

Small Satellites and Large Constellations: Space Debris Remediation and Perpetual Ownership

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Abstract

Large constellations are groups of small satellites deployed in large numbers, ranging from hundreds to thousands. Most of these are to be deployed in the Low Earth Orbit (LEO), one of the most crowded and sought after orbits around the Earth. The small sizes and large numbers of these satellites raise concerns about their removal from orbit upon becoming non-functional. The launching states which retain command and control over these satellites have no incentive for bearing the cost of their removal. The involvement of private parties adds a further layer of complication since the law of outer space in its current state does not directly impose obligations on these parties. This paper proposes regulating these constellations as a whole rather than regulating each satellite individually, since most challenges arise from the density and large number of satellites in the constellation.

1. Introduction

Space has long been understood as vast and empty. The very word originates from the French *espace* and ultimately the Latin *spacium*, meaning extension or area.¹ This perception is being challenged in the case of special orbits which are becoming increasingly congested. Adding to this congestion, an increasing number of companies has proposed or begun deployment of large satellite constellations, ranging from hundreds to thousands of satellites. These consist mostly of small satellites, ranging from 10kg to 500kg in mass.² The constellations themselves range from OneWeb's 720 satellites to the

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1 Gerald B. Guest, *Space, Studies in Iconography*, 33 (2012) 219-230.

2 Lucien Rapp and Maria Topka, *Small Satellites Constellations, Infrastructure Shift and Space Market Regulation*, in: Annette Froehlich (ed.), *Legal Aspects Around Satellite Constellations Vol. 2*, Springer, 2021, pp 29-46.

Starlink network's 4257.³ These are launched and controlled mostly by private entities for profit making purposes, adding further to the difficulties of regulation in a treaty-based governance system which applies to state parties. This increases the risk of multiple tragedies of commons, including interference with ground-based astronomy, changes in earth's upper atmosphere, and the potential for the creation of large amounts of space debris.⁴ This paper will focus on the problems relating to space debris.

The first chapter will define the terms used and examine large constellations from a legal perspective, looking at the interaction of large constellations with the Outer Space Treaty, 1967, the Liability Convention, 1972, and various soft law instruments on debris mitigation. The next chapter will elaborate on the legal impact of large numbers of small satellites becoming space debris— including the effects of the principle of perpetual ownership when large tracts of coveted orbits like the Low Earth Orbit (LEO) are occupied by non-functional objects. This chapter will also establish the obligations of states under the *corpus juris spatialis* for space debris created from large constellations. The third chapter will look at possible approaches to regulating debris creation from large constellations. This will include approaches targeting state actors as well as private actors.

2. Large Constellations and Space Law

General Definitions

Before we begin examining the issues relating to satellite large constellations, we must define what we mean by each of these terms.

While the term 'satellite constellation' finds no mention in treaty law, it refers, in its ordinary meaning, to "a group of artificial satellites cooperating together under common control"⁵ This implies some communication between the satellites, either through inter-satellite communications or through a common ground control. These are largely deployed for continuous coverage, whether it be for military, scientific, or commercial purposes.⁶ Large

3 Jonas Radtke, Christopher Kebschull, Enrico Stoll, Interactions of the space debris environment with mega constellations—Using the example of the OneWeb constellation, *Acta Astronautica* 55 (2017) 131.

4 Aaron Boley, Micheal Byers, Satellite mega-constellations create risks in Low Earth Orbit, the atmosphere and on Earth, *Sci. Rep.* 11 (2021) 10642.

5 Damian Bielicki, Legal aspects of satellite constellations. *Air and space law*, 45.3(2020) 245-263.

6 *Ibid.*

Constellations are defined in U.S. Orbital Debris Mitigation Standard Practices as constellations containing at least 100 satellites.⁷

An artificial satellite is another term which is widely used but not clearly defined in law. In absence of a treaty-based definition, we have to rely on its ordinary definition as “a manufactured object or vehicle intended to orbit the earth, the moon, or another celestial body.”⁸ In context of treaty law, the broader term ‘space object’ is used, and forms the locus of the international law of outer space. This term is circularly defined in the Liability Convention and the Registration Convention as including its own “component parts”.⁹ A more helpful definition is provided by scholars like Vladimir Kopal, who understood the term to mean any object designed to be launched into outer space.¹⁰ A small satellite is understood to refer to a satellite under 10kg to 500kg.¹¹

Definition of Space Debris

Space Debris has two kinds of definitions. It is defined in the IADC Debris Mitigation Guidelines as “human made objects including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional.” The focus is not on the perceived value of a space object but rather its status, making the criteria objective functionality rather than subjective utility. However, these guidelines are technical rather than legal. The IADC document itself states that the definitions therein need not be understood to apply generally.¹² The International Law Association (ILA) defines space debris in its Draft Instrument on Space Debris as “man-made objects which are non-functional and not useful, and in whose condition no change is to be reasonably expected.”¹³

7 5.1, U.S. Government Orbital Debris Mitigation Standard Practices, November 2019 Update,

https://orbitaldebris.jsc.nasa.gov/library/usg_orbital_debris_mitigation_standard_practices_november_2019.pdf (accessed 10.09.2023).

8 Merriam-Webster, subentry 2(b), *referred in* Frans Von der Dunk, International Satellite Law, (2019).

9 Convention on International Liability for Damage Caused by Space Objects, Mar. 29, 1972, 24 U.S.T. 2389, 961 U.N.T.S. 187 (hereinafter ‘Liability Convention’); Convention on Registration of Objects Launched into Outer Space, Jan. 14, 1975, 28 U.S.T. 695, 1023 U.N.T.S. 15, I(b) (hereinafter ‘Registration Convention’).

10 See Vladimir Kopal, Issues Involved in Defining Outer Space, Space Objects and Space Debris 34th Colloquium on the Law of Outer Space, Montreal, Canada, (1991) 38-44.

11 Rapp and Topka, *supra* note 2.

12 IADC Space Debris Mitigation Guidelines, p. 8.

13 Space Law Committee, 66 Int’l L. Ass’n Rep. Conf. 305, 325 (1994) (hereinafter ‘ILA Draft Instrument on Space Debris’).

The UNCOPUOS deems the definition from the Debris Mitigation Guidelines as not legally useful, since it would classify non-functional craft still considered useful by the owners as debris despite retaining some legal value.¹⁴ The International Law Association's definition, on the other hand, would allow states to conduct a subjective analysis and decide whether they want to designate a particular object as debris by designating it as 'not useful'. This definition has particular relevance when a satellite is part of a larger constellation; it may not be functional, but may retain usefulness by virtue of being part of the infrastructure, carrying certain intellectual property, etc. Under the current regime, all space debris still qualifies as space object under the space law. The state thus has the same rights and obligations in relation to space debris as it does for other space objects on its registry. However, if we were to propose certain rights be conceded by the state of registry once an object is designated as space debris, it is pertinent to give it some say in which objects are designated as such. This paper will therefore use the definition of space debris provided in the ILA's draft instrument.

Space Law

The treaty law governing outer space emerged in the shadow of the cold war. The first treaty was drafted well before the moon landings, and the primary focus of international law at the time was maintaining international peace and cooperation.¹⁵ The locus of regulation here is states, not private companies.

However, a number of provisions are framed broadly in anticipation of future events, and the paper will now proceed to look at how they affect large constellations.

Outer Space Treaty

The Outer Space Treaty declares the use and exploration of outer space to be the province of all mankind and provides for freedom of its exploration, use, and scientific investigation on the basis of equality.¹⁶ The plain text of the article does not seem relevant to us, but it must be read in context of UN General Assembly declarations on this subject. The 1963 Declaration, framed

14 Active Debris Removal— An Essential Mechanism for Ensuring the Safety and Sustainability of Outer Space. A Report of the International Interdisciplinary Congress on Space Debris Remediation and On-Orbit Satellite Servicing, UN Doc. A/AC.105/C.1/2012/CRP.16 (January 2012).

15 See Manfred Lachs, *The Law Of Outer Space: An Experience In Contemporary Law Making* Tanja Masson-Zwaan & Stephan Hobe eds., Martinus Nijhoff, 2010.

16 Art I, Outer Space Treaty.

before the Outer Space Treaty, focuses on the principle of equality.¹⁷ The more recent 1996 Declaration, on the other hand, focuses on equity, specifically the rights of developing nations.¹⁸ This already puts Art. I in tension with large constellations which occupy large tracts of orbit for a single company or state.

This conflict will be exacerbated by Art. II of the Outer Space Treaty, which embodies the principle of non-appropriation, stating that outer space shall be free of appropriation claim of sovereignty “by means of use or occupation, or by any other means.” It may be argued that large constellations are occupying or using large parts of orbits, and if a significant number become defunct it will hamper developing states’ access to exploration and use of outer space for a significant amount of time.

The Outer Space Treaty also holds states ‘internationally responsible’ for national activities in space, whether they are carried out by governmental or non-governmental entities. States bear responsibility for compliance with the Outer Space Treaty and must authorise and continually supervise the activities of non-governmental entities.¹⁹ This provision is important for the Newspace era in general and for satellite large constellations in particular, since states bear responsibility not only as launching states, but shall also bear international responsibility for actions of entities if they are considered the ‘appropriate state’ under this article.

A corollary to the international responsibility and liability is that states retain ‘command and control’ over ‘objects launched into outer space’ on their registry.²⁰ Objects launched into outer space is understood to be a precursor to ‘space object’ and likewise covers the small satellites which constitute large constellations. States also retain perpetual ownership over such objects unaffected by their presence on the earth, in space, or on another celestial body.²¹ This is especially relevant in context of space debris, which although no longer functional or useful, is still under the ownership of the state whose registry it was launched on.

The large number of small satellites deployed in large constellations inevitably have consequences for the environment. Article IX of the Outer Space Treaty embodies a number of environmental law principles, first among them being the obligation to conduct activities with due regard to the

17 G.A. Res. 18 (1962) Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space (Dec. 13, 1963) (‘hereinafter 1963 Declaration’).

18 G.A. Res. 51/122, Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries (Feb. 4, 1997) (‘hereinafter 1996 Declaration’).

19 Art VI, Outer Space Treaty.

20 Art VIII, Outer Space Treaty.

21 Art VIII, Outer Space Treaty.

interests of other states. States are required to avoid harmful contamination or adverse environmental changes. They are further required to engage in international consultations if they have reason to believe any activity of its nationals will result in harmful interference with space exploration and use by other states.²² Large constellations have already begun interfering with ground-based astronomy. The large number of small satellites also leads to increased collision risk, deposition of material not naturally found in the relevant orbits, and increased creation of untracked space debris.²³

Liability Convention

The Liability Convention elaborates on Art. VII of the Outer Space Treaty. It provides for fault-based liability for damage caused by a space object in outer space and absolute liability for damage caused by a space object in airspace or surface of the Earth.²⁴ This liability is borne by a 'launching state', a term defined very broadly as a state which (i) launches or procures the launch of a space object, or (ii) whose territory the space object is launched from.²⁵ This broad definition is understandable in context of the Liability Convention's victim centric approach.

This leads to a number of considerations for states in context of the increased privatisation of space exploration in general and large constellations in particular. Large constellations may have to be treated differently due to the sheer number of satellites involved. Different states may deal with this differently— they may enforce design norms through domestic legislation or licensing, require liability insurance, or take a different approach and decide to absorb the costs of liability to encourage such ventures. This will have a bearing on the design of satellites, the commercial viability of the constellations, and ultimately the safety of outer space.

Debris Mitigation Guidelines

Treaty making in space law has been stalled since the 1970s, when the Registration Convention and Moon Agreement were framed. Space debris was first discussed in the United Nations Committee for the Peaceful Uses of Outer Space (UNCOPUOS) in 1994.²⁶ The international community has therefore found alternative ways to coordinate its efforts in fighting this problem. National space agencies have formed the Inter Agency Debris Committee

22 Art IX, Outer Space Treaty.

23 Aaron Boley, Micheal Byers, *supra* note 4.

24 Arts II & III, Liability Convention.

25 Art I, Liability Convention.

26 *See* Comm. on the Peaceful Uses of Outer Space, Rep. of the Scientific and Technical Subcomm. on Its Thirty-First Session, U.N. Doc. A/AC.105/571, at 2, 12– 13 (1994).

(IADC). The IADC prepared the Debris Mitigation Guidelines, which can be considered the first ‘regulatory’ document on the subject. It must be noted that the language in these guidelines is suggestive, not prescriptive.

These Debris Mitigation Guidelines, despite being called voluntary, hold significant value. Since the IADC itself comprises the most prominent space agencies, the guidelines come from industry experts and reflect existing practices of the space agencies, as recognised by the UNCOPUOS and UN General Assembly.²⁷ The Debris Mitigation Guidelines thus reflect ‘soft law’, which is a legal norm which is non-binding but nevertheless affects the actions of states through its significant normative value.²⁸ The various guidelines are therefore important to understanding the framework around large constellations.

The Debris Mitigation Guidelines require the following:

- 1) Limitation of debris creation during “normal operations”
- 2) Minimising the chances of in-orbit breakups through design as well as continuous monitoring
- 3) Avoiding intentional destructions of space objects
- 4) Post mission disposal of space objects passing through LEO by means of de-orbiting, retrieval, or re-orbiting to a graveyard orbit with lifetime of 25 years or shorter.
- 5) Prevention of orbital collisions through appropriate planning, manoeuvring, and design.²⁹

In 2017, the IADC issued a Statement on “Large Constellations of Satellites in Low Earth Orbit” (hereinafter “Statement on Large Constellations”). It highlights the fact that the large numbers of small satellites in large constellations represents a ‘step change’ in the number of satellites operating in the low earth orbits, and that this change challenges some of the underlying assumptions behind the aforementioned Debris Mitigation Guidelines. Additionally, the large number of satellites involved means that the negative consequences of the guidelines not being implemented has a much larger potential impact. The IADC’s Statement on Large Constellations presents a number of ‘additional considerations’ in order to better tailor the Debris Mitigation Guidelines to large constellations (the document takes care to clarify that these are not additional guidelines but rather clarifications on how the existing guidelines should apply in this use case).³⁰

27 See G.A. Res. A/RES/62/217, at 7 (Dec. 22, 2007), *see also* Report of the Committee on the Peaceful Uses of Outer Space, A/62/20, paras. 117 and 118 and annex. (2007).

28 Alan Boyle, *Soft Law in International Law Making*, in: Malcolm D. Evans (ed.), *International Law*, OUP, 2010, p. 120.

29 IADC Space Debris Mitigation Guidelines, IADC-02-01 Rev. 3 (June 2021).

30 IADC Statement on Large Constellations of Satellites in Low Earth Orbit, IADC-15-003 (September 2017).

The recommendations in the Statement on Large Constellations require higher standards for the design of the satellite constellations. Design recommendations for individual space objects within the large constellations include the capability of collision avoidance in orbit and a higher level of structural integrity in order to minimise chances of explosions. They also recommend enhanced trackability, more efficient collision avoidance, better communication of orbital manoeuvres, and clear communication of planned trajectories. Individual space objects should be designed to include on-board redundancies for post mission disposal measures and monitoring of these measures. Re-orbiting the vast numbers of small satellites to graveyard orbits above 2000km can lead to orbital cascading, so the 25-year residual lifetime in this orbit is re-emphasised.³¹

State Responsibility for Debris Mitigation of Large Constellations

As discussed in the previous chapter, Article VI of the Outer Space Treaty holds states internationally responsible for national activities in outer space even when carried out by non-governmental entities. The authorization and continuous supervision under this article would be implemented by means of domestic regimes. However, this merely passes the buck, as states have no greater short-term incentive to mitigate or remediate space debris than do profit making entities. The obligations for states, once established, must flow to all governmental and non-governmental entities operating in these states by virtue of Art. VI.

We now have to ask what obligates or incentivises states to compel debris mitigation for large constellations. Under Article VIII of the Outer Space Treaty, states retain jurisdiction and control over space objects irrespective of functionality. Space debris (where its origin can be traced) can therefore not be removed by third parties without encroaching upon the rights of its state of registry. The previous chapters have already stated that the vast number of space objects composing large constellations poses a greater risk of collisions. If any significant number of these objects become space debris, large parts of orbit would be rendered unusable. This will affect free access to outer space as the orbit gets more encumbered due to debris. This blocking of orbits will violate the freedom of access conceived of in Article I of the Outer Space Treaty. It also exacerbates the tension between privately run large constellations from developed countries and the 1996 Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries.³² Space debris will deny large parts of potentially lucrative orbits such as the LEO and the GEO to other states, and

31 Statement on Large Constellations, pp. 7-10.

32 1996 Declaration, *supra* note 18.

just like a ‘place saving object’ will constitute an appropriation of that part of orbit in violation of Article II of the Outer Space Treaty.³³

States may also be held liable for damage caused by their space debris under the Liability Convention. The definition of launching state in the convention is very broad, and multiple launching states are jointly and severally liable.³⁴ The large number of expected space debris from large constellations means it is only a matter of time before it causes damage on the surface of the Earth, to aircraft in flight, or elsewhere. While it may not always be easy to establish fault-based liability under Art. III, launching states will be held absolutely liable under Art. II.³⁵

States have good reason to regulate large constellations such that the chances of being held liable are reduced and once such liability does incur, the state can recover any damages paid due to a non-governmental entity.

3. Approaches to Regulation

Current State of Law

We have established that states are obligated under space law to avoid the creation of space debris from their large constellations. Moreover, the threat of liability is a reason for them to regulate large constellations such that the state’s liability is minimised. We now have to find regulatory and other means of to minimise debris creation while also not inhibiting the growth of large constellations as an industry.

The first issue in focus for regulation of space activities is liability avoidance through debris mitigation measures. A number of legislations around the world have already incorporated parts of the Debris Mitigation Guidelines, either directly or as a requirement for authorisation or licensing. The US Orbital Debris Mitigation Standard Practices provide specific practices for large constellations and small satellites, which implement a number of recommendations found in the IADC Statement on Large Constellations such as higher probability of post mission disposal, preference of de-orbiting as means of post mission disposal, and the limitation of orbital lifetimes to less than 25 years post mission.³⁶ These guidelines are meant for governmental activities, but US law also requires private operators to submit a debris mitigation disclosure while obtaining authorisation or license for launch.³⁷ It is reasonable that the Standard Practices being followed by the government

33 P.M Sterns and L.I. Tennen, *Orbital Sprawl, Space Debris and The Geostationary Ring Space Policy*, 6.3(1990), p. 221.

34 Arts.VI, V, Liability Convention.

35 Art. II, Liability Convention.

36 U.S. Government Orbital Debris Mitigation Standard Practices, *supra* note 7, at 5.1-5.2.

37 47 CFR 5.64, <https://www.ecfr.gov/current/title-47/section-5.64> (accessed 14.09.2023).

will be the touchstone when assessing these plans. Similarly, UK's Space Industry Act, 2018 places the primary burden of complying with any space debris mitigation guidelines on the state regulator.³⁸ Australia and New Zealand also require formulation of debris mitigation plans prior to the grant of license.³⁹ A number of other states, such as the UK,⁴⁰ France,⁴¹ China,⁴² and Japan⁴³ include avoidance of debris creation or of 'harmful contamination' as conditions for licensing and authorisation.

Let us quickly suggest a few differences in approach: Some states such as the US, Australia, and New Zealand expressly require non-governmental entities to formulate debris mitigation plans, while others such as the UK, France, and Japan impose more general requirements to avoid debris creation, harmful contamination, or interference with the "peaceful exploration and use of outer space." Legislations of Japan and the UK make no mention of debris in relation to conditions for grant of license, instead referring to it obliquely through the term 'harmful contamination'. Similarly, Russian law refers to "safety of space operations" including ecological safety.⁴⁴ This leaves greater room for interpretation by the authorising agency. These differences imply varying levels of flexibility on part of the regulators and the operators of satellite constellations. It must be noted that this flexibility will be important in how regulators assess large constellations.

If liability cannot be avoided, states require non-governmental entities to indemnify them against claims brought against the state for actions caused by the non-governmental entity. In some states such, it is imperative for the non-governmental entity to indemnify the state, while in others the regulator or state merely have the option to demand such indemnity. In many states such as the UK and France, there is a cap on this liability.⁴⁵ Almost all states require operators to obtain third party liability insurance as a prerequisite to obtaining the relevant licenses. This allows the governments to ensure compensation for domestic victims recover any liability paid under the Liability Convention without putting sudden stress on the launching entity's

38 § 2(2)(h), Space Industry Act, 2018.

39 Australia Space (Launches and Returns) Act, 2018; New Zealand Outer Space and High Altitude Activities Act, 2017.

40 § 5(2), Outer Space Act, 1986.

41 Art. 5, LOI no 2008- 518 du 3 juin 2008 relative aux opérations spatiales, unofficial English translation at https://aerospace.org/sites/default/files/policy_archives/French%20Space%20Ops%20Act%202008%20unofficial%20translation.pdf (accessed 13.09.2023).

42 Interim Measures on the Administration of Permits for Civil Launch Projects.

43 Art. 22, Act on Launching of Spacecraft, etc. and Control of Spacecraft, (Act No. 76 of 2016).

44 No 104 - Statute on Licensing Space Operations, unofficial English translation at https://www.unoosa.org/oosa/en/ourwork/spacelaw/nationalspacelaw/russian_federation/decreedecree_104_1996E.html (accessed 13.09.2023).

45 § 5(3), Outer Space Act, 1986.

finances. Here too, there are fine differences between regulatory regimes in different states, such as the US where the licensee is allowed to choose between obtaining insurance or demonstrating ‘financial responsibility’, and the amount of insurance required is also capped.⁴⁶ France also provides a similar choice between insurance and ‘financial guarantee’.⁴⁷ The UK is the only state which appears to have adapted its policies for large constellations. Since 2018 the UK Space Agency has changed the requirements related to insurance from ‘per-satellite’ to ‘per-occurrence’. This will allow one insurance policy to cover the entire constellation, reducing the financial burden on the licensee while retaining the protection from insurance.⁴⁸

New Approach to Governing Large Constellations

A new approach to debris mitigation addressing large constellations has to take into account the peculiar nature of a constellation, namely that it is a single piece of infrastructure composed of a number of independent small satellites. It will have to account for the fact that in the Newspace era, the operators of these large constellations are driven by profit and need to be regulated without curbing their incentives to continue innovating.

One important solution here is to consider the satellite constellation as a whole rather than looking at the component satellites in isolation. This has consequences for debris mitigation as well as liability capping and insurance requirements. The IADC, a body comprising the 13 leading national space agencies, has already released the Statement on Large Constellations, which details how large constellations should be treated differently from normal satellite launches. States should incorporate these suggestions as requirements when licensing and authorising satellites which form part of large constellations. The other aspect of this would be to cap liabilities and fix insurance requirements for the constellation as a whole. This is important since many satellites in the constellations will be placed not only in the same orbit, but in close proximity to each other, leading to increased risk with each consecutive launch, but also affecting the risk profile of previously launched satellites.

These measures, and the increasing prevalence of large constellations, will also encourage the growth of ancillary industries over time such as active debris remediation. The demand for active debris removal would come from two sources: one is the reactive, and is already being undertaken by agencies and governments in order to reduce risks to active space objects in orbit, the proposed regime would create a proactive approach— undertaken by entities

46 51 U.S. Code § 50914.

47 Art. 6, LOI no 2008- 518 du 3 juin 2008 relative aux opérations spatiales.

48 Bielicki, D.M., 2020. Legal aspects of satellite constellations. *Air and space law*, 45(3).

launching large constellations in order to increase the useable life of satellites and reduce chances of liability.⁴⁹

4. Conclusion

The conception and implementation of large constellations represents a new era in the exploration and use of outer space. These present a number of new problems and challenges in the nature of a tragedy of commons, one of them being the large potential creation of space debris. While the *corpus juris spatialis* does not deal with space debris or large constellations, its provisions are broad and flexible. As such, the Outer Space Treaty places certain obligations on states which they will be seen to violate in view of debris creation from large constellations launched and operated by governmental or non-governmental entities within their jurisdiction. The Liability Convention subjects 'launching states' to liability for damage caused by their space objects or debris from their large constellations. Soft law instruments such as UN General Assembly Regulations, Debris Mitigation Guidelines of the IADC and UNCOPUOS, and the IADC's Statement on Large Constellations also hold normative power over states.

These considerations have led to various states enacting laws governing the licensing and authorisation of space activities. However, different states provide varying levels of flexibility to regulators, and almost all govern each satellite launch as disconnected from the larger constellation. This paper proposes some features which need to be incorporated in domestic regulatory regimes across jurisdictions in order to address the particular challenges posed by large satellite constellations:

- Licensing and authorisation of large constellations as a single entity, with individual launches of constituent space objects being treated as part of the larger planned structure of the constellation.
- Requirement of a debris mitigation plan as an essential part of the application for licensing and authorisation of space activities.
- Incorporation and publication of Debris Mitigation Guidelines, and the recommendation made in the Statement on Large Constellations as the basis for evaluation of the debris mitigation plan by the regulator.

49 Austin Link, Op-ed | Clearing space debris is good business, SpaceNews, August 12, 2021, at <https://spacenews.com/op-ed-clearing-space-debris-is-good-business/?fbclid=IwAR3BXhEJKryII3byIqnQcdpyYU7Dlp64O3K5TD2Kvf4SvoKKrPJlxWML8rs> (accessed 15.09.2023).

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- Holding the non-governmental entity directly liable for damage caused within the state, and liable to indemnify the state against claims paid by the state for damage caused by the non-governmental entity's space objects.
- Mandatory third-party liability insurance, taken on a per-occurrence basis and covering the entire constellation under a single policy.
- Capping of liability on case-by-case basis, determined by a risk assessment which rewards additional safety measures, more efficient end of life disposal, and the inclusion of satellite servicing.
- Penalties on creation of space debris resulting from non-compliance with the proposed plan or other forms of negligence by the non-governmental entity, to be collected in a 'national space debris fund'.
- Usage of the national space debris fund to improve debris mitigation technology and fund active debris removal where possible.

These measures will help regulate the emerging industry without imposing a regulatory burden which will hamper innovation. It will also help in developing ancillary industries around satellite servicing and active debris removal over time, hopefully averting the tragedy of the commons so often predicted for outer space.