BOOK REVIEW

***Space Debris Peril: Pathways to Opportunities: Capacity Building in the New Space Era*, Matteo Madi & Olga Sokolova (eds). CRC Press, Boca Raton, Florida, United States. 2021. 266pp. Hardback USD 120. ISBN 978-0-367-46945-0.**

Space debris is already an urgent environmental issue threatening the viability of today's space activities, and it will only continue to rise in importance as more and more spacecraft are placed in the space domain. There are numerous and substantial challenges in tracking the current population of operational and non-operational human-created space objects, and with mitigating the creation of even more debris. And yet, with more spacecraft planned to be launched in the next few years, space environmental sustainability challenges loom even larger. According to experts (including authors in this edited volume) even if less than half of the currently planned satellite constellations become operational, the population of operational spacecraft in the next decade will be between four and ten times larger than what it is currently. In light of this truly daunting issue, and the myriad complex social, legal, and technical aspects of the problem, *Space Debris Peril: Pathways to Opportunities – Capacity Building in the New Space Era* attempts to address space debris and space sustainability challenges from a variety of important perspectives.

The book consists of nine chapters, each taking a different approach and set of expertise to the issue of space debris and related fundamental sub-issues. It progresses thematically from a discussion and analysis of the space domain and facts of the current space debris situation, into de-orbiting technologies, regulation and legislation to address space debris mitigation and remediation, risk assessment and insurance approaches, and then finally to larger governance and risk consideration aspects. The chapters are written by technical, legal, and policy experts, and while the technical chapters, such as the opening chapter on space situational awareness (SSA) and space traffic management (STM), are quite detailed and complex, these chapters are usually never too difficult for the non-expert to understand. Only the final chapter on risk management is really beyond the understanding of the average (non-expert) reader.

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The book's introductory chapter, by Olga Sokolova, gives an overview of the following chapters and their interdisciplinary nature.

The second chapter, SSA & STM, by Dan Oltrogge and James Cooper, gives an overview of our knowledge of the near space environment and of the necessity for enhanced active awareness of this environment. The authors caution that while we are entering an exciting era of rapidly advancing and proliferating space activities, there are significant regulatory and environmental awareness protections to be addressed. The chapter includes authoritative definitions for critical terms such as SSA and STM. SSA is the 'knowledge and characterization of space objects and their operational environment to support safe, stable, and sustainable space activities'. A distinct concept (often wrongly used interchangeably) is STM, which is 'the planning, coordination, and on-orbit synchronization of activities to enhance the safety, stability, and sustainability of operations in the space environment'.

The third chapter, Space Debris Sustainability: Understanding and Engaging Outer Space Environments, by Michael Clorman and Nina Klimburg-Witjes, takes an approach to space debris from the Science and Technology Studies (STS) field, stressing that discussions about debris should not be merely in one vector – with the technical experts advising decision-makers, but more interdisciplinary and with a broad range of constituencies and stakeholders engaging in capacity building discussions and decisions. However, the authors also discuss space debris as 'bi-directional', as non-functional space objects run the risk of impacting the surface of the Earth, as well as polluting the space environment. However, as most all space debris completely burns up during re-entry, the risk to the surface of the Earth from space debris appears to be overstated in this chapter.

The fourth chapter, Overview of the Proposals for Space Debris De/Re-Orbiting from the Most Populated Orbits, by Andrey Baranov and Dmitry Grishko, gives explanations of the various proposed large space debris removal technologies, including how these might be operationally performed in different orbits and an overview of currently planned debris removal missions. This chapter will be especially interesting to non-technical experts who have heard of some of these techniques, but might not have a clear idea as to what they actually entail. Potential methods to remove large debris include tether systems, electrodynamic tethers, manipulators, contactless ion-beam systems, laser systems, and solar sails, and the authors spend a number of paragraphs explaining these different approaches in a relatively simple and clear fashion.

The fifth chapter, Space Debris Mitigation Based on Commercial Off-the-Shelf (COTS) Technologies, by Shinichi Kimura, goes into more technical detail on the challenges of active debris removal (ADR). It stresses that various technological challenges remain before ADR is a reality. Professor Kimura stresses that because communication links between the ground station and the ADR-

performing satellite will be limited, only part of any ADR mission will be performed and supported by teleoperation with ground stations. The final steps of arriving and capturing a piece of debris will need to be performed autonomously by the satellite itself, and will therefore need sophisticated cameras and onboard computers for the final guidance and navigation maneuvers. However, to keep costs low enough for ADR to be economically viable, these cameras and computers will likely need to be robust, COTS technologies, and these technologies have still yet to be sufficiently developed.

The sixth chapter, Addressing the Inevitable: Legal and Policy Issues Related to Space Debris Mitigation and Remediation, by Lucy Stewardson and Steven Freeland, broadens the book's focus to consider legal and policy aspects of space debris. The chapter splits its legal analysis first into debris mitigation (creating less debris), and then debris remediation (removal). In the context of debris mitigation, relevant sources of law include the 1967 Outer Space Treaty and the 1972 Liability Convention, along with various soft law instruments such as the Inter-Agency Space Debris Coordination Committee's Space Debris Mitigation Guidelines of 2002, the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) Space Debris Mitigation Guidelines adopted in 2007, and the Long-Term Sustainability Guidelines of Outer Space Activities, also adopted by COPUOS, from 2019. On the topic of debris remediation, the law is less specific, and Stewardson and Freeland caution that various legal hurdles exist, including the lack of a definition of space debris, questions of liability which might arise when conducting debris removal activities, and issues of intellectual property regarding sensitive data and technology which might arise in the course of space debris removal activities.

The seventh chapter, Risk Assessment of Space Activities in Light of Space Debris Issue, by Cécile Gaubert, takes a deeper look at the various risks associated with space debris, including risks which may arise in the course of removing space debris. Space debris removal may result in damage to the satellite to be removed, the satellite doing the removal, or to other objects in space, or damage may result on the surface of the Earth. While treaty provisions address these concerns at a State-to-State level, some of these risks may be transferred to the insurance market, and possible evolutions in the space insurance market could be sought, including with new regulations, to foster a sustainable space debris removal market.

The eighth chapter, Space Sector Resilience and Ways to its Governance, by Olga Sokolova and Matteo Mati, includes a thorough explanation of risks and how they are analysed and mitigated. Critical infrastructures require heightened attention and protection, and space-based assets and capabilities such as Global Navigation Satellite Services (GNSS), communications satellites, and Earth Observation (EO) systems are component parts of these critical infrastructures.

The paradigm for risk management (analysis, evaluation, research/control, communication, and monitoring) should all be used for space sector resilience, and the chapter offers some recommendations on how to perform risks management tasks for space sector resilience. In considering risks, stakeholders should consider which risks can be accepted, which risks can be transferred, which can be mitigated, and which risks can be avoided (including by not performing the risky activity). However, as space debris represents a systemic risk that threatens critical infrastructure, risk prevention from space debris is more beneficial over the long term than mere risk mitigation.

The ninth and final chapter, Pathways to Opportunities, by Matteo Madi, offers a summary and synthesis of the preceding chapters, along with some key observations and insights. To successfully address the space debris problem, he stresses that it is critical to first accept that the debris issue is a technical as well as social/legal/political challenge that is international in nature, and one that societies are not yet fully equipped and prepared to engage with. Additionally, public engagement might require asking them to consider the space debris issue as an environmental issue, and one where risks from debris exist and should be faced. Broad discussions on, for example, what level of risk from on-orbit collisions are acceptable, what are acceptable amounts of injury and damage from space debris re-entry, and what space missions and applications are the most valuable for society (and thus deserving heightened protection)?

In summary, the value of this book is its broadness. Approaches and views on space debris from a wide field of expertise will be the reason anyone seriously interested in space debris should investigate this book. The technical understandings of SSA, STM, and space debris removal technologies will be of interest to lawyers and policymakers seeking to understand these activities so that their subsequent legal understandings are fully informed and realistic. Likewise, scientists and engineers will receive a good high-level understanding of the various policy, law, and insurance issues; and the approaches from the social sciences, as well as the systems engineering approaches to risk management will be useful for anyone unfamiliar with those fields. Policy makers would be wise to engage with all of these fields of expertise. In that sense, the book can be seen as a consensus-building document, so that different stakeholders can begin to 'speak the same language' when facing the difficult and collective problem of space debris.

However, some sections and chapters, especially Chapter 8 on risk complexity and space debris governance, are not reader-friendly. Discerning the meaning of a sentence or passage may require patience and re-reading, along with reference to sources in the endnotes. And some sections replete with equations describing risk

remained incomprehensible to this reader. Nevertheless, the book is filled with sophisticated insights from authors at the forefront of their field, and with considerable insight into the problems of space debris and how to face it. These insights make this compendium of essays a valuable asset, and it is past time for greater understanding of the varied and complex aspects of the space debris problem.

Christopher D. Johnson
Space Law Advisor
Secure World Foundation
cjohnson@swfound.org