining [46]. In these industries, performance bonds are applied to decommissioning operational equipment at end-of-life and are often coupled with other incentives, such as subsidies, levies, and tax incentives, among others [47].

The trigger of a typical performance bond is twofold — an operational issue (which in the case of SDRBs would be the failure of the satellite), followed by the financial inability of the principal to remedy the issue (in practice this means the insolvency of the principal).

The satellite operator's financial position is therefore relevant to the bond's pricing and availability. This is likely to present a problem if the only operators which are able to procure coverage at commercially reasonable terms are those which already have the financial means to

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recover their satellites without insurer assistance. In the case of other operators they might be required to cash collateralize some or all of the value of the bond, potentially undermining the structure's value.

While performance bonds present many advantages including securing funding in advance and a precedence with other regulators such as in the mining, offshore wind, and maritime industries, recurrent drawbacks have been identified for performance bonds in Australia, Canada, and the US. Indeed, there is often a lack of enforceability by the responsible stakeholders. Performance bonds also only partially cover the estimated liabilities, which leave governments to pay the remaining part. For instance, in Canada, a report found that British Columbia struggled with compliance and enforcement of financial securities. Only half of the environmental liabilities have been covered by financial securities at major mines [48]. This however is not a fundamental criticism of the structure and could be addressed through larger limit requirements and fee agreements with IOS providers.

Typically, insurers prefer to issue policies lasting, at most, 12 months plus odd time. This allows them to re-underwrite risks in the light of poor results or emerging risk. Since the lifespan of most satellites is between 10 and 15 years, it is unclear whether any insurer will consider covering such a period of time. Therefore duration is an impediment to SDRBs. However, the surety bond market typically offers bonds in excess of this period in order to match the underlying project length.

Performance Bonds	
Advantages	**Disadvantages**
• Boost liquidity and financial flexibility and allow for other investments or paying down on debt. • Ensure funding for EOL in advance, depending on definition of decommissioning / thresholds set for space debris mitigation. • Have established precedent for bonds in the satellite industry.	• Lack enforceability and capacity of the government to enforce them. • Present uncertainty around performance bond value and timescale of satellite operators that could be agreed through satellite licensing process. • Lack of availability of surety bond coverage for all operators, and especially those which are most likely to be unable to fund IOS internally

5.3 Application of performance bonds to space sector & insurers' risks

In various sectors, the use of performance bonds, often in combination with other measures, ensures that funds are available at the end of operations to return the environment to its natural state. As has been explored above in relation to P&I mutuals, a variant of the performance bond for the space sector, the SDRB, could also be utilized to incentivize responsible PMD.

For SDRBs to work, there must be an initial commitment from operators to decommission their own satellites. For LEO, this means putting them on a degrading trajectory, which will eventually lead them to burn up in Earth's atmosphere. For GEO, it means moving them into a graveyard orbit. It is only if the operator is unable or unwilling to do either of these that the SDRB would be triggered. Given this requirement, SDRBs would only be available to operators which can by design deorbit their satellites. Those which do not have these initial capabilities would not be eligible. These

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capabilities may fail, under which circumstances IOS would be procured.

The best way to obtain this commitment is through government mandate or legislation. A complementary way would involve the operator using its assets as collateral against any costs incurred by insurers. It nevertheless does not address the fundamental issue of operators being unable to fund IOS costs themselves following an incident. The insurance industry already uses this procedure across many lines of business. If underwriters deem the assets insufficient, they can also take collateral in the form of cash or letters of credit. However, our research indicates that it is only if governments require operators to buy SDRBs that the insurance industry will be interested in supporting them.

If operators are paying for their own decommissioning, it would be valid to ask why they should also buy a SDRB. As mentioned earlier, the insurance industry exists to indemnify insureds against fortuitous loss, both foreseen and unforeseen. Therefore, the SDRB would ideally protect against what is called 'tail risk,", an event that is rare but catastrophic in nature. In the insurance industry, it is said that if someone wants "sleep at night" cover, they have to pay someone else to stay awake. However, given the difficulty that the existing market has in digesting current attritional losses it is unlikely that any insurer (or their prudential regulator) would be willing or able to take on the tail risk described up to the necessary limits.

Satellite insurers have considered space risk for over 50 years. Consultation with industry experts in the London insurance market has identified some initial appetite for covering catastrophic risk.

Tail risks it would be desirable to cover through traditional insurance, a state-backed reinsurance pool (akin to terrorism reinsurance pools), or through an insurance-linked securities (ILS) structure include:

- *Carrington Event*: This is when a coronal mass ejection causes an intense geomagnetic storm that hits Earth. Such an event was recorded in 1859 by Richard Carrington, hence the name. It not only caused auroras as far south as the Caribbean, but it also affected telegraph wires around the globe. If repeated, it would put at danger all electrical devices, including satellites. Our sources believe the effect will probably be temporary, and only result in a handful of total losses.
- *Kessler Syndrome*: As mentioned earlier, this is when two or more objects collide, and set off a chain reaction. Our sources believe around 20% of all LEO satellites could be rendered inoperable within 6 months of this happening.
- *Design Fault*: If a class of satellites is found to have a fault once they are launched, there is the risk of multiple failures.
- *Component Fault*: If a component common across all satellite classes is faulty, there is the risk of multiple failures.
- *Cyber Attack*: This is hard to assess and depends on the owners' systems. A denial of service, or ransomware, attack is more likely than an attempt to wreck a satellite's operating system.

  Notwithstanding this, the greatest risk to the insurance industry is the financial failure of the satellite operators.

5.4 Insurer's Way Forward on SDRB

There are a number of companies developing IOS and specifically debris removal services. Insurers can liaise with them to determine how much it would cost to decommission an owner's satellites. The premium payable will be based on this, and other factors.

Nose and tail coverage for insurers are ways to cover existing risks as well as risks after insurance availability. Indeed, "nose" coverage involves taking on existing risk. In other words, this includes all of the satellites an operator has in orbit at the inception date of their first policy. Underwriters will want to have the full details on these, and make a judgment call as to whether

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they are prepared to offer complete or partial cover.

”Tail” cover is what happens if insurance is no longer available, for whatever reason. The extent of this cover depends on the operator’s willingness to pay an additional premium, and underwriters’ view on how much extra risk they want to take on.

6. Areas for further research

6.1 Insurance-Linked Securities (ILSs)

Insurance-linked securities (ILSs) are another avenue worth further exploration. ILSs connect risk financing by insurance and reinsurance firms to the wider capital markets by ‘wagering’ on events. Fundamentally, an ILS is a bond issued by an insurer and bought by capital markets firms, and its repayment is contingent on an event *not* occurring. ILSs allow investors to speculate on events, including catastrophes such as hurricanes, volcanoes, earthquakes, and pandemics. If the event does not occur, the investors receive repayment of the principal and regular interest payments with an appropriate risk premium. If the event occurs (is ”triggered”), the bond does not need to be repaid. The insurer receives the collateral instead of investors. The investors lose their principal and unpaid interest payments.

In a typical situation, a reinsurer sets up an Insurance Special Purpose Vehicle (ISPV) and uses it to issue a bond, say on a catastrophe. Investors buy this bond, and the ISPV invests the capital in a low-risk market so that it receives some base return. The investors receive a coupon from their bond, above the base rate. At the end of the life of the bond (say three years), investors get their money back if no catastrophe has occurred. However, should the catastrophe occur, part or all of the capital reverts to the reinsurer who pays out the insurance companies. Crucially, insurers are permitted to use ILSs to satisfy capital-adequacy regulations. [49]

Until recently, natural catastrophe bonds (“Nat Cat Bonds”) have dominated the ILS world, especially those triggered by weather-based disasters in the Americas. There is no reason this should remain the case. Recently issuers have used the ILS market to offload life, accident, health, and other risks.

Space ILSs might be a way to provide more contingent capital to remove space debris. ILSs might range from a bet on a Kessler Syndrome, to de-orbiting of individual satellites, or individual satellite collision events. ILSs could work well in helping finance Space Debris Removal Bonds, but need further research.

7. Conclusion

Satellite operations once benefited from uncongested orbits and little debris from legacy activity. With the number of satellites forecast to grow exponentially in coming years, those historic advantages are diminishing as the potential cost to society from space debris increases. Action is required to protect space, and the insurance industry and the nascent IOS 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.

P&I clubs offer one potential route to provide an effective offering. However, they entail cost and operational burdens that make them an unlikely approach compared to available insurance

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products. Additionally, the structure of such clubs is controversial amongst both industry and government, with the groups coming under increasing scrutiny from competition regulators. Finally, the P&I club structure might limit the emergence of new and novel insurance products, hampering innovation in a fledgling but rapidly growing market.

Space Debris Retrieval Bonds (SDRBs) offer a potential solution, but will only be effective if regulators require operators to buy them. Insurance-linked securities (ILSs), may provide an additional avenue to finance SDRBs and warrant further investigation.

Ultimately, this paper intends to present a starting point for discussion. It will be for government and the insurance industry to come together and decide which solution is more appropriate in such a rapidly changing market. Only by working together can insurers, satellite operators, and governments create an environment that incentivizes responsible space operations.

Although the insurance outlined above is feasible in theory, the authors of this paper will not be taking the risk. It is for underwriters to assess whether it is insurable, and how much premium they want for it. What is needed are some events where insurers, the space industry, and governments can discuss the topic, learn each others' interest and appetite, and identify 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.

The Initiative is an important step in accelerating these critical discussions between the various stakeholders on how The City can play a pivotal role in shaping our response to the pressing issue of orbital debris.

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