Space Insurance and The Implications of In-orbit Collisions

Michael Audrey Gunawan Sigit Santoso

Institute of Air and Space Law

Faculty of Law

McGill University, Montreal

December 2024

A Thesis submitted to McGill University in partial fulfillment of the requirements of the degree of Master of Laws (LL.M.)

Table of Contents

ABSTRACT

Satellite operators invest substantial resources in designing, building, launching, and operating satellites. These investments are vulnerable to collision-related losses. Space insurance provides financial protection by covering risks associated with in-orbit collisions. It ensures that operators can recover financially if their satellites are damaged or destroyed, including protection from third-party claims.

Space insurance encourages responsible behavior of space activities by incentivizing operators to take precautions against failures, this includes collisions. But a significant insurance claim due to a loss would have an immediate and chilling effect on the space insurance market, affecting the entire industry.

As space becomes more congested, understanding liability and insurance mechanisms becomes critical. The congestion of space environment is due to the proliferation of satellites, space debris, and other objects in orbit. As more entities (both governmental and commercial) launch satellites, the risk of collisions grows exponentially. Collisions between satellites or with space debris can lead to catastrophic consequences.

These collisions jeopardize valuable assets, disrupt critical services (such as communication, weather monitoring, and navigation), and pose a threat to human safety. Without adequate insurance, investors and entrepreneurs might hesitate to participate in space ventures, hindering the growth of the space industry.

The space insurance market operates on risk assessment and premium calculations. A significant collision event could lead to substantial insurance claims. Such claims impact insurance companies, reinsurance markets, and overall industry stability. A sudden surge in claims could alter premium rates, coverage terms, and the availability of insurance.

As space becomes more crowded, sustainability becomes paramount. Responsible practices are essential to avoid creating an environment where collisions cascade into more debris, increasing the problem. By emphasizing the importance of responsible behavior, this thesis aligns with the long-term goal of maintaining a safe and sustainable space environment.

RÉSUMÉ

Les opérateurs de satellites investissent des ressources considérables dans la conception, la construction, le lancement et l'exploitation de satellites. Ces investissements sont vulnérables aux pertes liées aux collisions. L'assurance spatiale offre une protection financière en couvrant les risques associés aux collisions en orbite. Il garantit que les opérateurs peuvent se rétablir financièrement si leurs satellites sont endommagés ou détruits, y compris la protection contre les réclamations de tiers.

L'assurance spatiale encourage un comportement responsable des activités spatiales en incitant les opérateurs à prendre des précautions contre les défaillances, y compris les collisions. Mais, une réclamation d'assurance importante en raison d'un sinistre aurait un effet immédiat et dissuasif sur le marché de l'assurance spatiale, affectant l'ensemble de l'industrie.

À mesure que l'espace devient de plus en plus encombré, il devient essentiel de comprendre les mécanismes de responsabilité et d'assurance. L'encombrement de l'environnement spatial est dû à la prolifération des satellites, des débris spatiaux et d'autres objets en orbite. À mesure que de plus en plus d'entités (gouvernementales et commerciales) lancent des satellites, le risque de collisions augmente de façon exponentielle. Les collisions entre satellites ou avec des débris spatiaux peuvent avoir des conséquences catastrophiques.

Ces collisions mettent en péril des biens précieux, perturbent des services essentiels (tels que la communication, la surveillance météorologique et la navigation) et constituent une menace pour la sécurité humaine. En l'absence d'une assurance adéquate, les investisseurs et les entrepreneurs pourraient hésiter à participer à des entreprises spatiales, ce qui entraverait la croissance de l'industrie spatiale.

Le marché de l'assurance spatiale fonctionne sur l'évaluation des risques et le calcul des primes. Une collision importante pourrait entraîner des réclamations d'assurance importantes. De telles réclamations ont un impact sur les compagnies d'assurance, les marchés de la réassurance et la stabilité globale du secteur. Une augmentation soudaine des réclamations pourrait modifier les taux de prime, les conditions de couverture et la disponibilité de l'assurance.

À mesure que l'espace devient plus encombré, la durabilité devient primordiale. Des pratiques responsables sont essentielles pour éviter de créer un environnement où les collisions se transforment en débris, ce qui aggrave le problème. En mettant l'accent sur l'importance d'un comportement responsable, cette thèse s'aligne sur l'objectif à long terme de maintenir un environnement spatial sûr et durable.

Acknowledgements

Completing this thesis has been a remarkable journey, and I am deeply grateful to all those who have supported me along the way. First and foremost, I would like to express my heartfelt gratitude to my family. Your unwavering support, encouragement, and understanding have been my pillars of strength. Without your love and belief in me, this achievement would not have been possible. Thank you for always being there, cheering me on, and providing the emotional and moral support I needed to persevere.

I am immensely thankful to my professors, whose guidance and expertise have been invaluable throughout this process. A special thanks to my thesis supervisor, Professor Donal Patrick Hanley, for your insightful feedback, patience, and dedication to my academic growth. Your mentorship has been instrumental in shaping this work. I would also like to acknowledge my undergraduate law professor in Indonesia, Adrianus Adityo Vito Ramon, whose passion for air and space law inspired me to pursue this discipline. Your influence has been profound, and I am grateful for the foundation you provided.

To my classmates and colleagues, thank you for your camaraderie and support. The countless hours we spent discussing ideas, sharing resources, and encouraging each other have been a source of motivation and inspiration. Your friendship and collaboration have made this journey enjoyable and enriching. I am fortunate to have been surrounded by such a dedicated and supportive group of peers. Also, I would like to thank all of my Indonesian friend in Montreal, without them this journey would not be as wonderful.

Lastly, I would like to extend my gratitude to all the professionals who have contributed to my research. Your willingness to share your knowledge and experiences has greatly enriched my work. Special thanks to Professor Andrea Harrington for providing the initial resources and insights that were crucial to the early stages of my research. Your contributions have been invaluable, and I am deeply appreciative of your support. This thesis is a testament to the collective effort of everyone who has been part of this journey, and I am profoundly grateful to each one of you.

I

Introduction

I. Introduction to Space Insurance

Space exploration and commercialization have entered an exciting phase, with private companies, international collaborations, and technological advancements driving progress never seen before[1]. Amid this, space insurance plays a critical role in shaping the future of space activities[2]. Insurance is often the third biggest expense[3] in conducting a space activity, aside from the cost of the spacecraft and the launch[4]. This expense will inherently determine the development of space activities in the future.

However, due to the prevalence of space activities, an ever-growing number of satellites and debris are orbiting our planet[5]. As the space industry expands, so do the risks associated with in-orbit collisions. The space environment is no longer the exclusive domain of governments; private companies, research institutions, and even individuals now participate in space

---

[1] Bushnell, D. M. (2021). Futures of Deep Space Exploration, Commercialization, and Colonization: The Frontiers of the Responsibly Imaginable. NASA Technical Memorandum.

[2]Blimline, B. (2024) The evolution and future of Space Insurance, Todays Insurance Professional. Available at: https://blog.internationalinsuranceprofessionals.org/the-evolution-and-future-of-space-insurance/ (Accessed: 04 November 2024).

[3] Harrington, A.J. (2021) Space insurance and the law: Maximizing Private Activities in Outer Space. Cheltenham: Edward Elgar Publishing.

[4]AON (2016) Insuring space activities. Available at: https://www.aon.com/russia/files/Insuring_Space_Activities_whitepaper.pdf (Accessed: 04 November 2024).

[5]Bongers, A. and Torres, J.L. (2024) Low-earth orbit faces a spiraling debris threat, Scientific American. Available at: https://www.scientificamerican.com/article/low-earth-orbit-faces-a-spiraling-debris-threat/ (Accessed: 04 November 2024).

activities[6]. As the number of satellites increases, so does the likelihood of collisions[7]. These collisions pose risks not only to valuable assets but also to human safety. Space insurance is crucial in mitigating these risks, ensuring financial protection for satellite operators, entrepreneurs, and investors.

The concept of space insurance emerged alongside the space race of the mid-20th century. In 1965, the very first space insurance policy was issued by Lloyd's of London, specifically designed to cover the Intelsat 1 satellite, also known as the Early Bird. This satellite was the first commercial communications satellite that enable direct communication between North America and Europe. The insurance policy primarily covered physical damage during the pre-launch phase, marking a genesis in the evolution of satellite insurance[8].

As technology advanced and space missions became more complex, the scope of space insurance expanded to cover a broader range of risks, including launch failures[9] and satellite malfunctions[10]. The collaboration between government space agencies and private companies has further driven the development of comprehensive insurance policies tailored to the specific needs of space missions[11].

---

[6]Kennedy, B. (2023) Americans' views of space: U.S. role, NASA priorities and impact of private companies, Pew Research Center. Available at: https://www.pewresearch.org/science/2023/07/20/americans-views-of-space-u-s-role-nasa-priorities-and-impact-of-private-companies/ (Accessed: 04 November 2024).

[7]NASA (2023) Step 2 close approach risk assessment, NASA. Available at: https://www.nasa.gov/cara/step-2-close-approach-risk-assessment/ (Accessed: 04 November 2024).

[8]Sawyer, R. (2024) Space insurance: The promise of in-orbit repair, Lockton. Available at: https://global.lockton.com/gb/en/news-insights/space-insurance-the-promise-of-in-orbit-repair (Accessed: 04 November 2024).

[9]Berenguer, R. (2024) Satellite Insurance – an introductory guide, Insurance Business America. Available at: https://www.insurancebusinessmag.com/us/guides/satellite-insurance--an-introductory-guide-174465.aspx (Accessed: 04 November 2024).

[10]Rainbow, J. (2023) Space insurers brace for more claims after propulsion trouble on four Geo Satellites, SpaceNews. Available at: https://spacenews.com/space-insurers-brace-for-more-claims-after-propulsion-trouble-on-four-geo-satellites/ (Accessed: 04 November 2024).

[11]Enzian, A. (2024) Space and satellite insurance solutions: Munich re, Space and satellite insurance solutions | Munich Re. Available at: https://www.munichre.com/en/solutions/for-industry-clients/space-and-satellite-insurance-solutions.html (Accessed: 04 November 2024).

Currently the space insurance market is characterized by a diverse array of policies designed to address the risks of space activities[12]. These policies cover everything from pre-launch preparations to in-orbit operations and potential collisions with space debris. However, the industry faces significant challenges, such as the high cost of premiums[13], the unpredictability of space missions[14], and the evolving regulatory environment[15]. Insurers must continuously adapt to these challenges to provide effective coverage and maintain the viability of the space insurance market.

Insurance companies, like any other business, aim to make a profit. If the space insurance market becomes unprofitable[16], insurers may decide to exit the market. This could lead to a monopoly, where only a few companies provide space insurance. A monopoly in the space insurance market could result in higher premiums due to the lack of competition[17]. Higher premiums would increase the cost of space activities, making it less attractive for companies to invest in space exploration and satellite technology[18]. This could slow down progress in space exploration and reduce the availability of satellite technology, which is crucial for

---

[12]AXA (2024) Space insurance, Insurance for Space Industry and Telecommunications | AXA XL. Available at: https://axaxl.com/insurance/products/space-insurance (Accessed: 04 November 2024).

[13]Forrester, C. (2024) Space insurance market facing challenges, Advanced Television. Available at: https://advanced-television.com/2024/02/21/space-insurance-market-facing-challenges/ (Accessed: 04 November 2024).

[14]Mukhopadhyay, A. (2024) Space insurance market navigates uncertain terrain in 2024 amid capacity shifts: Gallagher - Reinsurance News, ReinsuranceNe.ws. Available at: https://www.reinsurancene.ws/space-insurance-market-navigates-uncertain-terrain-in-2024-amid-capacity-shifts-gallagher/ (Accessed: 04 November 2024).

[15]Blimline, B. (2024) The evolution and future of Space Insurance, Todays Insurance Professional. Available at: https://blog.internationalinsuranceprofessionals.org/the-evolution-and-future-of-space-insurance/ (Accessed: 04 November 2024).

[16]Todd, D. (2024) Space insurers wither from 'Worst Year' in over twenty years as claims get close to US$1 billion (updated and corrected), Seradata. Available at: https://www.seradata.com/space-insurers-wither-from-worst-year-ever-as-claims-get-close-to-us1-billion/ (Accessed: 04 November 2024).

[17]Gatti, E. (2022) #SPACEWATCHGL opinion: A review of the Space Insurance Market, SpaceWatch.GLOBAL. Available at: https://spacewatch.global/2022/09/spacewatchgl-opinion-a-review-of-the-space-insurance-market/ (Accessed: 04 November 2024).

[18]Spencer, E. (2024) Launch plus 1 satellite insurance - managing the risk of an expensive firework display, Taylor Wessing. Available at: https://www.taylorwessing.com/en/interface/2024/the-space-race/launch-plus-1-satellite-insurance (Accessed: 04 November 2024).

various applications on Earth, such as communication, navigation, and weather forecasting[19].

To prevent a monopoly and ensure a healthy space insurance market, it is essential to encourage competition among insurers. One way to do this is by providing incentives for new insurers to enter the market. Governments and regulatory bodies can play a crucial role in this by offering subsidies or tax breaks to new entrants. Additionally, creating a transparent and fair regulatory framework can help level the playing field[20] and make it easier for new companies to compete with established insurers. This would help keep premiums at a reasonable level and ensure that space activities remain financially viable.

Another important aspect of maintaining a healthy space insurance market is risk management[21]. Insurers need to have a thorough understanding of the risks associated with space activities and develop comprehensive risk assessment models[22]. This can be achieved through collaboration with space agencies, satellite operators, and other stakeholders in the space industry. By sharing data and expertise, insurers can better assess the risks and develop more accurate pricing models. This would help reduce the uncertainty and volatility in the space insurance market, making it more attractive for insurers to participate.

Innovation in insurance products is also crucial for a healthy space insurance market. Insurers should develop tailored insurance products that cater to the specific needs of different space activities. For example, comprehensive insurance products that include pre-

---

[19] Lafaye, M. (2017). Benefit Assessment of the Application of Satellite Earth Observation for Society and Policy: Assessing the Socioeconomic Impacts of the Development of Downstream Space-Based Earth Observation Applications. In: Onoda, M., Young, O. (eds) Satellite Earth Observations and Their Impact on Society and Policy. Springer, Singapore. https://doi.org/10.1007/978-981-10-3713-9_7

[20]Competition & Markets Authority (2020) Regulation and competition report. Available at: https://assets.publishing.service.gov.uk/media/5e184a9940f0b65dbfbc1c4b/Regulation_and_Competition_report_-_web_version.pdf (Accessed: 04 November 2024).

[21]March McLennan (2021) Aviation insurance market overview: Q1 2023, Space Insurance Market: Pricing and Risk Update - Q1 2021. Available at: https://www.marsh.com/us/industries/aviation-space/insights/space-insurance-market-pricing-and-risk-update-2021-q1.html (Accessed: 04 November 2024).

[22]AON (2024) Space Insurance and Risk Management, Aon. Available at: https://www.aon.com/en/capabilities/risk-transfer/space-insurance-and-risk-management (Accessed: 04 November 2024).

launch, launch, and in-orbit operations. This would have different risk profiles and coverage requirements, compared to the conventional separate insurance for each stage of launch. By offering a diverse range of insurance products, insurers can better meet the needs of their clients and attract more customers. This would help increase the overall volume of the space insurance market, making it more profitable for insurers.

Collaboration between insurers and the space industry is essential for the development of innovative insurance products. Insurers should work closely with satellite operators, space agencies, and other stakeholders to understand their needs and develop customized insurance solutions. This can be achieved through regular communication, joint research projects, and industry conferences[23]. By fostering a collaborative environment, insurers can stay up to date with the latest developments in the space industry and develop insurance products that are relevant and valuable to their clients.

International cooperation is crucial for a healthy space insurance market. Space activities are inherently global, and the risks associated with them often transcend national borders[24]. Therefore, it is important for countries to work together to develop a harmonized regulatory framework for space insurance. This can be achieved through international treaties and agreements that set common standards for space insurance[25]. By working together, countries can create a stable and predictable environment for insurers, which would help attract more companies to the space insurance market and ensure its long-term sustainability[26].

---

[23]SmartSat CRC (2024) SmartSat CRC and NZ Government announce four new joint research projects under Australia-NZ collaborative space program, Scoop. Available at: https://www.scoop.co.nz/stories/SC2407/S00051/smartsat-crc-and-nz-government-announce-four-new-joint-research-projects-under-australia-nz-collaborative-space-program.htm (Accessed: 04 November 2024).

[24]World Economic Forum (2022) Global risks report 2022, Crowding and Competition in Space. Available at: https://www.weforum.org/publications/global-risks-report-2022/in-full/chapter-5-crowding-and-competition-in-space/ (Accessed: 04 November 2024).

[25]UNOOSA (2024) United Nations Office for Outer Space Affairs, Space Law Treaties and Principles. Available at: https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties.html (Accessed: 04 November 2024).

[26]COPUOS (2024) United Nations Office for Outer Space Affairs, COPUOS 2024. Available at: https://www.unoosa.org/oosa/en/ourwork/copuos/2024/index.html (Accessed: 04 November 2024).

The increasing involvement of private companies in space exploration has introduced new dynamics to the space insurance industry. Companies like SpaceX, Blue Origin, and Virgin Galactic are pushing the boundaries of space travel, necessitating innovative insurance solutions to manage the associated risks. These private entities often collaborate with traditional insurers to develop customized policies that address the unique aspects of their missions[27]. This collaboration fosters innovation and ensures that the insurance industry can keep pace with the rapid advancements in space technology.

Looking ahead, the space insurance industry is poised for significant transformation. The commercialization of space activities, including space tourism and asteroid mining, will create new opportunities and challenges for insurers. Emerging technologies, such as reusable rockets and advanced satellite systems, will also influence the development of insurance policies. Additionally, the increasing focus on sustainability and space debris mitigation will shape the future of space insurance, as insurers seek to balance risk management with the promotion of responsible space practices.

Space insurance plays a vital role in supporting the growth and sustainability of the space industry. By providing financial protection against the inherent risks of space activities, insurance enables both government agencies and private companies to pursue ambitious missions with greater confidence. As the space industry continues to evolve, the space insurance market must adapt to new challenges and opportunities, ensuring that it remains a cornerstone of the final frontier.

[27]Araullo, K. (2024) Applied underwriters expands into Space Insurance Market, Insurance Business America. Available at: https://www.insurancebusinessmag.com/us/news/breaking-news/applied-underwriters-expands-into-space-insurance-market-510368.aspx (Accessed: 04 November 2024).

II. Problems with Space

Space congestion is becoming an increasingly critical issue as the number of satellites in Earth's orbit continues to grow. As of 2023, there are over 12,500 spacecraft in orbit, including around 3,300 inactive satellites[28], with thousands more planned for launch in the coming years. This rapid increase is driven by the demand for global internet coverage, Earth observation, and other satellite-based services. However, this growth also leads to a crowded orbital environment, making it more challenging to manage and track all objects in space. In 2023, the space insurance industry incurred nearly one billion USD of losses paid out, while only collecting around 550 million USD in premiums[29].

One of the most significant concerns related to space congestion is the Kessler Syndrome. Proposed by NASA scientist Donald Kessler in 1978, this theory suggests that collisions between objects in space could create a cascade effect, where each collision generates more debris, leading to further collisions[30]. This self-sustaining chain reaction could eventually render certain orbits unusable, posing a severe threat to both current and future space missions.

In-orbit collisions are a major risk associated with space congestion. Even small fragments of debris can cause significant damage to satellites and spacecraft due to their high velocities. For instance, a collision with a piece of debris as small as 1 cm can generate enough force to disable a satellite[31]. The increasing number of satellites and debris in orbit raises the

---

[28]Morris, S. (2024) State of satellite deployments & Orbital Operations – 2023 report, Slingshot Aerospace. Available at: https://www.slingshot.space/news/state-of-satellite-deployments-and-orbital-operations-2023 (Accessed: 04 November 2024).

[29] *id.*

[30] Thompson, A. (2021) The Kessler syndrome, National Space Centre. Available at: https://www.spacecentre.co.uk/news/space-now-blog/the-kessler-syndrome/ (Accessed: 04 November 2024).

[31]ESA (2024) Hypervelocity impacts and protecting spacecraft, ESA. Available at: https://www.esa.int/Space_Safety/Space_Debris/Hypervelocity_impacts_and_protecting_spacecraft (Accessed: 04 November 2024).

likelihood of such collisions, which can disrupt satellite operations and lead to the loss of valuable assets.

Orbital interference is another critical issue. With more satellites occupying the same or similar orbits, the risk of signal interference increases. This can affect the performance of communication, navigation, and Earth observation satellites, leading to degraded service quality and potential mission failures[32]. Additionally, the presence of numerous satellites in close proximity can complicate the coordination and management of space traffic, increasing the risk of accidental collisions.

The sheer number of satellites in orbit today is staggering. These objects range in size from small CubeSats to large communication satellites, all contributing to the congestion of Earth's orbital space. The proliferation of mega-constellations, such as SpaceX's Starlink and OneWeb, further exacerbates this issue, with plans to deploy tens of thousands of satellites in the near future. For example, SpaceX's Starlink plans to launch 42,000 satellites, with 12,000 satellites already approved[33], and around 6,400 operational satellites as of October 2024[34].

The congestion of space poses significant risks to space activities and exploration. The Kessler Syndrome highlights the potential for a catastrophic chain reaction of collisions, while in-orbit collisions and orbital interference threaten the safety and functionality of satellites. Managing the growing number of satellites and debris in orbit is crucial to ensuring the sustainability of space operations and the continued exploration of space.

---

[32]ITU (2020) HARMFUL INTERFERENCE TO SATELLITE SYSTEMS, World Radiocommunication Seminar 2020. Available at: https://www.itu.int/dms_pub/itu-r/md/19/wrs20/c/R19-WRS20-C-0013!!PDF-E.pdf (Accessed: 04 November 2024).

[33]Henry, C. (2023) SpaceX submits paperwork for 30,000 more Starlink Satellites, SpaceNews. Available at: https://spacenews.com/spacex-submits-paperwork-for-30000-more-starlink-satellites/ (Accessed: 04 November 2024).

[34]McDowell, J. (2024) Jonathan's space pages, Jonathan's Space Report | Space Statistics. Available at: https://planet4589.org/space/con/star/stats.html (Accessed: 04 November 2024).

III. Importance of Space Insurance

Exploring and using space also come with challenges, ranging from technical, environmental, legal, and financial challenges. One of the most pressing issues is the space debris problem, which poses significant risks to both manned and unmanned space missions. Space debris includes defunct satellites, spent rocket stages, and fragments from disintegration, erosion, and collisions[35]. These objects travel at high velocities, making even small pieces capable of causing catastrophic damage to another spacecraft[36]. The increasing number of satellites, especially with the trend of deploying mega-constellation satellites, adds to this problem, leading to an even higher probability of collisions and the creation of more debris[37].

Given these risks, the importance of space insurance cannot be understated. Space insurance provides financial protection against the loss or damage of spacecraft due to collisions, launch failures, and other perils. This type of insurance is crucial for satellite operators, space agencies, and private companies investing in space technologies. It helps mitigate the financial impact of potential accidents, ensuring that space missions can continue despite setbacks. Without adequate insurance, the financial burden of a single incident could be devastating, potentially halting other space missions.

---

[35]ASA (2007) GUIDE TO SPACE DEBRIS, ASA Guide to Space Debris. Available at: https://www.spaceacademy.net.au/watch/debris/debris.htm (Accessed: 04 November 2024).

[36] ESA (2021) *The impact of Space Debris*, *ESA*. Available at: https://www.esa.int/ESA_Multimedia/Images/2021/03/The_impact_of_space_debris (Accessed: 06 November 2024).

[37]Arroyo-Parejo, C., Sanchez-Ortiz, N. and Dominguez-Gonzalez, R. (2021) Effect of Mega-constellations on Collision Risk in Space, ESOC Conference Proceedings. Available at: https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/246/SDC8-paper246.pdf (Accessed: 04 November 2024).

Liability in space is another critical aspect that needs careful management. Under the international space law, particularly the Outer Space Treaty[38] and the Liability Convention[39], countries are liable for damages caused by their space objects. This includes damage to other countries' space objects and to people and property on Earth. The complexity of determining liability in space collisions, especially with the involvement of multiple private entities and international stakeholders, necessitates clear regulations and robust insurance mechanisms.

Space insurance policies typically cover various phases of a satellite's lifecycle, including pre-launch, launch, and in-orbit operations. These policies are designed to address the unique risks associated with each phase. For instance, the launch phase is particularly risky due to the possibility of launch vehicle failure[40]. In-orbit insurance covers risks such as collisions with space debris and operational failures. By providing comprehensive coverage, space insurance ensures that satellite operators can recover from losses and continue their operations[41].

The role of space insurance extends beyond financial protection. It also incentivizes better risk management practices among satellite operators[42]. Insurers often require operators to adhere to certain standards and practices to minimize risks. This includes implementing

[38] United Nations. (1967). Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies. New York: United Nations.

[39] United Nations. (1972). Convention on International Liability for Damage Caused by Space Objects. New York: United Nations.

[40]New Space Economy (2024) Overview of risks associated with Space Activities, New Space Economy. Available at: https://newspaceeconomy.ca/2024/01/08/overview-of-risks-associated-with-space-activities/ (Accessed: 04 November 2024).

[41]AON (2024) Space Insurance and Risk Management, Aon. Available at: https://www.aon.com/en/capabilities/risk-transfer/space-insurance-and-risk-management (Accessed: 04 November 2024).

[42]Mousinho, I. and Mifsud, G. (2024) Space insurance – the key to a sustainable space environment?, Clyde & Co. Available at: https://www.clydeco.com/en/insights/2024/01/space-insurance-the-key-to-a-sustainable-space-env (Accessed: 04 November 2024).

collision avoidance measures[43], maintaining up-to-date tracking of space objects[44], and following best practices for satellite design and operation[45]. By promoting these practices, space insurance contributes to the overall safety and sustainability of space activities.

In conclusion, as the space environment becomes increasingly congested, the importance of space insurance and liability management grows. These mechanisms not only provide financial protection but also promote responsible behavior among space actors. Effective management of collision risks through insurance and liability frameworks is essential for the continued growth and sustainability of space activities. By addressing these challenges, we can ensure that space remains a viable and safe domain for exploration and utilization.

IV. Research Objectives

1. Analyze Legal Frameworks: Investigate the existing legal frameworks governing space insurance and liability related to in-orbit collisions. This includes examining international treaties, national laws, and industry standards.
2. Evaluate Insurance Mechanisms: Assess the effectiveness of space insurance mechanisms in mitigating risks associated with in-orbit collisions. Understand the role of insurance companies, premiums, and coverage terms.

[43]UK CAA (2024) Launch Collision Avoidance Analysis (LCOLA), Civil Aviation Authority. Available at: https://www.caa.co.uk/space/guidance-and-resources/launch-collision-avoidance-analysis-lcola/ (Accessed: 04 November 2024).

[44]ESA (2020) Space surveillance and tracking - SST segment, Space Safety. Available at: https://www.esa.int/Space_Safety/Space_Surveillance_and_Tracking_-_SST_Segment (Accessed: 04 November 2024).

[45]OneWeb (2022) Satellite Orbital Safety Best Practices, SATELLITE ORBITAL SAFETY BEST PRACTICES. Available at: https://assets.oneweb.net/s3fs-public/2022-09/Satellite Orbital Safety Best Practices.pdf (Accessed: 04 November 2024).

3. Assess Industry Trends: Study trends in the space insurance market. Analyze historical data on collision incidents, insurance claims, and payouts. Identify industry customs related to space sustainability, collision avoidance, and satellite deorbiting.

4. Contribute to Space Sustainability: Highlight how this thesis contributes to the long-term sustainability of space activities. Emphasize balancing commercial interests with safety and environmental concerns while abiding by international laws. Develop recommendations for policy and regulatory changes that could foster a healthier space insurance market by incentivizing risk reduction.

V. Research Questions

1. What are the key international treaties, national laws, and industry standards that govern space insurance and liability for in-orbit collisions? How do these legal frameworks address the complexities of space activities and ensure accountability?

2. How effective are current space insurance mechanisms in mitigating the risks associated with in-orbit collisions? What are the roles of insurance companies, premiums, and coverage terms in managing these risks?

3. What are the current trends in the space insurance market regarding collision incidents, insurance claims, and payouts? How do industry customs related to space sustainability, collision avoidance, and satellite deorbiting influence these trends?

4. How can policy and regulatory changes foster a healthier space insurance market while promoting long-term sustainability of space activities? What recommendations can be made to balance commercial interests with safety and environmental concerns in compliance with international laws?

II

Legal Frameworks on Space Insurance

I. Overview of Space Law

Space law, a specialized field of international law, governs activities in outer space. Its origins trace back to the early 20th century, with significant developments occurring during the Cold War era[46]. The launch of Sputnik 1 by the Soviet Union in 1957 marked a pivotal moment, prompting the United States and other nations to recognize the need for a legal framework to manage space activities[47]. This led to the creation of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) in 1959, which played a crucial role in developing space treaties to ensure the peaceful exploration and use of outer space[48].

The Outer Space Treaty, formally known as the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, was adopted in 1967. This treaty is often considered the cornerstone of international space law[49]. It establishes that outer space, including the Moon and other celestial bodies, is

[46] The Impact of the Cold War on the Formation and Development of International Space Law. (2022). Miscellanea Historico-Iuridica, 21(2), 317-333.

[47]USDS (2009) The launch of Sputnik, 1957, Archive. Available at: https://2001-2009.state.gov/r/pa/ho/time/lw/103729.htm (Accessed: 04 November 2024).

[48]COPUOS (2024) United Nations Office for Outer Space Affairs, 2024 Session. Available at: https://www.unoosa.org/oosa/en/ourwork/copuos/index.html (Accessed: 04 November 2024).

[49]Britannica (2024) Outer Space Treaty, Encyclopædia Britannica. Available at: https://www.britannica.com/event/Outer-Space-Treaty (Accessed: 04 November 2024).

free for exploration and use by all countries and is not subject to national appropriation. This principle ensures that space remains a global common, accessible to all[50].

The Liability Convention, formally known as the Convention on International Liability for Damage Caused by Space Objects, was adopted in 1972 to elaborate on the liability provisions of the Outer Space Treaty. This convention establishes that a launching state is absolutely liable for damage caused by its space objects on the surface of the Earth or to aircraft in flight[51]. In space, liability is based on fault. This distinction ensures that states are held accountable for their space activities and provides a mechanism for compensation in case of damage[52].

Article II of the Liability Convention is particularly significant as it stipulates that a launching state is absolutely liable to pay compensation for damage caused by its space objects on the surface of the Earth or to aircraft in flight. This absolute liability means that the launching state must compensate for any damage, regardless of fault. Article 3 extends this liability to damage caused in outer space, but in this case, liability is based on fault, requiring proof that the damage was due to the fault of the launching state.

---

[50] Outer Space Treaty. Article I. "The exploration and use of outer space, including the moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind" (Outer Space Treaty, January 27, 1967)

[51] Liability Convention. (1972). Convention on International Liability for Damage Caused by Space Objects. Vienna: Austria. Articles 2 & 3:

- Article 2: A launching state shall be absolutely liable to pay compensation for damage caused by its space object on the surface of the earth or to aircraft in flight.

- Article 3: In the event of damage being caused elsewhere than on the surface of the earth to a space object of one launching state or to persons or property on board such a space object by a space object of another launching state, the latter shall be liable only if the damage is due to its fault or the fault of persons for whom it is responsible.

[52] States are bound to these treaties by Article 26 of the Vienna Convention on the Law of Treaties (VCLT) which reads: Every treaty in force is binding upon the parties to it and must be performed by them in good faith.

In recent years, the increasing number of space activities and the involvement of private entities have raised concerns about compliance with these treaties[53]. While most states adhere to the principles of the Outer Space Treaty and the Liability Convention, challenges remain. Issues such as the space debris problem, risk of collisions in space, and the potential for conflicts in space especially with private actors[54] require ongoing international cooperation and the development of new regulations to address emerging risks.

The current situation regarding states' compliance with space treaties is generally positive, with most countries recognizing the importance of adhering to international space law[55]. However, the rapid growth of the commercial space sector and the advent of new technologies necessitate continuous updates to the legal framework. The United Nations Office for Outer Space Affairs (UNOOSA) and COPUOS continue to play vital roles in facilitating dialogue and cooperation among nations to ensure the sustainable and peaceful use of outer space.

II. Article 6 OST and Space Insurance

The rapid advancement of space technology has led to an increase in both governmental and private space activities[56]. This necessitates a robust legal and insurance framework to manage the associated risks and liabilities. Article 6 of the Outer Space Treaty (OST) plays a

---

[53]Alhamed, M. et al. (2022) Loopholes and lacunae in International Space Law, OxJournal. Available at: https://www.oxjournal.org/loopholes-lacunae-space-law/ (Accessed: 04 November 2024).

[54]Erhart, L. (2023) Private parties in Space Law, Space Arbitration Association. Available at: https://space-arbitration.com/private-parties-in-space-law/ (Accessed: 04 November 2024).

[55]Boccardo, G. (2018) Planetary protection obligations of states pursuant to the space treaties and with special emphasis on National Legislations provisions, GlobaLex | Foreign and International Law Research. Available at: https://www.nyulawglobal.org/globalex/planetary_protection_obligations_states1.html (Accessed: 04 November 2024).

[56]World Economic Forum (2024) Space is booming. here's how to embrace the $1.8 trillion opportunity, World Economic Forum. Available at: https://www.weforum.org/stories/2024/04/space-economy-technology-invest-rocket-opportunity/ (Accessed: 04 November 2024).

pivotal role in this context, establishing the international responsibility of states for national space activities. Article 6 of the OST influences space insurance policies and the respective risk management strategies.

Article 6 of the OST mandates that states bear international responsibility for national space activities, whether conducted by governmental or non-governmental entities. This provision requires states to authorize and continuously supervise space activities to ensure compliance with the treaty. The responsibility extends to any damage caused by space objects, making states liable for space activities carried out under their jurisdiction. This framework aims to promote safe and responsible exploration and use of outer space, ensuring that space activities do not harm other states or the space environment[57].

The international responsibility outlined in Article 6 directly impacts the space insurance market. States must ensure that non-governmental entities comply with the treaty's provisions. A way that states make sure that private companies adheres with Article 6 includes obtaining adequate insurance coverage for space activities. Obtaining an insurance is part of a responsible behavior, and states through their national laws requires private companies to obtain space insurance. This requirement drives the demand for comprehensive insurance policies that cover potential liabilities arising from space missions. Insurers, in turn, assess the risks associated with each mission, considering factors such as the reliability of launch vehicles, the operational history of satellites, and the regulatory environment[58].

Effective risk management is essential for both states and private entities engaged in space activities. Article 6's emphasis on state responsibility also obliges states to apply continuous authorization and supervision measures. Space insurance plays a role in this measures by

---

[57]Erhart, L. and Boutovitskai, M. (2021) TRANSFORMING ARTICLE VI OF THE OUTER SPACE TREATY INTO AN EFFECTIVE MECHANISM OF SPACE DEBRIS MITIGATION, ESOC Proceedings. Available at: https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/223/SDC8-paper223.pdf (Accessed: 04 November 2024).

[58]Yap, J. (2023) Is the sky the limit for Space Insurance?, Landers & Rogers. Available at: https://www.landers.com.au/legal-insights-news/failure-in-orbit-planning-your-space-projects-with-space-insurance-in-mind (Accessed: 04 November 2024).

providing financial safeguards against potential damages and losses. Insurers conduct thorough risk assessments (underwriting), evaluating the technical and operational aspects of space missions to determine appropriate coverage levels[59]. This collaboration between states, private entities, and insurers helps to minimize risks and ensure compliance with international obligations.

While space insurance offers significant benefits, it also faces challenges such as the high cost of premiums and the complexity of assessing risks in an evolving space environment. The increasing number of private space ventures and the emergence of new technologies add to the complexity of risk management[60]. However, these challenges also present opportunities for innovation in insurance products and services. Insurers are developing new coverage options tailored to the needs of small satellite operators, commercial spaceflight companies, and other emerging players in the space industry[61].

As space activities continue to expand, the interplay between Article 6 of the OST and space insurance will become increasingly important. States must adapt their regulatory frameworks to address the evolving landscape of space exploration and ensure that non-governmental entities comply with international obligations. The insurance industry will play a crucial role in supporting this transition by offering innovative solutions that address emerging risks and promote sustainable space activities. Collaboration between states, private entities, and insurers will be key to achieving a safe and prosperous future in space.

Article 6 of the Outer Space Treaty establishes a foundational framework for the international responsibility of states in space activities. This framework significantly influences the space insurance market, driving the demand for comprehensive coverage and

---

[59] Katarzyna Malinowska, 'Risk Assessment in Insuring Space Endeavours: A Legal Approach', (2017), 42, Air and Space Law, Issue 3, pp. 329-347, https://kluwerlawonline.com/journalarticle/Air+and+Space+Law/42.3/AILA2017022

[60]Zisk, R. (2022) The Space Insurance Landscape, Payload. Available at: https://payloadspace.com/the-space-insurance-landscape/ (Accessed: 04 November 2024).

[61]Lloyd's (2019) Lloyd's launches New Space Risk Product and new analysis of the Space Sector, Lloyd's. Available at: https://www.lloyds.com/about-lloyds/media-centre/press-releases/lloyds-launches-new-space-risk-product-and-new-analysis-of-the-space-sector (Accessed: 04 November 2024).

effective risk management strategies. As the space sector continues to grow, the connection between legal obligations and insurance will be vital in ensuring the safe and sustainable exploration and use of outer space. By fostering collaboration and innovation, the space community can navigate the challenges and opportunities of this dynamic field.

III. Article 7 OST and Space Insurance

Article 7 of the OST stipulates that a state is internationally liable for damage caused by its space objects, whether the damage occurs on Earth, in airspace, or in outer space. Liability refers to the legal responsibility for one's actions or omissions that result in harm or damage to another party[62]. This means that liability in relation with Article 7 is the legal responsibility for a state's actions or omissions that harms or damages other states. This liability encompasses various obligations, including financial debts and legal accountability for wrongful acts.

This provision ensures that states bear responsibility for their space activities, promoting accountability and encouraging the safe conduct of space missions to all space actors doing space activities within their jurisdictions. The liability extends to both governmental and non-governmental entities, emphasizing the comprehensive nature of this international legal obligation.

The liability framework established by Article 7 necessitates that states and private entities seek insurance solutions to manage potential claims. Space insurance serves as a risk transfer mechanism, allowing stakeholders to mitigate the financial impact of liability

[62]Britannica (2024) Liability, Encyclopædia Britannica. Available at: https://www.britannica.com/dictionary/liability (Accessed: 04 November 2024).

claims[63]. By securing insurance coverage, entities can ensure compliance with international obligations while safeguarding their financial stability.

The importance of liability management through space insurance arises from the potential magnitude of claims that can result from space-related incidents. While first-party damage losses incurred by the owner of the space object is significant, third-party liabilities can be exponentially larger. For instance, if a satellite malfunctions and causes damage to another satellite or infrastructure on Earth, the financial effect to the operator could involve extensive compensation claims from affected parties.

Under Article 7 of the Outer Space Treaty, states are held liable for such damages, necessitating robust insurance coverage to protect against these high-stakes scenarios. Without adequate insurance, states and private operators may face crippling financial and legal liabilities that may threaten their ability to do space activities.

IV. Article 3 of the Liability Convention and Space Insurance

Article 3 of the Liability Convention addresses the liability of states for damage caused by their space objects in outer space. It stipulates that if a space object of one state causes damage to a space object of another state, the state at fault is liable for the damage. This article is significant because it establishes fault-based liability for incidents occurring in outer space, as opposed to the absolute liability for damage caused on Earth stipulated on Article 2.

Under Article 3, liability is determined based on fault. This means that the state responsible for the damage must be proven to have acted negligently or wrongfully. This provision is

[63]AON (2024) Space Insurance and Risk Management, Aon. Available at: https://www.aon.com/en/capabilities/risk-transfer/space-insurance-and-risk-management (Accessed: 04 November 2024).

essential for encouraging states to adopt stringent safety measures and protocols to prevent accidents in space. It also ensures that states are held accountable for their actions, promoting responsible behavior in outer space activities.

The fault-based liability regime established by Article 3 has significant implications for space insurance. Space insurance policies must account for the potential risks and liabilities associated with space activities. Insurers need to evaluate the likelihood of fault and the potential damages that could arise from such incidents. This assessment helps in determining the premiums and coverage limits for space insurance policies.

One of the challenges associated with Article 3 is determining fault in the complex environment of outer space. Space activities involve multiple actors, including states, private companies, and international organizations. Establishing fault requires thorough investigations and technical expertise to analyze the causes of accidents. This complexity can lead to prolonged disputes and challenges in obtaining compensation.

International cooperation is vital for the effective implementation of Article 3. States must collaborate to share information, conduct joint investigations, and establish mechanisms for dispute resolution. The Liability Convention encourages states to work together to ensure prompt and equitable settlement of claims. This cooperation is essential for maintaining the sustainability and safety of outer space activities.

The space insurance industry has evolved significantly since the adoption of the Liability Convention. Insurers have developed specialized policies to cover various aspects of space missions, including launch, in-orbit operations, and re-entry. These policies are designed to mitigate the financial risks associated with space activities and provide coverage for potential liabilities under Article 3.

In most insurance practices, an investigation is typically required to validate claims and determine fault, especially in complex scenarios like in-orbit collisions, where the international law basis is based on fault-based liability. However, there are some insurance policies designed to expedite the claims process with minimal investigation. These are often referred to as “parametric insurance” policies.

Parametric insurance pays out a predetermined amount based on the occurrence of a specific event, rather than the actual loss incurred[64]. For example, in the context of space activities, a parametric policy might pay out if a satellite's orbit deviates by a certain amount, regardless of the cause. This type of insurance can provide quicker payouts because it relies on predefined triggers rather than detailed investigations.

V. Risk transfer on Space Activities

The concept of mandating space agencies to use insurance as a risk transfer mechanism is gaining traction as space exploration becomes increasingly complex and costly. Governments around the world are recognizing the importance of mitigating financial risks associated with space missions. By requiring space agencies to procure insurance, governments can ensure that the financial burden of potential failures or accidents does not fall solely on taxpayers, as states are liable for damages on space activities, even if the space activity is being done by a private company, stipulated under the Outer Space Treaty and the Liability Convention. This approach not only promotes financial responsibility but also encourages the development of a robust space insurance market, which can provide tailored solutions to address the unique risks of space activities.

One of the primary benefits of mandating insurance for space agencies is the transfer of risk from the public sector to private insurers. Space missions, whether they involve satellite launches or manned space flights, are inherently risky and expensive. Insurance policies can cover a wide range of potential issues, from launch failures to in-orbit malfunctions and even third-party liabilities. By transferring these risks to insurance companies, governments can

[64]Svoboda, T. (2024) Demystifying Parametric Insurance Part I: What is It and How Does It Work, Conner Strong & Buckelew. Available at: https://www.torys.com/en/our-latest-thinking/torys-quarterly/q1-2024/parametric-insurance (Accessed: 04 November 2024).

protect their investments in space exploration and ensure that unforeseen events do not derail their space programs.

Moreover, the requirement for space agencies to obtain insurance can drive innovation and improve risk management practices within the space industry. Insurance companies, motivated by the need to minimize their own risks, often conduct thorough risk assessments and require stringent safety measures before providing coverage[65]. This can lead to the adoption of better technologies and practices by space agencies, ultimately enhancing the safety and success rates of space missions. Additionally, the presence of a well-developed space insurance market can attract more private investment into the space sector, as investors gain confidence in the availability of financial protection against potential losses.

Mandating space agencies to use insurance as a risk transfer mechanism is a prudent strategy for governments aiming to safeguard their investments in space exploration. This approach not only shifts financial risks from the public to the private sector but also fosters innovation and improved risk management within the space industry. As space missions continue to push the boundaries of human capability, the role of insurance in mitigating financial risks will become increasingly vital. By embracing this strategy, governments can ensure the sustainable growth and success of their space programs, for the future of space exploration advancements.

VI. Third-party liability and Full Coverage Space Insurance

Third-party liability insurance in space insurance primarily covers damages or injuries caused to third parties due to space activities. This type of insurance is crucial for space missions as it addresses the potential legal and financial liabilities that arise from incidents

[65]Matthewson, A. (2024) A guide to risk assessment in the insurance industry, A Guide to Risk Assessment in the Insurance Industry | InsurTech Digital. Available at: https://insurtechdigital.com/articles/what-is-risk-assessment (Accessed: 04 November 2024).

such as satellite collisions or debris damage[66]. For instance, if a satellite owned by one company collides with another satellite or causes damage to property on Earth, third-party liability insurance pay for the claims associated with such damage. This insurance is essential for compliance with the international space law, which holds nations and their entities liable for damage caused by their space objects.

On the other hand, full coverage space insurance encompasses a broader range of protections, including third-party liability, but also extends to cover the insured party's own assets and operations (first-party liability[67]). This can include coverage for the satellite itself, launch failures, and in-orbit operations. Moreover, there is second party liability, dealing with damages to those individuals with whom one contracts, such as the spacecraft passengers[68]. Full coverage is designed to mitigate the financial risks associated with the entire lifecycle of a space mission, from pre-launch to in-orbit operations and even decommissioning. This type of insurance is particularly important for private companies and government agencies that invest heavily in space technology and infrastructure, ensuring that their investments are protected against a wide array of potential risks.

While third-party liability insurance focuses on covering damage and legal liability to others, full coverage space insurance provides a comprehensive safety net that includes protection for the insured party's own assets and operations. The choice between these types of insurance depends on the specific needs and risk profiles of the space mission. For missions with significant investments in hardware and operations, full coverage offers a more robust protection, whereas third-party liability insurance is essential for meeting legal obligations and protecting against external claims.

---

[66]Ritz, B. (2022) Satellite Liability and insurance: In space, who's insured?, Thompson Coe. Available at: https://www.thompsoncoe.com/resources/publications/splash-and-crash-satellite-liability-and-insurance/ (Accessed: 04 November 2024).

[67] *id.*

[68] Harrington, A.J. (2021) Space insurance and the law: Maximizing Private Activities in Outer Space. Cheltenham: Edward Elgar Publishing.

Here are some examples of countries that mandate insurance for space launches, along with details on whether full coverage insurance is mandatory, only third-party liability insurance is needed, or determined case-by-case[69]:

Country	Third Party Liability Only	Full Coverage	Case-by-case
Australia[70]		v	
Austria[71]			v
Argentina[72]	v		
Belgium[73]			v
Brazil[74]	v		
Canada[75]	v		

[69] Jeanne Suchodolski, An Overview and Comparison of Aviation and Space Insurance, 14 J. Bus. & Tech. L. 469 (2019) Available at: https://digitalcommons.law.umaryland.edu/jbtl/vol14/iss2/4

[70] Australian Space (Launches and Returns) Act of 2018

[71] Austrian Space Act of 2011

[72] National Decree No 995/91 (1991)

[73] Loi du 17 septembre 2005 relative aux activités de lancement, d'opération de vol ou de guidage d'objets spatiaux [Law of 17 September 2005 on the Activities of Launching, Flight Operation or Guidance of Space Objects] of Sept. 17, 2005, MONITEUR BELGE [M.B.] [Official Gazzette of Belgium], Nov. 16, 2005, 48,818.

[74] Brazil's Space Activities Act of 2024

[75] Canadian Space Agency Act

Country	Third Party Liability Only	Full Coverage	Case-by-case
China[76]		v	
Denmark[77]			v
European Union[78]	v		
Finland[79]			v
France[80]	v		
Indonesia[81]		v	
Israel[82]	v		
Italy[83]	v		

[76] Measures for the Administration of Registration Space Objects, PRC Nat'l Def. Sci. & Tech. Indus. Comm. and PRC Ministry of Foreign Affairs, Feb. 8, 2001(China)

[77] The Danish Outer Space Act (English translation), Lov nr. 409 af 11.5.2016 at pt. 6, https://ufm.dk/en/legislation/prevailing-laws-andregulations/outer-space/outer-space-act.pdf

[78] EU Regulation 2021/696

[79] 63/2018 Act on Space Activities at § 8, http://finlex.fi/en/laki/kaannokset/2018/en20180063.pdf

[80] French Space Operations Act of 2008

[81] Indonesian Space Act No. 21/2013

[82] Space Agency Law of 1983

[83] Italian Space Economy Law of 2024

Country	Third Party Liability Only	Full Coverage	Case-by-case
Japan[84]	v		
Kazakhstan[85]			v
Luxembourg[86]	v		
Netherlands[87]		v	
New Zealand[88]			v
Norway[89]			v
Portugal[90]			v

[84] Law Concerning the National Space Development Agency of Japan, Law No. 50 of 1969, art. 24-2 (UNOOSA), http://www.unoosa.org/oosa/en/ourwork/spacelaw/nationalspacelaw/japan/nasda_1969E.html

[85] Law of the Republic of Kazakhstan on Space Activities, 528-IV, http://www.unoosa.org/documents/pdf/spacelaw/national/kazakhstan/528-IV_2012-01-06E.pdf

[86] Law of 20 July 2017 on the Exploration and Use of Space Resources art. 11 (English translation), https://spaceresources.public.lu/content/dam/spaceresources/news/Translation%20Of%20The%20Draft%20Law.pdf

[87] Order by the Minister of Economic Affairs, no. WJZ/15055654 (June 2015) (amending regulations governing license applications to require documentation of a liability insurance policy), http://www.unoosa.org/documents/pdf/spacelaw/national/Netherlands_BZ116174B.pdf.

[88] Outer Space and High-Altitude Activities Act 2017, ss 10(2), 18(2), 26(2), 34(2) (N.Z.), http://www.legislation.govt.nz/act/public/2017/0029/39.0/096be8ed815e3b58.pdf

[89] Norwegian Space Act of 1969

[90] Presidency of the Council of Ministers, Decree Law no. 16/2019 (Jan.22, 2019) at art. 19(3), https://www.ptspace.pt/wp-content/uploads/2019/03/space-law.pdf

Country	Third Party Liability Only	Full Coverage	Case-by-case
Russia[91]	v		
South Africa[92]			v
South Korea[93]		v	
Spain[94]	v		
Sweden[95]			v
Ukraine[96]			v
United Arab Emirates[97]	v		

[91] Federal Law No. 5663-1 on Space Activity

[92] Space Affairs Act 84 of 1993 § 14 (S. Afr.), http://www.unoosa.org/oosa/en/ourwork/spacelaw/nationalspacelaw/south_africa/space_affairs_act_1993E.html

[93] Act on Compensation for Damage Caused by Space Objects, Act. No. 8714, Dec. 21, 2007, amended by Act No. 8852, Feb. 29, 2008, art. 4 (S. Kor.)

[94] Royal Decree 158/2023 on Spanish Space Agency

[95] Lag om Rymdverksamhet [Law on Space Activities] 1982:963 (Swed.), http://www.unoosa.org/oosa/en/ourwork/spacelaw/nationalspace law/index.html

[96] Ordinance of the Supreme Soviet of Ukraine, On Space Activity Law of Ukraine of 15 November 1996 (VVRU, 1997, p. 2), UNITED NATIONS OFFICE FOR OUTER SPACE AFFAIRS (Dec. 20, 1996), http://www.unoosa.org/oosa/en/ourwork/spacelaw/nationalspacelaw/ukraine/ordinance_on_space_activity_1996E.html#sect04

[97] Federal Decree Law No. 46 of 2023

Country	Third Party Liability Only	Full Coverage	Case-by-case
United Kingdom[98]			v
United States of America[99]	v		

[98] Outer Space Act 1986, c. 38 (Eng.), http://www.legislation.gov.uk/ ukpga 1986/38/contents.

[99] 51 U.S.C. § 50914 (a) (1)(A) (2015).

III

Space Insurance Mechanisms

I. Space Insurance Products

Space insurance is a specialized field designed to manage the diverse risks associated with space activities, including satellite operations, space tourism, and interplanetary missions. Satellite launch and operations will be the main focus for the purpose of this thesis. There are multiple types of space insurance, each tailored to cover specific phases and aspects of space missions. These include pre-launch insurance, launch insurance, in-orbit insurance, and third-party liability insurance[100].

The separation of these insurance products allows for more precise risk management and ensures that each phase of a space mission is adequately covered[101]. As stated in the previous chapter, the Liability Convention separates liability for damages on the ground (Article 2) and damages in space (Article 3), and the latter requires fault to be proven. This has an influence on how the space insurance policy is written.

By separating insurance products, insurers can offer more specialized and accurate coverage, addressing the unique risks associated with each stage of a space mission. This segmentation not only helps in managing risks more effectively but also makes space insurance products more affordable and accessible to a broader range of space

[100] Malinowska, K. (2017) Space insurance: International legal aspects. Alphen aan den Rijn: Wolters Kluwer.

[101]Manikowski, P. (2004) The satellite insurance market as a part of the insurance market., THE SATELLITE INSURANCE MARKET AS A PART OF THE INSURANCE MARKET. Available at: https://www.dbc.wroc.pl/Content/15470/Manikowski_The%20Satellite_Insurance_Market_As_A_Part_2004.pdf (Accessed: 04 November 2024).

enterprises[102].

However, there are also practices on combining pre-launch, launch, and in-orbit operations insurance into a single, all-in-one policy that offers several benefits[103]. Firstly, it simplifies the insurance process for space missions by providing comprehensive coverage under one policy, reducing administrative burdens and potential gaps in coverage. This holistic approach ensures that all phases of a space mission are protected, from the preparation and launch to the operational period in orbit. Additionally, it can lead to cost savings for space operators, as bundling these coverages might result in lower premiums compared to purchasing separate policies for each phase. This integrated insurance model also facilitates better risk management and coordination among insurers, leading to more efficient claims processing and resolution.

However, there are also drawbacks to this all-in-one insurance approach. One significant challenge is the complexity of underwriting such comprehensive policies, as insurers must assess and price a wide range of risks associated with different mission phases. This can lead to higher premiums if insurers perceive the combined risks as too high. Moreover, the diverse nature of risks in each phase, such as technical failures during launch versus operational anomalies in orbit, requires specialized expertise, which might be diluted in a bundled policy.

In the event of a claim, disputes may arise over which phase of the mission the loss pertains to, potentially complicating the claims process and delaying settlements. Despite these challenges, the all-in-one insurance model remains an attractive option for many space operators seeking streamlined and comprehensive coverage.

---

[102]Enzian, A. (2024) Space and satellite insurance solutions: Munich re, Space and satellite insurance solutions | Munich Re. Available at: https://www.munichre.com/en/solutions/for-industry-clients/space-and-satellite-insurance-solutions.html (Accessed: 04 November 2024).

[103] AXA (2024) Space insurance, Insurance for Space Industry and Telecommunications | AXA XL. Available at: https://axaxl.com/insurance/products/space-insurance (Accessed: 04 November 2024).

II. Pre-Launch Insurance

Pre-launch insurance is a critical component of space insurance, designed to cover the risks associated with the period before a satellite or spacecraft is launched. This type of insurance provides comprehensive coverage for material damage that might occur during the various stages leading up to the launch[104]. These stages include the transportation of the satellite from the manufacturing facility to the launch site, the integration of the satellite into the launch vehicle, and all the preparatory activities at the launch site.

One of the primary risks covered by pre-launch insurance is the transportation of the satellite. This phase involves moving the satellite from the manufacturer's premises to the launch site, which can be a complex and delicate process. The satellite must be carefully handled to avoid any damage, and the insurance policy typically covers any material damage that might occur during this transit[105].

Once the satellite arrives at the launch site, it undergoes a series of preparations before it can be launched. These preparations include the integration of the satellite into the launch vehicle, which involves attaching the satellite to the rocket that will carry it into space. This phase is also covered by pre-launch insurance, as it involves significant risks of damage.

Pre-launch insurance also covers the final stages of launch preparation, which include various tests and inspections to ensure that the satellite and the launch vehicle are ready for launch. These activities are crucial for the success of the mission, and any damage or issues discovered during this phase can be costly. The insurance policy provides coverage for any material damage that might occur during these final preparations.

---

[104]Global Aerospace (2024) Space and satellite insurance: Global aerospace, Global Aerospace Aviation Insurance. Available at: https://www.global-aero.com/aviation-insurance-coverage/space-satellite-insurance/ (Accessed: 04 November 2024).

[105]Kunstadter, C. (2022) Space Insurance Update , AXA XL. Available at: https://www.nasa.gov/wp-content/uploads/2022/10/04_kunstadter_space_insurance_update_axa_xl_scaf_220111.pdf (Accessed: 04 November 2024).

In addition to covering material damage, pre-launch insurance can also include coverage for delays. Delays in the launch schedule can occur due to various reasons, such as technical issues, weather conditions, or regulatory approvals. These delays can result in additional costs, and pre-launch insurance can provide coverage for some of these expenses[106].

The scope of pre-launch insurance can vary depending on the specific needs of the satellite operator and the terms of the insurance policy. Some policies may offer broader coverage, including protection against a wider range of risks, while others may be more limited. It is essential for satellite operators to work closely with their insurers to ensure that their policy provides adequate coverage for their specific mission.

III. Launch Insurance

Launch insurance is designed to cover the risks associated with the launch phase of a space mission, typically being the riskiest[107]. This type of insurance normally begins where pre-launch insurance ends and extends through the initial operational phase of the satellite or spacecraft[108]. The primary purpose of launch insurance is to protect against the financial

[106]Beinsure (2024) Space & Satellite Insurance: Risk covering from pre-launch to operation in orbit - beinsure, Beinsure Media - Insurance, Reinsurance, InsurTech Insights. Available at: https://beinsure.com/space-satellite-insurance-risk-covering-from-pre-launch-to-operation-in-orbit/ (Accessed: 04 November 2024).

[107] Sawik, Bartosz. 2023. "Space Mission Risk, Sustainability and Supply Chain: Review, Multi-Objective Optimization Model and Practical Approach" Sustainability 15, no. 14: 11002. https://doi.org/10.3390/su151411002

[108]Luzadder, M. and Argetsinger, C. (2021) Privilege and the tripartite insurer-insured-counsel relationship, Insurance Laws and Products - Insurance - United States. Available at: https://www.mondaq.com/unitedstates/insurance-laws-and-products/1139612/privilege-and-the-tripartite-insurer-insured-counsel-relationship (Accessed: 04 November 2024).

losses that could result from a failed launch or a launch vehicle's inability to place the satellite in the correct orbit[109].

One of the key aspects of launch insurance is its coverage for complete launch failures. This means that if the launch vehicle fails to reach the intended orbit or if the satellite is destroyed during the launch, the insurance policy will compensate the insured party for their losses. This coverage is crucial for satellite operators and manufacturers, as the costs associated with building and launching a satellite can be astronomical[110].

In addition to covering complete launch failures, launch insurance also provides protection against partial failures. For instance, if the launch vehicle places the satellite in an incorrect orbit, the insurance policy may cover the costs associated with correcting the satellite's position. This can include expenses for additional fuel, maneuvers, or even launching a replacement satellite if necessary[111].

Launch insurance policies are typically tailored to the specific needs of the mission and the satellite operator. Factors such as the type of launch vehicle, the satellite's value, and the mission's objectives all play a role in determining the coverage and premiums[112]. Insurers work closely with satellite operators and launch service providers to assess the risks and develop customized insurance solutions.

The underwriting process for launch insurance involves a thorough evaluation of the technical and operational aspects of the mission. Insurers consider factors such as the

---

[109]FAA (2002) Commercial Space and Launch Insurance: Current Market and Future Outlook, Fourth Quarter 2002 Quarterly Launch Report . Available at: https://www.faa.gov/about/office_org/headquarters_offices/ast/media/q42002.pdf (Accessed: 04 November 2024).

[110] Gould, Allen J.; Linden, Orin M. (2000). "Estimating Satellite Insurance Liabilities". Casualty Actuarial Society.

[111] Mott, William H.; Sheldon, Robert B. (2000). Laser Satellite Communication: The Third Generation. Praeger. p. 142. ISBN 1-56720-329-9.

[112]FAA (2001) Selecting a Launch Vehicle: What Factors Do Commercial Satellite Customers Consider?, SECOND QUARTER 2001 QUARTERLY REPORT TOPIC. Available at: https://www.faa.gov/about/office_org/headquarters_offices/ast/media/q22001.pdf (Accessed: 04 November 2024).

reliability of the launch vehicle, the track record of the launch service provider, and the satellite's design and manufacturing quality[113]. This detailed assessment helps insurers determine the likelihood of a successful launch and set appropriate premiums.

Launch insurance is not only important for satellite operators but also for financial institutions and investors. Many satellite projects are financed through loans or investments, and lenders often require launch insurance as a condition for providing funding[114]. This ensures that their financial interests are protected in the event of a launch failure.

IV. In-Orbit Insurance

In-orbit insurance is a crucial aspect of space insurance, providing coverage for satellites and other space assets once they have been successfully launched and are operational in space. In-orbit insurance covers the risks associated with the operational phase of a satellite or space asset. This includes protection against technical failures, space debris impacts, and other unforeseen events that could impair the satellite's functionality[115]. The coverage typically begins after the satellite has completed its initial testing and is fully operational.

In-orbit insurance policies can vary widely but generally include coverage for total loss, partial loss, and degradation of performance. Total loss refers to the complete failure of the satellite, while partial loss might cover specific components or functionalities that fail.

---

[113]Aerospace (2019) Launch mission success: The Aerospace Corporation, Aerospace Corporation. Available at: https://aerospace.org/getting-it-right/jun-2019/launch-mission-success (Accessed: 04 November 2024).

[114]Export-Import Bank of the United States (2013) Ex-Im Bank Approves $105.4 Million Loan to Finance SpaceX Launch, EXIM. Available at: https://www.exim.gov/news/ex-im-bank-approves-1054-million-loan-finance-spacex-launch (Accessed: 04 November 2024).

[115]Enzian, A. (2024) Space and satellite insurance solutions: Munich re, Space and satellite insurance solutions | Munich Re. Available at: https://www.munichre.com/en/solutions/for-industry-clients/space-and-satellite-insurance-solutions.html (Accessed: 04 November 2024).

Degradation of performance covers scenarios where the satellite's performance is reduced but not entirely lost[116].

One of the primary risks covered by in-orbit insurance is technical failure. Satellites are complex machines with numerous subsystems that must function correctly for the satellite to perform its intended mission. If there is a technical problem that can't be solved remotely, then usually it will be a total loss claim, as current technology and economics don't support in-orbit servicing[117].

Another significant risk is the potential for collisions with space debris[118]. The increasing amount of debris in Earth's orbit poses a growing threat to operational satellites. In-orbit insurance can provide financial protection against damage caused by such collisions, helping satellite operators manage the financial impact of these incidents caused with the loss of said satellite[119].

The partial loss situation is where a satellite suffers damage or impairment that affects its performance but does not render it completely inoperable. Partial loss occurs when the satellite's functionality is reduced, but it can still operate to some extent. This could be due to technical faults, human error, or environmental factors in space. The insurance policy will cover the loss to the degree of capacity or lifetime lost by the satellite (indemnification)[120].

---

[116] *id.*

[117]Yap, J. and Tan, M. (2023) Is the sky the limit for Space Insurance?, Lander & Rogers. Available at: https://www.landers.com.au/legal-insights-news/failure-in-orbit-planning-your-space-projects-with-space-insurance-in-mind (Accessed: 04 November 2024).

[118]ESA (2024) About space debris, ESA. Available at: https://www.esa.int/Space_Safety/Space_Debris/About_space_debris (Accessed: 04 November 2024).

[119]Worthy, M. (2024) Your chance of getting hit by space junk is extremely low... but not zero!, Cranfill Sumner LLP. Available at: https://www.cshlaw.com/resources/the-current-universe-of-space-insurance/#_ftn14 (Accessed: 04 November 2024).

[120]Ritz, B. (2022) Satellite Liability and insurance: In space, who's insured?, Thompson Coe. Available at: https://www.thompsoncoe.com/resources/publications/splash-and-crash-satellite-liability-and-insurance/ (Accessed: 04 November 2024).

This means the insurer will compensate for the reduced performance or shortened operational life.

However, the insured party must provide evidence of the loss and demonstrate how the satellite's performance has been affected. If a satellite's communication capabilities are partially impaired due to a collision with space debris, but it can still transmit data, this would be considered a partial loss.

The scope of in-orbit insurance can vary depending on the specific needs of the satellite operator. Some policies may cover only partial losses, while others provide comprehensive coverage for total failures. Additionally, in-orbit insurance can include coverage for loss of revenue due to service interruptions, which is particularly important for commercial satellite operators who rely on continuous service to generate income.

In-orbit insurance is not only beneficial for satellite operators but also for manufacturers and investors. Manufacturers can secure coverage for potential liabilities arising from satellite malfunctions, while investors can mitigate financial risks associated with satellite operations. This comprehensive risk management approach helps foster confidence in the space industry and encourages further investment and innovation.

These policies are usually renewed on an annual basis, subject to the satellite's health evaluation by insurers[121]. The life expectancy of a satellite is typically around 10-15 years[122], and in-orbit insurance can be renewed each year to cover the entire operational lifespan. Premiums are determined by various factors, including the satellite's age, health, and operational history. Insurers conduct thorough evaluations of the satellite's condition to assess the risk and set appropriate premiums[123]. This ongoing assessment helps ensure that

---

[121]Rainbow, J. (2023) Connecting the dots: Double whammy for space insurance, SpaceNews. Available at: https://spacenews.com/connecting-the-dots-double-whammy-for-space-insurance/ (Accessed: 04 November 2024).

[122]Werner, D. (2023) How long should a satellite last: Five years, ten years, 15, 30?, SpaceNews. Available at: https://spacenews.com/how-long-should-a-satellite-last/ (Accessed: 04 November 2024).

[123]Spencer, E. (2024) Launch plus 1 satellite insurance - managing the risk of an expensive firework display, Taylor Wessing. Available at: https://www.taylorwessing.com/en/interface/2024/the-space-race/launch-plus-1-satellite-insurance (Accessed: 04 November 2024).

the coverage remains relevant and adequate throughout the satellite's operational life. In the event of a claim, the insured must provide detailed information about the failure or damage. Insurers may require telemetry data, failure analysis reports, and other documentation to assess the claim[124]. The process can be complex, given the technical nature of satellite operations. Insurance covering for the insured's own spacecraft against physical loss or damages during pre-launch, launch, and in-orbit operations is categorized as first-party insurance.

V. Third-Party Liability Insurance

Third-party liability insurance for space activities is a crucial component of the broader space insurance landscape. This type of insurance provides coverage for legal liabilities arising from damage to third parties during the launch or in-orbit operations of a spacecraft. Given the high-risk nature of space missions, this insurance is essential to mitigate financial risks associated with potential accidents or malfunctions that could impact other entities or individuals[125].

One of the primary reasons for third-party liability insurance in space is the potential for catastrophic events. These can include launch vehicle failures, collisions with other satellites, or debris falling back to Earth. Such incidents can cause significant damage to property or

[124] Bahareh Afshinpour, Roland Groz, Massih-Reza Amini. Telemetry-based Software Failure Prediction by Concept-space Model Creation. 2022 IEEE 22nd International Conference on Software Quality, Reliability and Security, Dec 2022, Guangzhou, China. pp.199, 10.1109/QRS57517.2022.00030. hal 03964083

[125] Manikowski, Piotr, "The Columbia Space Shuttle Tragedy: Third-Party Liability Implication for the Insurance of Space Losses" (2005) 8:1 Risk Management and Insurance Review 141.

even result in bodily injury. The insurance covers the costs that the insured party would be legally obligated to pay to third parties affected by these events[126].

The scope of third-party liability insurance typically includes coverage for both ground and in-orbit operations. This means that any damage caused during the preparation and launch phases, as well as during the satellite's operational life in space, is covered. This comprehensive coverage is vital because the risks are not confined to the launch alone; satellites can collide with other objects or malfunction at any point during their mission.

In addition to covering physical damage and bodily injury, third-party liability insurance also addresses the legal and regulatory aspects of space activities. International treaties, such as the Outer Space Treaty and the Liability Convention, impose liability on launching states for damage caused by their space objects. This means that countries and companies involved in space activities must have adequate insurance to comply with these international obligations. Third-party liability insurance is often mandated by national regulations, explained in Chapter 2, through "risk transfer" by the country that is held liable by international law, to private insurance companies. This varies depending on the country, but most countries mandate the bare minimum of third-party liability insurance.

Real-world examples highlight the importance of third-party liability insurance. For instance, the collision between the Iridium 33 and Cosmos 2251 satellites in 2009[127] underscored the need for robust insurance mechanisms. Such incidents can result in significant financial liabilities, and having adequate insurance coverage helps manage these risks effectively.

[126] UK Space Agency, (2018) Fact Sheet: Third-Party Liability Insurance for In-Orbit Activities.
[127] NASA (2009) *The collision of Iridium 33 and cosmos 2251: The shape of things to come* , *NASA Technical Reports Server*. Available at: https://ntrs.nasa.gov/citations/20100002023 (Accessed: 06 November 2024).

VI. Reinsurance

Given the high costs and potential for catastrophic losses, reinsurance allows primary insurers to spread these risks across multiple entities, ensuring that no single insurer bears the entire large amount of claim. This risk-sharing is essential in a field where the stakes are incredibly high, and the potential for loss is significant[128].

The importance of reinsurance in space insurance cannot be overstated. Space missions involve complex technologies and are subject to numerous unpredictable factors, such as technical failures, collisions with space debris, and adverse space weather conditions. By distributing the risk among several insurers, reinsurance provides a safety net that enhances the stability and resilience of the space insurance market. This, in turn, encourages more insurers to participate in the market, increasing the overall capacity and availability of space insurance coverage.

One of the primary reasons reinsurance is crucial in space insurance is the sheer scale of potential losses. The cost of manufacturing, launching, and operating a satellite can run into hundreds of millions of dollars[129]. In the event of a failure, the financial impact can be devastating. Reinsurance mitigates this risk by ensuring that the financial burden is shared, making it more feasible for insurers to offer coverage for such high-value assets. This risk-sharing mechanism is vital for maintaining the financial health of insurers and ensuring they can meet their obligations in the event of a claim.

Insurance companies typically resort to reinsurance during the launch phase of a satellite's lifecycle. The launch phase is considered the most perilous, with a higher probability of failure compared to other stages. The risks during this phase include launch vehicle

---

[128]Banton, C. (2021) Reinsurance explained: What it is, how it works, types, Investopedia. Available at: https://www.investopedia.com/ask/answers/08/reinsurance.asp (Accessed: 04 November 2024).

[129]Urban, R. (2024) How much does it cost to launch a Rocket? [by type & size], Space Impulse. Available at: https://spaceimpulse.com/2023/08/16/how-much-does-it-cost-to-launch-a-rocket/ (Accessed: 04 November 2024).

malfunctions, explosions, and failures to reach the intended orbit. Given the high stakes, insurers often seek reinsurance to protect themselves from the significant financial exposure associated with a launch failure. This practice ensures that even if a catastrophic event occurs, the financial impact on any single insurer is limited[130].

In addition to the launch phase, reinsurance is also used for in-orbit coverage. Once a satellite is in orbit, it faces ongoing risks such as collisions with space debris, technical malfunctions, and degradation of components over time. Reinsurance helps manage these risks by providing additional layers of financial protection. This is particularly important for satellites that are part of large constellations, where the failure of one satellite can have cascading effects on the entire network[131].

Reinsurance also plays a role in third-party liability coverage, which protects against claims arising from damage caused by a satellite to other space assets or terrestrial property. Given the increasing congestion in space and the growing number of satellites, the likelihood of collisions and resulting liability claims is rising. Reinsurance helps manage these potential liabilities by spreading the risk across multiple insurers, ensuring that the financial impact of any claims is manageable.

Space reinsurance can also include a cut-through clause[132]. A cut-through clause is a provision in a reinsurance contract that allows a third party, such as the original insured, to have direct rights against the reinsurer under specific circumstances, often when the main insurance company (ceding insurer) becomes insolvent or currently facing financial

---

[130]Gatti, E. (2022) #SPACEWATCHGL opinion: A review of the Space Insurance Market, SpaceWatch.GLOBAL. Available at: https://spacewatch.global/2022/09/spacewatchgl-opinion-a-review-of-the-space-insurance-market/ (Accessed: 04 November 2024).

[131]Boley, A.C. and Byers, M. (2021) Satellite mega-constellations create risks in low Earth orbit, the atmosphere and on Earth, Nature News. Available at: https://www.nature.com/articles/s41598-021-89909-7 (Accessed: 04 November 2024).

[132] Kagan, J. (2023) Cut-through clause: Meaning, how it's used, benefits, Investopedia. Available at: https://www.investopedia.com/terms/c/cutthrough-clause.asp (Accessed: 05 November 2024).

distress[133]. This clause ensures that the original insured can still receive payment even if the primary insurer is unable to fulfill its obligations. In this case, the space operator can claim directly to the reinsurance company. Or, if the space activity is being financed, the financier can claim directly to the reinsurer. By paying out the space operator / financier directly, the obligation of the reinsurer to pay the primary insurer is satisfied. This clause effectively "cuts through" the contractual relationship between the insurer and the reinsurer, granting rights to third parties who are not directly involved in the reinsurance agreement.

In the context of space activities and launches, where the stakes and potential losses are high, having such a clause can provide additional security and assurance to the parties involved, especially the space operator. This cut through clause is often seen in aviation reinsurance. The use of reinsurance in space insurance also fosters innovation and growth in the space industry. By providing a mechanism to manage financial risks, reinsurance encourages investment in new technologies and missions. This is particularly important as the space industry evolves, with new players entering the market and novel applications for satellites being developed. Reinsurance ensures that insurers can continue to offer coverage for these emerging risks, supporting the growth, development, overall health, and resilience of the space insurance market. This, in turn, fosters innovation and growth in the space industry, enabling continued exploration and utilization of space.

[133] Schiffer, L. (2001) Cut-through provisions in reinsurance agreements, IRMI. Available at: https://www.irmi.com/articles/expert-commentary/cut-through-provisions-in-reinsurance-agreements#:~:text=A%20cut-through%20provision%20allows%20a%20party%20not%20in,by%20specific%20events%20enumerated%20in%20the%20cut-through%20provision. (Accessed: 05 November 2024).

VII. Underwriting

Underwriting[134] in the context of space insurance is a highly specialized and technical process that involves assessing and managing the unique risks associated with space missions. This process begins well before the launch of a satellite or spacecraft and continues throughout its operational life. Underwriters must consider a wide range of factors, including the design and reliability of the satellite, the launch vehicle, and the mission profile[135]. Each of these elements presents its own set of risks that need to be carefully evaluated to determine the appropriate coverage and premiums.

One of the primary considerations in space insurance underwriting is the history and reliability of the satellite hardware, launch vehicle, and the operators themselves[136]. Underwriters look at the track record of the satellite's manufacturer and the specific components used. Satellites with a proven history of successful operations are generally considered lower risk. Additionally, the design redundancies and margins built into the satellite are scrutinized to ensure that it can withstand the harsh conditions of space and continue to operate even if some components fail[137].

The launch vehicle is another critical factor in the underwriting process. The flight history of the launch vehicle, including its success rate and any previous failures, is thoroughly

---

[134]KIN (2023) What is insurance underwriting?, KIN. Available at: https://www.progressive.com/answers/what-is-insurance-underwriting/ (Accessed: 04 November 2024).

[135]SELECT COMMITTEE OF THE UNITED STATES HOUSE OF REPRESENTATIVES (2024) The Commercial Space Insurance Industry, VOLUME II: Chapter 8/Technical Afterword. Available at: https://www.govinfo.gov/content/pkg/GPO-CRPT-105hrpt851/pdf/GPO-CRPT-105hrpt851-2-11.pdf (Accessed: 04 November 2024).

[136]Wheeler, J. and Stevens, N. (2023) Is the Space Insurance Market for leo sustainable?, March 2023. Available at: https://interactive.satellitetoday.com/via/march-2023/is-the-space-insurance-market-for-leo-sustainable (Accessed: 04 November 2024).

[137]Chen, Z. et al. (2023) Reliability Analysis and redundancy design of satellite communication system based on a novel Bayesian Environmental Importance, Reliability Engineering & System Safety. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0951832023007275 (Accessed: 04 November 2024).

analyzed. Launch vehicles with a high success rate and a robust safety record are preferred, as they reduce the risk of a catastrophic failure during launch. Underwriters also consider the specific mission profile, including the intended orbit and the complexity of the launch.

The underwriting process for space insurance also involves a detailed assessment of the insured's approach to risk management. This includes evaluating the technical oversight provided by the satellite's manufacturer and operator, as well as the measures in place to mitigate potential risks. Effective risk management practices can significantly reduce the likelihood of a claim and are therefore a key consideration for underwriters[138].

Another important aspect of space insurance underwriting is the consideration of space debris and collision risks. The increasing congestion in low Earth orbit (LEO) poses a significant threat to operational satellites[139]. Underwriters must assess the likelihood of collisions with other satellites or debris and the potential impact on the insured satellite. This assessment is becoming increasingly complex as the number of objects in space continues to grow.

The underwriting process for space insurance is highly individualized and can take several months to complete[140]. Each space mission is unique, and underwriters must tailor their coverage to the specific risks and requirements of the mission. This involves close collaboration with the insured, the satellite manufacturer, and other stakeholders to ensure that all potential risks are adequately covered. The goal is to provide comprehensive

[138]Monetary Authority of Singapore (2013) GUIDELINES ON RISK MANAGEMENT PRACTICES FOR INSURANCE BUSINESS - CORE ACTIVITIES. Available at: https://www.mas.gov.sg/regulation/guidelines/guidelines-on-risk-management-practices-for-insurance-business---core-activities (Accessed: 04 November 2024).

[139]Viasat (2022) Managing Mega-constellation Risks in LEO. Available at: https://www.viasat.com/content/dam/us-site/corporate/documents/Viasat White Paper-Managing Mega-Constellation Risks in LEO (Updated Nov 22) (A4).pdf (Accessed: 04 November 2024).

[140]Worthy, M. (2024) Your chance of getting hit by space junk is extremely low... but not zero!, Cranfill Sumner LLP. Available at: https://www.cshlaw.com/resources/the-current-universe-of-space-insurance/#_ftn14 (Accessed: 04 November 2024).

coverage that protects the insured's investment while also managing the insurer's exposure to risk.

However, space insurance underwriters face significant challenges due to the highly classified nature of the space industry and the stringent regulations, for example, the International Traffic in Arms Regulations (ITAR) in the United States of America[141]. ITAR controls the export and import of defense-related articles and services, including satellites and related technologies. This regulation aims to safeguard national security by preventing sensitive information from falling into the wrong hands. However, it also creates a complex environment for underwriters who need detailed information to accurately assess risks.

One of the primary issues is the lack of transparency in risk calculations. Under ITAR, many details about space missions, satellite technologies, and operational procedures are classified[142]. This means that underwriters often do not have access to the comprehensive data needed to evaluate the risks associated with insuring space assets. Without this information, it becomes challenging to determine the likelihood of failures or accidents, leading to potential underestimation or overestimation of risks.

The limited availability of data also affects the ability to apply the law of large numbers, a fundamental principle in insurance that relies on a large pool of similar risks to predict future losses accurately. In the space industry, the number of insurable satellites and missions is relatively small compared to other sectors like aviation or maritime. This small statistical pool makes it difficult for underwriters to develop reliable risk models, further complicating the risk assessment process.

Moreover, the technical complexity of space missions adds another layer of difficulty. Space insurance underwriters must possess specialized knowledge of space technology and

---

[141] FAA, DOC (2008) Introduction to U.S. Export Controls for the Commercial Space Industry. Available at: https://www.faa.gov/about/office_org/headquarters_offices/ast/media/Intro to US Export Controls.pdf (Accessed: 04 November 2024).

[142] Friedman, R. et al. (2024) New Export Control Rules present key regulatory changes for space-related items, activities: Insights, Holland & Knight. Available at: https://www.hklaw.com/en/insights/publications/2024/11/new-export-control-rules-present-key-regulatory-changes-for-space (Accessed: 06 November 2024).

operations to understand the risks involved. However, the classified nature of much of this information means that underwriters often have to rely on limited or outdated data, which can lead to inaccurate risk assessments. This situation is exacerbated by the rapid pace of technological advancements in the space industry, which can quickly render existing data obsolete.

The regulatory environment also poses legal and compliance risks for underwriters. Violations of ITAR can result in severe penalties, including hefty fines and restrictions on business operations[143]. This creates a cautious approach among underwriters, who may be reluctant to engage in space insurance without clear guidelines and assurances that they are not inadvertently violating export control laws. The fear of legal repercussions can stifle innovation and limit the availability of insurance products for the space industry.

Additionally, the relationship between space operators and insurers is governed by the principle of utmost good faith, which requires full disclosure of all material facts[144]. However, ITAR restrictions can hinder this transparency, leading to potential conflicts and disputes. For instance, if an underwriter is unaware of certain classified aspects of a mission, they may not be able to accurately price the insurance policy or may include exclusions that could lead to coverage disputes in the event of a claim.

The challenges are further compounded by the evolving nature of space activities. With the increasing commercialization of space, the risk landscape is continually changing. Underwriters must stay abreast of these developments and adapt their risk assessment models accordingly. However, the classified nature of many new technologies and missions makes this a daunting task.

[143] Ferster, W. (2023) U.S. satellite component maker fined $8 million for ITAR violations, SpaceNews. Available at: https://spacenews.com/37071us-satellite-component-maker-fined-8-million-for-itar-violations/ (Accessed: 06 November 2024).

[144] Thanasegaran, H. (2016). Duty of Utmost Good Faith. In: Good Faith in Insurance and Takaful Contracts in Malaysia. Springer, Singapore. https://doi.org/10.1007/978-981-10-0383-7_2

VIII. Factors Affecting Premiums

Space insurance premiums, particularly for satellites, are influenced by many factors that reflect the unique challenges and high risks associated with space operations. One of the primary factors is the type of satellite being insured. Communication satellites, for instance, often have higher premiums due to their critical role in global communications and the substantial revenue they generate[145]. Conversely, smaller satellites used for scientific research or Earth observation might have lower premiums[146], reflecting their different risk profiles and operational scopes.

Another significant factor is the launch vehicle's reliability. Insurance premiums are closely tied to the historical performance of the rockets used to deploy satellites. Launch vehicles with a proven track record of successful missions tend to attract lower premiums, as they present a lower risk of failure[147]. In contrast, newer or less reliable rockets can lead to higher premiums due to the increased likelihood of launch anomalies or failures[148].

The operational environment of the satellite also plays a crucial role. Satellites operating in Low Earth Orbits (LEO), which are more congested and have higher collision risks, may incur higher premiums compared to those in Geostationary Orbit (GEO)[149]. The harsh conditions

[145]Jewett, R. (2024) Inside Sia's 2024 state of the Satellite Industry Report, Via Satellite. Available at: https://www.satellitetoday.com/connectivity/2024/06/13/inside-sias-2024-state-of-the-satellite-industry-report/ (Accessed: 04 November 2024).

[146]The CAGRS of data traffic volumes and revenue in the satellite and space market (2022) Analysys Mason. Available at: https://www.analysysmason.com/research/content/articles/traffic-revenue-cagr-nsr/ (Accessed: 04 November 2024).

[147]NASA (2024) ARIANE5, Launch Vehicle. Available at: https://sma.nasa.gov/LaunchVehicle/ariane5.html (Accessed: 04 November 2024).

[148]Dowling, S. (2023) What are the odds of a successful space launch?, BBC News. Available at: https://www.bbc.com/future/article/20230518-what-are-the-odds-of-a-successful-space-launch (Accessed: 04 November 2024).

[149]Butterworth-Hayes, P. and Beechener, J. (2023) Low Earth Orbit 'at risk of experiencing multiple collisions' as satellite numbers increase, Unmanned airspace. Available at: https://www.unmannedairspace.info/commentary/low-earth-orbit-at-risk-of-experiencing-multiple-collisions-as-satellite-numbers-increase/ (Accessed: 04 November 2024).

of space, including exposure to solar radiation, extreme temperatures, and micrometeoroids[150], further complicate risk assessments and influence premium calculations.

Technological innovation and the satellite's design are additional factors. While cutting-edge technology can enhance a satellite's capabilities, it also introduces uncertainties that can affect insurance premiums. Insurers often prefer equipment with a well-documented history of reliability. Therefore, satellites incorporating new, untested technologies might face higher premiums due to the perceived higher risk[151].

The duration of the mission is another consideration. Longer missions increase the exposure to potential risks, such as component degradation or unforeseen space weather events[152], leading to higher premiums. Conversely, shorter missions might benefit from lower premiums as the risk exposure period is reduced.

The regulatory environment and international treaties also influence space insurance premiums. Compliance with regulations such as the Outer Space Treaty and national space laws can affect the risk profile of a satellite mission. Insurers consider the legal landscape and potential liabilities when determining premiums.

Market conditions and the overall economic climate play a role. The availability of insurance capacity, competition among insurers, and the financial health of the space industry can all impact premium rates. Periods of high demand for satellite launches or significant claims in

[150]ESA (2004) Surviving extreme conditions in space, ESA. Available at: https://www.esa.int/Science_Exploration/Space_Science/Extreme_space/Surviving_extreme_conditions_in_space (Accessed: 04 November 2024).

[151]Zach (2011) The Problems of Reusable Rockets, Seradata. Available at: https://www.seradata.com/the_problems_of_reusable_rocke/ (Accessed: 04 November 2024).

[152]Lopez-Calle, I. and Franco, A.I. (2023) Comparison of cubesat and microsat catastrophic failures in function of radiation and debris impact risk, Nature News. Available at: https://www.nature.com/articles/s41598-022-27327-z (Accessed: 04 November 2024).

the industry can lead to increased premiums[153], while a stable market with fewer claims might see lower rates.

The current market standard for insuring a satellite while still in its manufacturing process is 0,30%-0,55% of the total worth of the satellite. The rate for transport insurance from the manufacturing facility to the launch site is 0,12%-0,30% of the value. While pre-launch insurance's rate is 0,315%-0,45% of the satellite value at the launch moment, this phase usually excludes claims for damages to the production facility and launch pad[154]. While the rate for launch and in-orbit phase is not entirely apparent because of the greater risks involved and the variation of success rate between launch operators.

IX. Standard Satellite Insurance Contract

An insurance contract policy is a crucial document that outlines the terms and conditions under which an insurance company agrees to indemnify the insured against specific risks[155]. The importance of an insurance contract lies in its ability to provide financial protection and peace of mind[156]. By transferring the risk of loss from the policyholder to the insurer, it ensures that individuals and businesses can recover from unforeseen events such as accidents or other liabilities. This contractual agreement is legally binding and helps in

---

[153] Urban, R. (2024) How much does it cost to launch a Rocket? [by type & size], Space Impulse. Available at: https://spaceimpulse.com/2023/08/16/how-much-does-it-cost-to-launch-a-rocket/ (Accessed: 04 November 2024).

[154]Ritz, B. (2022) Satellite Liability and insurance: In space, who's insured?, Thompson Coe. Available at: https://www.thompsoncoe.com/resources/publications/splash-and-crash-satellite-liability-and-insurance/ (Accessed: 04 November 2024).

[155]ERGO (2017) GENERAL TERMS AND CONDITIONS OF INSURANCE CONTRACTS TI.0175.17. Available at: https://www.ergo.ee/fs-files/0000/0000/0002/files/Ravi_Yldtingimused_ENG%20al%2001.11.2017.pdf (Accessed: 04 November 2024).

[156]Prudential (2024) Importance of insurance - need & types of insurance: ICICI PRU life, icici prudential life insurance. Available at: https://www.iciciprulife.com/insurance/insurance-importance.html (Accessed: 04 November 2024).

mitigating financial uncertainties, making it an essential component of risk management strategies.

An insurance contract must be made as detailed as possible, including but not limited to, the scope of coverage, the obligations of both parties, and the procedures for handling claims. A well-drafted contract includes precise definitions of covered events[157], exclusions[158], policy limits, and the duration of coverage. It also specifies the premium amount, payment schedules, and any deductibles that apply. Detailed contracts help prevent misunderstandings and disputes by clearly outlining what is and isn't covered, thus ensuring that both the insurer and the insured have a mutual understanding of their responsibilities[159].

Space insurance contract policies are crucial for mitigating the financial risks associated with satellite launches. These policies provide coverage for various stages of a satellite's lifecycle, from pre-launch to in-orbit operations. Given the high costs and potential for catastrophic losses, having a comprehensive insurance policy ensures that satellite operators, manufacturers, and investors are protected against significant financial setbacks. This protection is especially important as the space industry continues to grow and the number of satellite launches increases, leading to higher risks of collisions and other incidents.

The level of detail in a space insurance contract is very high, reflecting the complexity and high stakes of space missions. Contracts typically include detailed descriptions of the satellite, launch vehicle, mission objectives, and the specific risks covered. This thorough documentation helps insurers accurately assess the risks and set appropriate premiums.

---

[157]Thomson Reuters (2024) Reduce the risk of claims with indemnification clauses in contracts, Indemnification Clauses in Commercial Contracts | Thomson Reuters. Available at: https://legal.thomsonreuters.com/en/insights/articles/indemnification-clauses-in-commercial-contracts (Accessed: 04 November 2024).

[158]Rondon Brokerage (2022) What do exclusions mean in an insurance policy? Available at: https://www.thimble.com/small-business-insurance/insurance-exclusions (Accessed: 04 November 2024).

[159]Faster Capital (2024) Avoiding Misunderstandings And Disputes. Available at: https://fastercapital.com/ (Accessed: 04 November 2024).

Additionally, the contract outlines the responsibilities of all parties involved, ensuring clarity and reducing the potential for disputes.

The coverage scope of a space insurance policy is broad, encompassing various risks associated with satellite launches. This includes physical damage to the satellite and launch vehicle and loss of revenue due to operational failures[160]. The policy period typically covers the entire lifecycle of the satellite, from pre-launch to the end of its operational life. Premiums are calculated based on the assessed risks and the value of the satellite and launch vehicle.

Important clauses in an insurance contract often include the insuring agreement, which outlines the insurer's promise to pay for covered losses, and the exclusions clause, which lists the events or conditions not covered by the policy. Other critical clauses include the conditions clause, detailing the obligations of the insured, such as timely premium payments and notification of claims. These clauses ensure that the contract is comprehensive and adaptable to specific needs.

Exclusions in space insurance policies are critical to understand, as they define the limits of coverage. Common exclusions might include losses due to war, intentional acts, or non-compliance with regulatory requirements. The claims process for space insurance involves detailed investigations to determine the cause of the loss and the extent of the damage. Liability coverage is also a key component, protecting against third-party claims arising from space activities, which are often mandated by most countries.

Performance guarantees in space insurance contracts ensure that the insured party meets specific operational standards and milestones[161]. These guarantees are essential for maintaining the policy's validity and ensuring that the insurer's risk is managed effectively.

---

[160]Meredith, P. (2007) Space insurance law with a Special Focus on Satellite Launch and In-Orbit Policies. Available at: https://www.kmazuckert.com/publications/space/Commerical_Space_-_Meredith_-_Space_Insurance_Law_2008.pdf (Accessed: 04 November 2024).

[161]Mainelli, M. (2023) In-orbit servicing and insurance markets: a symbiotic approach, International Astronautical Congress (IAC 2023). Available at: https://www.longfinance.net/media/documents/Astroscale_-_Insurance_-_Draft_v10.0_Final_Copy_Edited.pdf (Accessed: 04 November 2024).

Overall, an insurance contract policy, whether for traditional or specialized coverage like space insurance, is a vital tool for managing risk, providing financial security, and ensuring the smooth operation of various activities.

Payments for space insurance policies are usually structured in installments, with the first payment due before the launch. The claims process involves detailed documentation and investigation to determine the cause of the loss and the extent of the damage. Insurers work closely with satellite operators and manufacturers to ensure a smooth and efficient claims process.

To summarize, a satellite insurance contract typically includes these key terms to address the unique risks involved in space missions:

Clause	**Description**	**Example**
Coverage Scope	Defines what is covered by the policy, such as launch failures, in-orbit malfunctions, and physical damage from space debris.	*"In the event of a collision or other space-related incident, the insurer shall be responsible for all damages incurred, including but not limited to, the cost of repairs, loss of use, and any consequential damages. The insurer shall also indemnify and hold harmless the insured from any claims, demands, or actions arising out of or related to the incident."*

Policy Period	Specifies the duration of the coverage, which can include pre-launch, launch, and in-orbit phases.	*"The policy period for the pre-launch phase shall commence upon the satellite's arrival at the launch site and terminate upon the intentional ignition or lift-off of the launch vehicle."* *"The policy period for this insurance coverage commences at the initiation of the launch countdown and extends through the first 365 days following the successful separation of the satellite from the launch vehicle."* *"The policy period shall commence on the date of the satellite's successful launch and continue for a duration of 12 months, covering any losses or damages occurring within this timeframe."*
Premiums and Payments	Details the cost of the insurance and the payment schedule.	*"The insured shall pay all premiums for the satellite insurance policy in accordance with the payment schedule outlined in the policy terms."*
Third-Party Liability	Covers damages caused to third parties by the insured satellite.	*"Coverage for damage, loss, or injury sustained by third parties arising in any manner in connection with insured launch activities shall attach upon arrival of the satellite at*

		the launch site and terminate twelve months following the date of launch, unless otherwise specified."
Business Interruption / Loss of Revenue	Compensates for lost revenue if the satellite fails to perform its intended function.	*"The insurer will indemnify the insured for the actual loss of revenue sustained due to the necessary suspension of satellite operations during the period of restoration, provided the suspension is caused by direct physical loss or damage to the insured satellite by a covered peril."*
Exclusions	Lists specific scenarios that are not covered by the policy.	*"This policy does not cover any loss or damage caused by intentional acts, war, or the use of nuclear weapons."*
Performance Guarantees	Ensures the satellite will perform as expected, with provisions for compensation if it does not.	*"The insurer guarantees that the satellite will achieve and maintain its specified operational performance levels for a minimum period of five years from the date of launch, subject to the terms and conditions outlined in this policy."*
Claims Process	Describes the procedure for filing a claim, including required documentation and timelines.	*"The insured must notify the insurer of any circumstances that could give rise to a loss within 30 days and submit a detailed Proof of Loss within 90 days of the incident."*

IV

Challenges and Opportunities with Space Insurance

I. Determining Fault for Space Insurance Claim Process

The concepts of fault, negligence, and omissions play critical roles in determining liability under the Liability Convention that acts as a basis of fault for space insurance, especially for damages that happen in space, including in-orbit collisions. Fault refers to a breach of duty that results in damage, which can encompass intentional acts or negligent behavior. In the realm of space activities, fault is particularly significant because Article 3 of the Liability Convention specifies that a launching state is liable for damages caused by its space objects only if there is proof of fault. This creates a high bar for claimants, as they must demonstrate that the state failed to meet a certain standard of care in operating its satellites or managing debris.

Proving fault for damages in space involves navigating a complex legal landscape defined by the Liability Convention. Under Article 3 of the Convention, liability for damages caused by space objects is contingent upon establishing fault. This means that the claimant state must demonstrate that the launching state failed to meet a certain standard of care in its operations. States would need to show that the state suspected of damage did not comply with relevant national or international guidelines regarding debris mitigation or satellite management. This requirement for proof of fault complicates claims, particularly when dealing with untrackable debris or when multiple states are involved.

The challenge of proving fault is exacerbated by the nature of space debris, which often consists of small fragments that are difficult to trace back to their source[162]. While larger

[162]Sutter, P. (2024) Small, untrackable pieces of space junk are cluttering low Earth orbit, Astronomy Magazine. Available at: https://www.astronomy.com/space-exploration/small-untrackable-pieces-of-space-junk-are-cluttering-low-earth-orbit/ (Accessed: 04 November 2024).

pieces can be tracked and identified, many smaller fragments potentially harmful remain unmonitored, making it nearly impossible to establish a direct causal link between a specific piece of debris and the damage it caused. For example, if a collision occurs due to a small piece of debris that cannot be traced back to a specific satellite, it becomes challenging for the affected party to prove that the launching state was at fault. This lack of traceability raises significant issues regarding accountability and liability in an increasingly crowded orbital environment.

Additionally, the concept of fault itself lacks a clear definition within the existing legal framework, leading to ambiguity in its application. Proving fault typically requires establishing that the responsible party did not adhere to established standards or guidelines for space operations. However, these guidelines are often voluntary and non-binding[163], which complicates enforcement and accountability. As such, reforming international space law to clarify definitions and establish binding standards for debris mitigation could enhance the ability of states to prove fault and seek compensation for damages caused by space debris. This is crucial as the number of satellites continues to rise, increasing the likelihood of collisions and further complicating the already intricate liability landscape in outer space.

Finding fault can also be traced from negligence. Negligence is a failure to exercise reasonable care that results in harm[164]. Negligence could manifest in various ways, such as failing to adhere to established guidelines for debris mitigation or not conducting timely de-orbiting maneuvers for defunct satellites. For instance, if a state neglects its responsibilities to monitor orbital debris and fails to take action to prevent collisions, it may be deemed negligent. Such negligence could lead to liability if it can be shown that this failure directly contributed to a collision or damage caused by debris.

[163]Haager, A. (2018) The importance of non-binding instruments in international space law, ECSL Essay Contest. Available at: https://spacelaw.univie.ac.at/fileadmin/user_upload/p_npocspacelaw/ECSL_Essay_Contest_Sumbmission_Haager__Importance_of_soft_Law.pdf (Accessed: 04 November 2024).

[164]Adams, K. et al. (2021) Using the terms 'negligence' and 'gross negligence' in a contract, Adams on Contract Drafting. Available at: https://www.adamsdrafting.com/negligence-and-gross-negligence/ (Accessed: 04 November 2024).

Another way to find fault is to look for omission. Omission is a failure to act when there is a duty to do so. An intentional omission might occur if a state recognizes the risk of collision but chooses not to implement avoidance measures. This can complicate liability determinations because while an omission can constitute fault, proving that it directly led to damages can be challenging. For example, if a state identifies a potential collision risk with its satellite but decides against taking preventive action, this intentional omission could be interpreted as fault under the Liability Convention.

II. Emerging Risks in Insuring Space Activity

Satellite insurance is becoming increasingly complex and risky due to the rapid expansion of satellite constellations and the growing threat of in-orbit collisions. As the number of satellites in Low Earth Orbit (LEO) continues to rise, the risk of collisions with space debris and other satellites has become a significant concern for insurers. This congestion in space not only increases the likelihood of accidents but also complicates the underwriting process for satellite insurance policies[165].

One of the primary risks associated with satellite insurance is the potential for collisions with space debris. Space debris includes defunct satellites, spent rocket stages, and fragments from disintegration, erosion, and collisions. These objects travel at high velocities, and even small pieces can cause catastrophic damage to operational satellites[166]. The increasing amount of debris in LEO, where most commercial satellites operate, has led insurers to reassess their risk models and, in some cases, withdraw from providing coverage for satellites in these orbits.

[165] Kunstadter, C. T. W., (2022) What Keeps Space Insurers Up at Night?

[166]Pultarova, T. (2023) Old Soviet satellite breaks apart in orbit after space debris collision, Space.com. Available at: https://www.space.com/soviet-satellite-breaks-apart-after-debris-strike (Accessed: 04 November 2024).

The rapid deployment of large satellite constellations, such as SpaceX's Starlink and OneWeb, has escalated the collision risk. These constellations consist of thousands of small satellites, significantly increasing the density of objects in LEO. The higher the number of satellites, the greater the probability of collisions, which can create additional debris and further escalate the risk. Insurers are now faced with the challenge of evaluating the cumulative risk posed by these mega-constellations and determining appropriate premiums and coverage limits[167].

Technological advancements in satellite design and operation also present new risks. While modern satellites are equipped with advanced propulsion systems and collision avoidance technologies, these systems are not foolproof[168]. Failures in propulsion or navigation systems can lead to uncontrolled satellites, increasing the risk of collisions. Insurers must consider these technological vulnerabilities when underwriting satellite insurance policies.

The financial implications of in-orbit collisions are substantial. A collision can result in the total loss of a satellite, leading to significant financial losses for satellite operators and their insurers. The cost of replacing a satellite and launching a new one can be prohibitively high, and the loss of service can have far-reaching consequences for businesses and consumers. Insurers must account for these potential losses when setting premiums and coverage limits.

Mitigating the risks associated with in-orbit collisions requires a holistic approach. Improved tracking and monitoring of space debris, enhanced collision avoidance technologies, and international cooperation on space traffic management are essential. Insurers are increasingly advocating for these measures to reduce the risk of collisions and ensure the

[167]Viasat (2022) Managing Mega-constellation Risks in LEO. Available at: https://www.viasat.com/content/dam/us-site/corporate/documents/Viasat White Paper-Managing Mega-Constellation Risks in LEO (Updated Nov 22) (A4).pdf (Accessed: 04 November 2024).

[168]New Space Economy (2024) Overview of risks associated with Space Activities. Available at: https://newspaceeconomy.ca/2024/01/08/overview-of-risks-associated-with-space-activities/ (Accessed: 04 November 2024).

sustainability of space activities[169]. Collaboration between the space industry, governments, and insurers is crucial to developing effective risk mitigation strategies.

Despite the challenges, the space insurance market continues to evolve. Insurers are developing new products and coverage options to address the emerging risks associated with satellite operations. For example, some insurers are offering policies that cover the costs of active debris removal or on-orbit servicing, which can extend the operational life of satellites and reduce the risk of collisions. These innovative solutions demonstrate the industry's adaptability and commitment to supporting the growth of the space sector.

In conclusion, the emerging risks in space insurance, particularly for satellite insurance, are closely linked to the increasing threat of in-orbit collisions. As the number of satellites in LEO grows, so does the complexity of managing these risks. Insurers must navigate a challenging landscape of physical, technological, and legal risks to provide adequate coverage and support the sustainable development of space activities. Through collaboration and innovation, the space insurance industry can continue to evolve and address the unique challenges of this dynamic sector.

III. New Challenges Arising from Mega-constellations and Small Satellites

The rise of mega-constellations and small satellites has introduced several new challenges in the realm of space insurance, particularly concerning satellite insurance and in-orbit

[169]BSR (2024) Sustainability in space: The next frontier: Emerging issues: Sustainable business network and consultancy. Available at: https://www.bsr.org/en/emerging-issues/sustainability-in-space-the-next-frontier (Accessed: 04 November 2024).

collisions. Mega-constellations, such as SpaceX's Starlink[170] and OneWeb[171], involve deploying thousands of small satellites into low Earth orbit (LEO) to provide global internet coverage. While these constellations offer significant benefits[172], they also increase the risk of collisions due to the sheer number of satellites occupying the same orbital space.

One of the primary challenges is the increased congestion in LEO. With more satellites being launched, the probability of collisions between active satellites, as well as with space debris, has risen dramatically. This congestion complicates the task of tracking and managing satellite orbits, making it harder to predict and prevent potential collisions. The Kessler Syndrome, a scenario where the density of objects in LEO is high enough that collisions between objects could cause a cascade of further collisions, is a growing concern[173].

From an insurance perspective, this increased risk translates to higher premiums and more complex policies. Insurers must account for the heightened likelihood of collisions and the potential for significant financial losses. Traditional satellite insurance policies, which typically cover launch and in-orbit operations, may need to be re-evaluated and adapted to address the unique risks posed by mega-constellations. This includes considering the cumulative risk of multiple satellites within a single constellation and the potential for a single collision to impact numerous satellites.

Another challenge is the legal and regulatory framework governing space activities. Current space law, including the Outer Space Treaty and the Liability Convention, was not designed with mega-constellations in mind. These frameworks primarily address state liability for

[170]Starlink (2024) Satellite Technology. Available at: https://www.starlink.com/technology#:~:text=Each%20Starlink%20satellite%20contains%203%20space%20lasers%20%28Optical,that%20can%20connect%20customers%20anywhere%20in%20the%20world. (Accessed: 04 November 2024).

[171]IP Access International (2023) How oneweb's satellite Constellation Works: A beginner's guide. Available at: https://www.ipinternational.net/how-onewebs-satellite-constellation-works-a-beginners-guide/ (Accessed: 04 November 2024).

[172]Ben-Itzhak, S. (2022) The future of space technology and how it may benefit Humanity, Perry World House. Available at: https://global.upenn.edu/sites/default/files/perry-world-house/space-ben-itzhakthoughtpiece.pdf (Accessed: 04 November 2024).

[173] Johnson, N. L., (2018) Legal Aspects of Satellite Constellations.

damage caused by space objects, but the proliferation of private actors and the increasing number of satellites complicate the issue of liability[174]. Determining fault and responsibility in the event of a collision involving multiple satellites from different operators can be legally complex and contentious.

The insurance industry must also grapple with the technical challenges of assessing and mitigating collision risks. This involves sophisticated modeling and simulation to predict potential collision scenarios and their impacts. Insurers need to work closely with satellite operators to implement effective collision avoidance strategies and ensure that satellites are equipped with the necessary technology to maneuver and avoid potential collisions. This collaboration is crucial for reducing the overall risk and ensuring the sustainability of space operations.

The rapid pace of satellite launches and the deployment of mega-constellations outpaced the development of regulatory measures and international agreements. This gap creates uncertainty for insurers, as the rules governing space activities may change and impacts liability and risk assessments. Insurers must stay updated for the newest regulatory developments and adapt their policies accordingly to remain effective and relevant in this evolving landscape.

The environmental impact of mega-constellations also poses a challenge. The increased number of satellites contributes to the growing problem of space debris, which can escalate the risks of collision. Insurers need to consider the long-term implications of space debris and the potential costs associated with debris mitigation and removal efforts. This adds another layer of complexity to satellite insurance policies, as insurers must factor in the environmental sustainability of space operations.

Moreover, there is a potential problem that will occur when satellites from the same launching state collide. Mega-constellations accentuate these problems and might create an international liability problem with the risk of collision originating from the satellite constellation. This risk of collision originates from their operating nature, by having a

[174] von der Dunk, F. G., (2015) Liability for Space Debris: A Legal Analysis.

congested orbital height, great number of satellites, and with a criss-crossing orbital pattern in orbit[175]. The international liability framework sets liability for damages that happen between two launching states. When satellites part of a mega-constellation collide with each other, state liability will be applicable for the third party liability insurance. While the debris it created is an international problem and risks the safety of other satellites[176].

Mega-constellations and small satellites present significant challenges for space insurance, particularly in terms of satellite insurance and in-orbit collisions. The increased congestion in LEO, the evolving legal and regulatory framework, and the technical and environmental challenges all contribute to a more complex and dynamic risk landscape. Insurers must adapt to these changes by developing more sophisticated risk assessment models, collaborating with satellite operators, and staying informed about regulatory developments to effectively manage and mitigate the risks associated with mega-constellations.

IV. Dead Satellites

The issue of dead satellites and their insurance is an evolving topic within space law and space insurance. Dead satellites, or satellites that are no longer operational, pose significant risks in space, primarily due to their potential to collide with other active satellites or space debris[177]. The question is whether dead satellites still need insurance or are worth insuring.

One argument for insuring dead satellites is the potential liability for damages they might cause. Under the Outer Space Treaty and the Liability Convention, states are liable for

[175] Zhang, W., Wang, X., Cui, W. et al. Self-induced collision risk of the Starlink constellation based on long-term orbital evolution analysis. Astrodyn 7, 445–453 (2023). https://doi.org/10.1007/s42064-023-0171-7

[176] Santoso, M. "Potential Liabilities of Space Debris From Satellite Constellation". Thesis, Parahyangan Catholic University (2023).

[177] McFall-Johnsen, M. (2024) A dead Russian spacecraft almost collided with a NASA satellite. the crash could have sent 7,500 bits of debris rocketing around Earth., Business Insider. Available at: https://www.businessinsider.com/russian-spacecraft-nasa-satellite-collision-earth-debris-2024-3 (Accessed: 04 November 2024).

damages caused by their space objects, this includes dead satellites. If a dead satellite were to collide with an active satellite, the resulting damage and space debris generated could be substantial, both in terms of cost and operational disruption for the affected party with the active satellite. Insurance could provide a financial safety net for such incidents, ensuring that the responsible party can cover the costs of any damages.

Additionally, insuring dead satellites could incentivize better management and mitigation of space debris. Insurance companies might require satellite operators to adhere to certain standards or practices to minimize the risk of collisions, such as deorbiting satellites at the end of their operational life or using technologies to move them to a graveyard orbit. This could lead to a more sustainable space environment, reducing the overall risk of collisions and the creation of additional debris.

On the other hand, there are arguments against insuring dead satellites. One major consideration is the cost. Insuring a satellite that is no longer generating revenue might not be economically viable for many operators. The premiums for such insurance could be prohibitively high, especially given the long-term nature of the risk[178]. This could deter operators from purchasing insurance for dead satellites, particularly smaller companies or those with limited budgets[179].

Moreover, the effectiveness of insurance for dead satellites is debatable. While insurance can cover financial losses, it does not address the root cause of the problem, the presence of non-functional objects in orbit. Some experts argue that resources would be better spent on active debris removal technologies or international agreements to manage space debris

[178]Weltman, A. (2024) Slingshot Aerospace Report highlights record insurance market losses in 2023, Via Satellite. Available at: https://www.satellitetoday.com/sustainability/2024/05/01/slingshot-aerospace-reveals-record-insurance-losses-in-2023-in-new-satellite-deployments-report/ (Accessed: 04 November 2024).

[179]Garcia, P. (2023) The satelite insurance market, MAPFRE Global Risks. Available at: https://www.mapfreglobalrisks.com/en/risks-insurance-management/article/the-satelite-insurance-market/ (Accessed: 04 November 2024).

more effectively[180]. These measures could provide a more permanent solution to the problem of space debris, rather than relying on insurance as a financial safety net.

Another consideration is the difficulty in assessing the risk associated with dead satellites. Unlike active satellites, which can be monitored and controlled to some extent, dead satellites are unpredictable. Their orbits can decay over time, and they can be affected by various factors such as space weather[181]. This unpredictability makes it challenging for insurers to accurately assess the risk and set appropriate premiums, potentially leading to either underpricing or overpricing of insurance policies.

There is also the issue of morality. If satellite operators know that their dead satellites are insured, they might be less incentivized to take proactive measures to mitigate the risk of collisions. This could lead to a situation where operators rely on insurance as a safety net, rather than investing in technologies or practices that could reduce the overall risk of space debris. This moral hazard could undermine efforts to create a more sustainable space environment.

While there are valid arguments both for and against insuring dead satellites, the decision ultimately depends on a balance of economic, legal, and practical considerations. Insuring dead satellites could provide a financial safety net and incentivize better debris management practices, but it also comes with significant costs and challenges. As the space industry continues to evolve, finding effective solutions to the problem of space debris will require a combination of regulatory measures, technological innovations, and potentially, insurance mechanisms.

---

[180] Khasanah, Nur Barokah Uswatun, and Marc Johan Atsawin. 2024. "Mechanisms for Addressing Space Debris from the Perspective of International Law". International Law Discourse in Southeast Asia 3 (1), 107-34. https://doi.org/10.15294/ildisea.v3i1.78885.

[181]Sutter, P. (2024) Small, untrackable pieces of space junk are cluttering low Earth orbit, Astronomy Magazine. Available at: https://www.astronomy.com/space-exploration/small-untrackable-pieces-of-space-junk-are-cluttering-low-earth-orbit/ (Accessed: 04 November 2024).

V. Implications for Insurance Coverage and Risk Management

Insuring a satellite involves a complex interplay of risk management and insurance coverage, given the unique challenges and high stakes associated with space operations. There are implications for insurance coverage, including various phases of a satellite's lifecycle, from pre-launch to in-orbit operations. Each phase presents distinct risks that must be carefully assessed and managed to ensure comprehensive coverage and mitigate potential losses.

Pre-launch insurance covers the period from the satellite's construction to its transportation and integration with the launch vehicle. This phase involves risks such as damage during manufacturing, testing, and transportation. Insurers must evaluate the reliability of the manufacturing process, the experience of the launch service provider, and the logistics involved in transporting the satellite to the launch site. Effective risk management at this stage includes thorough inspections, quality control measures, and contingency planning for potential delays or damages[182].

Launch insurance is perhaps the most critical and expensive component of satellite insurance. It covers the satellite from the moment of launch until it reaches its designated orbit[183]. The risks during this phase are significant, including launch failure, explosion, and failure to achieve the correct orbit. Insurers assess the historical performance of the launch vehicle, the track record of the launch service provider, and the specific conditions of the launch. Risk management strategies include selecting reliable launch providers, conducting rigorous pre-launch testing, and having backup plans in place.

In-orbit insurance covers the satellite once it is operational in space[184]. This phase involves risks such as collision with space debris, technical malfunctions, and environmental factors

[182]AON (2016) Insuring space activities. Available at: https://www.aon.com/russia/files/Insuring_Space_Activities_whitepaper.pdf (Accessed: 04 November 2024).

[183] *id.*

[184] *id.*

like solar radiation. Insurers must consider the satellite's design, its operational environment, and the measures in place to mitigate these risks. Effective risk management includes regular monitoring of the satellite's health, implementing collision avoidance protocols, and ensuring robust technical support for in-orbit operations.

Third-party liability insurance is essential for covering damages that a satellite might cause to other space assets or terrestrial property[185]. This includes collisions with other satellites or space debris and potential damage caused by falling debris if a satellite re-enters the Earth's atmosphere. Insurers must evaluate the satellite's operational trajectory, the density of space traffic in its orbit, and the potential impact of debris on Earth. Risk management strategies involve adhering to international space traffic management guidelines and maintaining accurate tracking of the satellite's position.

Business interruption insurance covers the financial losses that might occur if a satellite fails to operate as intended. This includes loss of revenue from disrupted services, such as telecommunications or broadcasting. Insurers assess the satellite's expected revenue streams, the contractual obligations of the satellite operator, and the potential financial impact of service interruptions. Risk management involves diversifying revenue sources, having backup satellites or ground-based alternatives, and ensuring robust contractual protections.

Regulatory compliance is a critical aspect of satellite insurance and risk management. Satellite operators must comply with international treaties, national regulations, and licensing requirements. Insurers need to understand the legal landscape and ensure that the satellite operator adheres to all relevant laws and guidelines. Risk management includes staying updated on regulatory changes, maintaining proper documentation, and engaging with regulatory bodies to address any compliance issues.

Technological advancements in satellite design and operation continuously influence insurance coverage and risk management. Innovations such as miniaturized satellites, reusable launch vehicles, and advanced propulsion systems can alter the risk landscape.

---

[185] *id.*

Insurers must stay abreast of these developments and adjust their risk assessments and coverage options accordingly. Risk management involves investing in research and development, collaborating with technology providers, and adopting best practices in satellite operations.

International collaboration plays a vital role in managing the risks associated with satellite operations. Space is a global common, and the actions of one entity can impact others. Insurers and satellite operators must engage in international forums, share data on space debris, and collaborate on best practices for space traffic management. Effective risk management includes participating in international agreements, contributing to global efforts to mitigate space debris, and fostering a culture of cooperation among space-faring nations.

These considerations highlight the intricate balance between insurance coverage and risk management in the satellite industry. By addressing the unique challenges at each phase of a satellite's lifecycle and fostering international collaboration, insurers and satellite operators can better navigate the complexities of space operations and ensure the sustainability of their ventures.

VI. Debris Mitigation and Collision Avoidance

Debris mitigation and collision avoidance are critical aspects of satellite operations, especially in the context of satellite insurance. As the number of satellites in orbit increases, so does the risk of collisions with space debris. This risk is a significant concern for satellite insurers, who must account for potential damages and losses in their policies. Effective debris mitigation strategies, such as designing satellites to minimize debris generation and implementing end-of-life disposal plans, can reduce the likelihood of collisions and, consequently, insurance claims[186].

[186] Bourbonniere, M., (2016) Space Debris Mitigation and Liability: A Comparative Analysis.

Collision avoidance involves maneuvering satellites to prevent potential collisions with other objects in space. This process requires precise tracking and prediction of the orbits of both the satellite and the debris[187]. Satellite operators use conjunction assessment tools to evaluate the risk of close approaches and decide on necessary maneuvers. These maneuvers can be costly and complex, but they are essential for protecting the satellite and maintaining its operational lifespan.

In the context of satellite insurance, policies often include clauses that require the insured to take reasonable measures to mitigate risks. This can include adhering to international guidelines for debris mitigation and collision avoidance[188]. For instance, the Inter-Agency Space Debris Coordination Committee (IADC)[189] provides guidelines that satellite operators are encouraged to follow. Failure to comply with these guidelines could potentially affect insurance coverage or claims.

There are instances where the insured must actively engage in debris mitigation and collision avoidance to maintain their insurance coverage. For example, if a satellite operator is aware of a potential collision and fails to take appropriate action, the insurer may deny a claim for damages resulting from the collision. This requirement ensures that satellite operators remain vigilant and proactive in managing collision risks.

Insurance policies may also specify certain technologies or practices that must be implemented for coverage to be valid. This could include the use of propulsion systems capable of performing collision avoidance maneuvers or the integration of tracking systems that provide real-time data on potential collision threats. By mandating these measures,

---

[187]Assmann, K., Berger, J. and Grothkopp, S. (1970) The Cola Collision Avoidance Method, ESA Proceedings Database. Available at: https://conference.sdo.esoc.esa.int/proceedings/sdc5/paper/68 (Accessed: 04 November 2024).

[188]CORDIS (2013) Final report summary - revus (reducing the vulnerability of space systems): FP7: CORDIS: European Commission, CORDIS. Available at: https://cordis.europa.eu/project/id/262156/reporting/de (Accessed: 04 November 2024).

[189] Inter-Agency Space Debris Coordination Committee (IADC). "IADC Space Debris Mitigation Guidelines." Revised 2007. Available at: UNOOSA

insurers can reduce the overall risk and ensure that satellite operators are equipped to handle collision threats.

The increasing density of objects in low Earth orbit (LEO) has led to more stringent requirements for debris mitigation and collision avoidance. Insurers are particularly concerned about the potential for cascading collisions, known as the Kessler Syndrome, where one collision generates debris that causes further collisions. To mitigate this risk, insurers may require operators to follow best practices for satellite design, operation, and end-of-life disposal[190].

In addition to technical measures, regulatory frameworks play a crucial role in debris mitigation and collision avoidance. National[191] and international regulations often mandate specific actions that satellite operators must take to minimize debris generation and avoid collisions[192]. Compliance with these regulations is typically a condition of insurance coverage, ensuring that operators adhere to industry standards and contribute to the overall safety of the space environment.

Debris mitigation, collision avoidance, and satellite insurance are mutually beneficial. Effective risk management practices reduce the likelihood of collisions and insurance claims, while insurance policies incentivize operators to adopt these practices. This dynamic helps to maintain the sustainability of space operations and protect valuable satellite assets.

[190]Swinhoe, D. (2022) FCC considering 5-year disposal rule for end-of-life leo satellites, DCD. Available at: https://www.datacenterdynamics.com/en/news/fcc-considering-5-year-disposal-rule-for-end-of-life-leo-satellites/ (Accessed: 04 November 2024).

[191]Foust, J. (2023) FCC approves New Orbital Debris Rule, SpaceNews. Available at: https://spacenews.com/fcc-approves-new-orbital-debris-rule/ (Accessed: 04 November 2024).

[192]Novaspace (2024) Space sustainability regulations: new constraints and opportunities for space businesses. Available at: https://nova.space/in-the-loop/ (Accessed: 04 November 2024).

VII. Role of Insurance in Collision Avoidance Measures

Insurance plays a crucial role in incentivizing collision mitigation measures for space operators. As the space industry grows, the risk of collisions between satellites and space debris increases, posing significant financial and operational threats. Insurance companies, by assessing these risks, can encourage operators to adopt better collision mitigation practices. By offering lower premiums to operators who implement robust mitigation strategies, insurers create a financial incentive for responsible behavior in space.

One of the primary ways insurances incentivize collision mitigation is through risk assessment and premium differentiation. Insurers evaluate the likelihood of collisions based on an operator's adherence to best practices, such as deorbiting defunct satellites and avoiding high-risk orbits. Operators who follow these guidelines are seen as lower risk and are rewarded with reduced insurance costs[193]. This not only promotes safer space operations but also encourages the development and adoption of new technologies aimed at reducing collision risks.

Moreover, insurance policies can include specific requirements for collision avoidance measures. For instance, insurers might mandate the use of advanced tracking systems and collision avoidance maneuvers as part of the coverage terms. This ensures that operators are actively engaged in monitoring and mitigating potential collision threats. By embedding these requirements into insurance contracts, insurers can drive industry-wide improvements in safety standards and operational practices.

The role of insurance extends beyond financial incentives, it also fosters a culture of accountability and transparency. Operators are more likely to share data on their satellites' positions and movements if it impacts their insurance premiums. This increased transparency helps improve the overall situational awareness in space, making it easier to

[193]Logistics UK (2024) Tips for reducing your insurance premiums, Road Insurance, risk management and loss control. Available at: https://logistics.org.uk/compliance-and-advice/road/insurance-risk-management-and-loss-control/tips-for-reducing-your-insurance-premiums (Accessed: 04 November 2024).

predict and prevent potential collisions. Collaborative efforts between operators, facilitated by insurance requirements, can lead to more effective and coordinated collision mitigation strategies.

Furthermore, insurance companies can play a pivotal role in shaping regulatory frameworks for space operations. By working closely with policymakers, insurers can advocate for regulations that promote collision mitigation and responsible behavior. This collaboration can lead to the establishment of industry standards and best practices that are aligned with insurance requirements, creating a more cohesive and effective approach to managing collision risks in space.

The financial stability provided by insurance also allows operators to invest in research and development of new collision mitigation technologies. Knowing that they have coverage in case of an incident, operators can allocate resources towards innovative solutions without the fear of catastrophic financial loss. This can accelerate the advancement of technologies such as autonomous collision avoidance systems and improved debris tracking capabilities.

VIII. Strategies for Minimizing Collision Risks

Minimizing collision risks in space is crucial for the sustainability of space activities and the protection of valuable assets. One of the primary strategies involves enhancing space situational awareness (SSA). SSA encompasses the tracking and cataloging of space objects, including active satellites and debris[194]. By improving the accuracy and comprehensiveness of SSA, operators can better predict potential collisions and take preventive measures. Advanced radar and optical tracking systems, along with data-sharing agreements between space-faring nations, are essential components of this strategy.

[194]ESA (2024) Space situational awareness - SSA, ESA. Available at: https://www.esa.int/About_Us/ESAC/Space_Situational_Awareness_-_SSA (Accessed: 04 November 2024).

Maneuverability is another critical factor in mitigating collision risks. Satellites equipped with propulsion systems can adjust their orbits to avoid potential collisions. This requires precise and timely data from SSA systems to execute effective maneuvers. The development of autonomous collision avoidance systems[195], which can make real-time decisions based on incoming data, is a promising advancement. These systems reduce the reliance on ground-based control and can respond more quickly to imminent threats.

Debris removal is a proactive approach to reducing collision risks. Active debris removal (ADR) technologies aim to capture and deorbit defunct satellites and large debris objects[196]. Methods such as robotic arms, harpoons, and nets are being tested for this purpose. By removing large debris, the likelihood of collisions that generate further debris is minimized. This is particularly important in densely populated orbits like low Earth orbit (LEO), where the risk of cascading collisions, known as the Kessler Syndrome, is higher.

In the context of space insurance, these strategies play a vital role in risk assessment and premium calculation. Insurers need to evaluate the effectiveness of an operator's collision avoidance measures and debris mitigation plans. Operators with robust SSA capabilities, maneuverable satellites, and active participation in debris removal initiatives are likely to receive more favorable insurance terms. This incentivizes the adoption of best practices and technologies that enhance space safety.

International collaboration is essential for the success of these strategies. Space is a global common, and the actions of one operator can impact many others. International guidelines and agreements, such as those developed by the Inter-Agency Space Debris Coordination Committee (IADC) and the United Nations Office for Outer Space Affairs (UNOOSA), provide frameworks for responsible behavior in space. Compliance with these guidelines is often a prerequisite for obtaining space insurance, further encouraging adherence to best practices.

---

[195] Stroe, I.F. et al. (2021) Autonomous Collision Avoidance System, ESA Proceedings Database. Available at: https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/161 (Accessed: 06 November 2024).

[196]ESA (2024) Active debris removal, ESA. Available at: https://www.esa.int/Space_Safety/Space_Debris/Active_debris_removal (Accessed: 04 November 2024).

Technological innovation continues to drive improvements in collision risk mitigation. Advances in artificial intelligence and machine learning[197] are enhancing the predictive capabilities of SSA systems. These technologies can analyze vast amounts of data to identify potential collision scenarios and recommend optimal avoidance maneuvers. Additionally, new propulsion technologies are making satellites more agile and capable of executing complex maneuvers with greater precision.

Regulatory frameworks also play a crucial role. National and international regulations that mandate debris mitigation measures, such as end-of-life disposal plans and passivation of defunct satellites, help reduce the long-term risk of collisions[198]. Space insurance policies often require compliance with these regulations, ensuring that operators adhere to established safety standards. This regulatory oversight is vital for maintaining a sustainable space environment.

Finally, public awareness and education are important for fostering a culture of safety in space operations. By raising awareness about the risks of space debris and the importance of collision avoidance, stakeholders can build a collective commitment to preserving the space environment. Educational initiatives and public outreach programs can help inform the next generation of space professionals about best practices and the ethical responsibilities of space exploration. These strategies, when implemented collectively, can significantly reduce the risk of collisions in space, ensuring the long-term sustainability of space activities and the protection of valuable assets.

---

[197] ESA (2024) Artificial Intelligence in space, ESA. Available at: https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Artificial_intelligence_in_space (Accessed: 04 November 2024).

[198] ESA (2015) End-of-life disposal of satellites. Available at: https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/End-of-life_disposal_of_satellites (Accessed: 06 November 2024).

IX. Legal Uncertainties

Satellite insurance is a complex and evolving field, with legal uncertainties that pose significant challenges for insurers, satellite operators, and regulators. Satellites must endure extreme conditions, including intense solar radiation, vacuum exposure, and drastic temperature fluctuations[199]. Despite rigorous engineering and testing, failures can still occur, making it challenging for insurers to accurately assess and price these risks. The limited statistical data available for space operations further complicates risk assessment, as the relatively small number of insurable satellites does not provide a robust data pool for actuarial analysis.

The inaccessibility of satellites once they are in orbit adds another layer of complexity. Most communication satellites operate at altitudes where direct repair is impossible, meaning that any malfunction or damage can result in a total loss. This inaccessibility necessitates innovative solutions like in-orbit servicing (IOS), which are still in developmental stages and introduce new risks and uncertainties for insurers to consider.

Collision risks in space are a major concern. The increasing number of satellites, particularly with the advent of mega-constellations, raises the likelihood of collisions with space debris or other satellites. The legal framework for addressing such collisions is not well-defined, leading to potential disputes over liability and compensation. This uncertainty is exacerbated by the fact that space debris can remain in orbit for decades or even centuries, posing long-term risks.

The rapid pace of technological innovation in the satellite industry presents another challenge. While innovation is essential for advancing space capabilities, it can conflict with insurers' preference for proven, reliable equipment. New technologies often lack a track record of performance, making it difficult for insurers to evaluate their reliability and

[199] Horne, R. B., et al. (2013), Space weather impacts on satellites and forecasting the Earth's electron radiation belts with SPACECAST, Space Weather, 11, 169–186, doi:10.1002/swe.20023.

associated risks[200]. This can lead to volatile insurance markets, where a few large claims can significantly impact annual premium income.

Regulatory differences between countries further complicate the legal landscape of satellite insurance. Each country has its own licensing requirements and liability regimes, which can vary widely. This lack of harmonization can create legal uncertainties for satellite operators who must navigate multiple regulatory environments. It also poses challenges for insurers in crafting policies that comply with diverse legal standards.

The emergence of new space activities, such as space tourism and asteroid mining, introduces additional legal uncertainties. These activities are not fully covered by existing international treaties, leaving gaps in the legal framework that insurers must address. The novelty of these activities also means there is little historical data to inform risk assessments, adding to the complexity of providing adequate insurance coverage.

The potential for geopolitical tensions impacting space operations is a problem everybody needs to be aware of. Space is increasingly becoming a domain of strategic importance, and conflicts between nations could lead destructions of satellites, either deliberately or accidentally, physically or systematically. The legal implications of such incidents are unclear, particularly in terms of liability and compensation. Insurers must consider these geopolitical risks when underwriting satellite policies, adding another layer of uncertainty to an already complex field.

These legal uncertainties highlight the need for ongoing dialogue and cooperation between international bodies, national regulators, satellite operators, and insurers to develop a more robust and cohesive legal framework for satellite insurance. This will be essential for managing the risks associated with the rapidly evolving space industry and ensuring the sustainability of space activities.

---

[200]USDT and FAA (1998) Special Report: Update of the Space and Launch Insurance Industry, Commercial Space Transportation QUARTERLY LAUNCH REPORT. Available at: https://www.faa.gov/about/office_org/headquarters_offices/ast/media/sr_98_4q.pdf (Accessed: 04 November 2024).

X. Unresolved Legal Questions

Satellite insurance is a complex and evolving field, with several unresolved legal questions that continue to spark debate among experts. One of the primary issues is the determination of liability in the event of a collision involving a defunct satellite or unidentified debris. The Outer Space Treaty and the Liability Convention provide a framework for addressing these issues, but they leave many questions unanswered. For instance, while the Liability Convention establishes that launching states are liable for damage caused by their space objects, it does not clearly define how liability is apportioned when multiple states are involved or when the responsible party cannot be identified. However, these issue under the treaties do not impair coverage terms under third-party liability insurance.

Another significant legal question pertains to the identification and tracking of space debris. With over 170 million pieces of debris orbiting the Earth[201], it is challenging to attribute responsibility for collisions. The current tracking systems are not always capable of identifying smaller debris, which can still cause significant damage to operational satellites. This raises questions about the adequacy of existing legal frameworks and the need for more robust international cooperation and technological advancements in debris tracking and mitigation.

The issue of fault, negligence, and omission in space collisions is also a contentious topic. The Liability Convention requires proof of fault for damage caused in space, but proving fault can be exceedingly difficult. Factors such as the unpredictable nature of space debris, the limitations of current tracking technology, and the lack of clear guidelines on the standard of care expected from satellite operators also complicate the determination of negligence and omission. But, third-party liability insurance is not hindered by challenges in proving fault or causation under the Liability Convention where a legal obligation exists under state law.

---

[201]ESA (2024) How many space debris objects are currently in orbit?, ESA. Available at: https://www.esa.int/Space_Safety/Clean_Space/How_many_space_debris_objects_are_currently_in_orbit (Accessed: 04 November 2024).

Insurance coverage for space activities is another area fraught with legal ambiguities. While pre-launch and in-orbit insurance policies are well-established, the scope of coverage for collisions involving space debris remains unclear. Insurers are increasingly concerned about the rising risk of collisions and the potential for catastrophic losses. This has led to calls for more comprehensive policies that explicitly address debris-related risks and for the development of new insurance products tailored to the unique challenges of space operations.

The role of national and international regulations in governing satellite insurance is also a topic of ongoing debate. Different countries have varying requirements for insurance coverage, and there is no universally accepted standard. This lack of harmonization can create legal uncertainties for satellite operators and insurers, particularly in cases involving cross-border operations. There is a growing consensus on the need for more consistent and coordinated regulatory frameworks to address these challenges.

The question of liability for damage caused by defunct satellites is particularly pressing. Many satellites are left in orbit long after they have ceased to function, posing a significant collision risk. The current legal frameworks do not adequately address the responsibility of satellite operators to deorbit or otherwise mitigate the risks posed by defunct satellites. This has led to calls for stricter regulations and enforcement mechanisms to ensure that satellite operators take proactive measures to prevent collisions.

Another unresolved issue is the liability for damage caused by unidentified debris. When a collision occurs, it is often difficult to determine the source of the debris, making it challenging to assign liability. This is particularly problematic in the case of small debris, which is not tracked by existing systems. The lack of clear guidelines on how to handle such cases creates significant legal and financial uncertainties for satellite operators and insurers.

Finally, the potential for future legal developments in space law adds another layer of complexity to satellite insurance. As space activities continue to expand, there is a growing recognition of the need for more comprehensive and forward-looking legal frameworks. This includes not only addressing current issues but also anticipating future challenges, such as the increasing commercialization of space and the potential for new types of space activities.

The ongoing evolution of space law will undoubtedly have significant implications for satellite insurance and the management of collision risks.

XI. The Need for Updated International Agreements

The rapid expansion of space activities necessitates updated international agreements to address emerging challenges, particularly those related to liability and in-orbit collisions. The current legal framework, primarily based on the Outer Space Treaty of 1967 and the Liability Convention of 1972, is increasingly seen as inadequate for modern space operations. These treaties were established during an era when space activities were predominantly conducted by a few state actors. Today, the landscape has dramatically changed with the entry of numerous private entities and the proliferation of small satellites, making the need for updated agreements more pressing.

One of the critical issues that is often discussed is the ambiguity surrounding liability for in-orbit collisions. The Liability Convention stipulates that launching states are liable for damage caused by their space objects, but it does not clearly define the standards of fault or negligence. However, for third-party liability insurance, legal obligation under state law prevails. As space becomes more congested, the risk of collisions increases, a more precise and comprehensive international liability regime that can effectively address these incidents and ensure fair compensation will be needed to harmonize international space law[202].

In-orbit collisions not only pose a threat to operational satellites but also contribute to the growing problem of space debris. Each collision generates fragments that can remain in orbit

[202]Annamaria, N. and Valerio, R. (2013) Needs of an international policy and regulation framework for orbital debris mitigation systems, Thales Alenia Space Italy. Available at: https://conference.sdo.esoc.esa.int/proceedings/sdc6/paper/84/SDC6-paper84.pdf (Accessed: 04 November 2024).

for decades, posing a hazard to other space objects[203]. The Kessler Syndrome, a scenario where the density of objects in low Earth orbit is high enough to cause a cascade of collisions, is a real and growing concern. Updated international agreements must include robust measures for debris mitigation and active debris removal to prevent such catastrophic scenarios.

The involvement of private companies in space activities further complicates the liability landscape. While the Liability Convention holds states responsible for the actions of their nationals, the increasing number of commercial operators necessitates clearer guidelines on the extent of state liability and the responsibilities of private entities. Clearer state laws governing responsibility for injury and loss arising from in-orbit collisions, for which third party liability insurance would avail would be needed, ensuring that victims of space-related incidents are adequately compensated.

There is a pressing need for enhanced international cooperation among spacefaring nations to establish comprehensive guidelines and regulations governing the deployment and operation of mega constellations. This includes creating frameworks for data sharing and collision avoidance maneuvers, which are crucial for managing the risks associated with increased satellite density in LEO[204]. With the established rules for aviation and maritime collision avoidance, similar protocols should also be developed for space. These protocols would provide clear guidelines on how satellite operators should respond to potential collision risks, including thresholds for when to execute avoidance maneuvers[205].

---

[203] Bongers, A. and Torres, J.L. (2024) Low-earth orbit faces a spiraling debris threat, Scientific American. Available at: https://www.scientificamerican.com/article/low-earth-orbit-faces-a-spiraling-debris-threat/ (Accessed: 04 November 2024).

[204]Silverstein, B. (2022) How governments should address the increasing risks of satellite collision - carnegie endowment for international peace | carnegie endowment for international peace. Available at: https://carnegieendowment.org/posts/2022/04/how-governments-should-address-the-increasing-risks-of-satellite-collision?lang=en (Accessed: 04 November 2024).

[205] *Id.*

The Outer Space Treaty (1967) and other related treaties need reinforcement to address contemporary challenges posed by mega constellations. This includes clarifying obligations regarding environmental impact assessments and liability for collisions involving satellites, as well as ensuring that all nations adhere to principles of responsible space use[206]. Developing clear liability frameworks, both for international space law and state law is essential to address potential damages caused by collisions between satellites, particularly those involving private operators. This would involve defining responsibilities and establishing mechanisms for compensation in case of accidents[207].

There is a call for the creation of new regulatory authorities or enhancement of existing ones to oversee space traffic management effectively. These authorities would be responsible for monitoring satellite operations, conducting conjunction assessments, and enforcing compliance with international guidelines. To support the development and implementation of updated international agreements and authorities, several forums can be utilized. The United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) is a primary platform for discussing and negotiating space law. COPUOS has a long history of facilitating international cooperation and can play a crucial role in drafting new treaties or amending existing ones. Additionally, the International Telecommunication Union (ITU)[208] can contribute by addressing issues related to satellite communications and orbital slots.

---

[206] Byers M, Boley A. Mega-constellations and International Law. In: Who Owns Outer Space?: International Law, Astrophysics, and the Sustainable Development of Space. Cambridge Studies in International and Comparative Law. Cambridge University Press; 2023:77-113.

[207]Johnson, C. (2019) The legal status of MegaLEO constellations and Concerns About Appropriation of Large Swaths of Earth Orbit. Available at: https://swfound.org/media/206951/johnson2020_referenceworkentry_thelegalstatusofmegaleoconstel.pdf (Accessed: 04 November 2024).

[208] ITU (2024) International Telecommunication Union, committed to connecting the world. Available at: https://www.itu.int/ (Accessed: 06 November 2024).

The International Astronautical Federation (IAF)[209] and its annual International Astronautical Congress (IAC)[210] provide another valuable forum for stakeholders from government, industry, and academia to discuss space policy and legal issues. These gatherings can foster dialogue and consensus-building among diverse actors, paving the way for more comprehensive and inclusive agreements. Furthermore, regional organizations such as the European Space Agency (ESA) and the Asia-Pacific Space Cooperation Organization (APSCO)[211] can facilitate regional cooperation and contribute to the global regulatory framework.

The role of non-governmental organizations (NGOs) and public policy institutes should not be underestimated. Entities like the Secure World Foundation[212] and the Space Policy Institute[213] can provide research, advocacy, and policy recommendations to support the development of effective international agreements. Their expertise and independent perspectives can help identify gaps in the current legal framework and propose innovative solutions.

The dynamic and evolving nature of space activities demands updated international agreements and state laws that address liability and in-orbit collision issues comprehensively. By leveraging various international and regional forums, the global community can develop a robust legal framework that ensures the sustainable and safe use of outer space for all. This collaborative approach will be essential in navigating the

---

[209] IAF (2024) International Astronautical Federation. Available at: https://www.iafastro.org/ (Accessed: 06 November 2024).

[210] IAF (2024) IAF : International Astronautical Congress (IAC), International Astronautical Congress IAC : space sessions for all. Available at: https://www.iafastro.org/events/iac/ (Accessed: 06 November 2024).

[211] APSCO (2024) Asia-Pacific Space Cooperation Organization. Available at: http://www.apsco.int/ (Accessed: 06 November 2024).

[212] Secure World Foundation (2024) Promoting Cooperative Solutions for Space Sustainability. Available at: https://swfound.org/ (Accessed: 06 November 2024).

[213] Space Policy Institute (2024) Space Policy Institute, THE ELLIOTT SCHOOL OF INTERNATIONAL AFFAIRS. Available at: https://spi.elliott.gwu.edu/ (Accessed: 06 November 2024).

complexities of modern space operations and safeguarding the interests of all space-faring nations and entities.

V

Space Insurance Market and Industry Resilience

I. Shift in Space Insurance Claims

Space insurance has evolved significantly since the early days of space exploration. Initially, the primary parties involved were government space agencies like NASA[214] and Roscosmos[215], along with a few pioneering insurance companies willing to underwrite the high risks associated with space missions[216]. These early policies, which were first party property insurance for the spacecraft, were primarily focused on launch failures, which were common due to the technology at that time. Claims during this period were often straightforward, as the failures were usually catastrophic and total, leaving little room for dispute.

As private companies like SpaceX, Blue Origin, and Virgin Galactic entered the space race, the landscape of space insurance began to change. These companies brought with them a new set of risks and challenges, including more frequent launches and a broader range of missions, from satellite deployments to space tourism[217]. Insurance companies had to adapt by developing more sophisticated policies that could cover a wider array of potential

[214]NASA (2024) NASA. Available at: https://www.nasa.gov/ (Accessed: 04 November 2024).

[215]Britannica (2024) Roskosmos, Encyclopædia Britannica. Available at: https://www.britannica.com/topic/Roskosmos (Accessed: 04 November 2024).

[216]Atlas Magazine (2007) Space insurance, Insurance News Around the World. Available at: https://www.atlas-mag.net/en/article/space-insurance#:~:text=The%20first%20indemnification%20of%20a%20claim%20dates%20back,industries%20triggered%20the%20manufacture%20of%20satellites%20and%20launchers. (Accessed: 04 November 2024).

[217]Martin, G. (2015) NewSpace: The Emerging Commercial Space Industry, NASA Ames Research Center. Available at: https://ntrs.nasa.gov/api/citations/20150023562/downloads/20150023562.pdf (Accessed: 04 November 2024).

failures, including partial failures and in-orbit anomalies. This period saw an increase in the number of claims, but also a rise in possible disputes as the complexity of missions grew.

One notable trend in space insurance claims has been the shift from launch failures to in-orbit failures. As rocket and satellite technology improved, the likelihood of a successful launch increased[218], but the risk of in-orbit failures remained significant. These failures could be due to a variety of factors, including technical malfunctions, collisions with space debris, or even software errors[219]. Claims for in-orbit failures are often more complex and contentious, as they may involve partial losses or degradation of satellite capabilities, leading to disputes over the extent of the coverage and the valuation of the loss.

The process of filing and settling space insurance claims has also evolved. Initially, claims were handled on a case-by-case basis, often involving lengthy investigations and negotiations. However, as the industry matured, standardized procedures and protocols were developed to streamline the process. Despite these improvements, disputes still arise, particularly in cases involving partial failures or ambiguous policy terms. These disputes can sometimes lead to litigation, adding another layer of complexity to the claims process[220].

One of the most significant challenges in space insurance is the accurate assessment of risk. Insurers rely heavily on historical data and statistical models to predict the likelihood of failures and set premiums accordingly. However, the rapid pace of technological advancement in the space industry means that historical data can quickly become

[218]Padhi, S. (2023) How technology is revolutionizing space travel , OrbitBeyond. Available at: https://www.orbitbeyond.com/blog/how-technology-is-revolutionizing-space-travel (Accessed: 04 November 2024).

[219]Thomson, J. (2024) Intelsat 33e satellite designed by Boeing breaks up in Orbit, Newsweek. Available at: https://www.newsweek.com/satellite-orbiting-earth-broken-intelsat-lost-1972438 (Accessed: 04 November 2024).

[220]Clyde & Co (2024) Space law and arbitration: Dispute Resolution Mechanisms for space-related disputes, Clyde & Co LLP. Available at: https://www.clydeco.com/en/insights/2024/03/overview-of-dispute-resolution-mechanisms-for-spac (Accessed: 04 November 2024).

outdated[221]. This has led to instances where insurers have either underpriced or overpriced policies, resulting in financial losses for both the insurers and the insured parties.

Given the high potential losses associated with space missions[222], primary insurers often seek to spread the risk by purchasing reinsurance. This practice helps to stabilize the market and ensure that insurers can cover large claims without facing financial ruin. However, the reinsurance market is also subject to its own set of challenges, including the need to accurately assess and price the risks associated with space missions.

In recent years, the space insurance market has faced several high-profile claims that have tested the resilience of the industry. For example, the loss of the UAE's Falcon Eye-1 satellite in 2019 resulted in a claim of $415 million, one of the largest in history[223]. Such large claims have prompted insurers to re-evaluate their risk models and pricing strategies, leading to a tightening of the market and an increase in premiums.

Looking ahead, the future of space insurance will likely be shaped by the continued growth of the commercial space sector and the increasing complexity of space missions. As more private companies and even individuals venture into space, the demand for comprehensive and flexible insurance policies will grow. Insurers will need to stay ahead of technological advancements and develop innovative solutions to manage the evolving risks of space exploration.

---

[221]Signé, L. and Dooley, H. (2024) How space exploration is fueling the Fourth Industrial Revolution, Brookings. Available at: https://www.brookings.edu/articles/how-space-exploration-is-fueling-the-fourth-industrial-revolution/ (Accessed: 04 November 2024).

[222]Growth Market Reports (2024) Space insurance market analysis, size, share & forecast 2031. Available at: https://growthmarketreports.com/report/space-insurance-market-global-industry-analysis (Accessed: 04 November 2024).

[223]Henry, C. (2023) Big claims, record-low rates: Reshaping the space insurance game, SpaceNews. Available at: https://spacenews.com/big-claims-record-low-rates-reshaping-the-space-insurance-game/ (Accessed: 04 November 2024).

II. Understanding the Space Insurance Market

Space Insurance is a big market, with total space assets, insured and not, that are currently orbiting the earth are estimated to be around $150 billion, with around $24 billion of those are insured as of 2023[224]. The space insurance market, especially for first party insurance, has evolved significantly over the past few decades, driven by the increasing commercialization of space activities and the growing number of satellites launched into orbit. However, the total number of insurance company with dedicated space insurance is approximately 30 to 40 worldwide[225]. The dynamics of this market can lead to significant fluctuations in premiums based on recent losses or accidents because of the small size of the market.

The space insurance industry faces challenges related to revenue generation and loss management. In recent years, there has been a decline in the number of insured launches, which directly impacts premium income for insurers. The cyclical nature of the market means that after periods of high claims or catastrophic losses, insurers often raise premiums to mitigate risks, leading to a hardening market where coverage becomes scarce and expensive.

Historically, significant claims have arisen from catastrophic failures during launch or operational phases. For example, notable incidents include the loss of high-value GEO satellites due to launch failures or malfunctioning systems shortly after deployment[226]. Such events not only result in substantial financial losses but also influence future underwriting

---

[224]Russell, L. and Durrett, M. (2024) Strained satellite insurance market could be in jeopardy, Connectivity Business News. Available at: https://connectivitybusiness.com/news/strategy-markets/strained-satellite-insurance-market-could-be-in-jeopardy (Accessed: 04 November 2024).

[225]The Space Report (2024) Space Insurance Industry Estimates, 2003-2022, The Space Report. Available at: https://www.thespacereport.org/resources/space-insurance-industry-estimates-2003-2022/ (Accessed: 04 November 2024).

[226]Khan, R. (2023) Troubles with GEO satellites pose new insurance challenges, Open Access Government. Available at: https://www.openaccessgovernment.org/troubles-with-geo-satellites-pose-new-insurance-challenges/168028/ (Accessed: 04 November 2024).

practices as insurers reassess risk profiles based on these incidents. The limited number of launches complicates risk assessment further, as underwriters lack extensive historical data to inform their decisions.

The increasing congestion in LEO presents new challenges for insurers. With more satellites being launched, many with lower values than traditional GEO satellites insurers are concerned about the sustainability of coverage options in this segment. The rise of mega-constellations like Starlink complicates risk modeling due to their unique operational characteristics and potential collision risks. Insurers are questioning whether they can maintain profitability while covering these diverse risks.

Regulatory frameworks are evolving as governments recognize the need for sustainable practices in space operations. There is growing discourse on implementing insurance requirements related to space debris management to protect both governmental interests and commercial operators. This could lead to new standards that ensure adequate coverage without stifling innovation or increasing operational costs excessively.

To promote a healthier insurance market, there is an urgent need for establishing sustainability standards within the space industry. These standards could enhance reliability and reduce risks associated with new satellite technologies. By demonstrating quality assurance through standardized practices, companies can improve their risk profiles, making them more attractive to insurers. The future viability of this market hinges on improved risk assessment methodologies, regulatory support for sustainable practices, and collaborative efforts among industry players to foster a more resilient environment for space operations.

III. Space Insurance Industry Responses

The downtrend in insurance companies willing to insure satellite launches is primarily driven by the increasing frequency and severity of claims. High-profile incidents, such as the

failures of the ViaSat-3 and Inmarsat-6 F2 satellites, have resulted in substantial claims that have significantly impacted the market[227]. These incidents have led insurers to reassess their risk appetite, with some exiting the market entirely due to the high financial risks involved. The result is a reduced pool of insurers, which in turn drives up premiums for satellite operators.

In response to this trend, the space insurance industry has seen a shift towards higher premiums and more stringent underwriting criteria. Insurers are now more cautious, often requiring detailed risk assessments and proof of reliability for both the satellite and the launch vehicle. This has made it more challenging for satellite operators to secure affordable insurance, particularly for missions involving new or unproven technologies. The increased costs and difficulty in obtaining coverage can delay or even cancel planned launches, impacting the broader space industry.

The consolidation of the space insurance market has raised concerns about the potential for monopolistic behavior. With fewer insurers willing to cover satellite launches, the remaining players have greater pricing power and can dictate terms more aggressively. This lack of competition can lead to higher costs for satellite operators and reduced innovation in the sector[228]. However, the specialized nature of space insurance and the high barriers to entry make it unlikely that a true monopoly will form, as new entrants could still emerge if market conditions become favorable.

Several factors discourage insurance companies from completely pulling out of the space insurance market. One significant factor is the potential for high returns. Despite the risks, the premiums for space insurance can be substantial, and successful missions without claims

[227]Foust, J. (2023) Insurers brace for viasat-3 claim, SpaceNews. Available at: https://spacenews.com/insurers-brace-for-viasat-3-claim/ (Accessed: 04 November 2024).

[228]SELECT COMMITTEE OF THE UNITED STATES HOUSE OF REPRESENTATIVES (2024) The Commercial Space Insurance Industry, VOLUME II: Chapter 8/Technical Afterword. Available at: https://www.govinfo.gov/content/pkg/GPO-CRPT-105hrpt851/pdf/GPO-CRPT-105hrpt851-2-11.pdf (Accessed: 04 November 2024).

can be highly profitable[229]. Additionally, the growing demand for satellite services, driven by advancements in telecommunications, Earth observation, and space exploration, ensures a steady stream of potential clients for insurers.

Technological advancements in satellite design and launch systems also play a role in retaining insurers in the market. Improvements in reliability and safety measures can reduce the likelihood of failures, making the risks more manageable for insurers. Furthermore, the development of in-orbit servicing technologies, which can extend the operational life of satellites and mitigate some risks, provides additional assurance to insurers.

The space insurance industry is also exploring innovative risk-sharing mechanisms to manage the high costs associated with satellite launches. Pooling resources and spreading risks across multiple insurers can help mitigate the financial impact of large claims[230]. This collaborative approach can make it more feasible for insurers to continue offering coverage while managing their exposure to catastrophic losses.

While the downtrend in insurers willing to cover satellite launches poses significant challenges, the industry is adapting through higher premiums, stricter underwriting, and innovative risk management strategies. The potential for high returns, technological advancements, regulatory requirements, and collaborative risk-sharing mechanisms all contribute to keeping insurers engaged in the space insurance market. However, the reduced competition and higher costs underscore the need for ongoing innovation and adaptation to ensure the sustainability of this critical sector.

[229]SpaceNews (2023) Cost of insuring satellite launches down by $10 million, SpaceNews. Available at: https://spacenews.com/cost-insuring-satellite-launches-down-10-million/ (Accessed: 04 November 2024).

[230]FAA (2002) Commercial Space and Launch Insurance: Current Market and Future Outlook, Fourth Quarter 2002 Quarterly Launch Report . Available at: https://www.faa.gov/about/office_org/headquarters_offices/ast/media/q42002.pdf (Accessed: 04 November 2024).

IV. Underwriting Practices Based on Collision Risks

Underwriting practices for satellite collision risk involve a detailed assessment[231] of various factors that could impact the likelihood and severity of collisions in space. Insurance companies evaluate the satellite's orbit, the density of space debris in that orbit, and the satellite's ability to maneuver to avoid collisions. They also consider the satellite's design, including its shielding and redundancy systems, which can mitigate damage from smaller debris. The underwriting process often includes a review of the satellite operator's track record and their adherence to best practices in space traffic management[232].

One of the primary concerns for insurers is the increasing congestion in low Earth orbit (LEO), where many commercial satellites operate. The rapid deployment of large satellite constellations, such as those by OneWeb and Starlink, has heightened the risk of collisions. Insurers are particularly wary of the potential for catastrophic collisions that could generate large amounts of space debris, further increasing the risk for other satellites. This has led some insurers to limit their exposure to LEO or to withdraw from this market segment altogether[233].

To manage these risks, insurers often include specific clauses in their policies that address satellite collision risks. These clauses typically define the conditions under which a collision is covered, including the types of objects involved (e.g., other satellites, space debris, micrometeoroids). Policies may also specify the required actions by the satellite operator to

[231]Lexis Nexis (2024) Advanced analytics for underwriting, LexisNexis Risk Solutions. Available at: https://risk.lexisnexis.com/insurance/data-analytics-and-modeling/advanced-analytics-for-underwriting (Accessed: 04 November 2024).

[232]Hiscox (2024) Space congestion increases collision risk, Hiscox Group. Available at: https://www.hiscoxgroup.com/news/press-releases (Accessed: 04 November 2024).

[233]Yap, J. and Tan, M. (2023) Is the sky the limit for Space Insurance?, Failure in orbit: Planning your space projects with space insurance in mind. Available at: https://www.landers.com.au/legal-insights-news/failure-in-orbit-planning-your-space-projects-with-space-insurance-in-mind (Accessed: 04 November 2024).

mitigate collision risks[234], such as maintaining active collision avoidance systems and adhering to international guidelines[235] for space debris mitigation[236].

One common clause in satellite insurance policies is the "all-risks" coverage, which provides protection against all losses except those explicitly excluded. Typical exclusions might include war, terrorism, and cyber-attacks[237]. Under this type of policy, collisions with space debris and micrometeoroids are generally covered, provided the satellite operator has taken reasonable steps to avoid such collisions. This approach ensures that operators are incentivized to maintain high standards of operational safety.

Another important aspect of underwriting is the assessment of the satellite's end-of-life plan. Insurers look for robust plans by the satellite operator to deorbit or move the satellite to a graveyard orbit at the end of its operational life[238]. This reduces the long-term risk of collision and helps to manage the overall space debris environment. Policies may include clauses that require operators to demonstrate their end-of-life plans and to comply with international standards for space debris mitigation.

[234]ISO (2023) ISO 24113:2023, ISO. Available at: https://www.iso.org/standard/83494.html (Accessed: 04 November 2024).

[235]IADC (2007) IADC Space Debris Mitigation Guidelines. Available at: https://www.unoosa.org/documents/pdf/spacelaw/sd/IADC-2002-01-IADC-Space_Debris-Guidelines-Revision1.pdf (Accessed: 04 November 2024).

[236]UNOOSA (2010) Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space. Available at: https://www.unoosa.org/pdf/publications/st_space_49E.pdf (Accessed: 04 November 2024).

[237]CRC Group (2022) New War & Terrorism Exclusions Complicate Cyber Market , Wholesale & Specialty Insurance . Available at: https://www.crcgroup.com/Tools-Intel/post/new-war-terrorism-exclusions-complicate-cyber-market (Accessed: 04 November 2024).

[238]NOAA (2016) Graveyard orbits and the satellite afterlife, National Environmental Satellite, Data, and Information Service. Available at: https://www.nesdis.noaa.gov/news/graveyard-orbits-and-the-satellite-afterlife (Accessed: 04 November 2024).

The underwriting process also may involve the use of advanced modeling[239] and simulation tools to predict collision probabilities and potential damage scenarios[240]. These tools help insurers to quantify the risks and to set appropriate premiums. They also enable insurers to offer tailored coverage options that reflect the specific risk profile of each satellite mission. This level of customization is crucial in a rapidly evolving space environment where new risks are continually emerging.

In recent years, there has been a growing interest in on-orbit servicing (OOS) and active debris removal (ADR) technologies. These technologies can extend the operational life of satellites and reduce the risk of collisions by removing defunct satellites and large debris from orbit[241]. Insurers are beginning to recognize the potential of these technologies to stabilize the space environment and are incorporating them into their underwriting practices. Policies may include clauses that provide coverage for OOS and ADR activities, reflecting the evolving nature of space operations.

Overall, the underwriting of satellite collision risk is a complex and dynamic process that requires a deep understanding of both the technical and operational aspects of space missions. Insurers must balance the need to provide comprehensive coverage with the need to manage their own risk exposure. By leveraging advanced technologies and adopting best practices in risk management, insurers can help to support the sustainable growth of the space industry while protecting their own financial interests.

---

[239]Earnix (2024) Top six benefits of automated underwriting system in insurance. Available at: https://earnix.com/blog/what-are-the-top-six-benefits-of-an-automated-underwriting-system-in-insurance/ (Accessed: 04 November 2024).

[240]Matura, P. (2020) Numerical Analysis of satellite collisions in orbit - fraunhofer EMI, Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI. Available at: https://www.emi.fraunhofer.de/en/business-units/space/research/numerische-untersuchungen-satellitenkollisionen-im-orbit.html (Accessed: 04 November 2024).

[241]Davis, J., Mayberry, J. and Penn, J. (2019) ON-ORBIT SERVICING: INSPECTION, REPAIR, REFUEL, UPGRADE, AND ASSEMBLY OF SATELLITES IN SPAC, Aerospace. Available at: https://aerospace.org/sites/default/files/2019-05/Davis-Mayberry-Penn_OOS_04242019.pdf (Accessed: 04 November 2024).

V. Resilience of the Space Insurance Market During Significant Events

The space insurance market has demonstrated remarkable resilience during significant events, adapting to the evolving landscape of space activities and the associated risks[242]. Historically, the market has faced numerous challenges, including high-profile satellite failures, launch mishaps, and the increasing complexity of space missions. Despite these hurdles, the industry has managed to sustain itself and even grow[243], thanks to innovative risk management strategies and the development of specialized insurance products. For instance, the late 1990s and early 2000s saw significant losses that affected premium rates and market capacity, yet the market rebounded by adjusting its underwriting practices and leveraging advancements in space technology.

One of the key factors contributing to the resilience of the space insurance market is its ability to adapt to new challenges. Insurers respond to challenges by conducting comprehensive risk assessments, collaborating with industry experts, and utilizing data analytics to better understand and mitigate risks. For example, big insurance losses from high-profile claims triggers the insurance market to raise premiums across their space insurance portfolios, causing the space insurance market to re-evaluate.

Insurers now tend to focus on long-term sustainability[244] rather than short-term gains. This proactive approach has enabled the market to remain robust even as the nature of space activities continues to evolve. Insurers also implement stricter underwriting criteria and

[242]Mukhopadhyay, A. (2024) Space insurance market navigates uncertain terrain in 2024 amid capacity shifts: Gallagher - Reinsurance News, ReinsuranceNe.ws. Available at: https://www.reinsurancene.ws/space-insurance-market-navigates-uncertain-terrain-in-2024-amid-capacity-shifts-gallagher/ (Accessed: 04 November 2024).

[243]Pandey, V., Dataintelo and Sharma, R. (2024) Space Insurance Market Research Report 2032, Research Report 2032. Available at: https://dataintelo.com/report/space-insurance-market/ (Accessed: 04 November 2024).

[244]ESSI (2024) UN speech: Implementing the long-term sustainability (LTS) guidelines. Available at: https://www.essi.org/news/un-speech-implementing-the-long-term-sustainability-lts-guidelines (Accessed: 04 November 2024).

leverage technological advancements to improve risk assessment[245]. This adaptability has been crucial in maintaining the market's stability and ensuring its continued growth.

The resilience of the space insurance market is also evident in its response to emerging risks. As space activities become more ambitious, new risks such as cybersecurity threats and space weather events have emerged. Insurers have had to develop innovative solutions to address these risks, including the use of advanced modeling techniques and the incorporation of new data sources. This ability to innovate and adapt to changing risk landscapes has been a key factor in the market's resilience.

Looking ahead, the potential for satellite collisions presents a significant challenge for the space insurance market. With the increasing number of satellites in orbit, the risk of collisions has become more pronounced. A major collision could result in substantial financial losses and disrupt space operations. However, the market's past resilience suggests that it is well-equipped to handle such events[246]. Insurers are likely to develop new products and risk management strategies to address the unique challenges posed by satellite collisions.

In the event of a significant satellite collision, the space insurance market would likely see an initial spike in premium rates as insurers reassess the risks associated with satellite operations. However, the market's history of resilience suggests that it would eventually stabilize. Insurers would likely implement stricter underwriting criteria and leverage advancements in satellite technology to improve risk assessment and mitigation. This adaptive approach would help the market recover and continue to provide essential coverage for space activities.

The resilience of the space insurance market during significant events is also supported by the collaboration between insurers, satellite operators, and regulatory bodies. This

[245]Yap, J. and Tan, M. (2023) Is the sky the limit for Space Insurance?, Failure in orbit: Planning your space projects with space insurance in mind. Available at: https://www.landers.com.au/legal-insights-news/failure-in-orbit-planning-your-space-projects-with-space-insurance-in-mind (Accessed: 04 November 2024).

[246]Speed, R. (2024) Insurers make record-breaking loss as space gets cramped, The Register® - Biting the hand that feeds IT. Available at: https://www.theregister.com/2024/05/01/space_insurer_record_loss/ (Accessed: 04 November 2024).

collaboration ensures that all stakeholders are aligned in their efforts to manage risks and promote the sustainability of space activities. By working together, these stakeholders can develop comprehensive risk management strategies that address the unique challenges of the space environment.

VI. Addressing Space Insurance When In-Orbit Collision Happens

When a collision occurs in space involving an insured satellite, the implications extend beyond the immediate damage to the satellite itself. The creation of space debris from such collisions poses significant risks to other satellites operating in similar orbital paths. This situation raises important questions regarding liability and the ability of indirectly affected parties to make claims.

Upon a collision, the directly affected satellite's operator will typically initiate a claims process with their insurance provider. The insurance policy will cover damages based on the terms outlined in the contract, which may include compensation for repair costs or total loss, this is a first party insurance. However, depending on the type of insurance policy, the insurer might investigate the incident to determine liability, which is crucial for processing claims for third-party liability insurance. If the collision results in significant debris, this can increase risks for other satellites in the vicinity, potentially leading to further incidents.

For parties not directly involved in a collision but who may suffer increased risk due to resulting debris, the ability to file claims is less straightforward. While third-party liability insurance typically covers damages caused by operational activities, claims from those indirectly affected, such as other satellite operators at similar orbital heights, can be complex. These parties may argue that they face heightened risks due to increased space debris but must establish a legal basis for their claims.

Indirectly affected parties can pursue third-party liability claims if they can demonstrate that their operations are significantly impacted by the collision's aftermath. However,

establishing fault is crucial. The Liability Convention allows for claims against the responsible party only if fault can be proven. Thus, indirectly affected operators would need to show that the original operator failed to exercise due diligence in preventing the collision or mitigating debris risks[247]. They must establish a direct link between the collision and their increased risk, which may include evidence of how debris from the incident poses a threat to their operations. Here, state laws will also be able to avail for purposes of third-party liability insurance claims.

If an indirect party believes they have a valid claim, another option is to pursue compensation through diplomatic channels as outlined in Article 9 of the Liability Convention[248]. This process involves presenting claims through state representatives and could lead to negotiations or arbitration if no settlement is reached within a specified timeframe. However, this route can be lengthy and complex, often requiring significant legal resources and political will[249].

[247]Aoki, S. (2012) The Standard of Due Diligence in Operating a Space Object, International Institute of Space Law. Available at: https://www.elevenjournals.com/tijdschrift/iisl/2012/3%20The%20International%20Legal%20Regulation%20of%20Outer%20Space%20within%20the%20Scope%20of%20Public%20International%20Law/IISL_2012_055_003_002 (Accessed: 04 November 2024).

[248] Convention on International Liability for Damage Caused by Space Objects. (1972). Open for signature March 29, 1972, 961 U.N.T.S. 187. Article IX.

[249]Mansors (2024) Liability for damage caused by Space Objects, Mansors. Available at: https://mansors.com/blog/liability-for-damage-caused-by-space-objects (Accessed: 04 November 2024).

VI

Recommendations and Future Directions for Space Insurance

I. Enhancing Space Safety

Enhancing space safety, particularly considering the increasing risk of satellite collisions, requires a technological, regulatory frameworks, and international cooperation approach. Improving the tracking and cataloging of space objects is essential. Governments and private entities should invest in advanced Space Situational Awareness (SSA) technologies to monitor and predict the trajectories of satellites and debris more accurately. This includes deploying more ground-based and space-based sensors and enhancing data-sharing protocols among space-faring nations.

Establishing standardized collision avoidance protocols is crucial. Space agencies and satellite operators should adopt best practices for maneuvering satellites to avoid potential collisions. This includes pre-launch planning, real-time monitoring, and automated collision avoidance systems that can react swiftly to potential threats. To mitigate the growing problem of space debris, policies should support the development and deployment of active debris removal technologies. Governments can incentivize private companies to invest in these technologies through grants, tax breaks, or public-private partnerships. Successful demonstration missions should be prioritized to validate these technologies.

Space safety is a global concern that requires international cooperation. Countries should work together to establish binding international treaties and agreements that outline responsibilities and protocols for space operations. This includes sharing SSA data, coordinating collision avoidance efforts, and jointly developing debris mitigation strategies. Policies should also mandate that all new satellites be designed with collision avoidance capabilities and end-of-life disposal plans. This includes equipping satellites with propulsion

systems for deorbiting and ensuring they can be safely removed from orbit at the end of their operational life. Regulatory bodies should enforce compliance with these standards.

Promoting responsible behavior among all space actors, including commercial entities is also necessary. This can be achieved through a combination of regulatory measures and incentives. For example, operators who adhere to best practices for collision avoidance and debris mitigation could receive financial incentives or priority access to launch services.

As the number of satellites in orbit increases, effective space traffic management becomes essential. Governments should invest in developing Space Traffic Management (STM) systems that can coordinate the movements of satellites and prevent collisions. These systems should be capable of handling the complexities of mega-constellations and other emerging space activities[250].

Continuous investment in research and development is necessary to stay ahead of the evolving challenges in space safety. Governments and private entities should fund research into new technologies and methods for collision avoidance, debris removal, and space traffic management. Collaboration with academic institutions and international partners can accelerate innovation in this field.

II. Policy Recommendations to Prevent Collisions

Promoting responsible behavior and preventing collisions of satellites is crucial for the sustainability of space operations. One key policy recommendation is the implementation of comprehensive space traffic management (STM) systems. These systems would involve real-time tracking and monitoring of all active satellites and space debris, ensuring that operators have up-to-date information on potential collision risks. By establishing a centralized STM

[250] Hertzfeld, H. R., & von der Dunk, F. G, (2019) Space Traffic Management: Assessing the Risks and Challenges.

authority, coordination between different satellite operators can be improved, reducing the likelihood of accidental collisions.

Another important policy is the mandatory sharing of orbital data among satellite operators[251]. This would include information on satellite positions, planned maneuvers, and any anomalies that could affect their orbits. By fostering a culture of transparency and cooperation, operators can better anticipate and avoid potential collisions. This policy could be enforced through international agreements and supported by technological solutions that facilitate secure and efficient data exchange.

Regulatory frameworks should also be strengthened to include stricter guidelines for satellite design and end-of-life disposal. Satellites should be equipped with reliable propulsion systems and collision avoidance technologies to enable timely maneuvers. Additionally, regulations should mandate that satellites be deorbited or moved to a graveyard orbit at the end of their operational life to minimize the risk of creating space debris.

Economic incentives can play a significant role in promoting responsible behavior. Governments and international organizations could offer financial rewards or tax benefits to companies that adhere to best practices in satellite operations and debris mitigation. Conversely, penalties could be imposed on operators who fail to comply with established guidelines, creating a financial disincentive for irresponsible behavior.

International collaboration is essential for addressing the global nature of space activities. Countries should work together to develop and enforce common standards for satellite operations and debris mitigation. This could be achieved through existing international bodies such as the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS)

[251]World Economic Forum (2024) Space Situational Awareness Data and Information Sharing Principles. Available at: https://www3.weforum.org/docs/WEF_Space_Situational_Awareness_Data_and_Information_Sharing_Principles_2024.pdf (Accessed: 04 November 2024).

or by establishing new multilateral agreements specifically focused on space sustainability[252].

Public awareness and education campaigns can also contribute to promoting responsible behavior[253]. By raising awareness about the risks associated with space debris and the importance of sustainable space operations, the general public and stakeholders can be encouraged to support and comply with relevant policies. Educational programs targeting satellite operators, engineers, and policymakers can help build a culture of responsibility and safety in the space industry.

Technological innovation should be encouraged to develop new solutions for collision avoidance and debris mitigation. This includes advancements in autonomous maneuvering systems, improved tracking and monitoring technologies, and innovative methods for debris removal[254]. Governments and private sector entities can collaborate to fund research and development in these areas, accelerating the deployment of effective solutions.

Finally, continuous review and adaptation of policies are necessary to keep pace with the rapidly evolving space environment. Regular assessments of the effectiveness of existing regulations and the identification of emerging risks can help ensure that policies remain relevant and effective. Stakeholder feedback and scientific research should inform these reviews, enabling a proactive approach to space sustainability[255]. By implementing these policy recommendations, we can promote responsible behavior among satellite operators

---

[252] Hobe, S., & Froehlich, A. (Eds.). (2019) Space Law: Current Problems and Perspectives for Future Regulation.

[253]Wells, R. (2023) New NASA-funded study hopes to put risks of space junk on People's Radar, University of Central Florida News | UCF Today. Available at: https://www.ucf.edu/news/new-nasa-funded-study-hopes-to-put-risks-of-space-junk-on-peoples-radar/ (Accessed: 04 November 2024).

[254]NASA (2024) Spacecraft to remove orbital debris, NASA. Available at: https://technology.nasa.gov/patent/MSC-TOPS-90 (Accessed: 04 November 2024).

[255]World Economic Forum (2024a) The path forward for sustainable space exploration, World Economic Forum. Available at: https://www.weforum.org/agenda/2024/07/sustainable-space-exploration-path-forward/ (Accessed: 04 November 2024).

and significantly reduce the risk of collisions, ensuring the long-term sustainability of space activities.

III. Mandatory Full-coverage Insurance Requirements

As the number of satellites in orbit continues to grow, the need for comprehensive insurance coverage for satellite operators becomes increasingly important. Countries considering laws for mandatory insurance requirements must weigh several factors. Full coverage insurance, beyond just third-party liability, would encompass risks associated with the satellite's entire lifecycle, including pre-launch, launch, in-orbit operations, and decommissioning. This holistic approach ensures that satellite operators are financially protected against a wide range of potential incidents, from launch failures to in-orbit collisions and even space debris damage.

One of the primary advantages of mandatory full coverage insurance is the enhanced financial security it provides to satellite operators. By covering all potential risks, operators can mitigate the financial impact of unforeseen events, ensuring business continuity and stability[256]. This is particularly important for smaller companies and startups that may not have the financial resilience to absorb significant losses. Additionally, comprehensive insurance can foster greater investor confidence, encouraging more investment in the space sector and promoting innovation and growth.

Moreover, mandatory full coverage insurance can contribute to better risk management practices within the industry. Insurance companies, in their role as risk assessors, would likely impose stringent safety and operational standards on satellite operators to minimize potential claims. This could lead to improved design, manufacturing, and operational

[256]Zisk, R. (2022) The Space Insurance Landscape, Payload. Available at: https://payloadspace.com/the-space-insurance-landscape/ (Accessed: 04 November 2024).

procedures, ultimately enhancing the overall safety and reliability of space missions[257]. In turn, this would benefit not only the insured operators but also the broader space community by reducing the likelihood of accidents and collisions.

However, there are also potential drawbacks to consider. The cost of full coverage insurance can be prohibitively high, especially for smaller operators and emerging space faring nations. Mandatory insurance requirements could create a financial barrier to entry, limiting participation in the space industry to only those with substantial financial resources[258]. This could stifle innovation and reduce the diversity of players in the market, potentially slowing the overall progress of space exploration and commercialization[259].

Another concern is the complexity of determining appropriate coverage levels and premiums. The space environment is inherently unpredictable, with risks that are difficult to quantify[260]. Insurance companies would need to develop sophisticated models to assess these risks accurately, which could lead to higher premiums and more stringent policy conditions. This complexity could also result in disputes over coverage and claims, adding an additional layer of legal and administrative challenges for satellite operators.

From a regulatory perspective, implementing mandatory full coverage insurance would require significant coordination and cooperation among international space-faring nations. Space activities are inherently global, and a fragmented regulatory approach could lead to inconsistencies and loopholes. An international framework or treaty might be necessary to

[257]StudySmarter UK (2024) Spacecraft Reliability. Available at: https://www.studysmarter.co.uk/explanations/engineering/aerospace-engineering/spacecraft-reliability/ (Accessed: 04 November 2024).

[258]Yap, J. (2023) Is the sky the limit for Space Insurance?, Landers & Rogers. Available at: https://www.landers.com.au/legal-insights-news/failure-in-orbit-planning-your-space-projects-with-space-insurance-in-mind (Accessed: 04 November 2024).

[259]Gatti, E. (2022) #SPACEWATCHGL opinion: A review of the Space Insurance Market, SpaceWatch.GLOBAL. Available at: https://spacewatch.global/2022/09/spacewatchgl-opinion-a-review-of-the-space-insurance-market/ (Accessed: 04 November 2024).

[260]OECD (2020) Space sustainability, OECD. Available at: https://www.oecd.org/en/topics/sub-issues/space-sustainability.html (Accessed: 04 November 2024).

ensure uniform standards and enforcement, which could be a lengthy and complex process to negotiate and implement.

Furthermore, there is the question of enforcement and compliance. Ensuring that all satellite operators adhere to mandatory insurance requirements would require robust monitoring and enforcement mechanisms. This could place additional burdens on regulatory bodies and necessitate the development of new oversight capabilities. Non-compliance could result in penalties or restrictions, but enforcing these measures on a global scale presents significant challenges.

While mandatory full coverage insurance for satellite operators offers substantial benefits in terms of financial security, risk management, and industry standards, it also presents notable challenges related to cost, complexity, and regulatory enforcement. Countries considering such laws must carefully balance these pros and cons to develop a framework that supports the sustainable and safe growth of the space industry. Collaborative international efforts and innovative insurance solutions will be key to addressing these challenges and ensuring the long-term viability of space activities.

IV. Collaboration and Transparency

Collaboration and transparency are pivotal in the space insurance industry, given the high stakes and complex nature of space missions. The industry encompasses a wide range of activities, from satellite launches to space tourism, each with unique risks and challenges. Effective collaboration among insurers, space agencies, and private companies ensures comprehensive risk assessments and the development of robust insurance solutions. Transparency, on the other hand, fosters trust and facilitates the sharing of critical information, which is essential for accurately assessing risks and determining premiums[261].

[261]Fiveable (2024) Transparency in decision-making, Fiveable. Available at: https://library.fiveable.me/key-terms/risk-management-insurance/claims-handling-guidelines (Accessed: 04 November 2024).

The vision for the space insurance industry is to create a resilient and adaptive framework that can support the rapid advancements in space technology and exploration[262]. This vision includes fostering innovation in insurance products to cover emerging risks, such as those associated with space debris and cyber threats that may lead to in-orbit collisions. By leveraging advanced data analytics and predictive modeling, the industry aims to provide more accurate risk assessments and tailored insurance solutions. This proactive approach not only mitigates financial risks but also supports the sustainable growth of the space sector.

Collaboration is important in order to achieve this goal. Insurers work closely with space agencies, satellite operators, and other stakeholders to understand the specific risks associated with different missions. This collaborative approach enables the development of customized insurance products that address the unique needs of each mission. Additionally, partnerships with academic institutions and research organizations help insurers stay abreast of the latest technological advancements and emerging risks in the space sector.

Transparency is equally crucial in the space insurance industry. Open communication and information sharing among all stakeholders ensure that risks are accurately assessed and managed. This includes sharing data on past incidents, near-misses, and emerging threats. Transparency also extends to the claims process, where clear and fair procedures help build trust between insurers and their clients. By fostering a culture of transparency, the industry can enhance its credibility and reliability.

The space insurance industry also plays a vital role in promoting best practices and standards in space operations. Through collaboration with regulatory bodies and international organizations, insurers help to establish guidelines and protocols that enhance the safety and sustainability of space activities. These efforts contribute to reducing the overall risk profile of the space sector, making it more attractive to investors and stakeholders.

[262]ESA (2024) Space in support for the insurance sector, ESA Commercialisation Gateway. Available at: https://commercialisation.esa.int/2021/11/space-in-support-for-the-insurance-sector/ (Accessed: 04 November 2024).

Looking ahead, the space insurance industry is poised to play a critical role in the commercialization of space. As private companies take on more ambitious projects, such as space tourism and asteroid mining, the demand for specialized insurance products will grow. The industry's vision is to support these ventures by providing innovative and flexible insurance solutions that can adapt to the rapidly changing landscape of space exploration.

In conclusion, collaboration and transparency are fundamental to the success of the space insurance industry. By working together and sharing information openly, insurers and their partners can develop effective risk management strategies that support the sustainable growth of the space sector. The industry's vision and mission are centered on fostering innovation, ensuring financial viability, and promoting best practices, all of which are essential for navigating the challenges and opportunities of the final frontier.

V. Transparency in Reporting Incidents

Encouraging transparency in reporting incidents in space is crucial for maintaining the safety and sustainability of space activities. As the number of space missions increases, so does the potential for collisions, malfunctions, and other incidents. Transparent reporting helps build trust among space-faring nations and commercial entities, fostering a collaborative environment where information is shared openly to prevent future mishaps. This transparency is essential for developing effective policies and protocols that ensure the long-term viability of space operations[263].

[263]UNDC Working Group II (2023) Recommendations to promote the practical implementation of transparency and confidence-building measures in outer space activities with the goal of preventing an arms race in outer space, in accordance with the recommendations set out in the report of the Group of Governmental Experts on Transparency and Confidence-Building Measures in Outer Space Activities. Available at: https://docs-library.unoda.org/United_Nations_Disarmament_Commission_-_(2023)/Recommendations_UNDC_WG_II_AS_ADOPTED.pdf (Accessed: 04 November 2024).

One of the primary benefits of transparency is the enhancement of space situational awareness (SSA)[264]. By openly sharing data about satellite positions, potential hazards, and incidents, space agencies and companies can better track objects in orbit and predict potential collisions[265]. This collaborative approach reduces the risk of accidents and ensures that all parties are aware of the current state of space traffic. Improved SSA can lead to more informed decision-making and timely responses to potential threats, ultimately safeguarding both human and robotic missions.

Transparency also plays a vital role in fostering international cooperation. Space is a global commons, and its sustainable use requires the participation and collaboration of all space-faring nations[266]. By committing to transparent reporting practices, countries can demonstrate their dedication to responsible space stewardship. This commitment can lead to the development of international norms and agreements that promote the peaceful use of outer space. Such agreements can help mitigate conflicts and ensure that space remains a domain for scientific exploration and commercial development.

Moreover, transparent reporting of space incidents can drive technological innovation[267]. When incidents are reported openly, the data can be analyzed to identify patterns and underlying causes. This analysis can inform the design of more resilient spacecraft and the development of advanced technologies to prevent similar incidents in the future.

---

[264]Dragonfly Aerospace (2024) 3 applications of Space Situational Awareness, Dragonfly Aerospace. Available at: https://dragonflyaerospace.com/3-uses-for-space-situational-awareness/ (Accessed: 04 November 2024).

[265]Lafleur, A. (2024) Strengthening Space Situational Awareness Through Data Sharing: World Economic Forum Briefing Paper, Space Impulse. Available at: https://spaceimpulse.com/2024/09/25/strengthening-space-situational-awareness-through-data-sharing-world-economic-forum-briefing-paper/ (Accessed: 04 November 2024).

[266]Yap, X. et al. (2023) Four alternative scenarios of commons in space: Prospects and challenges, International Journal of the Commons. Available at: https://thecommonsjournal.org/articles/10.5334/ijc.1272 (Accessed: 04 November 2024).

[267]UNOOSA (2024) Space Exploration and Innovation , Space Exploration and Innovation. Available at: https://www.unoosa.org/oosa/sk/ourwork/topics/space-exploration-and-innovation.html (Accessed: 04 November 2024).

Transparency in reporting thus not only addresses immediate safety concerns but also contributes to the long-term advancement of space technology.

In addition to technological benefits, transparency in reporting incidents can enhance public trust and support for space activities[268]. The general public often views space exploration with a mix of fascination and concern. By being open about the challenges and incidents that occur, space agencies and companies can build credibility and demonstrate their commitment to safety and accountability[269]. This transparency can help garner public support for space missions and funding, which is essential for the continued growth of the space sector.

Legal frameworks also benefit from transparent reporting practices. Clear and consistent reporting can help establish liability and accountability in the event of an incident. This is particularly important in the context of international space law, where determining responsibility for damages can be complex. Transparent reporting can provide the necessary evidence to resolve disputes and ensure that responsible parties are held accountable. This legal clarity can, in turn, encourage more responsible behavior among space actors.

Furthermore, transparency in reporting incidents can facilitate better risk management. By understanding the frequency and nature of incidents, space agencies and companies can develop more effective risk mitigation strategies. This proactive approach can reduce the likelihood of incidents and minimize their impact when they do occur. Transparent reporting thus supports a culture of continuous improvement and risk reduction in space operations.

[268]New Space Economy (2024) The importance of transparent communication in space exploration, New Space Economy. Available at: https://newspaceeconomy.ca/2024/01/15/the-importance-of-transparent-communication-in-space-exploration/ (Accessed: 04 November 2024).

[269]Jones, A. (2023) Artemis Accords signatories seek to boost transparency and safety in lunar exploration, SpaceNews. Available at: https://spacenews.com/artemis-accords-signatories-seek-to-boost-transparency-and-safety-in-lunar-exploration/ (Accessed: 04 November 2024).

VI. Towards Sustainable Space Activities

Creating sustainable space activities to reduce space debris is crucial for the future of space exploration and satellite operations. One of the primary strategies is to implement stringent space debris mitigation guidelines. These guidelines, such as those proposed by the Inter-Agency Space Debris Coordination Committee (IADC)[270], include measures like designing spacecraft to minimize debris release during normal operations and ensuring that satellites are disposed of properly at the end of their missions[271]. By adhering to these guidelines, space agencies and private companies can significantly reduce the amount of new debris generated.

Another essential approach is the development and deployment of active debris removal (ADR) technologies. These technologies aim to capture and remove existing debris from orbit. Various methods are being explored, including robotic arms, nets, harpoons, and even laser systems to nudge debris into lower orbits where it can burn up upon re-entry. Investing in and advancing these technologies will help clean up the existing clutter in space, making it safer for future missions[272].

International collaboration and policy development are also vital. Space is a global commons, and its sustainability requires cooperation among all space-faring nations. Establishing international treaties and agreements that mandate debris mitigation and removal practices can ensure that all countries contribute to maintaining a clean space environment.

---

[270] Inter-Agency Space Debris Coordination Committee. (2002). IADC Space debris mitigation guidelines (Revision 1, 2007). Retrieved from https://www.unoosa.org/documents/pdf/spacelaw/sd/IADC_space_debris_mitigation_guidelines.pdf

[271] *Id.* at 8.

[272] Lloyd's (2024) Astroscale: Mission to clean up space. Available at: https://www.lloyds.com/about-lloyds/our-market/what-we-insure/space/crowded-space/astroscale (Accessed: 04 November 2024).

Additionally, creating a global space traffic management system can help prevent collisions and manage the increasing number of satellites and debris in orbit[273].

Innovative design and engineering solutions can further enhance sustainability[274]. For instance, developing satellites with modular designs allows for easier repairs and upgrades, reducing the need to launch new satellites and thereby decreasing potential debris. Using materials that are less likely to fragment upon collision[275] and designing spacecraft with built-in deorbiting mechanisms can also help mitigate debris creation[276].

Promoting the use of sustainable propulsion systems is another key factor. Traditional chemical propulsion systems can contribute to space debris through the release of residual propellants and components. In contrast, electric propulsion systems, which use ion thrusters, are more efficient and produce less debris[277]. Encouraging the adoption of these cleaner technologies can significantly reduce the environmental impact of space activities.

Public and private sector partnerships can drive innovation and implementation of sustainable practices. Governments can incentivize private companies to develop and adopt debris mitigation technologies through grants, subsidies, and regulatory frameworks[278].

---

[273]NASA (2024) Space Traffic Management (STM) architecture, NASA Technology Transfer Program. Available at: https://technology.nasa.gov/patent/TOP2-294 (Accessed: 04 November 2024).

[274]ESA (2024) The ESA green agenda, ESA. Available at: https://www.esa.int/About_Us/Climate_and_Sustainability/The_ESA_Green_Agenda (Accessed: 04 November 2024).

[275]Noah Chemicals (2024) Conquering the Final Frontier: Navigating the Satellite Surge in Limited Space, Space race challenges in material science. Available at: https://noahchemicals.com/blog/satellites-space-race-challenges-in-material-science/ (Accessed: 04 November 2024).

[276]The Aerospace Corporation (2021) Novel satellite deorbiting method can help mitigate space debris crisis. Available at: https://aerospace.org/article/novel-satellite-deorbiting-method-can-help-mitigate-space-debris-crisis (Accessed: 04 November 2024).

[277]EDI (2016) Electric Propulsion Systems: The Future of Eco-Friendly Spaceflight, EDI Weekly: Engineered Design Insider. Available at: https://www.ediweekly.com/electric-propulsion-systems-the-future-of-eco-friendly-spaceflight/ (Accessed: 04 November 2024).

[278]Heath, V. (2024) Effective space debris mitigation norms: A review of the UN guidelines, Space Generation Advisory Council. Available at: https://spacegeneration.org/effective-space-debris-mitigation-norms-a-review-of-the-un-guidelines (Accessed: 04 November 2024).

Collaboration between public agencies and private enterprises can accelerate the development of solutions and ensure that best practices are widely adopted[279].

Education and awareness campaigns are also crucial. By raising awareness about the risks of space debris and the importance of sustainable practices, stakeholders can foster a culture of responsibility among current and future space operators. Educational programs and public outreach can help build a broad consensus on the need for sustainable space activities[280].

Finally, continuous monitoring and research are essential to adapt and improve strategies to achieve a sustainable space activity over time. Investing in advanced tracking systems to monitor space debris and conducting ongoing research into new mitigation and removal technologies[281] will ensure that the space environment remains safe and sustainable for future generations. By staying informed and proactive, the global space community can effectively address the challenges posed by space debris.

VII. Vision for a Sustainable Space Environment

The long-term vision for a safe and sustainable space environment must contain technological, regulatory, and collaborative efforts. As space activities increase, the need for sustainable practices becomes more critical. This vision aims to ensure that space remains

[279]Brown, J. and Kazel, M. (2024) Public-Private Partnerships (ppps): Definition, how they work, and examples, GOVERNMENT SPENDING. Available at: https://www.investopedia.com/terms/p/public-private-partnerships.asp (Accessed: 04 November 2024).

[280]ESA & UNOOSA (2021) ESA & UNOOSA Space Debris Infographics and podcast, ESA. Available at: https://www.esa.int/Space_Safety/Space_Debris/ESA_UNOOSA_space_debris_infographics_and_podcast (Accessed: 04 November 2024).

[281]StartUs Insights (2023) Explore 5 top space debris solutions, StartUs Insights. Available at: https://www.startus-insights.com/innovators-guide/5-top-debris-retrieval-monitoring-solutions-impacting-the-space-industry/ (Accessed: 04 November 2024).

accessible and beneficial for future generations[282], avoiding the pitfalls of orbital debris and other hazards. Key stakeholders, including space agencies, private companies, and international organizations, are working together to develop and implement strategies that promote sustainability in space.

One of the primary concerns in achieving a sustainable space environment is the mitigation of orbital debris. With thousands of satellites and other objects orbiting Earth[283], the risk of collisions and the creation of additional debris is significant. Agencies like NASA[284] and ESA[285] are investing in technologies to track and remove debris[286], as well as developing guidelines for the responsible disposal of defunct satellites[287]. These efforts are crucial in preventing the Kessler Syndrome, a scenario where the density of objects in low Earth orbit is high enough to cause a cascade of collisions[288].

In addition to debris mitigation, the long-term vision includes the promotion of a circular economy in space. This concept involves reusing and recycling materials in orbit to reduce

---

[282]UNOOSA (2024) Access to Space for All and the benefits of space, United Nations Office for Outer Space Affairs. Available at: https://www.unoosa.org/oosa/en/ourwork/access2space4all/AccSpace4All_memberstates.html (Accessed: 04 November 2024).

[283] For in-orbit satellite visualization, see: https://platform.leolabs.space/visualization

[284]NASA (2024) Spacecraft to remove orbital debris, NASA Technology Transfer Program. Available at: https://technology.nasa.gov/patent/MSC-TOPS-90 (Accessed: 04 November 2024).

[285]ESA (2019) Esa Commissions World's first space debris removal, ESA. Available at: https://www.esa.int/Newsroom/Press_Releases/ESA_commissions_world_s_first_space_debris_removal (Accessed: 04 November 2024).

[286]Capitol University (2020) Advanced technology to remove space debris from orbit, Washington D.C. & Maryland Area | Capitol Technology University. Available at: https://www.captechu.edu/blog/advanced-technology-remove-space-debris-orbit (Accessed: 04 November 2024).

[287]Foust, J. (2023) NASA study assesses costs and benefits of orbital debris removal, SpaceNews. Available at: https://spacenews.com/nasa-study-assess-costs-and-benefits-of-orbital-debris-removal/ (Accessed: 04 November 2024).

[288]Mariappan, A. and Crassidis, J.L. (2023) Kessler's Syndrome: A challenge to humanity, Frontiers. Available at: https://www.frontiersin.org/journals/space-technologies/articles/10.3389/frspt.2023.1309940/full (Accessed: 04 November 2024).

waste and the need for new resources[289]. For example, in-orbit servicing and refueling of satellites can extend their operational life, reducing the frequency of launches and the associated environmental impact[290]. The European Space Agency (ESA) is actively pursuing this approach, aiming to implement a space circular economy by 2050[291].

Regulatory frameworks play a vital role in ensuring the sustainability of space activities. The United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) has developed guidelines for the long-term sustainability of outer space activities[292]. These guidelines encourage international cooperation and the adoption of best practices to minimize risks and promote the peaceful use of space. By adhering to these guidelines, countries and organizations can contribute to a safer and more sustainable space environment.

International collaboration is essential for the success of these initiatives. Space is a global common, and its sustainability depends on the collective efforts of all space-faring nations. Collaborative projects, such as the International Space Station (ISS)[293], demonstrate the benefits of working together towards common goals. Future missions to the Moon and Mars will also require international partnerships to ensure their success and sustainability[294].

---

[289]NASA (2017) Full circle: NASA to demonstrate refabricator to recycle, Reuse, repeat, NASA. Available at: https://www.nasa.gov/missions/station/full-circle-nasa-to-demonstrate-refabricator-to-recycle-reuse-repeat/ (Accessed: 04 November 2024).

[290]Jessica (2022) Recycling in space: Wannabe or reality? Available at: https://blogs.esa.int/cleanspace/2022/01/10/recycling-in-space-wannabe-or-reality/ (Accessed: 04 November 2024).

[291]ESA (2023) ESA moves ahead with in-orbit servicing missions, ESA. Available at: https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/ESA_moves_ahead_with_In-Orbit_Servicing_missions2 (Accessed: 04 November 2024).

[292]United Nations (2024) The Guidelines in all official languages of the United Nations, Awareness-raising and capacity-building related to the implementation of the Guidelines for the Long-term Sustainability of Outer Space Activities. Available at: https://spacesustainability.unoosa.org/content/the_guidelines (Accessed: 04 November 2024).

[293]NASA (2023) International Space Station Cooperation, NASA. Available at: https://www.nasa.gov/international-space-station/space-station-international-cooperation/ (Accessed: 04 November 2024).

[294]NASA (2024) Artemis, NASA. Available at: https://www.nasa.gov/feature/artemis/ (Accessed: 04 November 2024).

Technological innovation is another cornerstone of the long-term vision for space sustainability. Advances in propulsion, materials science, and artificial intelligence can enhance the efficiency and safety of space operations[295]. For instance, autonomous spacecraft can perform complex tasks with minimal human intervention[296], reducing the risk of errors and increasing the reliability of missions. Continued investment in research and development is crucial to drive these innovations forward.

Public awareness and education are also important components of this vision. By raising awareness about the challenges and opportunities of space sustainability, stakeholders can garner support for necessary policies and initiatives. Educational programs can inspire the next generation of scientists, engineers, and policymakers to contribute to the sustainable exploration and use of space. Engaging the public in discussions about space sustainability can also foster a sense of shared responsibility for the preservation of this valuable resource[297].

Finally, the long-term vision for a safe and sustainable space environment includes the development of policies that balance economic growth with environmental protection[298]. As the commercial space sector expands, it is important to ensure that economic activities do not compromise the sustainability of space. Policies that incentivize sustainable practices and penalize harmful behaviors can help achieve this balance. By integrating sustainability into the economic framework of space activities, we can ensure that space remains a viable and valuable domain for future generations.

---

[295]NASA (2024) Advanced in-space propulsion (AISP), NASA. Available at: https://www.nasa.gov/directorates/stmd/game-changing-development-program/advanced-in-space-propulsion-aisp/ (Accessed: 04 November 2024).

[296]Castano, R. et al. (2022) Operations for autonomous spacecraft. Available at: https://ai.jpl.nasa.gov/public/documents/papers/castano-etal-AERO2022.pdf (Accessed: 04 November 2024).

[297]ESA (2024) Clean space days, Indico at ESA / ESTEC (Indico). Available at: https://indico.esa.int/event/516/timetable/?view=standard_inline_minutes (Accessed: 04 November 2024).

[298]Cohen, S. (2020) Economic Growth and Environmental Sustainability, State of the Planet. Available at: https://news.climate.columbia.edu/2020/01/27/economic-growth-environmental-sustainability/ (Accessed: 04 November 2024).

VIII. Role of Insurance for the Future of Space

Insurance has a big role in shaping the future of space, particularly as humanity's ambitions in outer space continue to expand. Space insurance provides a financial safety net for various space activities, including satellite launches, space tourism, and even potential human settlements on other planets. By mitigating the financial risks associated with these high-stakes ventures, insurance enables companies and governments to pursue innovative projects with greater confidence. This financial protection is crucial for fostering a sustainable and thriving space industry.

One of the primary ways insurances can make space safer is by encouraging the adoption of best practices and advanced technologies. Insurers often require rigorous risk assessments and adherence to safety protocols before providing coverage[299]. This incentivizes space companies to invest in reliable technologies and robust safety measures, reducing the likelihood of accidents and failures. As a result, the overall safety of space missions improves, which can lead to lower insurance premiums over time.

Moreover, insurance can drive innovation in risk management and mitigation strategies. For instance, the development of more accurate predictive models for space weather[300] and debris tracking[301] can help insurers better assess and price risks. These advancements not only benefit the insurance industry but also enhance the safety and reliability of space operations. By fostering a culture of continuous improvement and innovation, insurance can contribute to a safer and more sustainable space environment.

---

[299]Monetary Authority of Singapore (2013) GUIDELINES ON RISK MANAGEMENT PRACTICES FOR INSURANCE BUSINESS . Available at: https://www.mas.gov.sg/-/media/MAS/Regulations-and-Financial-Stability/Regulatory-and-Supervisory-Framework/Risk-Management/Risk-Management-Guidelines_Insurance-Core-Activities.pdf (Accessed: 04 November 2024).

[300]Natras, R. and Smith, M. (2021) Machine Learning Model Development for Space Weather Forecasting in the Ionosphere. Available at: https://ceur-ws.org/Vol-3052/short10.pdf (Accessed: 04 November 2024).

[301] To see debris tracking, see also: https://app.keeptrack.space/

The reduction of insurance premiums is another significant benefit of improved safety and risk management. As space missions become safer and more predictable, the likelihood of costly accidents decreases. This reduction in risk can lead to lower insurance premiums[302], making space activities more affordable for a broader range of participants. Lower premiums can also attract new entrants to the space industry, further driving innovation and growth.

In addition to financial protection and risk management, insurance plays a crucial role in addressing the legal and regulatory aspects of space activities. Space law, including treaties and national regulations, often requires operators to have adequate insurance coverage to protect against third-party liabilities[303]. This ensures that victims of space-related accidents, such as satellite collisions, can receive compensation. By providing a legal framework for accountability and compensation, insurance supports the responsible and sustainable use of outer space.

The evolving landscape of space activities, including the rise of commercial spaceflight and space tourism[304] also presents new challenges and opportunities for the insurance industry. Insurers must adapt to these emerging risks by developing innovative products and coverage options. For example, insurance policies tailored to mega-constellations can address the unique risks associated[305], compared to insuring a singular satellite. By staying ahead of industry trends and anticipating future needs, insurance can continue to play a vital role in the growth and sustainability of the space sector.

Collaboration between insurers, space companies, and regulatory bodies is essential for the continued development of effective space insurance solutions. By working together, these

[302]Insurance Ireland (2024) Understanding insurance premiums, Understanding Insurance. Available at: https://www.understandinginsurance.ie/understanding-insurance-premiums (Accessed: 04 November 2024).

[303] See chapter II.vi

[304] Bensoussan, Denis, "Space Tourism Risks: A Space Insurance Perspective" (2010) 66 Acta Astronautica 1633.

[305]Zajac, M. (2017) Overview of Space Insurance, SCOR. Available at: https://www.scor.com/en/expert-views/overview-space-insurance (Accessed: 04 November 2024).

stakeholders can share knowledge, develop best practices, and create standardized frameworks for risk assessment and management. This collaborative approach can lead to more comprehensive and reliable insurance products, further enhancing the safety and sustainability of space activities.

The role of insurance in the future of space is indispensable. By providing financial protection, promoting safety and innovation, reducing premiums, and supporting legal and regulatory frameworks, insurance enables the sustainable growth of space activities. As humanity's presence in outer space continues to expand, the insurance industry will remain a critical partner in ensuring that these ventures are safe, responsible, and economically viable.

VII

Conclusion

I. Summary of Findings

Space insurance typically covers the insured's own spacecraft against physical loss or damage during various phases, including pre-launch, launch, and in-orbit operations, categorized as first-party insurance. Meanwhile, third-party liability insurance covers damages caused to third parties, such as bodily injury or property damage resulting from the insured's space activities. The main risks of space activities include launch failures, in-orbit collisions, and re-entry risks. While launch failures and the risk of re-entry impacts the surface of the earth, in-orbit collisions impact the safety of the orbit of the earth, risking its sustainability and future space missions.

Space insurance is a specialized form of coverage designed to protect satellite operators and other stakeholders from financial losses due to various risks associated with space operations, including in-orbit collisions. As the number of satellites and debris in low Earth orbit (LEO) increases, the potential for collisions rises significantly, leading to greater importance for space insurance. Insurers assess the likelihood of collisions based on data from space situational awareness (SSA) systems that catalog objects in orbit. As collision probabilities rise, the cost of insurance may also increase due to heightened risk assessments. Current active debris removal technologies are not yet developed enough to effectively mitigate the problem on a large scale, leaving many pieces of debris floating in orbit indefinitely.

The relationship between space insurance and in-orbit collisions is increasingly significant as the number of satellites in LEO continues to grow. Enhanced monitoring systems, a clearer liability framework, and proactive risk management strategies will be essential for satellite

operators to navigate the complexities of space operations while minimizing financial risks associated with potential collisions.

Current international space law lacks clear liability guidelines for damages caused by on-orbit collisions. There is a proposal for a liability regime where satellite operators would be held responsible for the debris they create, thus incentivizing adherence to debris mitigation practices. This framework could lead to more comprehensive insurance policies that reflect the operator's responsibility for collision risks.

By linking liability with insurance coverage, operators may be encouraged to invest in technologies that minimize debris creation and enhance collision avoidance strategies. This could include adopting best practices for satellite design and end-of-life disposal. Operators must integrate collision risk assessments into their operational protocols. Insurance providers may require detailed risk management plans as part of the underwriting process, which can influence operational decisions regarding satellite maneuvers and maintenance. As regulatory bodies push for stricter compliance with debris mitigation guidelines, operators who fail to adhere may face higher insurance premiums or difficulty obtaining coverage altogether.

In recent years, there have been numerous high claims exceeding revenue from premiums, leading to a dramatic space insurance policy rate hike. The small number of insurable satellites compared to other industries like aviation complicates risk assessment. This limited statistical pool makes it harder for insurers to accurately evaluate risks. Rapid technological advancements also introduce new uncertainties. Underwriters prefer reliable equipment, but innovative designs and untested technologies complicate risk evaluation. Problems like ITAR restrictions also leaves underwriters in the dark, being unable to give out accurate risk calculations.

High-profile satellites incidents and failures have resulted in substantial losses, prompting insurers to reevaluate their risk appetites and capacities. Some insurers have withdrawn from the market entirely. Despite these challenges, the space insurance market is evolving. Technological innovations aimed at in-orbit servicing (IOS), such as docking mechanisms and robotic manipulators, hold promise for reducing claims costs and stabilizing the market.

Insurers are adapting by focusing on detailed risk information and requiring strong risk management policies from operators. Building long-term relationships with insurers and providing transparent risk management strategies can improve coverage options. While the space insurance market is volatile and faces numerous challenges, it is not becoming uninsurable. Instead, it is undergoing transformations to address these issues, leveraging technological advancements to stabilize and strengthen the market.

The accumulation of space debris poses significant challenges to the viability of space insurance, but it does not necessarily mean that space will become uninsurable entirely. However, the increasing risk associated with debris accumulation could lead to higher premiums or more stringent underwriting requirements for satellite operators and space-related activities.

Lack of binding international regulations for mitigating space debris hinders effective control over the problem. Guidelines and best practices exist but are not universally enforced, contributing to ongoing concerns. Despite these challenges, the space industry is exploring solutions through advanced technologies and policy reforms. For instance, initiatives focused on designing satellites with deorbiting capabilities and implementing stringent safety standards aim to reduce the risk associated with space debris.

Ongoing efforts to develop better tracking systems, removal technologies, and more efficient deorbiting methods could help manage the debris problem effectively, thereby stabilizing the insurance landscape. Strengthened international cooperation and binding regulations could encourage more responsible behavior from satellite operators, reducing the overall burden on insurers and making space activities more sustainable.

While the accumulation of space debris poses significant risks that could impact insurance costs and availability, it does not necessarily mean that all forms of space-related activity will become uninsurable. Instead, insurers are likely to adjust their strategies by requiring better risk management practices from operators and investing in technologies aimed at mitigating these risks.

International treaties like the Liability Convention dictate that launching states are absolutely liable for damage caused by their space objects on Earth or to aircraft in flight. While in-orbit collisions follow a fault-based liability regime, determining fault can be complex and may require minimum negligence standards. The lack of clear regulations regarding liability for damages caused by space debris or collisions creates uncertainty. This ambiguity affects insurers' ability to fully mitigate risks associated with these events.

Despite technological advancements aimed at mitigating collision risks through active debris avoidance mechanisms and deorbiting capabilities, there is still no foolproof method to prevent all potential collisions entirely. In summary, while space insurance provides critical financial protection against losses resulting from in-orbit collisions, it does not completely solve the underlying liability issues due to regulatory gaps, technical limitations, and the complexity of assigning fault in such incidents. Comprehensive solutions will likely involve a combination of advanced technologies, robust international regulations, and collaborative efforts among stakeholders to ensure safer operations in space.

II. Future Research

The evolving landscape of space insurance presents a unique set of challenges and opportunities that necessitate comprehensive research. As the number of satellites and space activities increase, so does the complexity of risks associated with these endeavors. Future research must focus on several key areas to ensure that the space insurance market adapts effectively to these changes.

One of the foremost areas for future research is the development of robust space policies that address the increasing congestion in near-Earth orbits. Policymakers need to establish clear guidelines that govern satellite launches, operations, and end-of-life disposal to mitigate risks associated with space debris. Future research should explore how existing international treaties can be adapted to enforce compliance with best practices in debris mitigation. This will require collaboration between governments, international

organizations, and private stakeholders to create a unified approach to space governance, and probably to achieve customary international law on space debris mitigation.

The role of industry stakeholders in shaping the future of space insurance cannot be overstated. Research should investigate how satellite operators, launch service providers, and insurers can work together to develop innovative risk management strategies. This includes exploring partnerships that leverage technology for real-time tracking and collision avoidance systems. Engaging industry stakeholders in discussions about shared responsibilities and risk-sharing mechanisms can lead to more sustainable practices that benefit all parties involved.

Academia has a crucial role in advancing knowledge about space insurance through interdisciplinary research. Future studies should focus on developing predictive models that assess risks associated with satellite operations and space debris. This research can provide valuable insights into how insurers can better price their products and manage their portfolios. Additionally, academic institutions can facilitate workshops and conferences to promote dialogue between insurers, policymakers, and industry leaders, fostering a collaborative environment for knowledge exchange.

Legal frameworks governing space activities must evolve to address the complexities introduced by commercial space ventures. Future research should analyze existing national laws and international agreements to identify gaps that may hinder effective risk management in the context of space insurance. Proposals for legal reforms could include establishing liability frameworks that clearly define responsibilities for damages caused by satellite collisions or debris. Such reforms would provide clarity for insurers and operators alike while promoting accountability in space activities.

As the space industry grows, so does the need for innovative insurance products tailored to specific risks associated with various missions. Research should focus on developing new insurance models that incorporate advanced technologies such as artificial intelligence and satellite data analytics. This approach could enhance transparency and efficiency in claims processing while providing customized coverage options for clients.

The increasing threat posed by space debris requires urgent attention from researchers in the field of space insurance. Future studies should evaluate the effectiveness of current debris mitigation strategies and explore new technologies that could enhance tracking capabilities or facilitate active debris removal. Insurers need comprehensive data on debris risks to adjust their pricing models accordingly. Research could also investigate how insurers might incentivize operators to adopt better debris management practices through premium discounts or other financial mechanisms.

Given the global nature of space activities, international collaboration is essential for addressing shared challenges related to space insurance. Research should explore frameworks for data sharing among nations regarding satellite tracking and collision avoidance efforts. Collaborative initiatives could lead to standardized practices that enhance safety across borders while also improving risk assessment methodologies used by insurers. Such partnerships can foster a culture of responsibility among nations engaged in space exploration.

Future research on space insurance must encompass an approach involving policy development, stakeholder engagement, academic contributions, legal reforms, innovative product design, debris management strategies, international collaboration, and more. By addressing these areas comprehensively, the space insurance industry can evolve alongside the rapidly changing landscape of space activities, ensuring both sustainability and safety for future generations of explorers and innovators in outer space.

III. Alternative to Space Insurance

Traditional models of space insurance, while effective to some extent, may not adequately address the complexities and scale of modern space activities. In this context, the idea of a

space liability fund[306] emerges as a promising alternative, offering a sustainable and collective approach to managing liabilities arising from space operations. A space liability fund is envisioned as a permanent financial resource designed to compensate victims of damages caused by space activities. Unlike conventional space insurance, which is often temporary and linked to specific missions, and in some countries are optional to the space operator or launcher, a liability fund would operate continuously, accumulating contributions from various space actors over time. This ensures that funds are readily available for potential claims, providing a safety net for those affected by accidents or incidents in outer space.

The fundamental premise of a space liability fund is one of collective responsibility. All contributors share the burden of liabilities incurred by individual space activities, fostering a sense of community and mutual support among operators. This contrasts sharply with traditional insurance models, which emphasize individual responsibility for securing coverage. By pooling resources, the fund can provide more robust protection against the financial repercussions of space-related damages.

Space liability fund could implement a funding mechanism based on contributions from space operators. These contributions might be calculated as a percentage of profits generated from their activities, ensuring that those who benefit from the commercial opportunities in space also contribute to mitigating the risks associated with those activities. This model mirrors existing structures in other high-risk industries, such as nuclear energy, where collective funding mechanisms have proven effective in managing liabilities.

The concept of a space liability fund draws inspiration from established liability regimes around the world. The Price-Anderson Act in the United States[307] which was passed in 1957, provides a framework for compensating victims of nuclear incidents through a dedicated

[306]Bhat, S. (2020) Space liability insurance: Concerns and way forward, Athens Journal of Law - Volume 6, Issue 1, January 2020 – Pages 37-50. Available at: https://www.athensjournals.gr/law/2020-6-1-2-Bhat.pdf (Accessed: 04 November 2024).

[307] US Department of Energy (2023) Price-Anderson Act | Department of Energy. Available at: https://www.energy.gov/gc/price-anderson-act (Accessed: 04 November 2024).

fund. The establishment of a space liability fund offers several significant benefits. First and foremost, it increases protection for victims of space disasters by ensuring that compensation is available regardless of an individual operator's insurance status and claims process. This is particularly important in an industry where accidents can have catastrophic consequences and where determining fault can be complex. By providing a reliable mechanism for addressing liabilities, it alleviates some regulatory burdens on individual operators while promoting safety and accountability in outer space operations. This collective approach encourages responsible behavior among operators, as they are incentivized to contribute to the fund and mitigate risks collaboratively.

The concept of a space liability fund represents an innovative approach to addressing the complexities of liability in an era marked by increasing commercial involvement in outer space. By promoting collective responsibility and providing permanent financial resources for compensation, such a fund could enhance safety and accountability of the whole space industry while alleviating pressures on the individual operators. As we continue to explore new frontiers in space, adopting mechanisms like a liability fund will be essential and an alternative to space insurance that can manage risks effectively and protect both operators and those impacted by their activities.

Bibliography

International Treaties

Convention on International Liability for Damage Caused by Space Objects, 29 March 1972, 961 UNTS 187.

Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, 27 January 1967, 610 UNTS 205

Vienna Convention on the Law of Treaties, 23 May 1969, 1155 UNTS 331.

National Laws

51 U.S.C. § 50914 (2015) (United States of America)

Act on Compensation for Damage Caused by Space Objects, Act. No. 8714, Dec. 21, 2007, amended by Act No. 8852, Feb. 29, 2008, art. 4 (South Korea)

Act on Space Activities 63/2018 (Finland)

Space (Launches and Returns) Act of 2018 (Australia)

Space Act of 2011 (Austria)

Space Activities Act of 2024 (Brazil)

Space Agency Act (Canada)

EU Regulation 2021/696 (European Union)

Federal Decree Law No. 46 of 2023 (United Arab Emirates)

Federal Law No. 5663-1 on Space Activity (Russia)

Space Operations Act of 2008 (France)

Space Act No. 21/2013 (Indonesia)

Space Economy Law of 2024 (Italy)

Law on Space Activities 1982:963 (Sweden)

Law No. 50 of 1969 (Japan)

Law of 20 July 2017 on the Exploration and Use of Space Resources (Luxembourg)

Law on Space Activities, 528-IV (Kazakhstan)

Law on Space Activities 1982:963 (Sweden)

Law of 17 September 2005 on the Activities of Launching, Flight Operation or Guidance of Space Objects (Belgium)

Measures for the Administration of Registration Space Objects, PRC Nat'l Def. Sci. & Tech. Indus. Comm. and PRC Ministry of Foreign Affairs, Feb. 8, 2001 (China)

National Decree No 995/91 (1991) (Argentina)

Order by the Minister of Economic Affairs, no. WJZ/15055654 (2015) (Netherlands)

Ordinance of the Supreme Soviet of Ukraine, On Space Activity Law of Ukraine of 15 November 1996 (VVRU, 1997) (Ukraine)

Outer Space Act 1986, c. 38 (United Kingdom)

Outer Space Act, Lov nr. 409 af 11.5.2016 (Denmark)

Outer Space and High-Altitude Activities Act 2017 (New Zealand)

Presidency of the Council of Ministers, Decree Law no. 16/2019 (Portugal)

Royal Decree 158/2023 on Spanish Space Agency (Spain)

Space Act of 1969 (Norway)

Space Affairs Act 84 of 1993 § 14 (South Africa)

Space Agency Law of 1983 (Israel)

Articles, Books, Journals, Websites

Adams, K. et al. (2021) Using the terms 'negligence' and 'gross negligence' in a contract, Adams on Contract Drafting. Available at: https://www.adamsdrafting.com/negligence-and-gross-negligence/ (Accessed: 04 November 2024).

Aerospace (2019) Launch mission success: The Aerospace Corporation, Aerospace Corporation. Available at: https://aerospace.org/getting-it-right/jun-2019/launch-mission-success (Accessed: 04 November 2024).

Alhamed, M. et al. (2022) Loopholes and lacunae in International Space Law, OxJournal. Available at: https://www.oxjournal.org/loopholes-lacunae-space-law/ (Accessed: 04 November 2024).

Annamaria, N. and Valerio, R. (2013) Needs of an international policy and regulation framework for orbital debris mitigation systems, Thales Alenia Space Italy. Available at: https://conference.sdo.esoc.esa.int/proceedings/sdc6/paper/84/SDC6-paper84.pdf (Accessed: 04 November 2024).

Aoki, S. (2012) The Standard of Due Diligence in Operating a Space Object, International Institute of Space Law. Available at: https://www.elevenjournals.com/tijdschrift/iisl/2012/3%20The%20International%20Legal%20Regulation%20of%20Outer%20Space%20within%20the%20Scope%20of%20Public%20International%20Law/IISL_2012_055_003_002 (Accessed: 04 November 2024).

AON (2016) Insuring space activities. Available at: https://www.aon.com/russia/files/Insuring_Space_Activities_whitepaper.pdf (Accessed: 04 November 2024).

AON (2024) Space Insurance and Risk Management, Aon. Available at: https://www.aon.com/en/capabilities/risk-transfer/space-insurance-and-risk-management (Accessed: 04 November 2024).

APSCO (2024) Asia-Pacific Space Cooperation Organization. Available at: http://www.apsco.int/ (Accessed: 06 November 2024).

Araullo, K. (2024) Applied underwriters expands into Space Insurance Market, Insurance Business America. Available at: https://www.insurancebusinessmag.com/us/news/breaking-news/applied-underwriters-expands-into-space-insurance-market-510368.aspx (Accessed: 04 November 2024).

Arroyo-Parejo, C., Sanchez-Ortiz, N. and Dominguez-Gonzalez, R. (2021) Effect of Mega-constellations on Collision Risk in Space, ESOC Conference Proceedings. Available at: https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/246/SDC8-paper246.pdf (Accessed: 04 November 2024).

ASA (2007) GUIDE TO SPACE DEBRIS, ASA Guide to Space Debris. Available at: https://www.spaceacademy.net.au/watch/debris/debris.htm (Accessed: 04 November 2024).

Assmann, K., Berger, J. and Grothkopp, S. (1970) The Cola Collision Avoidance Method, ESA Proceedings Database. Available at: https://conference.sdo.esoc.esa.int/proceedings/sdc5/paper/68 (Accessed: 04 November 2024).

Atlas Magazine (2007) Space insurance, Insurance News Around the World. Available at: https://www.atlas-mag.net/en/article/space-insurance#:~:text=The%20first%20indemnification%20of%20a%20claim%20dates%20b

ack,industries%20triggered%20the%20manufacture%20of%20satellites%20and%20launchers. (Accessed: 04 November 2024).

AXA (2024) Space insurance, Insurance for Space Industry and Telecommunications | AXA XL. Available at: https://axaxl.com/insurance/products/space-insurance (Accessed: 04 November 2024).

Bahareh Afshinpour, Roland Groz, Massih-Reza Amini. Telemetry-based Software Failure Prediction by Concept-space Model Creation. 2022 IEEE 22nd International Conference on Software Quality, Reliability and Security, Dec 2022, Guangzhou, China. pp.199, 10.1109/QRS57517.2022.00030. hal 03964083

Banton, C. (2021) Reinsurance explained: What it is, how it works, types, Investopedia. Available at: https://www.investopedia.com/ask/answers/08/reinsurance.asp (Accessed: 04 November 2024).

Beinsure (2024) Space & Satellite Insurance: Risk covering from pre-launch to operation in orbit - beinsure, Beinsure Media - Insurance, Reinsurance, InsurTech Insights. Available at: https://beinsure.com/space-satellite-insurance-risk-covering-from-pre-launch-to-operation-in-orbit/ (Accessed: 04 November 2024).

Ben-Itzhak, S. (2022) The future of space technology and how it may benefit Humanity, Perry World House. Available at: https://global.upenn.edu/sites/default/files/perry-world-house/space-ben-itzhakthoughtpiece.pdf (Accessed: 04 November 2024).

Bensoussan, Denis, "Space Tourism Risks: A Space Insurance Perspective" (2010) 66 Acta Astronautica 1633.

Berenguer, R. (2024) Satellite Insurance – an introductory guide, Insurance Business America. Available at: https://www.insurancebusinessmag.com/us/guides/satellite-insurance--an-introductory-guide-174465.aspx (Accessed: 04 November 2024).

Bhat, S. (2020) Space liability insurance: Concerns and way forward, Athens Journal of Law - Volume 6, Issue 1, January 2020 – Pages 37-50. Available at: https://www.athensjournals.gr/law/2020-6-1-2-Bhat.pdf (Accessed: 04 November 2024).

Blimline, B. (2024) The evolution and future of Space Insurance, Todays Insurance Professional. Available at: https://blog.internationalinsuranceprofessionals.org/the-evolution-and-future-of-space-insurance/ (Accessed: 04 November 2024).

Boccardo, G. (2018) Planetary protection obligations of states pursuant to the space treaties and with special emphasis on National Legislations provisions, GlobaLex | Foreign and International Law Research. Available at: https://www.nyulawglobal.org/globalex/planetary_protection_obligations_states1.html (Accessed: 04 November 2024).

Boley, A.C. and Byers, M. (2021) Satellite mega-constellations create risks in low Earth orbit, the atmosphere and on Earth, Nature News. Available at: https://www.nature.com/articles/s41598-021-89909-7 (Accessed: 04 November 2024).

Bongers, A. and Torres, J.L. (2024) Low-earth orbit faces a spiraling debris threat, Scientific American. Available at: https://www.scientificamerican.com/article/low-earth-orbit-faces-a-spiraling-debris-threat/ (Accessed: 04 November 2024).

Bourbonniere, M., (2016) Space Debris Mitigation and Liability: A Comparative Analysis.

Britannica (2024) Liability, Encyclopædia Britannica. Available at: https://www.britannica.com/dictionary/liability (Accessed: 04 November 2024).

Britannica (2024) Outer Space Treaty, Encyclopædia Britannica. Available at: https://www.britannica.com/event/Outer-Space-Treaty (Accessed: 04 November 2024).

Britannica (2024) Roskosmos, Encyclopædia Britannica. Available at: https://www.britannica.com/topic/Roskosmos (Accessed: 04 November 2024).

Brown, J. and Kazel, M. (2024) Public-Private Partnerships (ppps): Definition, how they work, and examples, GOVERNMENT SPENDING. Available at: https://www.investopedia.com/terms/p/public-private-partnerships.asp (Accessed: 04 November 2024).

BSR (2024) Sustainability in space: The next frontier: Emerging issues: Sustainable business network and consultancy. Available at: https://www.bsr.org/en/emerging-issues/sustainability-in-space-the-next-frontier (Accessed: 04 November 2024).

Bushnell, D. M. (2021). Futures of Deep Space Exploration, Commercialization, and Colonization: The Frontiers of the Responsibly Imaginable. NASA Technical Memorandum.

Butterworth-Hayes, P. and Beechener, J. (2023) Low Earth Orbit 'at risk of experiencing multiple collisions' as satellite numbers increase, Unmanned airspace. Available at: https://www.unmannedairspace.info/commentary/low-earth-orbit-at-risk-of-experiencing-multiple-collisions-as-satellite-numbers-increase/ (Accessed: 04 November 2024).

Byers M, Boley A. Mega-constellations and International Law. In: Who Owns Outer Space?: International Law, Astrophysics, and the Sustainable Development of Space. Cambridge Studies in International and Comparative Law. Cambridge University Press; 2023:77-113.

Capitol University (2020) Advanced technology to remove space debris from orbit, Washington D.C. & Maryland Area | Capitol Technology University. Available at: https://www.captechu.edu/blog/advanced-technology-remove-space-debris-orbit (Accessed: 04 November 2024).

Castano, R. et al. (2022) Operations for autonomous spacecraft. Available at: https://ai.jpl.nasa.gov/public/documents/papers/castano-etal-AERO2022.pdf (Accessed: 04 November 2024).

Chen, Z. et al. (2023) Reliability Analysis and redundancy design of satellite communication system based on a novel Bayesian Environmental Importance, Reliability Engineering & System Safety. Available at:

https://www.sciencedirect.com/science/article/abs/pii/S0951832023007275 (Accessed: 04 November 2024).

Clyde & Co (2024) Space law and arbitration: Dispute Resolution Mechanisms for space-related disputes, Clyde & Co LLP. Available at: https://www.clydeco.com/en/insights/2024/03/overview-of-dispute-resolution-mechanisms-for-spac (Accessed: 04 November 2024).

Cohen, S. (2020) Economic Growth and Environmental Sustainability, State of the Planet. Available at: https://news.climate.columbia.edu/2020/01/27/economic-growth-environmental-sustainability/ (Accessed: 04 November 2024).

Competition & Markets Authority (2020) Regulation and competition report. Available at: https://assets.publishing.service.gov.uk/media/5e184a9940f0b65dbfbc1c4b/Regulation_and_Competition_report_-_web_version.pdf (Accessed: 04 November 2024).

Convention on International Liability for Damage Caused by Space Objects. (1972). Open for signature March 29, 1972, 961 U.N.T.S. 187. Article IX.

COPUOS (2024) United Nations Office for Outer Space Affairs, 2024 Session. Available at: https://www.unoosa.org/oosa/en/ourwork/copuos/index.html (Accessed: 04 November 2024).

COPUOS (2024) United Nations Office for Outer Space Affairs, COPUOS 2024. Available at: https://www.unoosa.org/oosa/en/ourwork/copuos/2024/index.html (Accessed: 04 November 2024).

CORDIS (2013) Final report summary - revus (reducing the vulnerability of space systems): FP7: CORDIS: European Commission, CORDIS. Available at: https://cordis.europa.eu/project/id/262156/reporting/de (Accessed: 04 November 2024).

CRC Group (2022) New War & Terrorism Exclusions Complicate Cyber Market , Wholesale & Specialty Insurance . Available at: https://www.crcgroup.com/Tools-Intel/post/new-war-terrorism-exclusions-complicate-cyber-market (Accessed: 04 November 2024).

Davis, J., Mayberry, J. and Penn, J. (2019) ON-ORBIT SERVICING: INSPECTION, REPAIR, REFUEL, UPGRADE, AND ASSEMBLY OF SATELLITES IN SPAC, Aerospace. Available at: https://aerospace.org/sites/default/files/2019-05/Davis-Mayberry-Penn_OOS_04242019.pdf (Accessed: 04 November 2024).

Dennerley, J. (2018), State Liability for Space Object Collisions: The Proper Interpretation of 'Fault' for the Purposes of International Space Law, European Journal of International Law, Volume 29, Issue 1, February 2018, Pages 281–301, https://doi.org/10.1093/ejil/chy003

Dowling, S. (2023) What are the odds of a successful space launch?, BBC News. Available at: https://www.bbc.com/future/article/20230518-what-are-the-odds-of-a-successful-space-launch (Accessed: 04 November 2024).

Dragonfly Aerospace (2024) 3 applications of Space Situational Awareness, Dragonfly Aerospace. Available at: https://dragonflyaerospace.com/3-uses-for-space-situational-awareness/ (Accessed: 04 November 2024).

Earnix (2024) Top six benefits of automated underwriting system in insurance. Available at: https://earnix.com/blog/what-are-the-top-six-benefits-of-an-automated-underwriting-system-in-insurance/ (Accessed: 04 November 2024).

EDI (2016) Electric Propulsion Systems: The Future of Eco-Friendly Spaceflight, EDI Weekly: Engineered Design Insider. Available at: https://www.ediweekly.com/electric-propulsion-systems-the-future-of-eco-friendly-spaceflight/ (Accessed: 04 November 2024).

Enzian, A. (2024) Space and satellite insurance solutions: Munich re, Space and satellite insurance solutions | Munich Re. Available at: https://www.munichre.com/en/solutions/for-industry-clients/space-and-satellite-insurance-solutions.html (Accessed: 04 November 2024).

ERGO (2017) GENERAL TERMS AND CONDITIONS OF INSURANCE CONTRACTS TI.0175.17. Available at: https://www.ergo.ee/fs-files/0000/0000/0002/files/Ravi_Yldtingimused_ENG%20al%2001.11.2017.pdf (Accessed: 04 November 2024).

Erhart, L. (2023) Private parties in Space Law, Space Arbitration Association. Available at: https://space-arbitration.com/private-parties-in-space-law/ (Accessed: 04 November 2024).

Erhart, L. and Boutovitskai, M. (2021) Transforming Article VI Of The Outer Space Treaty Into An Effective Mechanism Of Space Debris Mitigation, ESOC Proceedings. Available at: https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/223/SDC8-paper223.pdf (Accessed: 04 November 2024).

ESA (2004) Surviving extreme conditions in space, ESA. Available at: https://www.esa.int/Science_Exploration/Space_Science/Extreme_space/Surviving_extreme_conditions_in_space (Accessed: 04 November 2024).

ESA (2015) End-of-life disposal of satellites. Available at: https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/End-of-life_disposal_of_satellites (Accessed: 06 November 2024).

ESA (2019) Esa Commissions World's first space debris removal, ESA. Available at: https://www.esa.int/Newsroom/Press_Releases/ESA_commissions_world_s_first_space_debris_removal (Accessed: 04 November 2024).

ESA (2020) Space surveillance and tracking - SST segment, Space Safety. Available at: https://www.esa.int/Space_Safety/Space_Surveillance_and_Tracking_-_SST_Segment (Accessed: 04 November 2024).

ESA (2023) ESA moves ahead with in-orbit servicing missions, ESA. Available at: https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/ESA_moves_ahead_with_In-Orbit_Servicing_missions2 (Accessed: 04 November 2024).

ESA (2024) About space debris, ESA. Available at: https://www.esa.int/Space_Safety/Space_Debris/About_space_debris (Accessed: 04 November 2024).

ESA (2024) Active debris removal, ESA. Available at: https://www.esa.int/Space_Safety/Space_Debris/Active_debris_removal (Accessed: 04 November 2024).

ESA (2024) Artificial Intelligence in space, ESA. Available at: https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Artificial_intelligence_in_space (Accessed: 04 November 2024).

ESA (2024) Clean space days, Indico at ESA / ESTEC (Indico). Available at: https://indico.esa.int/event/516/timetable/?view=standard_inline_minutes (Accessed: 04 November 2024).

ESA (2024) How many space debris objects are currently in orbit?, ESA. Available at: https://www.esa.int/Space_Safety/Clean_Space/How_many_space_debris_objects_are_currently_in_orbit (Accessed: 04 November 2024).

ESA (2024) Hypervelocity impacts and protecting spacecraft, ESA. Available at: https://www.esa.int/Space_Safety/Space_Debris/Hypervelocity_impacts_and_protecting_spacecraft (Accessed: 04 November 2024).

ESA (2021) The impact of Space Debris, ESA. Available at: https://www.esa.int/ESA_Multimedia/Images/2021/03/The_impact_of_space_debris (Accessed: 06 November 2024).

ESA (2024) Space in support for the insurance sector, ESA Commercialisation Gateway. Available at: https://commercialisation.esa.int/2021/11/space-in-support-for-the-insurance-sector/ (Accessed: 04 November 2024).

ESA (2024) Space situational awareness - SSA, ESA. Available at: https://www.esa.int/About_Us/ESAC/Space_Situational_Awareness_-_SSA (Accessed: 04 November 2024).

ESA (2024) The ESA green agenda, ESA. Available at: https://www.esa.int/About_Us/Climate_and_Sustainability/The_ESA_Green_Agenda (Accessed: 04 November 2024).

ESA & UNOOSA (2021) ESA & UNOOSA Space Debris Infographics and podcast, ESA. Available at: https://www.esa.int/Space_Safety/Space_Debris/ESA_UNOOSA_space_debris_infographics_and_podcast (Accessed: 04 November 2024).

ESSI (2024) UN speech: Implementing the long-term sustainability (LTS) guidelines. Available at: https://www.essi.org/news/un-speech-implementing-the-long-term-sustainability-lts-guidelines (Accessed: 04 November 2024).

Export-Import Bank of the United States (2013) Ex-Im Bank Approves $105.4 Million Loan to Finance SpaceX Launch, EXIM. Available at: https://www.exim.gov/news/ex-im-bank-approves-1054-million-loan-finance-spacex-launch (Accessed: 04 November 2024).

FAA (2001) Selecting a Launch Vehicle: What Factors Do Commercial Satellite Customers Consider?, SECOND QUARTER 2001 QUARTERLY REPORT TOPIC. Available at: https://www.faa.gov/about/office_org/headquarters_offices/ast/media/q22001.pdf (Accessed: 04 November 2024).

FAA (2002) Commercial Space and Launch Insurance: Current Market and Future Outlook, Fourth Quarter 2002 Quarterly Launch Report . Available at: https://www.faa.gov/about/office_org/headquarters_offices/ast/media/q42002.pdf (Accessed: 04 November 2024).

FAA (2002) Commercial Space and Launch Insurance: Current Market and Future Outlook, Fourth Quarter 2002 Quarterly Launch Report . Available at: https://www.faa.gov/about/office_org/headquarters_offices/ast/media/q42002.pdf (Accessed: 04 November 2024).

FAA, DOC (2008) Introduction to U.S. Export Controls for the Commercial Space Industry. Available at: https://www.faa.gov/about/office_org/headquarters_offices/ast/media/Intro to US Export Controls.pdf (Accessed: 04 November 2024).

Faster Capital (2024) Avoiding Misunderstandings And Disputes. Available at: https://fastercapital.com/ (Accessed: 04 November 2024).

Ferster, W. (2023) U.S. satellite component maker fined $8 million for ITAR violations, SpaceNews. Available at: https://spacenews.com/37071us-satellite-component-maker-fined-8-million-for-itar-violations/ (Accessed: 06 November 2024).

Fiveable (2024) Transparency in decision-making, Fiveable. Available at: https://library.fiveable.me/key-terms/risk-management-insurance/claims-handling-guidelines (Accessed: 04 November 2024).

Forrester, C. (2024) Space insurance market facing challenges, Advanced Television. Available at: https://advanced-television.com/2024/02/21/space-insurance-market-facing-challenges/ (Accessed: 04 November 2024).

Foust, J. (2023) FCC approves New Orbital Debris Rule, SpaceNews. Available at: https://spacenews.com/fcc-approves-new-orbital-debris-rule/ (Accessed: 04 November 2024).

Foust, J. (2023) Insurers brace for viasat-3 claim, SpaceNews. Available at: https://spacenews.com/insurers-brace-for-viasat-3-claim/ (Accessed: 04 November 2024).

Foust, J. (2023) NASA study assesses costs and benefits of orbital debris removal, SpaceNews. Available at: https://spacenews.com/nasa-study-assess-costs-and-benefits-of-orbital-debris-removal/ (Accessed: 04 November 2024).

Friedman, R. et al. (2024) New Export Control Rules present key regulatory changes for space-related items, activities: Insights, Holland & Knight. Available at: https://www.hklaw.com/en/insights/publications/2024/11/new-export-control-rules-present-key-regulatory-changes-for-space (Accessed: 06 November 2024).

Garcia, P. (2023) The satelite insurance market, MAPFRE Global Risks. Available at: https://www.mapfreglobalrisks.com/en/risks-insurance-management/article/the-satelite-insurance-market/ (Accessed: 04 November 2024).

Gatti, E. (2022) #SPACEWATCHGL opinion: A review of the Space Insurance Market, SpaceWatch.GLOBAL. Available at: https://spacewatch.global/2022/09/spacewatchgl-opinion-a-review-of-the-space-insurance-market/ (Accessed: 04 November 2024).

Global Aerospace (2024) Space and satellite insurance: Global aerospace, Global Aerospace Aviation Insurance. Available at: https://www.global-aero.com/aviation-insurance-coverage/space-satellite-insurance/ (Accessed: 04 November 2024).

Gould, Allen J.; Linden, Orin M. (2000). "Estimating Satellite Insurance Liabilities". Casualty Actuarial Society.

Growth Market Reports (2024) Space insurance market analysis, size, share & forecast 2031. Available at: https://growthmarketreports.com/report/space-insurance-market-global-industry-analysis (Accessed: 04 November 2024).

Haager, A. (2018) The importance of non-binding instruments in international space law, ECSL Essay Contest. Available at: https://spacelaw.univie.ac.at/fileadmin/user_upload/p_npocspacelaw/ECSL_Essay_Contest_Sumbmission_Haager__Importance_of_soft_Law.pdf (Accessed: 04 November 2024).

Harrington, A.J. (2021) Space insurance and the law: Maximizing Private Activities in Outer Space. Cheltenham: Edward Elgar Publishing.

Heath, V. (2024) Effective space debris mitigation norms: A review of the UN guidelines, Space Generation Advisory Council. Available at: https://spacegeneration.org/effective-space-debris-mitigation-norms-a-review-of-the-un-guidelines (Accessed: 04 November 2024).

Henry, C. (2023) Big claims, record-low rates: Reshaping the space insurance game, SpaceNews. Available at: https://spacenews.com/big-claims-record-low-rates-reshaping-the-space-insurance-game/ (Accessed: 04 November 2024).

Henry, C. (2023) SpaceX submits paperwork for 30,000 more Starlink Satellites, SpaceNews. Available at: https://spacenews.com/spacex-submits-paperwork-for-30000-more-starlink-satellites/ (Accessed: 04 November 2024).

Hertzfeld, H. R., & von der Dunk, F. G, (2019) Space Traffic Management: Assessing the Risks and Challenges.

Hiscox (2024) Space congestion increases collision risk, Hiscox Group. Available at: https://www.hiscoxgroup.com/news/press-releases (Accessed: 04 November 2024).

Hobe, S., & Froehlich, A. (Eds.). (2019) Space Law: Current Problems and Perspectives for Future Regulation.

Horne, R. B., et al. (2013), Space weather impacts on satellites and forecasting the Earth's electron radiation belts with SPACECAST, Space Weather, 11, 169–186, doi:10.1002/swe.20023.

IADC (2007) IADC Space Debris Mitigation Guidelines. Available at: https://www.unoosa.org/documents/pdf/spacelaw/sd/IADC-2002-01-IADC-Space_Debris-Guidelines-Revision1.pdf (Accessed: 04 November 2024).

IAF (2024) IAF : International Astronautical Congress (IAC), International Astronautical Congress IAC : space sessions for all. Available at: https://www.iafastro.org/events/iac/ (Accessed: 06 November 2024).

IAF (2024) International Astronautical Federation. Available at: https://www.iafastro.org/ (Accessed: 06 November 2024).

Insurance Ireland (2024) Understanding insurance premiums, Understanding Insurance. Available at: https://www.understandinginsurance.ie/understanding-insurance-premiums (Accessed: 04 November 2024).

Inter-Agency Space Debris Coordination Committee (IADC). "IADC Space Debris Mitigation Guidelines." Revised 2007. Available at: UNOOSA

Inter-Agency Space Debris Coordination Committee. (2002). IADC Space debris mitigation guidelines (Revision 1, 2007). Retrieved from https://www.unoosa.org/documents/pdf/spacelaw/sd/IADC_space_debris_mitigation_guidelines.pdf

IP Access International (2023) How oneweb's satellite Constellation Works: A beginner's guide. Available at: https://www.ipinternational.net/how-onewebs-satellite-constellation-works-a-beginners-guide/ (Accessed: 04 November 2024).

ISO (2023) ISO 24113:2023, ISO. Available at: https://www.iso.org/standard/83494.html (Accessed: 04 November 2024).

ITU (2020) HARMFUL INTERFERENCE TO SATELLITE SYSTEMS, World Radiocommunication Seminar 2020. Available at: https://www.itu.int/dms_pub/itu-r/md/19/wrs20/c/R19-WRS20-C-0013!!PDF-E.pdf (Accessed: 04 November 2024).

ITU (2024) International Telecommunication Union, Committed to connecting the world. Available at: https://www.itu.int/ (Accessed: 06 November 2024).

Jeanne Suchodolski, An Overview and Comparison of Aviation and Space Insurance, 14 J. Bus. & Tech. L.469 (2019) Available at: https://digitalcommons.law.umaryland.edu/jbtl/vol14/iss2/4

Jessica (2022) Recycling in space: Wannabe or reality? Available at: https://blogs.esa.int/cleanspace/2022/01/10/recycling-in-space-wannabe-or-reality/ (Accessed: 04 November 2024).

Jewett, R. (2024) Inside Sia's 2024 state of the Satellite Industry Report, Via Satellite. Available at: https://www.satellitetoday.com/connectivity/2024/06/13/inside-sias-2024-state-of-the-satellite-industry-report/ (Accessed: 04 November 2024).

Johnson, C. (2019) The legal status of MegaLEO constellations and Concerns About Appropriation of Large Swaths of Earth Orbit. Available at: https://swfound.org/media/206951/johnson2020_referenceworkentry_thelegalstatusofmegaleoconstel.pdf (Accessed: 04 November 2024).

Johnson, N. L., (2018) Legal Aspects of Satellite Constellations.

Jones, A. (2023) Artemis Accords signatories seek to boost transparency and safety in lunar exploration, SpaceNews. Available at: https://spacenews.com/artemis-accords-signatories-seek-to-boost-transparency-and-safety-in-lunar-exploration/ (Accessed: 04 November 2024).

Kagan, J. (2023) Cut-through clause: Meaning, how it's used, benefits, Investopedia. Available at: https://www.investopedia.com/terms/c/cutthrough-clause.asp (Accessed: 05 November 2024).

Katarzyna Malinowska, 'Risk Assessment in Insuring Space Endeavours: A Legal Approach', (2017), 42, Air and Space Law, Issue 3, pp. 329-347, https://kluwerlawonline.com/journalarticle/Air+and+Space+Law/42.3/AILA2017022

Kennedy, B. (2023) Americans' views of space: U.S. role, NASA priorities and impact of private companies, Pew Research Center. Available at: https://www.pewresearch.org/science/2023/07/20/americans-views-of-space-u-s-role-nasa-priorities-and-impact-of-private-companies/ (Accessed: 04 November 2024).

Khan, R. (2023) Troubles with GEO satellites pose new insurance challenges, Open Access Government. Available at: https://www.openaccessgovernment.org/troubles-with-geo-satellites-pose-new-insurance-challenges/168028/ (Accessed: 04 November 2024).

Khasanah, Nur Barokah Uswatun, and Marc Johan Atsawin. 2024. "Mechanisms for Addressing Space Debris from the Perspective of International Law". International Law Discourse in Southeast Asia 3 (1), 107-34. https://doi.org/10.15294/ildisea.v3i1.78885.

KIN (2023) What is insurance underwriting?, KIN. Available at: https://www.progressive.com/answers/what-is-insurance-underwriting/ (Accessed: 04 November 2024).

Kunstadter, C. (2022) Space Insurance Update , AXA XL. Available at: https://www.nasa.gov/wp-content/uploads/2022/10/04_kunstadter_space_insurance_update_axa_xl_scaf_220111.pdf (Accessed: 04 November 2024).

Kunstadter, C. T. W., (2022) What Keeps Space Insurers Up at Night?

Lafaye, M. (2017). Benefit Assessment of the Application of Satellite Earth Observation for Society and Policy: Assessing the Socioeconomic Impacts of the Development of Downstream Space-Based Earth Observation Applications. In: Onoda, M., Young, O. (eds) Satellite Earth Observations and Their Impact on Society and Policy. Springer, Singapore. https://doi.org/10.1007/978-981-10-3713-9_7

Lafleur, A. (2024) Strengthening Space Situational Awareness Through Data Sharing: World Economic Forum Briefing Paper, Space Impulse. Available at: https://spaceimpulse.com/2024/09/25/strengthening-space-situational-awareness-through-data-sharing-world-economic-forum-briefing-paper/ (Accessed: 04 November 2024).

Lexis Nexis (2024) Advanced analytics for underwriting, LexisNexis Risk Solutions. Available at: https://risk.lexisnexis.com/insurance/data-analytics-and-modeling/advanced-analytics-for-underwriting (Accessed: 04 November 2024).

Lloyd's (2019) Lloyd's launches New Space Risk Product and new analysis of the Space Sector, Lloyd's. Available at: https://www.lloyds.com/about-lloyds/media-centre/press-releases/lloyds-launches-new-space-risk-product-and-new-analysis-of-the-space-sector (Accessed: 04 November 2024).

Lloyd's (2024) Astroscale: Mission to clean up space. Available at: https://www.lloyds.com/about-lloyds/our-market/what-we-insure/space/crowded-space/astroscale (Accessed: 04 November 2024).

Logistics UK (2024) Tips for reducing your insurance premiums, Road Insurance, risk management and loss control. Available at: https://logistics.org.uk/compliance-and-advice/road/insurance-risk-management-and-loss-control/tips-for-reducing-your-insurance-premiums (Accessed: 04 November 2024).

Lopez-Calle, I. and Franco, A.I. (2023) Comparison of cubesat and microsat catastrophic failures in function of radiation and debris impact risk, Nature News. Available at: https://www.nature.com/articles/s41598-022-27327-z (Accessed: 04 November 2024).

Luzadder, M. and Argetsinger, C. (2021) Privilege and the tripartite insurer-insured-counsel relationship, Insurance Laws and Products - Insurance - United States. Available at: https://www.mondaq.com/unitedstates/insurance-laws-and-products/1139612/privilege-and-the-tripartite-insurer-insured-counsel-relationship (Accessed: 04 November 2024).

Mainelli, M. (2023) In-orbit servicing and insurance markets: a symbiotic approach, International Astronautical Congress (IAC 2023). Available at: https://www.longfinance.net/media/documents/Astroscale_-_Insurance_-_Draft_v10.0_Final_Copy_Edited.pdf (Accessed: 04 November 2024).

Malinowska, K. (2017) Space insurance: International legal aspects. Alphen aan den Rijn: Wolters Kluwer.

Manikowski, P. (2004) The satellite insurance market as a part of the insurance market., THE SATELLITE INSURANCE MARKET AS A PART OF THE INSURANCE MARKET. Available at: https://www.dbc.wroc.pl/Content/15470/Manikowski_The%20Satellite_Insurance_Market_As_A_Part_2004.pdf (Accessed: 04 November 2024).

Manikowski, Piotr, "The Columbia Space Shuttle Tragedy: Third-Party Liability Implication for the Insurance of Space Losses" (2005) 8:1 Risk Management and Insurance Review 141.

Mansors (2024) Liability for damage caused by Space Objects, Mansors. Available at: https://mansors.com/blog/liability-for-damage-caused-by-space-objects (Accessed: 04 November 2024).

March McLennan (2021) Aviation insurance market overview: Q1 2023, Space Insurance Market: Pricing and Risk Update - Q1 2021. Available at: https://www.marsh.com/us/industries/aviation-space/insights/space-insurance-market-pricing-and-risk-update-2021-q1.html (Accessed: 04 November 2024).

Mariappan, A. and Crassidis, J.L. (2023) Kessler's Syndrome: A challenge to humanity, Frontiers. Available at: https://www.frontiersin.org/journals/space-technologies/articles/10.3389/frspt.2023.1309940/full (Accessed: 04 November 2024).

Martin, G. (2015) NewSpace: The Emerging Commercial Space Industry, NASA Ames Research Center. Available at: https://ntrs.nasa.gov/api/citations/20150023562/downloads/20150023562.pdf (Accessed: 04 November 2024).

Matthewson, A. (2024) A guide to risk assessment in the insurance industry, A Guide to Risk Assessment in the Insurance Industry | InsurTech Digital. Available at: https://insurtechdigital.com/articles/what-is-risk-assessment (Accessed: 04 November 2024).

Matura, P. (2020) Numerical Analysis of satellite collisions in orbit - fraunhofer EMI, Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI. Available at: https://www.emi.fraunhofer.de/en/business-units/space/research/numerische-untersuchungen-satellitenkollisionen-im-orbit.html (Accessed: 04 November 2024).

McDowell, J. (2024) Jonathan's space pages, Jonathan's Space Report | Space Statistics. Available at: https://planet4589.org/space/con/star/stats.html (Accessed: 04 November 2024).

McFall-Johnsen, M. (2024) A dead Russian spacecraft almost collided with a NASA satellite. the crash could have sent 7,500 bits of debris rocketing around Earth., Business Insider. Available at: https://www.businessinsider.com/russian-spacecraft-nasa-satellite-collision-earth-debris-2024-3 (Accessed: 04 November 2024).

Meredith, P. (2007) Space insurance law with a Special Focus on Satellite Launch and In-Orbit Policies. Available at: https://www.kmazuckert.com/publications/space/Commerical_Space_-_Meredith_-_Space_Insurance_Law_2008.pdf (Accessed: 04 November 2024).

Monetary Authority of Singapore (2013) GUIDELINES ON RISK MANAGEMENT PRACTICES FOR INSURANCE BUSINESS . Available at: https://www.mas.gov.sg/-/media/MAS/Regulations-and-Financial-Stability/Regulatory-and-Supervisory-Framework/Risk-Management/Risk-Management-Guidelines_Insurance-Core-Activities.pdf (Accessed: 04 November 2024).

Morris, S. (2024) State of satellite deployments & Orbital Operations – 2023 report, Slingshot Aerospace. Available at: https://www.slingshot.space/news/state-of-satellite-deployments-and-orbital-operations-2023 (Accessed: 04 November 2024).

Mott, William H.; Sheldon, Robert B. (2000). Laser Satellite Communication: The Third Generation. Praeger. p. 142. ISBN 1-56720-329-9.

Mousinho, I. and Mifsud, G. (2024) Space insurance – the key to a sustainable space environment?, Clyde & Co. Available at:

https://www.clydeco.com/en/insights/2024/01/space-insurance-the-key-to-a-sustainable-space-env (Accessed: 04 November 2024).

Mukhopadhyay, A. (2024) Space insurance market navigates uncertain terrain in 2024 amid capacity shifts: Gallagher - Reinsurance News, ReinsuranceNe.ws. Available at: https://www.reinsurancene.ws/space-insurance-market-navigates-uncertain-terrain-in-2024-amid-capacity-shifts-gallagher/ (Accessed: 04 November 2024).

NASA (2009) The collision of Iridium 33 and cosmos 2251: The shape of things to come , NASA Technical Reports Server. Available at: https://ntrs.nasa.gov/citations/20100002023 (Accessed: 06 November 2024).

NASA (2017) Full circle: NASA to demonstrate refabricator to recycle, Reuse, repeat, NASA. Available at: https://www.nasa.gov/missions/station/full-circle-nasa-to-demonstrate-refabricator-to-recycle-reuse-repeat/ (Accessed: 04 November 2024).

NASA (2023) International Space Station Cooperation, NASA. Available at: https://www.nasa.gov/international-space-station/space-station-international-cooperation/ (Accessed: 04 November 2024).

NASA (2023) Step 2 close approach risk assessment, NASA. Available at: https://www.nasa.gov/cara/step-2-close-approach-risk-assessment/ (Accessed: 04 November 2024).

NASA (2024) Advanced in-space propulsion (AISP), NASA. Available at: https://www.nasa.gov/directorates/stmd/game-changing-development-program/advanced-in-space-propulsion-aisp/ (Accessed: 04 November 2024).

NASA (2024) ARIANE5, Launch Vehicle. Available at: https://sma.nasa.gov/LaunchVehicle/ariane5.html (Accessed: 04 November 2024).

NASA (2024) Artemis, NASA. Available at: https://www.nasa.gov/feature/artemis/ (Accessed: 04 November 2024).

NASA (2024) NASA. Available at: https://www.nasa.gov/ (Accessed: 04 November 2024).

NASA (2024) Space Traffic Management (STM) architecture, NASA Technology Transfer Program. Available at: https://technology.nasa.gov/patent/TOP2-294 (Accessed: 04 November 2024).

NASA (2024) Spacecraft to remove orbital debris, NASA Technology Transfer Program. Available at: https://technology.nasa.gov/patent/MSC-TOPS-90 (Accessed: 04 November 2024).

NASA (2024) Spacecraft to remove orbital debris, NASA. Available at: https://technology.nasa.gov/patent/MSC-TOPS-90 (Accessed: 04 November 2024).

Natras, R. and Smith, M. (2021) Machine Learning Model Development for Space Weather Forecasting in the Ionosphere. Available at: https://ceur-ws.org/Vol-3052/short10.pdf (Accessed: 04 November 2024).

New Space Economy (2024) Overview of risks associated with Space Activities. Available at: https://newspaceeconomy.ca/2024/01/08/overview-of-risks-associated-with-space-activities/ (Accessed: 04 November 2024).

New Space Economy (2024) The importance of transparent communication in space exploration, New Space Economy. Available at: https://newspaceeconomy.ca/2024/01/15/the-importance-of-transparent-communication-in-space-exploration/ (Accessed: 04 November 2024).

NOAA (2016) Graveyard orbits and the satellite afterlife, National Environmental Satellite, Data, and Information Service. Available at: https://www.nesdis.noaa.gov/news/graveyard-orbits-and-the-satellite-afterlife (Accessed: 04 November 2024).

Noah Chemicals (2024) Conquering the Final Frontier: Navigating the Satellite Surge in Limited Space, Space race challenges in material science. Available at: https://noahchemicals.com/blog/satellites-space-race-challenges-in-material-science/ (Accessed: 04 November 2024).

Novaspace (2024) Space sustainability regulations: new constraints and opportunities for space businesses. Available at: https://nova.space/in-the-loop/ (Accessed: 04 November 2024).

OECD (2020) Space sustainability, OECD. Available at: https://www.oecd.org/en/topics/sub-issues/space-sustainability.html (Accessed: 04 November 2024).

OneWeb (2022) Satellite Orbital Safety Best Practices, SATELLITE ORBITAL SAFETY BEST PRACTICES. Available at: https://assets.oneweb.net/s3fs-public/2022-09/Satellite Orbital Safety Best Practices.pdf (Accessed: 04 November 2024).

Padhi, S. (2023) How technology is revolutionizing space travel , OrbitBeyond. Available at: https://www.orbitbeyond.com/blog/how-technology-is-revolutionizing-space-travel (Accessed: 04 November 2024).

Pandey, V., Dataintelo and Sharma, R. (2024) Space Insurance Market Research Report 2032, Research Report 2032. Available at: https://dataintelo.com/report/space-insurance-market/ (Accessed: 04 November 2024).

Prudential (2024) Importance of insurance - need & types of insurance: ICICI PRU life, icici prudential life insurance. Available at: https://www.iciciprulife.com/insurance/insurance-importance.html (Accessed: 04 November 2024).

Pultarova, T. (2023) Old Soviet satellite breaks apart in orbit after space debris collision, Space.com. Available at: https://www.space.com/soviet-satellite-breaks-apart-after-debris-strike (Accessed: 04 November 2024).

Rainbow, J. (2023) Connecting the dots: Double whammy for space insurance, SpaceNews. Available at: https://spacenews.com/connecting-the-dots-double-whammy-for-space-insurance/ (Accessed: 04 November 2024).

Rainbow, J. (2023) Space insurers brace for more claims after propulsion trouble on four Geo Satellites, SpaceNews. Available at: https://spacenews.com/space-insurers-brace-for-more-claims-after-propulsion-trouble-on-four-geo-satellites/ (Accessed: 04 November 2024).

Ritz, B. (2022) Satellite Liability and insurance: In space, who's insured?, Thompson Coe. Available at: https://www.thompsoncoe.com/resources/publications/splash-and-crash-satellite-liability-and-insurance/ (Accessed: 04 November 2024).

Rondon Brokerage (2022) What do exclusions mean in an insurance policy? Available at: https://www.thimble.com/small-business-insurance/insurance-exclusions (Accessed: 04 November 2024).

Russell, L. and Durrett, M. (2024) Strained satellite insurance market could be in jeopardy, Connectivity Business News. Available at: https://connectivitybusiness.com/news/strategy-markets/strained-satellite-insurance-market-could-be-in-jeopardy (Accessed: 04 November 2024).

Santoso, M. "Potential Liabilities of Space Debris From Satellite Constellation". Thesis, Parahyangan Catholic University (2023).

Sawik, Bartosz. 2023. "Space Mission Risk, Sustainability and Supply Chain: Review, Multi-Objective Optimization Model and Practical Approach" Sustainability 15, no. 14: 11002. https://doi.org/10.3390/su151411002

Sawyer, R. (2024) Space insurance: The promise of in-orbit repair, Lockton. Available at: https://global.lockton.com/gb/en/news-insights/space-insurance-the-promise-of-in-orbit-repair (Accessed: 04 November 2024).

Schiffer, L. (2001) Cut-through provisions in reinsurance agreements, IRMI. Available at: https://www.irmi.com/articles/expert-commentary/cut-through-provisions-in-reinsurance-agreements#:~:text=A%20cut-through%20provision%20allows%20a%20party%20not%20in,by%20specific%20events%20enumerated%20in%20the%20cut-through%20provision. (Accessed: 05 November 2024).

Secure World Foundation (2024) Promoting Cooperative Solutions for Space Sustainability. Available at: https://swfound.org/ (Accessed: 06 November 2024).

Select Committee of The United States House Of Representatives (2024) The Commercial Space Insurance Industry, VOLUME II: Chapter 8/Technical Afterword. Available at: https://www.govinfo.gov/content/pkg/GPO-CRPT-105hrpt851/pdf/GPO-CRPT-105hrpt851-2-11.pdf (Accessed: 04 November 2024).

Signé, L. and Dooley, H. (2024) How space exploration is fueling the Fourth Industrial Revolution, Brookings. Available at: https://www.brookings.edu/articles/how-space-exploration-is-fueling-the-fourth-industrial-revolution/ (Accessed: 04 November 2024).

Silverstein, B. (2022) How governments should address the increasing risks of satellite collision - carnegie endowment for international peace | carnegie endowment for international peace. Available at: https://carnegieendowment.org/posts/2022/04/how-governments-should-address-the-increasing-risks-of-satellite-collision?lang=en (Accessed: 04 November 2024).

SmartSat CRC (2024) SmartSat CRC and NZ Government announce four new joint research projects under Australia-NZ collaborative space program, Scoop. Available at: https://www.scoop.co.nz/stories/SC2407/S00051/smartsat-crc-and-nz-government-announce-four-new-joint-research-projects-under-australia-nz-collaborative-space-program.htm (Accessed: 04 November 2024).

Space Policy Institute (2024) Space Policy Institute, THE ELLIOTT SCHOOL OF INTERNATIONAL AFFAIRS. Available at: https://spi.elliott.gwu.edu/ (Accessed: 06 November 2024).

SpaceNews (2023) Cost of insuring satellite launches down by $10 million, SpaceNews. Available at: https://spacenews.com/cost-insuring-satellite-launches-down-10-million/ (Accessed: 04 November 2024).

Speed, R. (2024) Insurers make record-breaking loss as space gets cramped, The Register® - Biting the hand that feeds IT. Available at: https://www.theregister.com/2024/05/01/space_insurer_record_loss/ (Accessed: 04 November 2024).

Spencer, E. (2024) Launch plus 1 satellite insurance - managing the risk of an expensive firework display, Taylor Wessing. Available at: https://www.taylorwessing.com/en/interface/2024/the-space-race/launch-plus-1-satellite-insurance (Accessed: 04 November 2024).

Spencer, E. (2024) Launch plus 1 satellite insurance - managing the risk of an expensive firework display, Taylor Wessing. Available at: https://www.taylorwessing.com/en/interface/2024/the-space-race/launch-plus-1-satellite-insurance (Accessed: 04 November 2024).

Starlink (2024) Satellite Technology. Available at: https://www.starlink.com/technology#:~:text=Each%20Starlink%20satellite%20contains%203%20space%20lasers%20%28Optical,that%20can%20connect%20customers%20anywhere%20in%20the%20world. (Accessed: 04 November 2024).

StartUs Insights (2023) Explore 5 top space debris solutions, StartUs Insights. Available at: https://www.startus-insights.com/innovators-guide/5-top-debris-retrieval-monitoring-solutions-impacting-the-space-industry/ (Accessed: 04 November 2024).

Stroe, I.F. et al. (2021) Autonomous Collision Avoidance System, ESA Proceedings Database. Available at: https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/161 (Accessed: 06 November 2024).

StudySmarter UK (2024) Spacecraft Reliability. Available at: https://www.studysmarter.co.uk/explanations/engineering/aerospace-engineering/spacecraft-reliability/ (Accessed: 04 November 2024).

Sutter, P. (2024) Small, untrackable pieces of space junk are cluttering low Earth orbit, Astronomy Magazine. Available at: https://www.astronomy.com/space-exploration/small-untrackable-pieces-of-space-junk-are-cluttering-low-earth-orbit/ (Accessed: 04 November 2024).

Svoboda, T. (2024) Demystifying Parametric Insurance Part I: What is It and How Does It Work, Conner Strong & Buckelew. Available at: https://www.torys.com/en/our-latest-thinking/torys-quarterly/q1-2024/parametric-insurance (Accessed: 04 November 2024).

Swinhoe, D. (2022) FCC considering 5-year disposal rule for end-of-life leo satellites, DCD. Available at: https://www.datacenterdynamics.com/en/news/fcc-considering-5-year-disposal-rule-for-end-of-life-leo-satellites/ (Accessed: 04 November 2024).

Thanasegaran, H. (2016). Duty of Utmost Good Faith. In: Good Faith in Insurance and Takaful Contracts in Malaysia. Springer, Singapore. https://doi.org/10.1007/978-981-10-0383-7_2

The Aerospace Corporation (2021) Novel satellite deorbiting method can help mitigate space debris crisis. Available at: https://aerospace.org/article/novel-satellite-deorbiting-method-can-help-mitigate-space-debris-crisis (Accessed: 04 November 2024).

The CAGRS of data traffic volumes and revenue in the satellite and space market (2022) Analysys Mason. Available at: https://www.analysysmason.com/research/content/articles/traffic-revenue-cagr-nsr/ (Accessed: 04 November 2024).

The Impact of the Cold War on the Formation and Development of International Space Law. (2022). Miscellanea Historico-Iuridica, 21(2), 317-333.

The Space Report (2024) Space Insurance Industry Estimates, 2003-2022, The Space Report. Available at: https://www.thespacereport.org/resources/space-insurance-industry-estimates-2003-2022/ (Accessed: 04 November 2024).

Thompson, A. (2021) The Kessler syndrome, National Space Centre. Available at: https://www.spacecentre.co.uk/news/space-now-blog/the-kessler-syndrome/ (Accessed: 04 November 2024).

Thomson Reuters (2024) Reduce the risk of claims with indemnification clauses in contracts, Indemnification Clauses in Commercial Contracts | Thomson Reuters. Available at: https://legal.thomsonreuters.com/en/insights/articles/indemnification-clauses-in-commercial-contracts (Accessed: 04 November 2024).

Thomson, J. (2024) Intelsat 33e satellite designed by Boeing breaks up in Orbit, Newsweek. Available at: https://www.newsweek.com/satellite-orbiting-earth-broken-intelsat-lost-1972438 (Accessed: 04 November 2024).

Todd, D. (2024) Space insurers wither from 'Worst Year' in over twenty years as claims get close to US$1 billion (updated and corrected), Seradata. Available at: https://www.seradata.com/space-insurers-wither-from-worst-year-ever-as-claims-get-close-to-us1-billion/ (Accessed: 04 November 2024).

UK CAA (2024) Launch Collision Avoidance Analysis (LCOLA), Civil Aviation Authority. Available at: https://www.caa.co.uk/space/guidance-and-resources/launch-collision-avoidance-analysis-lcola/ (Accessed: 04 November 2024).

UK Space Agency, (2018) Fact Sheet: Third-Party Liability Insurance for In-Orbit Activities.

UNDC Working Group II (2023) Recommendations to promote the practical implementation of transparency and confidence-building measures in outer space activities with the goal of preventing an arms race in outer space, in accordance with the recommendations set out in the report of the Group of Governmental Experts on Transparency and Confidence-Building Measures in Outer Space Activities. Available at: https://docs-library.unoda.org/United_Nations_Disarmament_Commission_-_(2023)/Recommendations_UNDC_WG_II_AS_ADOPTED.pdf (Accessed: 04 November 2024).

United Nations (2024) The Guidelines in all official languages of the United Nations, Awareness-raising and capacity-building related to the implementation of the Guidelines for the Long-term Sustainability of Outer Space Activities. Available at: https://spacesustainability.unoosa.org/content/the_guidelines (Accessed: 04 November 2024).

UNOOSA (2010) Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space. Available at: https://www.unoosa.org/pdf/publications/st_space_49E.pdf (Accessed: 04 November 2024).

UNOOSA (2024) Access to Space for All and the benefits of space, United Nations Office for Outer Space Affairs . Available at: https://www.unoosa.org/oosa/en/ourwork/access2space4all/AccSpace4All_memberstates.html (Accessed: 04 November 2024).

UNOOSA (2024) Space Exploration and Innovation , Space Exploration and Innovation. Available at: https://www.unoosa.org/oosa/sk/ourwork/topics/space-exploration-and-innovation.html (Accessed: 04 November 2024).

UNOOSA (2024) United Nations Office for Outer Space Affairs, Space Law Treaties and Principles. Available at: https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties.html (Accessed: 04 November 2024).

Urban, R. (2024) How much does it cost to launch a Rocket? [by type & size], Space Impulse. Available at: https://spaceimpulse.com/2023/08/16/how-much-does-it-cost-to-launch-a-rocket/ (Accessed: 04 November 2024).

US Department of Energy (2023) Price-Anderson Act | Department of Energy. Available at: https://www.energy.gov/gc/price-anderson-act (Accessed: 04 November 2024).

USDS (2009) The launch of Sputnik, 1957, Archive. Available at: https://2001-2009.state.gov/r/pa/ho/time/lw/103729.htm (Accessed: 04 November 2024).

USDT and FAA (1998) Special Report: Update of the Space and Launch Insurance Industry, Commercial Space Transportation QUARTERLY LAUNCH REPORT. Available at: https://www.faa.gov/about/office_org/headquarters_offices/ast/media/sr_98_4q.pdf (Accessed: 04 November 2024).

Viasat (2022) Managing Mega-constellation Risks in LEO. Available at: https://www.viasat.com/content/dam/us-site/corporate/documents/Viasat White Paper-Managing Mega-Constellation Risks in LEO (Updated Nov 22) (A4).pdf (Accessed: 04 November 2024).

Viasat (2022) Managing Mega-constellation Risks in LEO. Available at: https://www.viasat.com/content/dam/us-site/corporate/documents/Viasat White Paper-Managing Mega-Constellation Risks in LEO (Updated Nov 22) (A4).pdf (Accessed: 04 November 2024).

von der Dunk, F. G., (2015) Liability for Space Debris: A Legal Analysis.

Wells, R. (2023) New NASA-funded study hopes to put risks of space junk on People's Radar, University of Central Florida News | UCF Today. Available at: https://www.ucf.edu/news/new-nasa-funded-study-hopes-to-put-risks-of-space-junk-on-peoples-radar/ (Accessed: 04 November 2024).

Weltman, A. (2024) Slingshot Aerospace Report highlights record insurance market losses in 2023, Via Satellite. Available at: https://www.satellitetoday.com/sustainability/2024/05/01/slingshot-aerospace-reveals-record-insurance-losses-in-2023-in-new-satellite-deployments-report/ (Accessed: 04 November 2024).

Werner, D. (2023) How long should a satellite last: Five years, ten years, 15, 30?, SpaceNews. Available at: https://spacenews.com/how-long-should-a-satellite-last/ (Accessed: 04 November 2024).

Wheeler, J. and Stevens, N. (2023) Is the Space Insurance Market for leo sustainable?, March 2023. Available at: https://interactive.satellitetoday.com/via/march-2023/is-the-space-insurance-market-for-leo-sustainable (Accessed: 04 November 2024).

World Economic Forum (2022) Global risks report 2022, Crowding and Competition in Space. Available at: https://www.weforum.org/publications/global-risks-report-2022/in-full/chapter-5-crowding-and-competition-in-space/ (Accessed: 04 November 2024).

World Economic Forum (2024) Space is booming. here's how to embrace the $1.8 trillion opportunity, World Economic Forum. Available at: https://www.weforum.org/stories/2024/04/space-economy-technology-invest-rocket-opportunity/ (Accessed: 04 November 2024).

World Economic Forum (2024) Space Situational Awareness Data and Information Sharing Principles. Available at: https://www3.weforum.org/docs/WEF_Space_Situational_Awareness_Data_and_Information_Sharing_Principles_2024.pdf (Accessed: 04 November 2024).

World Economic Forum (2024) The path forward for sustainable space exploration, World Economic Forum. Available at: https://www.weforum.org/agenda/2024/07/sustainable-space-exploration-path-forward/ (Accessed: 04 November 2024).

Worthy, M. (2024) Your chance of getting hit by space junk is extremely low... but not zero!, Cranfill Sumner LLP. Available at: https://www.cshlaw.com/resources/the-current-universe-of-space-insurance/#_ftn14 (Accessed: 04 November 2024).

Yap, J. (2023) Is the sky the limit for Space Insurance?, Landers & Rogers. Available at: https://www.landers.com.au/legal-insights-news/failure-in-orbit-planning-your-space-projects-with-space-insurance-in-mind (Accessed: 04 November 2024).

Yap, X. et al. (2023) Four alternative scenarios of commons in space: Prospects and challenges, International Journal of the Commons. Available at: https://thecommonsjournal.org/articles/10.5334/ijc.1272 (Accessed: 04 November 2024).

Zach (2011) The Problems of Reusable Rockets, Seradata. Available at: https://www.seradata.com/the_problems_of_reusable_rocke/ (Accessed: 04 November 2024).

Zajac, M. (2017) Overview of Space Insurance, SCOR. Available at: https://www.scor.com/en/expert-views/overview-space-insurance (Accessed: 04 November 2024).

Zhang, W., Wang, X., Cui, W. et al. Self-induced collision risk of the Starlink constellation based on long-term orbital evolution analysis. Astrodyn 7, 445–453 (2023). https://doi.org/10.1007/s42064-023-0171-7

Zisk, R. (2022) The Space Insurance Landscape, Payload. Available at: https://payloadspace.com/the-space-insurance-landscape/ (Accessed: 04 November 2024).