



SPACE SUSTAINABILITY REPORT

Making the case for ESG regulation, international standards and safe practices in Earth orbit





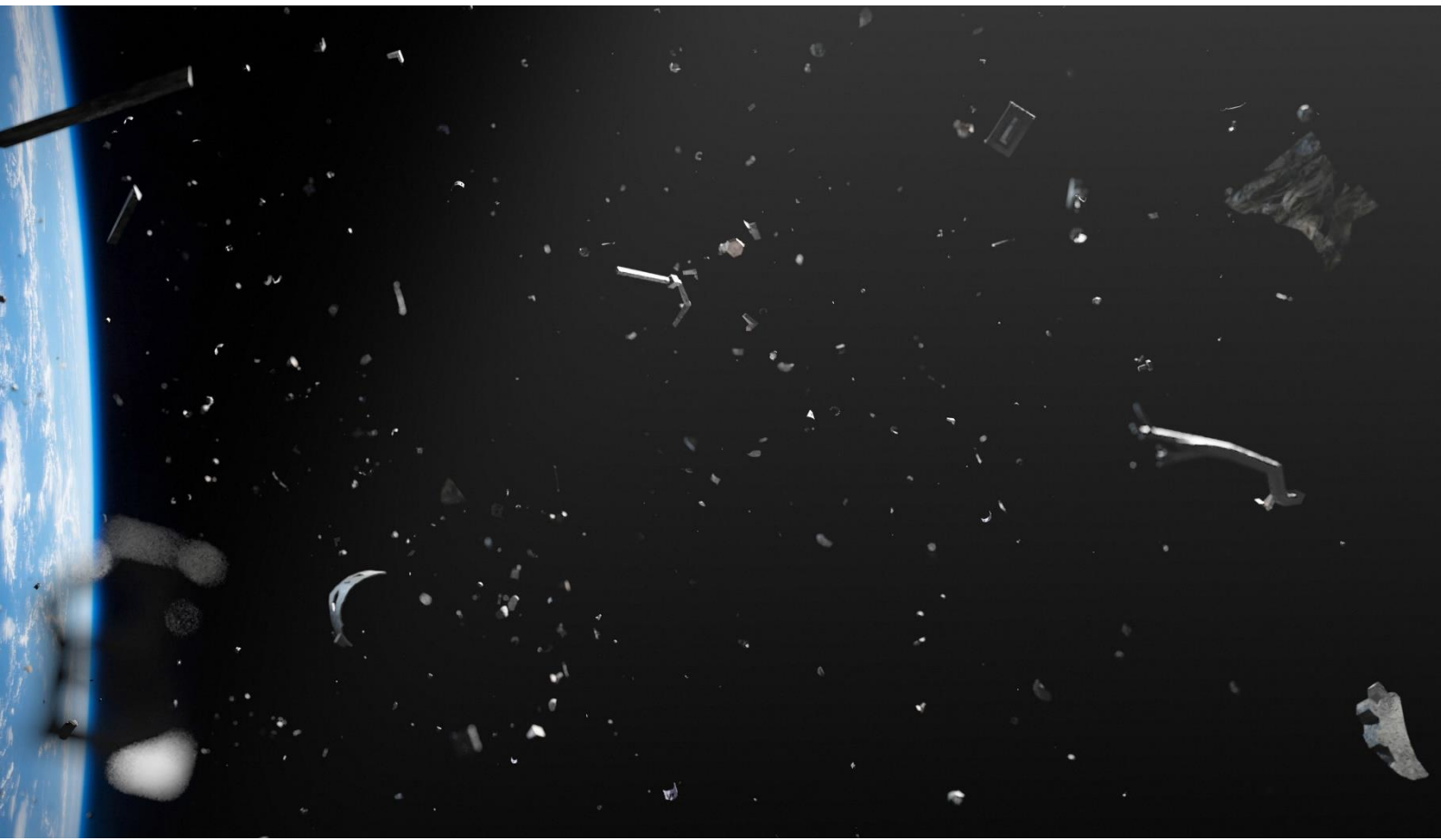
ABOUT

This report explains how we might start down the path of space sustainability with practical and actionable initiatives that can be immediately adopted by all satellite operators.

Inmarsat is committed to taking an industry lead in changing this state of affairs by advocating for changes in operational practices, sound regulation, and a greater sense of space environmentalism.

ACKNOWLEDGEMENTS

An Inmarsat report supported by AstroAnalytica.



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FOREWORD

BY RAJEEV SURI, CHIEF
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This report seeks to break through bottlenecks in the space sustainability debate by contributing innovative and practical proposals that can be taken by all participants in the space regime both immediately and into the longer term. I recognise that we live in the real world, so not all of the recommendations include in the report will come to pass, but the time has come to move on from recognising the problem towards taking meaningful action.



Given the stakes – our total dependence on space and the unquestioned benefits that we all enjoy from the fullest exploitation of space in all manner of ways – we must be of the mind that there is much to lose and not all of the risks are apparent even now. The lesson of environmental clean-up is that prevention is better than the cure and I urge that mindset to all who care about and have interest in space.

Ultimately, this contribution is intended to spur debate and action by all who are placed to act. I trust that it will be taken as a constructive contribution to the space sustainability cause and that we move to a new era of responsible conduct in space.

EXECUTIVE SUMMARY

- **We must change the way in which we view space and its relationship to Earth.**
Space environmentalism is a cultural mindset that should be at the heart of all satellite operations with the aim of using the space domain responsibly and with consideration for other users and for future generations.
- **There is cause for deep concern about the mid to long-term usability and sustainability of Earth's orbits.**
The space community is not a good steward of the domain in which it operates.
- **By the end of this decade, we are likely going to see tens of thousands of operational satellites in LEO.**
The source of the growing congestion in LEO is the rise of megaconstellations over the past decade. Thousands of satellites will be deployed in LEO every year by 2030, with around 100,000 already proposed as part of active projects.
- **The risk from space debris is most acute in LEO.**
With the rise of LEO megaconstellations the Kessler Syndrome risk becomes less theoretical and much more likely with each additional orbital insertion of multiple satellites.
- **The risk of catastrophic accidental collisions is increasingly high.**
LEO is where all human activity in space currently takes place, with further activity expected as commercial space stations become operational over the next decade.
- **There is an insufficient provision of technical capabilities, interoperable standards and regulatory tools with respect to Space Situational Awareness (SSA) and Space Traffic Management (STM).**
Satellite operators of all types from various countries are operating with incomplete and inaccurate data resulting from an absence of international standards in object characterisation, cataloguing and broader modelling assumptions.
- **The unwieldy UN process is moving too slowly on the truly meaningful space issues confronting the sector.**
It is time for a “coalition of the willing” established at the highest political level among participating countries, and which would commit collectively to shared principles, regulations and coordinating mechanisms for safe space operations and orbital development.
- **Sharp and predatory practices by government and commercial satellite operators are putting space operations at risk.**
Sharp practices by some commercial and government satellite operators are decisions and activities that can lead to monopolised orbits; or where certain governments can carry out intrusive and dangerous activities with impunity and disregard to any safety considerations.

- **Orbital exclusion stifles healthy competition and innovation.**
This behaviour by satellite operators is anti-competitive in nature and discourages innovation. Distinguishing between good-faith space business strategy and “sharp practices” that manipulate systemic blindspots for corporate or indeed national advantage is highly important in the broader context of rules and norms for the future sustainability of space.
- **Certain states engage in what is increasingly being recognised as “space sector capture”.**
This is a type of economic warfare that also impacts commercial satellite operators and can lead to a form of orbital exclusion; it requires a different set of responses.
- **Running against the space sustainability “trend” is also set to become a much more risky and public affair than before.**
If done properly and implemented along ESG principles, space sustainability can, for example, quickly expose commercial or governmental operators who might be merely green-labelling their activities in orbit.
- **Environmental challenges in outer space have traditionally been assumed to be separate and insulated from the environmental problems on Earth.**
There is emerging evidence to suggest that this may no longer be the case for much longer if the various megaconstellation projects currently in progress or planned go ahead to completion.
- **Space objects falling down from orbit contribute to unpredictable climate effects.**
The sheer number of satellites that will de-orbit and decay into the Earth’s upper atmosphere will deposit more aluminium particulates there than all of the meteorites that have entered the atmosphere.
- **Interference with astronomical observations is not a marginal issue.**
Megaconstellations are having a drastic impact on invaluable scientific work that cost billions of dollars, most of which is funded by governments.
- **The ethos of next-generation orbital management must be grounded in an international approach.**
As things stand now, we are moving toward a possible scenario where low-Earth orbit and beyond becomes unusable.

SUMMARY OF RECOMMENDATIONS

1. National regulators need to address sustainability issues when they consider market access.
2. Countries with a strong space presence (such as US, UK or the EU) need to come together to agree on basic standards.
3. ITU to be given broader mandate and resources for long-term solution.

Group or Forum	Recommendation
United Nations (general: UNCOPUOS, ISO, UNSC)	<ul style="list-style-type: none"> • Place carrying capacity on the space sustainability agenda. • Adoption of binding rules and a formal mechanism for communication and coordination of collision avoidance manoeuvres among all major satellite constellation operators, as a first step towards an international STM framework. • Pioneer an Active Debris Removal (ADR) capability under UN Security Council control, drawing on peacekeeping operations models.
G7, national governments	<ul style="list-style-type: none"> • Promote adoption of kinetic anti-satellite (ASAT) testing moratoriums and/or adherence to the moratorium announced by the US in April 2022. • Add a permanent “space track” to G7 meetings, as a forum for high-level space policy coordination. • New “plurilateral” coalition of the willing on space sustainability, potentially building on the Artemis Accords. • New allied national security space dialogue at the National Security Adviser level, separate from allied military coordination in space. • Lower threshold calling out nefarious or reckless activity in orbit by other governments. • Formal threat intelligence sharing mechanisms between governments and commercial satellite operators.

	<ul style="list-style-type: none"> • Include satellite technologies and services as part of foreign aid policies to counteract space sector capture by rivals;
IADC	<ul style="list-style-type: none"> • Reduce the “25-year rule” to 5-10 years. • Implement carrying capacity metrics.
ISO	<ul style="list-style-type: none"> • Promote quality standards in SSA data collection, cataloguing processes (including formats), sharing and modelling. • Technical standards for satellite design and constellation architecture to demonstrate ability to comply with (revised) international End of Life guidelines; to increase reliability and reduce failure rates; and to include back-up systems/procedures to safely dispose of inoperable satellites.
ITU	<ul style="list-style-type: none"> • Start the process to expand ITU's remit from spectrum to LEO orbital regulation. • Coordinate specific technical sustainability criteria for LEO, to be included as part of national regulators' licensing processes.
National regulators (leading by example)	<ul style="list-style-type: none"> • Tie LEO licensing to orbital carrying capacity criteria. • Global Navigation Satellite Systems (GNSS) on LEO satellites as standard; operators to provide precise ephemeris data for all satellites in a timely manner to SSA entities. • Require LEO megaconstellation launches to include an initial insertion into a placeholder orbit below 400km to confirm operational status before boosting to final deployment altitude. • Require contingency plans for guaranteed continued safe constellation operation regardless of a company's financial and ownership status. • Points-based penalty system for operators (similar to that for drivers) linked to the licensing process, to incentivise good behaviour (e.g. active cooperation on data sharing, conjunction deconfliction etc) • Condition the award of service and/or operating licences to foreign satellite companies on their home government's adherence to kinetic ASAT testing moratorium.

	<ul style="list-style-type: none"> • Make analysis of the wider economic context for large LEO constellations a statutory part of the licensing process. • Require environmental assessments (under existing national legislation) as part of the licensing process.
Private sector, governments	<ul style="list-style-type: none"> • Invest in more and better SSA sensors (especially in remote regions to increase direct coverage of blindspots around the world). • Small beacon transponders on future LEO spacecraft (and rocket boosters) until or in addition to integrating GNSS receivers.
Banks, investment firms, insurers and other players active in the space market	<ul style="list-style-type: none"> • Develop and promote Space ESG principles and criteria to drive space sustainability cultural change across industry. Promote space environmentalism. • Kitemark standard for satellite investment, insurance and operations, linked to sustainability criteria. • Encourage shareholder activism to drive more sustainable operational practices and company policies.

FORUMS AND ORGANISATIONS WITH INFLUENCE

Organisation	Description
National Regulators	<p>Satellite Filings: National regulatory bodies for communications, like US Federal Communications Commission (FCC), France's Autorité de Régulation des Communications Électroniques (ARCEP) or the UK Office of Communications (Ofcom) act as the national notifying administrations under ITU procedures in relation to international management of the radio spectrum and orbit resources, submitting and managing satellite filings to the ITU on behalf of organisations registered.</p> <p>Spaceflight: National aviation regulatory bodies like the U.S. Federal Aviation Administration (FAA) or the UK Civil Aviation Authority (CAA) manage and provide licences for spaceflight operations conducted from their respective national territory.</p>
The International Telecommunication Union (ITU)	The ITU is a specialised agency of the United Nations responsible for many matters related to information and communication technologies, including the allocation of radio frequency spectrum and physical orbital slots to all satellite operators. The foundation of the ITU legal framework is the ITU Constitution and Convention (CC) and the Radio Regulations
The UN Committee for the Peaceful Uses of Outer Space (UN COPUOS)	Through its group of experts, UN COPUOS has developed a range of space sustainability guidelines that can form the basis for international standard making in bodies such as the ISO.
Inter-Agency Space Debris Coordination Committee (IADC)	The IADC is an international governmental forum for the worldwide coordination of activities related to the issues of man-made and natural debris in space. It has produced the <i>Space Debris Mitigation Guidelines (2002)</i> , with its latest revision in June 2021. The guidelines are non-binding and non-compliance cannot be reviewed or sanctioned, but several countries have adopted them in their respective national legislation.

International Organization for Standardization (ISO)	The ISO is an independent, non-governmental international organization with a membership of 167 national standards bodies. Through its members, it brings together experts to develop voluntary, consensus-based, market relevant international standards. Transforming the guidelines and best practices from the IADC, United Nations, and other regulatory bodies into a comprehensive set of standards, the ISO has been publishing <i>Space Debris Mitigation Standards</i> since 2010.
Group of Seven (G7)	The G7 consists of the United States, United Kingdom, France, Germany, Italy, Canada, and Japan, plus the European Union. As most big commercial satellite constellation operators are headquartered in a G7 country, the G7 can be an important forum for policy alignment and discussions on space sustainability across these key nations.
Space Data Association (SDA)	The Space Data Association (SDA) is an international organization that brings together satellite operators to support the controlled, reliable, and efficient sharing of data critical to the safety and integrity of the space environment. The SDA membership includes some of the world's largest satellite communications companies.
<i>Other groups and actors with influence</i>	<ul style="list-style-type: none"> • Space agencies (e.g. NASA, ESA, UKSA etc) • Banks and insurers • Satellite operators • Shareholders of commercial satellite operators • Scientific community • SSA networks (national and commercial)

INTRODUCTION

An underlying, yet prominent, trope within the global space community is that it is an environmentally friendly sector that makes significant contributions to combating climate change, environmental degradation, and solving many of the Earth's greatest challenges such as tracking the spread of diseases or documenting war crimes. To the extent that space science and exploration, satellite communications, and Earth observation are essential to greater understanding of our planet and its myriad, complex interactions and challenges, the space community certainly has a great deal to be proud of.

But the complete, real picture is slightly different. Many of the rocket boosters that place satellites into orbit, as well as large numbers of satellites that must burn up in the atmosphere at the end of their operational lifetimes – are in fact setting the stage for an environmental crisis in space that, ironically, could further compound the climate challenge on Earth.

The space community – whether civil, commercial, or military actors – are not the good stewards of space that they all too often assume. Moreover, there is growing evidence that the parlous state of the space environment, through human-made space debris and crowded orbits, may even impact the climate change crisis on Earth.

Independent of this, there is cause for deep concern about the mid to long-term usability and sustainability of Earth's orbits and, as a result, about the reliability and continuity of vital services provided by satellites for global connectivity and communications, positioning, navigation, and timing (PNT) services, and Earth observation. In this context, we should remind ourselves that “sustainability” is not an attribute of individual satellites or constellations – but of all satellites and systems, in aggregate, that occupy space.

Without space modern society would simply stop working. It is trite to suggest that there are viable and currently available alternatives to the space-based services that sustain local and global critical infrastructures, economic connectivity, and national security readiness. The fact is that the wellbeing of people across the world depends upon satellites in myriad ways. It is therefore both in national governments' and commercial companies' interest that robust and bold steps are taken to arrest the deteriorating state of the space environment and make serious efforts to render it a domain that can sustain commercial, scientific, and national security activities for generations to come.

SPACE ESG

Space sustainability – the best practices, regulations, and policies that ensure everyone “can continue to use outer space for peaceful purposes and socioeconomic benefit now and in the long term”¹ – has become more than a technical issue. It is now a popular term among many policy makers, analysts, and commercial space executives in recent years, and has emerged alongside the rise of environmental, social, and governance (ESG) issues in corporate culture and practice.

Against a background of global concern about climate change, ESG criteria can play an important role in screening the suitability of investments, especially in their impact beyond the purely financial. A coal-burning power plant may indeed be a financially profitable venture, but its immediate and longer-term environmental harm and cost outweighs any shorter-term profit margin. As an insufficiently mature concept ESG has also been an easy target for criticism – from all sides – for being ideologically driven. But the fact is that global business culture is changing and rightly incorporating more sustainability principles into its operating models. Space will be no exception – and change brings its own opportunities.

If done properly and implemented along ESG principles, space sustainability can, for example, quickly expose commercial or governmental operators who might be merely green-labelling their activities in orbit. Space sustainability is already good for business today – let alone in the years to come – and any company or government that sees economic opportunity in space should understand that long-term commercial viability rests on adopting and implementing the best practices, regulations, and policies required to ensure that profits can be made well into the future. In other words, space sustainability is not only a worthy end in and of itself, for the betterment of the space environment: it is increasingly vital business-wise.

Running against the space sustainability “trend” is also set to become a much more risky and public affair than until now. The space domain becomes increasingly transparent thanks to the spread of space domain and situational awareness capabilities. It is progressively easier to detect – and call out to a global audience – unsafe and irresponsible space actions and operations undertaken by governments and commercial

¹ Secure World Foundation, “Space Sustainability: A Practical Guide,” Washington, DC: Secure World Foundation, p. 4, 2018, URL: https://swfound.org/media/206407/swf_space_sustainability_booklet_2018_web.pdf

operators. Space operators are therefore under increasing pressure to make good on, and follow through with, their pledges to adopt space sustainability measures.

Despite these helpful developments, the stack of problems is rising even faster and the sustainability picture is worsening. Our collective use of the space domain is threatened not only by growing space debris and congested and crowded orbits, but also by sharp, even irresponsible, practices by some government and commercial satellite operators. These practices involve everything from uninvited close-proximity operations with inspection satellites that can approach a rival nation's military and commercial communication satellites at very close range in geostationary orbit (GEO) at 36,000 kilometres above the Earth's surface through to some megaconstellation operators in low-Earth orbit (LEO) neglecting to deconflict orbital conjunctions or placing non-functioning satellites in orbits where it will take them centuries to decay.

Such practices are not only irresponsible and dangerous they are also unsustainable for all commercial, civil, and military space operators. Commercial, scientific, and even strategic imperatives can be achieved and fulfilled while simultaneously ensuring sustainable space operations that preserve the space environment and, more particularly, Earth's orbits for future use.

Apart from implementing practical solutions to manage congested orbits and to proscribe sharp practices, there is also a growing need for the whole of the space community to proactively adopt space environmentalism in its vision for the future.

Space environmentalism is a cultural mindset that should be at the heart of all satellite operations with the aim of using the space domain responsibly and with consideration for other users and for future generations. Space environmentalism means satellite operators demonstrate responsible behaviour and practices in their actions not just in their marketing materials or government statements. This cultural mindset will not be adopted overnight by the global space sector – cultural change takes time and is uneven in its distribution. But space environmentalism can be promoted through regulation, investor activism – through substantive ESG criteria in the commercial sector – international norm building, and tying the international standards system to the regulation of satellite operations and the financing of new systems.

As Rajeev Suri, Inmarsat's CEO, noted recently, "for space to support sustainability on Earth, there needs to be sustainability in space. And, to be blunt, we are moving in the

wrong direction here.”² According to him, there are three primary areas where the space community at large is failing to adopt space sustainability:

- addressing the growing risk of catastrophic incidences in space stemming from space debris;
- a lack of space environmentalism and understanding of how environmental problems in space contribute to environmental problems on Earth; and
- the challenge of orbital exclusion as a result of sharp and predatory practices carried out by some commercial and governmental satellite operators.

This report analyses these three issues in greater depth and then provides recommendations for policy makers and industry executives to move the space sector on to a substantively more sustainable path – not only in words but also in discernible actions.

² Rajeev Suri, “Satellite communications in reducing emissions in aviation and maritime,” speech given to the Royal Aeronautical Society, London, UK, 26 April 2022: <https://www.inmarsat.com/en/insights/corporate/2022/satellite-communications-in-reducing-emissions.html>

BACK FROM THE BRINK: ADDRESSING CONGESTION, DEBRIS AND COLLISION RISK

Only eight years ago there were approximately 1,400 operational satellites in LEO. Today that number has grown to over 4,000³ – and keeps rising ever faster. The trend is exponential. By the end of this decade we are likely going to see tens of thousands of operational satellites in LEO, not to mention thousands upon thousands of other human-made objects such as spent launch boosters, other rocket parts, and satellites that are no longer operational or were inoperable once launched.

All of these satellites and objects orbit several hundred kilometres above the Earth's surface in a complex choreography of orbital planes and intersections. Even today, we have a limited understanding of what is actually happening in LEO at any one time, and relatively few capabilities such as telescopes and radars to monitor who is doing what.

Current mass (t) in orbit per object type and orbital regime										
Orbital Regime	PL	PF	PD	PM	RB	RF	RD	RM	UI	Total
LEO	2264.2	1.5	0	11.4	1319.6	0.2	0	12.4	0	3609.3
GEO	2473.9	0	0	1	135.6	0	0	0	0	2610.5
EGO	800	0	0	4.9	355.3	0	0	0.2	0	1160.5
GTO	118.9	0	0	1	551	0	0	25.1	0	696
NSO	354.6	0	0	0.4	209.5	0	0	0	0	564.4
MEO	69.8	0	0	0.3	26.8	0	0	2	0	98.9
LMO	66.1	0	0	8.4	428.2	0	0	88.1	0	590.8
MGO	92.9	0	0	1.9	289.4	0	0	0	0	384.1
HEO	42	0	0	0.1	96.6	0	0	0	0	138.7
Other	66.6	0	0	0.1	8.1	0	0	0	0	74.8
Total	6348.9	1.5	0	29.4	3419.9	0.2	0	127.9	0	9927.9

³ Union of Concerned Scientists, "UCS Satellite Database," updated 01 January 2022, URL: <https://www.ucsusa.org/resources/satellite-database>

Figure 1 - Current mass (t) in orbit per object type and orbital regime⁴.

Categories of identifiable objects in the Space environment: *Payloads (PL); Payload mission related objects (PM); Payload fragmentation debris (PF); Payload debris (PD); Rocket body (RB); Rocket mission related objects (RM); Rocket fragmentation debris (RF); Rocket debris (RD).*

Orbital Regimes: *Geostationary Orbit (GEO); Inclined Geosynchronous Orbit (IGO); Extended Geostationary Orbit (EGO); Navigation Satellites Orbit (NSO); GEO Transfer Orbit (GTO); Medium Earth Orbit (MEO); GEO-superGEO Crossing Orbits (GHO); Low Earth Orbit (LEO); High Altitude Earth Orbit (HAO); MEO-GEO Crossing Orbits (MGO); Highly Eccentric Earth Orbit (HEO); LEO-MEO Crossing Orbits (LMO)*

As well as operational satellites for Earth observation and communications, LEO is also where all human activity in space currently takes place. The International Space Station and the Chinese Tiangong space station operate in LEO with their human crews and the regular resupply missions from Earth to sustain human presence there. In the coming years it is likely that we will also see private space stations operated by the likes of Axiom Space or Blue Origin in LEO.⁵ Moreover, countries such as the United States and China are working on sending crewed missions to cislunar⁶ space and the surface of the Moon in the coming years. They will have to traverse an increasingly crowded and complex LEO environment where the risk of catastrophic accidental collisions is increasingly high.

⁴ European Space Agency, "Space Environment Statistics," updated 10 May 2022, URL: <https://sdup.esoc.esa.int/discosweb/statistics/>

⁵ Stephanie Schierholz & Gary Jordan, "NASA Selects Companies to Develop Commercial Destinations in Space," NASA Press Release, 02 December 2021, URL: <https://www.nasa.gov/press-release/nasa-selects-companies-to-develop-commercial-destinations-in-space>

⁶ Technically defined as the area between the Earth and the Moon, for practical and policy purposes cislunar space refers to the region stretching beyond GEO out to the lunar orbits and up to the surface of the Moon.

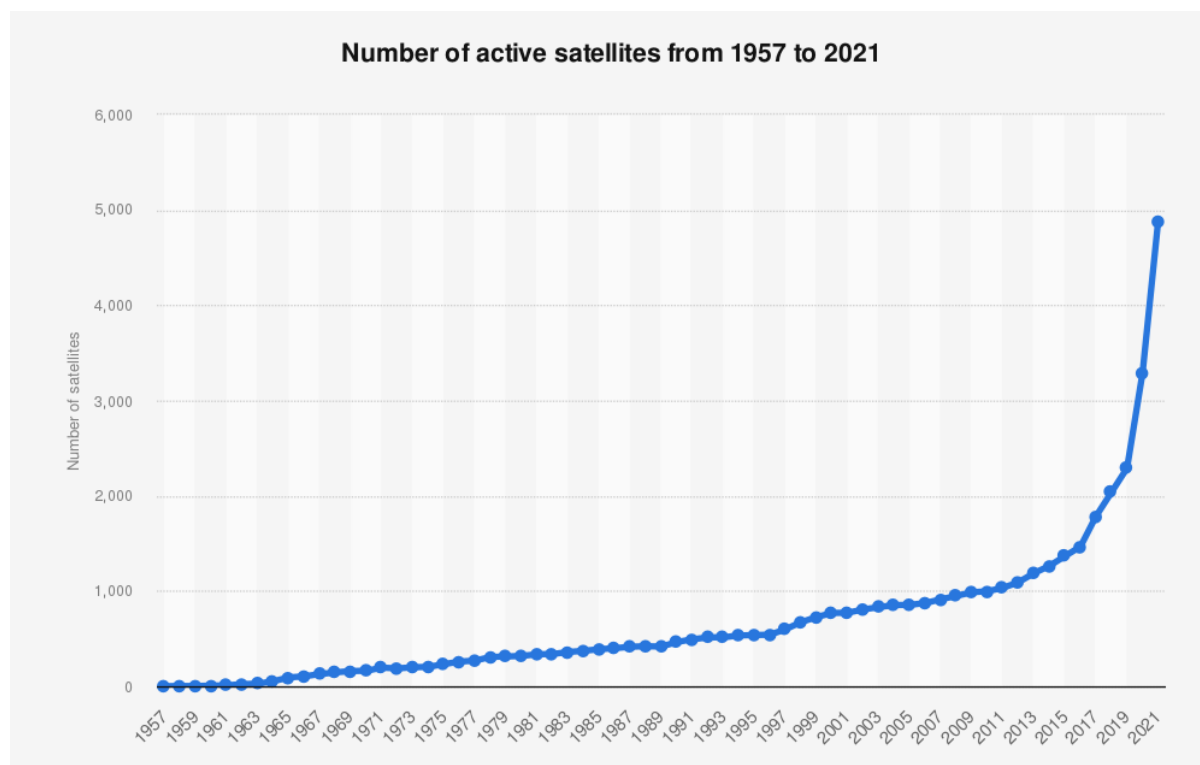


Table 1 – Number of active satellites from 1957 to 2021.⁷

THE MEGA-PROBLEM

The main driver of the growing congestion in LEO is the emergence of megaconstellation projects in this orbital regime over the past decade. They include commercial satellite communications providers such as Starlink, OneWeb, Telesat, and the Project Kuiper megaconstellation to be built out by Amazon; governmental projects such as the hundreds of satellites comprising the National Defense Space Architecture being developed by the US Department of Defense's Space Development Agency (SDA); or the 13,000 communication satellites being developed by China for its sovereign use. Other countries such as South Korea and Russia, as well as the EU, are also mulling building their own LEO megaconstellations.

⁷ Source: Jonathan McDowell, "Jonathan's Space Pages", accessed May 2022, URL: <https://planet4589.org/space/stats/stats1.html>

Constellation	Company	No. of Satellites
Approved/In Development		
Guowang	China Satellite Network Group	12,992
Starlink	SpaceX	11,943
Project Kuiper	Amazon	3,236
OneWeb	OneWeb	648
Lightspeed	Telesat	298
Spire Global	Spire Global	175
Boeing	Boeing	147
Subtotal, Approved/In Development: 29,439		
Proposed		
Starlink	SpaceX	30,000
Astra Constellation	Astra Space	13,620
OneWeb	OneWeb	6,372
Boeing	Boeing	5,670
Project Kuiper	Amazon	4,538
Hughes Network	Hughes Network Systems	1,440
Lightspeed	Telesat	1,373
SpinLaunch	SpinLaunch	1,190
Intelsat	Intelsat	216
Kuiper Systems	Kuiper Systems	199
Inmarsat	Inmarsat	198
Subtotal, Proposed: 64,816		
Total (Approved/In Development and Proposed): 94,255 ⁸		

Table 2 – D. Messier, 'Planned Comsat Constellations Now Exceed 94,000 Satellites',⁹

⁸ Greg Wyler's recently-announced E-Space system would add 100,000 proposed satellites to the total figure, but details are severely lacking.

⁹ Parabolic Arc, 08 November 2021, URL: www.parabolicarc.com/2021/11/08/planned-comsat-constellations-now-exceed-94000-satellites/

It is undeniable that all too often these megaconstellation programmes are developed, architected, launched, and operated with very little consideration for other legitimate users – including the end-users of satellite services. Most damagingly, there is insufficient pressure (internal or external) on these companies to implement solutions for how their satellites can be safely and responsibly disposed of if they fail in orbit after launch or when they reach the end of their operational lifetimes.

Of more immediate importance is the complete lack of formal mechanisms or legal requirements for satellite operators to communicate with each other in a crisis, let alone on how to resolve it. Such crises include situations when it is necessary to take safe and timely actions to deconflict possible orbital conjunctions and avoid collisions; or to clarify and manage other unwanted incidences such as proximity operations. As this requires a global approach, such a framework should be placed under the aegis of the UN.

OUT-JUNKED

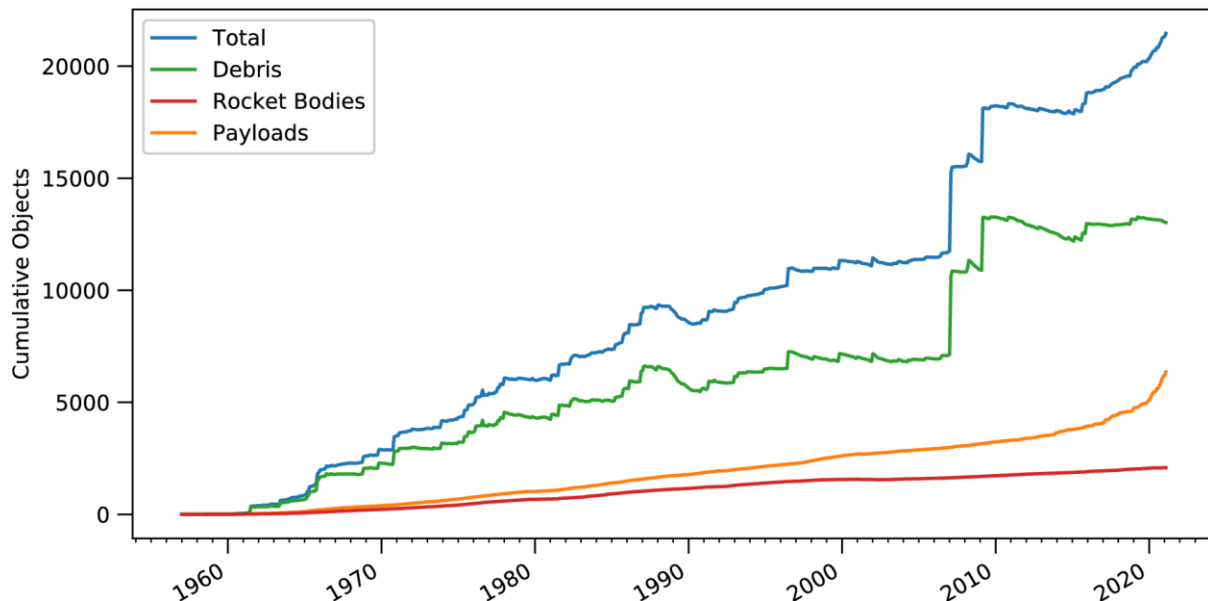
The problem of space debris or “space junk” is likewise growing quickly. It affects all the major orbits – LEO, medium Earth orbit (MEO – at around 22,000 kilometres altitude) and geostationary Earth orbit (GEO – at 36,000 kilometres altitude), but the concentration and therefore risks in LEO are the most acute. Enough space junk in LEO would effectively turn it into a minefield that could threaten reliable access to higher orbital belts as well as deep space.

As more and more satellites – some of them “defunct” and uncontrollable – orbit the Earth at various altitudes and orbital planes, their orbital flight path interactions become ever more complex. In an environment rife with debris, this only increases the risk of catastrophic collisions that create even more space debris.

Should further collisions occur in LEO in the years ahead – and the chances of that are only growing – this could trigger an irreversible catastrophe for all space operators.

Subsequent fields of space debris that are created could make safe and reliable operations in LEO increasingly difficult and dangerous and hold the potential to cause a cascading

effect of space debris clouds colliding with other space debris clouds – an effect known as the Kessler Syndrome.¹⁰



The growth in orbital debris¹¹

While the dangers of the Kessler Syndrome have long been acknowledged by scientists and satellite operators alike, the theoretical likelihood of it occurring has, so far, been rather remote. With the rise of LEO megaconstellations, however, the triggering of an uncontrollable chain of space impacts becomes more likely. With megaconstellation satellites being deployed in batches of several dozens at a time, each new launch only aggravates the risk profile in LEO – without any corresponding measures to mitigate it. This is the very definition of “unsustainable”.

¹⁰ This is named after former NASA scientist Donald Kessler who, along with his co-author Burton Cour-Palais, laid out the risk of cascading space debris effects in their 1978 paper titled, “Collision Frequency of Artificial Satellites: The Creation of a Debris Belt,” published in the *Journal of Geophysical Research: Space Physics*. In that paper, Kessler and Cour-Palais write that, “[S]atellite collisions would produce orbiting fragments, each of which would increase the probability of further collisions, leading to the growth of a belt of debris around the Earth. The debris flux in such an Earth-orbiting belt could exceed the natural meteoroid flux, affecting future spacecraft designs.” Donald Kessler & Burton Cour-Palais, “Collision frequency of artificial satellites: The creation of a debris belt,” *Journal of Geophysical Research, Space Physics*, Volume 83, Issue A6, p. 2637-2646, 01 June 1978, URL: <https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/JA083iA06p02637>

¹¹ Source: Aaron Boley & Michael Byers, “Satellite mega-constellations create risks in Low Earth Orbit, the atmosphere and on Earth,” *Nature Scientific Reports*, 10642 (2021), 20 May 2021, URL: <https://www.nature.com/articles/s41598-021-89909-7>

ASATs

An additional problem impacting the space operational domain has been that of direct-ascent anti-satellite (ASAT) missile testing by a small number of major space powers over the past several decades. They include the United States, Russia, China, and India, all of whom have carried out destructive ASAT tests or operations in LEO. Although in each case the target was a self-owned satellite, these events created significant fields of debris that are a problem for everyone operating in those orbits.

In April 2022 the United States has announced a moratorium on kinetic ASAT¹² testing in space and the hope is that as many countries as possible will adhere to it in the near future. The last such operation conducted by the US military was in 2008 when a modified SM-3 missile launched from an AEGIS destroyer was used to destroy – in a controlled hit with minimal generation of debris – a failing U.S. National Reconnaissance Office satellite in the name of public safety due to the large amounts of hydrazine on board the satellite.¹³

China, Russia, and India have all tested direct-ascent ASAT missiles launched from the Earth's surface at older satellites used as test targets. In January 2007 China launched a direct-ascent ASAT missile at a defunct Chinese weather satellite in LEO that caused a debris field consisting of over 3,000 objects,¹⁴ most of which persist to this day in LEO and has caused other operators – including the International Space Station – to take evasive manoeuvres to avoid the risk of collision.¹⁵

In March 2019 India also tested its own direct-ascent ASAT missile against an Indian microsatellite.¹⁶ Unlike the Chinese test, however, the Indian Defence Research and

¹² Vice President Kamala Harris, "Remarks by Vice President Harris on the Ongoing Work to Establish Norms in Space," speech made by Vice President Harris, Vandenberg Space Force Base, California, U.S., 18 April 2022, URL: <https://www.whitehouse.gov/briefing-room/speeches-remarks/2022/04/18/remarks-by-vice-president-harris-on-the-ongoing-work-to-establish-norms-in-space/>

¹³ Dwayne Day, "Burning Frost, the view from the ground: shooting down a spy satellite in 2008," *The Space Review*, 21 June 2021, URL: <https://www.thespacereview.com/article/4198/1>

¹⁴ Brian Weeden, "2007 China Anti-Satellite Test," *Secure World Foundation*, Updated 23 November 2010, URL: https://swfound.org/media/9550/chinese_asat_fact_sheet_updated_2012.pdf; Marcia Smith, "The Chinese ASAT Test – Nine Years Later," *Space Policy Online*, 11 January 2016, URL: <https://spacepolicyonline.com/news/the-chinese-asat-test-nine-years-later/>

¹⁵ Joey Roulette, "The space station just dodged debris from a 2007 Chinese weapons test", *The New York Times*, 10 November 2021, URL: <https://www.nytimes.com/2021/11/10/science/china-debris-space-station.html#:~:text=The%20space%20station%20just%20dodged%20debris%20from%20a%202007%20Chinese%20weapons%20test.,-Nov.&text=On%20Wednesday%2C%20about%20six%20hours,antisatellite%20weapon%20test%20in%202007.>

¹⁶ Shounak Set, "India's Space Power: Revisiting the Anti-Satellite Test," *Carnegie India*, 06 September 2019, URL: https://carnegieendowment.org/files/7-30-19_Set_India_ASAT_Test.pdf

Development Organisation placed its test target in a sun-synchronous LEO orbit of 282 kilometres altitude. As a result, the Indian ASAT test, while roundly condemned by the international community, at least took place at an altitude where the risks caused from its debris cloud of around 400 fragments was largely mitigated as the debris decayed and burned up in the atmosphere soon after.

Year	Country	Intercept Altitude	Tracked Debris	Debris Still on Orbit	Total Debris Lifespan
20 October 1968	Russia		253	79	50+ years
23 October 1970	Russia		147	35	50+ years
25 February 1971	Russia		117	52	50+ years
03 December 1971	Russia		28	0	3.3 years
17 December 1976	Russia		127	58	45+ years
19 May 1978	Russia		72	64	40+ years
18 April 1980	Russia		48	5	40+ years
19 June 1982	Russia		62	59	35+ years
13 September 1985	U.S.	530km	285	0	18+ years
05 September 1986	U.S.		16	0	< 1 year
26 December 1994	Russia		27	24	25+ years
11 January 2007	China	880km	3527	2763	15+ years
20 February 2008	U.S.	220km	174	0	1+ year
27 March 2019	India	300km	128	1	2+ years
August-December 2019	Russia		27	14	3+ years
15 November 2021	Russia		1402	1225	Unknown
		Total	6440	4379	

Table 3 – Source: Secure World Foundation¹⁷

¹⁷ “SWF Applauds US Policy to Commit not to Conduct Destructive ASAT tests, Urges Other States to Join,” 18 April 2022, URL: <https://swfound.org/news/all-news/2022/04/swf-applauds-us-policy-to-commit-not-to-conduct-destructive-asat-tests-urges-other-states-to-join>

In November 2021 the military of the Russian Federation conducted their own direct-ascent ASAT missile test against a defunct Russian satellite at an altitude of around 500 kilometres in LEO, creating a debris cloud consisting of approximately 1,500 objects.¹⁸ This test caused a large number of orbital conjunction alerts where other satellites were placed at high risk of collision, and the seven astronauts on board the International Space Station at the time – including two Russian cosmonauts – had to take emergency shelter on multiple occasions as the space station’s orbit intersected with the debris cloud. The 2021 Russian ASAT test was the first one carried out by Moscow since the fall of the Soviet Union. Like the United States, during the Cold War the Soviets carried out multiple ASAT tests in LEO; but that happened at a time when there were very few satellites operating in LEO.

Led by the US and UK, there is a robust diplomatic push underway at the UN to establish norms of safe and predictable behaviour among all satellite operators. The aim is to prevent an arms race in space, including through a universal moratorium on debris-creating ASAT tests – whether they be direct-ascent missiles launched from the Earth’s surface or co-orbital capabilities that either collide with, or detonate close to, other satellites in orbit.¹⁹

The efforts in this regard of the United Kingdom, United States, Canada, and other like-minded countries are to be welcomed and encouraged, and it is hoped that China, India, Russia, as well as other countries with latent kinetic ASAT capabilities and ambitions, will soon follow suit despite current geopolitical tensions. These countries should announce and implement ASAT testing moratoriums as soon as possible, if only to help preserve the use of LEO and other orbits for their own satellite operations today and into the future.

ORBITAL CARRYING CAPACITY

Rapid megaconstellation deployment coupled with a growing debris population is a powerful combination that can be devastating to LEO. But where exactly is that threshold, in such a dynamic and complex environment? There is a need for a single, clear, objective way of

¹⁸ BBC News, “Russian anti-satellite missile test draws condemnation,” 16 November 2021, URL: <https://www.bbc.co.uk/news/science-environment-59299101>

¹⁹ Foreign, Commonwealth & Development Office & The Rt Hon James Cleverly MP, “UN General Assembly’s First Committee approves UK push to tackle threatening space behaviour”, 01 November 2021, URL: <https://www.gov.uk/government/news/un-general-assemblys-first-committee-approves-uk-push-to-tackle-threatening-space-behaviour>; Theresa Hitchens, “UN Committee Votes ‘Yes’ On UK-US-Backed Space Rules Group,” *Breaking Defense*, 01 November 2021, URL: <https://breakingdefense.com/2021/11/un-committee-votes-yes-on-uk-us-backed-space-rules-group/>

measuring how that overall risk – or aggregate collision probability – changes with each new satellite addition to LEO.

One concept that can serve this purpose is orbital carrying capacity.²⁰ It neatly reflects a basic fact about Earth orbits, and LEO in particular: that it is a limited resource that, under Outer Space Treaty principles, needs to be allocated equitably among nations.

The specifics of quantifying LEO carrying capacity is a matter of technical debate, where specialists have to determine things like the upper limit of predicted conjunctions (which may, for example, be something like 10^8) where even a very low residual collision probability leads to an intolerable expected number of collisions. One of the many challenges, of course, is that the input data – exactly where objects are, and their characteristics, including satellite failure rates – is not only incomplete, but also changes all the time.

But beyond the strictly technical aspect, carrying capacity requires a wider debate precisely because of its regulatory potential. If done right, it can really move the dial for space sustainability by defining clearer rules for LEO admittance control, which is ultimately the core issue. The question of how to shape and then advance a carrying capacity regulatory agenda at the international level should become a priority for the space community starting right now.

As already noted, a key difficulty to overcome is the increasing complexity attached to the very notion of “sustainability”, which is a function of *all* satellites and constellations taken *in aggregate* rather than individually. Yet regulators are set up to evaluate sustainability criteria – such as orbital debris mitigation – on an individual satellite/filing basis.

Reconciling this growing contradiction is one of the great tasks before space leaders today. Carrying capacity, if standardised and widely adopted, has the potential to provide that bridge between the broad perspective required for context in order to safeguard sustainability as a common good; and the specific attention demanded by each licence application in the name of fairness, practicality as well as sovereign interests.

²⁰ Orbital capacity can be defined as number and type of satellites that can be sustainably deployed. Also see: *ESPI Report 82 – Space Environment Capacity: Policy, regulatory and diplomatic perspectives on threshold-based models for space safety & sustainability*, available at: <https://espi.or.at/news/espi-report-82-space-environment-capacity>

SSA GAPS

Compounding unsafe and irresponsible practices in LEO by some megaconstellation and government operators is the insufficient provision of technical capabilities, interoperable standards and regulatory tools with respect to space situational awareness (SSA)²¹ and space traffic management (STM) at a global level.

Today the majority of SSA capabilities are operated by militaries, with the US military the lead provider of public SSA data in the world through its Space Surveillance Network. The Pentagon's SSA capability portfolio comprises of ground-based optical telescopes and radars such as the Space Fence located around the globe including in allied nations like the UK or Australia, as well as certain space-based assets for military use.

Despite this considerable infrastructure there are whole sections of the orbital environment that are not covered/observed directly by any significant SSA systems partly because of geographical and political constraints on where such equipment can be located. This has only marginal significance in day-to-day operations given that objects in almost all orbital regimes pass through the field of view of one sensor or another daily. Nonetheless, these coverage gaps – where orbital manoeuvres can be executed with a lower chance of detection – can be critical to national security interests. Reliable and worldwide transparency of operations would be beneficial to the safety and behavioural goals of space sustainability – and this requires further investment in SSA sensors.

China, Russia, India, and European countries also operate their own SSA capabilities, albeit with a more constrained performance and capacity compared to the United States. In recent years, private companies such as the US-based LeoLabs have also begun to expand ground-based radar coverage of LEO, but again large swathes of this crowded orbital regime remain unmonitored.²²

The problem can be looked at from the space-end as well – not just in terms of what can be done to improve ground infrastructure. In this sense, one way to improve the data picture would be to ensure that, at the very least, future LEO spacecraft carry small beacon transponders. This would facilitate more accurate location determination, with benefits for collision avoidance and continuous control of LEO satellites throughout their orbits. Similar

²¹ Or space domain awareness (SDA) in a military context.

²² ESA Earth Observation Portal, "LeoLabs commercial ground-based tracking service for small satellites," accessed May 2022, URL: <https://directory.eoportal.org/web/eoportal/satellite-missions/l/leolabs>

solutions can be applied to and have been suggested for rocket boosters. But ideally, national regulators would require that all future LEO satellites be equipped with Global Navigation Satellite System (GNSS) receivers so that operators can provide precise ephemeris data for all their satellites in a timely manner to SSA entities.

As well as gaps in the global SSA coverage, there are serious challenges with the reliability and accuracy of the catalogues of space objects kept by the various SSA providers. These can be government-maintained, such as France's *Almanac* which contains data from the country's GRAVES radar; or provided by private firms such as ExoAnalytics.

Understanding and knowing what is happening in LEO and beyond is dependent upon the modelling each SSA operator uses and the assumptions that inform those models.²³ Data collected in these catalogues is therefore incomplete (and sometimes even inaccurate in the case of so-called "dirty data" and the tens of thousands of objects that remain undetected by current SSA capabilities). The information for the same object can also vary from catalogue to catalogue.

In other words, the catalogue of space objects maintained by the US military – the gold standard in global space traffic management – will differ from those maintained by China, Russia, India, and SSA sensor operators in Europe, such as France. These disparities are mostly the result of a lack of international standards in object characterisation and cataloguing and broader modelling assumptions across all operators.²⁴ The bottom line is that satellite operators of all types and from all nationalities are operating in an already precarious space environment with incomplete and inaccurate, and often contradictory, baseline SSA data.

The solution to this certainly requires an improvement in global SSA sensor capabilities both in terms of area coverage and in terms of resolution. But as important and more difficult will be to forge common, global standards for accurate orbital modelling, space object characterisations, cataloguing, and data sharing.²⁵ This is not only a government-to-government challenge, but also one for industry. We should be striving for a future where all

²³ It is not often understood, in the general public conversation, that the precise location of space objects at any one time is determined by mathematical models based on measurements taken when these objects pass through the field of view of SSA sensors (or, in the case of some satellites, when they transmit their position data to a ground station along their flightpath) – not by direct, "live" observation.

²⁴ David Finkleman, "Is International Collaboration for Space Situational Awareness Possible?", *Space News*, 05 October 2021, URL: <https://spacenews.com/op-ed-is-international-collaboration-for-space-situational-awareness-possible/>

²⁵ Lt Col Andrea Console, "Command and Control of a Multinational Space Surveillance and Tracking Network," *The Joint Air Power Competence Centre*, Chapter 7, p. 51-59, June 2019, URL: https://www.japcc.org/wp-content/uploads/JAPCC_C2SST_2019_screen.pdf

satellite operators, while commercially competing with each other, nonetheless operate their constellations using the same agreed-upon SSA data standards.

SDA MODEL

Private industry has been moving in this direction for some time, with the Space Data Association (SDA) pooling operational flight data directly from its member companies as well as other sources, which is then used to support a conjunction warning service.²⁶ Apart from the data-sharing aspect, the SDA provides a forum for more effective coordination of collision avoidance manoeuvres among its own members. The downside is that the proprietary member data available to the SDA covers only a fraction of the overall space environment picture. The rest of the data provided is only as good as the object characterisation standards and modelling assumptions used by non-SDA providers.

The value of an initiative like the SDA as a platform for coordination has been highlighted by documented instances where non-SDA satellite operators were *not* responsive to communications from other companies and countries regarding possible orbital conjunctions.²⁷

Similarly, there is anecdotal evidence that Chinese satellite operators are gaining a poor reputation for their failure to engage with other satellite operators to deconflict and avoid orbital conjunctions. Even China, however, is beginning to understand that its own interests are at stake too. Last year Beijing mandated that “small satellites should be capable of collision avoidance manoeuvres, as well as lowering orbits following the end of missions. State departments may take relevant ‘appropriate measures’ if a company does not track, report on, and deorbit its satellites.”²⁸

²⁶ Jean-Luc Froeliger, “An Overview of the Space Data Association and its Services,” n.d., URL: https://swfound.org/media/206314/froeliger_keynote.pdf

²⁷ Jonathan O’Callaghan, “SpaceX Declined To Move A Starlink Satellite At Risk Of Collision With A European Satellite,” *Forbes*, 02 September 2019, URL: <https://www.forbes.com/sites/jonathanocallaghan/2019/09/02/spacex-refused-to-move-a-starlink-satellite-at-risk-of-collision-with-a-european-satellite/?sh=72bc9b151f62>

²⁸ Andrew Jones, “Chinese satellite propulsion startup secures funding as country’s constellation project grows,” *Space News*, 16 May 2022, <https://spacenews.com/chinese-satellite-propulsion-startup-secures-funding-as-countrys-constellation-projects-grow/>

TOWARDS A GLOBAL STM REGIME

It should be stressed that SSA/STM is not and can never be, by itself, a “silver bullet” for space sustainability. Similarly to terrestrial air traffic management, even the most complete, capable, integrated STM regime imaginable, using the best possible data, can only work within clear congestion limits. Sometimes there is a tendency in industry to focus on STM as the main solution to our sustainability problems; this can be counterproductive if it shifts attention away from the core issue, which is managing the physical congestion of LEO in particular.

That being said, STM is an absolutely vital and indispensable component of space sustainability, and improvements are urgently needed if only to keep pace with the escalating risks in orbit. In time there will have to be a standardised and comprehensive international STM regime, especially for LEO, backed by interoperable technological solutions. This is impossible without standardised and comprehensive space situational awareness data collection and cataloguing processes and improved modelling of the space environment.

Even if significant progress can be made on the SSA front there would still be tremendous challenges in establishing and implementing a global STM regime, not least due to geopolitical tension and competition among the great spacefaring powers. Another challenge will be the technical “untangling” of the current orbital regime required to make STM a workable solution.²⁹

Still, international civil aviation has managed to come up with an international regime that governs international air traffic and sets standards of safety and transparency among the airlines of all member states of the International Civil Aviation Organization (ICAO) and has managed to do so even through substantial geopolitical tensions and tumult.³⁰ As difficult as things might seem today, there is historical precedent for addressing complex problems with competing political interests.

²⁹ Hjalte Frandsen, “Looking for the Rules-of-the-Road of Outer Space: A search for basic traffic rules in treaties, guidelines and standards,” *Journal of Space Safety Engineering*, February 2022, URL: <https://www.sciencedirect.com/science/article/pii/S2468896722000064>

³⁰ International Civil Aviation Organization, “The History of ICAO and the Chicago Convention,” accessed May 2022, URL: www.icao.int/about-icao/history/pages/default.aspx

Space Debris by the Numbers³¹

Number of rocket launches since the start of the space age in 1957

- About 6200 (excluding failures)

Number of satellites these rocket launches have placed into Earth orbit

- About 13100

Number of these still in space

- About 8410

Number of these still functioning

- About 5800

Estimated number of break-ups, explosions, collisions, or anomalous events resulting in fragmentation

- More than 630

Total mass of all space objects in Earth orbit

- More than 9900 tonnes

Estimated number of debris objects based on statistical models:

- 36,500 space debris objects greater than 10 cm
- 1,000,000 space debris objects from greater than 1 cm to 10 cm
- 130 million space debris objects from greater than 1 mm to 1 cm

Number of debris objects tracked by Space Surveillance Networks and maintained in catalogues:

- 31,440

DEBRIS MITIGATION

Space debris is a challenge that can be mitigated now, and the possibility of a Kessler Syndrome scenario can be arrested and even reversed, if appropriate actions are taken now. Some might seek solace in the notion that active debris removal (ADR) technologies can

³¹ European Space Agency, "Space Environment Statistics," updated 10 May 2022, URL: <https://sdup.esoc.esa.int/discosweb/statistics/>

address the growing challenge of space debris in a timely manner. The problem, however, is that the scale of the space debris challenge today, never mind in the coming years if space sustainability practices are not adopted and implemented, is beyond current and projected technological solutions.

Most of the debris currently in Earth's orbits is undetectable by SSA capabilities, and therefore too numerous and small to be dealt with by ADR. Moreover, current ADR technologies under development are designed for dealing with very particular debris removal scenarios, such as larger objects to include spent launcher boosters and defunct or inoperable satellites.

ADR technology undoubtedly has a role to play in addressing the space debris problem, particularly if it can be scaled up quickly in the coming years – but funding will likely remain the decisive challenge. Diffusion of ADR solutions will bring its own risks from a political point of view, given the inherent dual-use nature of these capabilities.

One potential way to square these political problems would be to create an ADR capability under UN Security Council control with appropriate safeguards in place. This initiative could draw on UN peacekeeping operations frameworks. It would guarantee full transparency and would mitigate concerns from certain nations that such a capability could be used to target their own assets. Incentives could include a carefully-negotiated measure degree of technical data sharing as well as knowledge transfer.

The prize would be the prudent development of a politically-neutral technological solution to address the global problem of space debris, which could at any moment escalate into a global crisis. Furthermore, an UNSC ADR capability could give a new impetus to international efforts towards global space regime rulemaking fit for the 21st century.

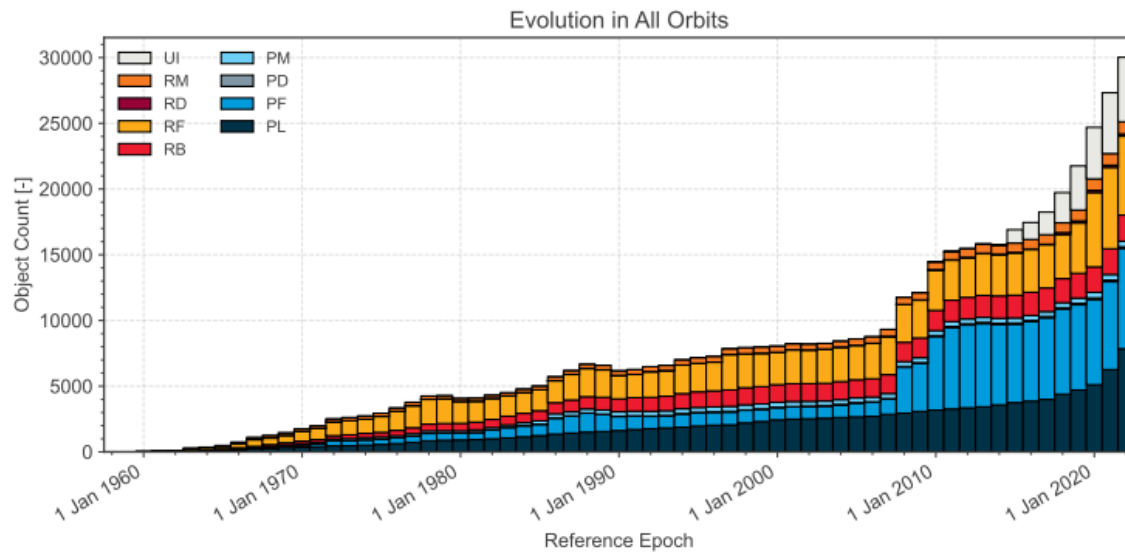


Figure 2 - Evolution of Number of Objects in All Orbits (catalogued only).³²

Beyond private sector-provided (and perhaps UN-controlled) ADR, the more impactful measures required today to address the debris challenge are likely to be driven by non-tech approaches. The answer lies in mix of regulatory innovation and enforcement together with the application of international standards and ESG criteria in satellite constellation financing, architecture, launch, and operations.

In particular, national regulators should develop debris mitigation regulations as part of their remit and only approve licences for launch and operations once the applicant demonstrates that it can actively mitigate debris risks. For example Britain has already implemented this requirement in its UK's Civil Aviation Authority (CAA)'s space licensing guidance, based on the sustainability principle:

The focus of this principle is to ensure that activities licensed in orbit are sustainable. A sustainable activity (or mission) is one that meets the requirements of the present without compromising the ability of subsequent generations to embark on activities (or missions) to meet their own requirements in the future. Sustainability is inherently linked to safety and security: whereas safety and security look to mitigate impacts of spacecraft activities on the operations of existing spacecraft, sustainability attempts to mitigate the impacts of spacecraft activities on the future environment.³³

³² European Space Agency, "ESA's Annual Space Environment Report", p. 19, 22 April 2022, URL: https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf

³³ Civil Aviation Authority, "Guidance for Orbital Operator licence applicants and Orbital Operator Licensees," Crawley, West Sussex: Civil Aviation Authority, p. 24, 2021, URL: [https://publicapps.caa.co.uk/docs/33/Guidance%20for%20Orbital%20Operator%20licence%20applicants%20and%20Orbital%20Operator%20Licensees%20\(CAP2210\).pdf](https://publicapps.caa.co.uk/docs/33/Guidance%20for%20Orbital%20Operator%20licence%20applicants%20and%20Orbital%20Operator%20Licensees%20(CAP2210).pdf)

The CAA further states that regulators require licence applicants to demonstrate how they will “prevent on-orbit break-ups, either from collisions with other objects in orbit or fragmentations, [...] limit the number of objects released in normal operations,” and, lastly, “remove spacecraft and orbital stages that have reached the end of their operations from the most used, useful and densely populated orbital regions.”³⁴

These regulatory principles raise the question of what *specific*, technical sustainability criteria are used by UK authorities in approving the licences of megaconstellation operators such as Oneweb, beyond IADC or ISO provisions. Any regulator must balance the cost and benefits of each additional layer of regulatory requirements for a given economic activity. When it comes to space licences, more specificity to mandated technical requirements carries the risk of stifling innovation and placing more costs on the commercial sector, with knock-on effects on sector competitiveness – ultimately, therefore, clashing with higher economic interests at a national political level. If rival nations cut more corners, they can gain a competitive edge for their space companies – which only proves that the real way forward is through coordinated action at the international level (for example, through the ITU) where everyone aligns to the same principles.

More recently, in France, the agency responsible for radio frequency allocations and licences for satellite operators, Arcep, upheld its decision to issue a licence to Starlink to operate in France. This decision was made despite numerous objections by major satcom operators and even by the French space agency CNES itself. The objections submitted during the comment period centred around concerns with the likely increase in space debris resulting from LEO megaconstellations, their impact on satellite operators in GEO, and the threat of orbital exclusion of other operators in LEO that could be crowded out from operating there. Arcep argued that it had no choice but to approve Starlink’s operating licence application as the agency’s legal remit prevents it from taking into account any environmental concerns about a licensee’s proposal other than whether its use of a radio frequency band has received the proper approvals of the national regulator from where the licensee is headquartered and the International Telecommunication Union (ITU).³⁵

³⁴ *Ibid.*

³⁵ See Jason Rainbow, “Starlink regains permission to operate in France,” *Space News*, June 6 2022, URL: <https://spacenews.com/starlink-regains-permission-to-operate-in-france/>

REGULATING SUSTAINABILITY

These examples point to the urgent need for all national regulators to apply explicit environmental and space sustainability criteria to their licensing processes and approvals, and then rigorously enforce them in practice.

The following are suggestions for what these regulations might look like:

- Require that all LEO constellations, considered in the context of the existing LEO population and known future plans, do not exceed the LEO carrying capacity.
- Demonstrate in satellite design and constellation architecture the ability to move satellites at the end of their operational lifetime to a disposal orbit or into a rapidly decaying orbit where the system will harmlessly burn up as it enters Earth's atmosphere;
- Require LEO megaconstellation providers to initially insert newly-launched satellites into a placeholder orbit below 400 kilometres altitude until the operator can verify that all satellites are operational. Those that are verified as operational can then be boosted into their intended operational orbits while those that are inoperable (usually two to four percent of all satellites launched are 'dead upon arrival') can then be left to harmlessly decay into the Earth's atmosphere;
- Require all satellite operators to submit detailed contingency plans for removal of any inoperable satellites (possibly via ADR) and other objects regardless of circumstances that are to be assessed by a third-party panel of neutral experts. This plan should include contingency plans for continued safe operation of any satellite constellation owned by a commercial entity in the event that bankruptcy occurs;
- Require all satellite operators to actively coordinate and cooperate with other satellite operators on satellite flightpath data and deconfliction of potential orbital conjunctions in a safe and timely manner, per existing ISO standards. Autonomous collision avoidance systems should not be accepted as the primary means of deconfliction until the technology is fully mature, proven and standardised. A points-based penalty system (similar to UK's Points System for drivers) should be developed in order to incentivise good behaviour among operators. Link the system to the licensing process so that a company's operating record will impact the outcome and speed of its future licence applications.
- Refuse to approve service and/or operating licences of any satellite operator that is headquartered in any country that has not formally committed to a kinetic ASAT

testing moratorium. Similarly, refuse to licence any satellite operator from a country whose government engages in 'sharp practices' in Earth orbits and deep space;

INDUSTRY INCENTIVES

In addition to robust regulatory reform and enforcement, other measures can be implemented outside of government by financial and insurance institutions, shareholders, as well as international bodies such as the International Standardization Organization and other professional and expert bodies.

For example, banks and investment firms active in the space market should adopt space sustainability criteria as part of their investment decision-making process and risk reduction assessments. The criteria should focus on debris mitigation, safe and responsible operations, and end-of life disposal of satellites. Implementation can be supported at the national level, perhaps in cooperation with national regulators, through a national standard or system.

In the UK, for example, it has been suggested that the satellite industry adopt a "kitemark" standard for financing, insurance, and operations. A kitemark would signify the minimum standard a satellite operator would have to meet to qualify for investment and insurance from UK based institutions. It could also be integrated into future iterations of space-related regulatory approval processes, rewarding good practices and cutting regulatory costs. A kitemark approach could become the template for similar formal criteria being adopted elsewhere, and in turn, lead to a form of regulatory harmonisation across many countries.

Once it becomes a norm, any satellite operator that is unable or unwilling to meet kitemark standards will then stand out in the market, leading to increased difficulties in accessing financing and insurance from UK providers. Of course, an operator that does not earn a kitemark seal of approval could go elsewhere for financing and insurance, but such a move will only make the satellite operator and its prospective investors and insurers vulnerable to further industry and regulatory disapproval through possible litigation and reputational damage.

As the risk from space debris grows, satellite underwriters will likely become wary of operators who do not take due care and attention to space sustainability and space debris mitigation in particular. As well as insisting on responsible corporate policies and operations, insurers can leverage much higher premiums against those operators who continue with irresponsible and unsafe practices, or who look to add thousands of satellites into one orbital

regime. Such a move might discipline operators with outsized ambitions and may, in turn, actually compel more finely honed business plans as well as better, more sustainable, operational practices.

Shareholders of commercial satellite operators should be greatly concerned about the long-term commercial viability of their companies. They should therefore insist that responsible and sustainable practices be adopted and implemented by their executive boards and enshrined in company policies and governance structures. Activist shareholders may look to harness the power of the voting rights as well as litigation against those executive boards that refuse to adhere to safer and more sustainable practices.

Such elements add up to a potent combination for driving change and raising the sustainability game across the global sector. It requires: a robust and enforced regulatory regime; kitemark-style standards and criteria (across the financial, insurance, and launch satellite manufacturing sectors); and positive shareholder activism. Promoted and implemented together, these measures and behaviours will, in the first instance, raise the standards and apply pressure on those space corporate actors who are not living up to their obligations. But more broadly, they can also give a new impetus to a normative movement across the developed world for more sustainable practices in Earth's orbit and beyond.

INTERNATIONAL STANDARDS

The primary focus for solutions to the growing space debris challenge are national regulators and the industrial and financial sectors – but there are some initiatives that can be taken up and applied internationally. To illustrate, the UN Committee for the Peaceful Uses of Outer Space (COPUOS) has developed a range of space sustainability guidelines that now provide the basis for international standard making in bodies such as the ISO. International standards already exist for LEO megaconstellations but regulators and operators alike are not always adhering to them.

For example, ISO 24113 ed. 3 (2019) on satellite post-mission disposal requires operators to ensure that no less than 90 percent of their satellites can be safely disposed of.³⁶ At present – based on IADC³⁷ End of Life guidelines compliance rates between 2010 and 2020 – only

³⁶ See International Organization for Standardization (ISO), ISO 24113:2019: Space systems — Space debris mitigation requirements (Geneva, Switzerland: ISO, 2019), URL: <https://www.iso.org/standard/72383.html>

³⁷ Inter-Agency Space Debris Coordination Committee, the principal inter-governmental forum for the worldwide coordination of activities related to the issues of man-made and natural debris in space.

between 23 and 50 percent (depending on class) of LEO satellites above 10kg in mass are being safely disposed of³⁸ – and there are no enforceable regulatory or legal consequences on operators who fail to comply.

The IADC's so-called 25-year rule³⁹ – which is in fact a nonbinding guideline – does not indicate how it has to be achieved, but there are voluntary orders of preference for various methodologies, from controlled re-entry to accelerated natural orbital decay. Nor is the 25-year rule adequate anymore in the age of megaconstellations. This benchmark should be updated to a shorter period of between five and 10 years, and regulators such as the FCC which have megaconstellations within their purview should take a global lead in enforcing the new benchmark at a national level. This should lead to most megaconstellation operators including an active de-orbiting capability in their satellite designs rather than relying on passive means.

There is a normative case for further international standards to be developed for responsible satellite design and operations, building collision avoidance and end-of-life disposal requirements into the technical baseline for future spacecraft. There is also an urgent need to use standards and regulatory pressure for better and more reliable designs to reduce the failure rate in orbit. In absence of clear standards or rules, the drive to maximise profit margins can encourage companies to throw into orbit cheap, disposable satellites and cut corners on sustainability. Even small failure rates of one to three per cent, when scaled at megaconstellation-level, can add dozens or up to thousands of dead satellites to the existing debris in orbit.

Similarly, further international standards may also be developed for safer and sustainable constellation architectures. International standards have recently become the subject of geopolitical competition between developed countries led by the United States on one hand and China on the other over technologies such as 5G and 6G telecommunications, and there is no reason to expect that satellite international standards should be any different.

This will require international leadership among developed countries, but if done properly international standards for responsible satellite operations can become the basis for future robust national regulation and industry standards for financing and insurance whereby

³⁸ European Space Agency, "ESA's Annual Space Environment Report", p. 19, 22 April 2022, URL: https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf

³⁹ Which requires that satellite lifetime after disposal will not exceed 25 years.

satellite constellation proposals that do not meet ISO criteria are not approved, financed, and insured.

Another international imperative is to build on the pledges for space sustainability made by G7 countries at recent annual summits⁴⁰ and seek to add a permanent “space track” to its structure that can become a meaningful forum for high-level multilateral space policy coordination. The majority of commercial satellite constellation operators, whether they are of smaller size or are megaconstellations, are headquartered in a G7 country. The G7 consists of the United States (which hosts Starlink, Kuiper, Intelsat, Planet, Satellogic, etc.), United Kingdom (Inmarsat, Oneweb), France (Eutelsat), Germany, Italy, Canada (Telesat), and Japan, plus the European Union.

The G7 often aligns these countries along a range of complex, and even at times intractable, policy issues and there is little reason why similar policy alignments cannot be attempted on space sustainability. The incoming Japanese presidency of the G7 in 2023 will have the opportunity to move the dial in this direction. But we should be even more ambitious.

COALITION OF THE WILLING

Indeed, with the unwieldy UN process arguably moving too slowly – if at all – to achieve global consensus on the truly meaningful legal norms, frameworks and measures required to safeguard the future sustainability of the space environment, a new and bolder political approach is needed. It is time for a “coalition of the willing” established at the highest political level among participating countries, and which would commit collectively to shared principles, regulations and coordinating mechanisms for safe space operations and orbital development. One aim, for example, could be to harmonise national SSA data catalogues. Another could be to agree and implement an orbital carrying capacity agenda, from technical standards to coordinated regulatory implementation.

The reticence expressed in some quarters towards the notion of creating new inter-governmental space regime coordinating structures outside the UN system is to be understood. As with the debates over “re-opening” or updating the Outer Space Treaty, there is concern over the possibility that such a process might lead to an unravelling of the

⁴⁰ UK Space Agency, “G7 nations commit to the safe and sustainable use of space,” 13 June 2021, URL: <https://www.gov.uk/government/news/g7-nations-commit-to-the-safe-and-sustainable-use-of-space>

structures and agreements that we *do* have in place now and that, while not perfect, at least have global legitimacy.

These are valid concerns but have been arguably overtaken by events. We must face reality, which presents us with two facts. Firstly, the world is experiencing a profound geopolitical transformation with the return of great-power competition and indeed the return of major inter-state warfare. Leading nations have already started to adjust by expanding their military space programmes: space is now more strategically-important to more nations than ever before. This is a very different environment not only to the Cold War when the present international space regime was designed, but especially to the post-Cold War period of the past 30 years.

The other fundamental fact to consider against the *status quo* is precisely the scale of the space sustainability challenge and the extraordinarily high stakes attached to it. The leading developed countries are extraordinarily dependent on space – and will be disproportionately affected by systemic disruptions of the orbital environment going forward. Again, this situation is radically different from the age when the current space governance structures were conceived.

Rather than creating a completely new platform or forum, this “coalition of the willing” could use the Artemis Accords as a basis for a new “plurinational” approach to orbital sustainability. The Accords have been intended for lunar coordination but they have already successfully tested the political principle of a custom-designed space framework. They could be expanded to include orbital sustainability, not least because future Moon missions will have to contend with Earth orbit debris fields. Additionally, the fact that the Accords are US-led should make it easier to reconcile the aims of a future sustainability framework with the questions revolving around US-based megaconstellations like Starlink or Kuiper.

Alongside the move towards this new “coalition” – or perhaps integrated with it from the beginning – it is essential to develop a national security space dialogue among participating allies, at the political-strategic level. This would be distinct – but not isolated – from allied military space coordination structures such as the US Combined Force Space Component Command (CFSCC). With space power becoming an ever more important element of national and allied power in a wider, it is now time to politically upgrade the space conversation between allied governments to the national security level.

Orbital congestion and the rules shaping the nature of the commercial competition in the space domain are acquiring heavy political meaning. With its knock-on effects on innovation and capability development, it impacts the future military posture and military advantage of

the entire Western alliance. What may look like a commercial win for one company today can in fact play into the hands of strategic adversaries tomorrow.

Allied governments must recognise space sustainability as a strategic issue and put in place the necessary mechanisms for joint action.

EXPANDING THE ITU'S ROLE

The International Telecommunication Union (ITU), a Geneva-based United Nations organisation, is responsible for allocating radio frequency spectrum to all satellite operators worldwide. It also governs the allocation of physical orbital slots in GEO. The ITU process is laborious and complex, often involving highly-technical negotiations and trade-offs among all the national regulators who apply for radio frequency spectrum allocations and orbital slots on behalf of satellite operators from their home countries.

The ITU is also the subject of geopolitical rivalries and grievances, for example, developing countries threatening to create a rival spectrum allocation organisation because of allegations that the current ITU process is rigged in favour of developed nations. There is certainly a case for reform of the ITU to ensure a more equitable process for all, in general. But whatever its shortcomings, we should not lose sight of the fact that the ITU is still the best international forum to discuss and indeed solve complex space governance issues: reform must be approached with care, and the coming leadership change at the top of the organisation offers a chance for new initiatives.

One *evolutionary* move that would update the ITU for the megaconstellation era would be to expanding the ITU's remit from spectrum to *orbital* regulation in LEO⁴¹, bearing in mind its responsibilities as regards GEO orbital slots. It is important, in the long run, to have an international body recognised by all, that plays a role in overseeing orbital regime allocations and that can take a clear and complete perspective on LEO deployments from a global sustainability point of view.

There is no suggestion that this can provide any immediate solutions to the urgent problems at hand; those are likely to be found at national or “plurilateral” level. The challenges with this ITU initiative will be considerable and the process will be complex and likely slow. But a new leadership team at the ITU, due in the near future, could take up this mission with fresh energy and credibility.

⁴¹ See Joseph Gangestad, “Orbital Slots for Everyone”, The Aerospace Corporation, March 2017. Available at: https://aerospace.org/sites/default/files/2018-05/OrbitalSlots_0.pdf

CURBING ORBITAL EXCLUSION AND 'SHARP PRACTICES': LEVELLING THE ORBITAL PLAYING FIELD

While the challenge posed by space debris garners the most attention among policymakers and analysts, a second major issue is looming increasingly large in the global space sector: something we may call, “sharp practices”.

Sharp practices by some commercial and government satellite operators are decisions and activities that can lead to monopolised orbits; or where certain governments can carry out intrusive and dangerous activities with impunity and disregard to any safety considerations. While usually not technically illegal under national or international law, these behaviours operate like fine, sharp instruments carving strategic advantages for their beneficiaries right around and among the normative hardpoints that do exist in the space domain. They take place just below the line of acceptable and responsible behaviour.

These sharp practices may, for example, consist of flooding LEO with thousands of satellites potentially blocking others from operating in the same orbit in any meaningful way. Or they may involve foreign governments carrying out intrusive proximity operations and other military and intelligence activities targeting foreign commercial assets.

ORBITAL EXCLUSION

Orbital exclusion can result from monopolistic behaviour by a satellite operator that is anti-competitive in nature and that squashes and discourages innovation. Orbital exclusion can also result from intimidating and dangerous tactics carried out by some government operators against both commercial satellites and government satellites operated by other countries.

In commercial terms these might be referred to as monopolistic and antitrust issues, in geopolitical terms they might be referred to as hybrid warfare or grey zone activities. In any case, such activities place responsible operators on the backfoot and tilt the playing field against them.

Some LEO megaconstellation operators have obtained regulatory approvals for system architectures consisting of thousands or tens of thousands of satellites. There has been little

evidence, in the process, of serious thought being given to safeguarding the principles of free market competition with respect to other potential players in those orbital regimes; or indeed to the sustainability of these enormous systems themselves through the sustainment of follow-on replenishment in the decades to come.

Another aspect noted widely in the industry is that the business case for some of these megaconstellations is finely balanced at best. In most other fields this would be of no concern to third parties; but in space – given its unique characteristics that can propagate risks much easier across the entire operating environment – these is a legitimate point of interest.

In this sense, observers have noted that some of these “satellite broadband” companies have proceeded without securing landing rights to operate in large markets such as India and China. This raises the prospect that such shortfalls might thus compel government support going forward, either directly or indirectly via government acting as an anchor client for capabilities and services that it does not necessarily require. Distinguishing between good-faith space business strategy and “sharp practices” that manipulate systemic blindspots for corporate or indeed national advantage is highly important in the broader context of rules and norms for the future sustainability of space.

It might be claimed that, for example, US regulators approved Starlink and, more recently, Amazon’s Kuiper due to concerns that if an American company did not place a megaconstellation into LEO then China certainly will. Whether true or not, the US regulators have missed an important opportunity to set and implement *in practice* sustainable and responsible standards. Irrespective of the other virtues and public benefits offered by a company like Starlink – and its critical role in Ukraine is well recognised – the practices by which it seized its place in LEO should give pause for thought. It appears to have not only unfairly undermined international competition – including, ironically, from close allies – but it has also put all other US companies looking to operate in LEO at a disadvantage.

By crowding LEO with an extraordinarily high number of satellites, companies such as Starlink may well end up in a position to dictate market terms and conditions to governments and individual users.

But there is another important potential risk to the US government and taxpayer, as well as the wider US commercial satellite sector. What if one of these megaconstellation companies goes bankrupt or is bought out and split up, for example? What happens to these companies and their thousands of assets in LEO? More likely, just as with the infamous case of Iridium in the late 1990s, the US taxpayer may end up footing the bill as a US government department, such as the Pentagon, takes control of the system – a system in search of a requirement.

Again from a space sustainability perspective it is worth highlighting the vast gulf between the certain, inevitable safety problems that Amazon's Kuiper will introduce into the LEO environment, and the uncertain, unclear commercial logic behind this project. The case for it seems particularly questionable since it is far from clear what capability and service it would provide to consumers that Starlink and OneWeb are not already or committed to delivering.

Based on recent filings made to the FCC, Amazon intends to place around 7,000 satellites into an already crowded LEO and is years away from even its initial deployment.⁴² By the time Amazon reaches a launch stride that sees it populating its proposed constellation with significant numbers of satellites, the megaconstellations operated by Starlink, OneWeb and China's 13,000-satellite Guowang may well be fully operational by then.⁴³

An analysis of this wider economic context for such systems must be made a statutory component of the licencing process – otherwise, narrow-focused regulators will slide ever more into being part of the orbital exclusion problem rather than the solution. Any government policy that advocates for free markets and space sustainability but that has not conducted (and acted upon) such impact studies by recognized third-party experts may be entangled in a plethora of contradictions.

HYBRID WARFARE IN SPACE

From a geopolitical perspective, the sharp practices of countries such as China, Iran, and Russia also pose a challenge for policy makers and industry executives. All of these countries engage in actions that are detrimental to safe and good order in space. For example, Iran constantly jams communication satellites and spoofs global navigation satellite systems (GNSS), disrupting regional navigation and undermining legitimate commercial activities provided by satellite communication providers.⁴⁴

⁴² Todd Shields, "Amazon Seeks Another 4,538 Satellites to Challenge Musk's SpaceX," *Bloomberg*, 05 November 2021, URL: www.bloomberg.com/news/articles/2021-11-05/amazon-seeks-to-add-4-538-satellites-to-challenge-musk-s-spacex

⁴³ Andrew Jones, "China is developing plans for a 13,000-satellite megaconstellation," *Space News*, 21 April 2021, URL: <https://spacenews.com/china-is-developing-plans-for-a-13000-satellite-communications-megaconstellation/>

⁴⁴ Todd Harrison et al., "Space Threat Assessment 2021," *Aerospace Center for Strategic and International Studies*, p. 19-20, April 2021, URL: https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/210331_Harrison_SpaceThreatAssessment2021.pdf?gVYhCn79enGCOZtcQnA6MLkeKlcwqqks; Todd Harrison et al., "Space Threat Assessment 2020," *Aerospace Center for Strategic and International Studies*, p. 32-33, March 2020, URL: https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/200330_SpaceThreatAssessment20_WEB_FINAL1.pdf?6sNra8FsZ1LbdVj3xY867tUVu0RNHw9V

An increasing phenomenon in orbit is nations “inspecting” both military and commercial satellites in GEO, manoeuvring close to target spacecraft without prior knowledge or permission of those operators. For example, Russia has also been accused of using its Luch military satellite to “inspect” US and French military communication satellites in GEO, as well as commercial communication satellites in GEO operated by Intelsat among others. These inspections, as the Russians characterised them, were in fact intrusive close-proximity manoeuvres undertaken without the prior knowledge or permission of the satellite operators in question. Such manoeuvres could have led to a catastrophic collision. Russia, China, the United States and others are conducting demonstrations of rendezvous and proximity operations in GEO and other orbits with increased frequency. But the distinguishing factor is the degree of transparency, coordination and demonstrable intent to adhere to safety principles. With non-cooperative engagement now being demonstrated by some for debris removal, there is greatly increased opportunity for error in understanding intent and avoiding accidents.

Finally, China is garnering a reputation for not engaging in STM procedures with other space users. Repeated attempts by satellite operators to communicate with their Chinese counterparts to deconflict orbital conjunctions and other coordination initiatives go unanswered. Such state-led sharp practices have been described as a form of political or hybrid warfare in space.⁴⁵ On one level, these hybrid space operations involve provocative and dangerous tactics and manoeuvres such as laser dazzling of satellite optical cameras, satellite communications jamming and spoofing, intrusive rendezvous and proximity operations, and cyber-attacks against space systems.

Space hybrid operations, for the most part conducted by China and Russia, target both government and commercial satellites. At minimum, they can disrupt operations, ultimately leading to revenue losses. But they can also hold at direct risk the technical functioning of satellites that can lead to their outright failure. Again, in an industry where margins are tight, such a failure can mean the difference between continued business or bankruptcy and can

⁴⁵ Dr. Jana Robinson of the Prague Security Studies Institute, a leading authority on hybrid practices in the space domain, defines space hybrid operations as “intentional, sometimes reversible, and often harmful space actions/activities specifically designed to exploit the links to other domains [land, sea, air, cyberspace, and the electromagnetic spectrum] and conducted just below the threshold of requiring meaningful military or political retaliatory responses.” Jana Robinson, “Prominent Security Risks Stemming from Space Hybrid Operations,” in Cassandra Steer and Matthew Hersch (eds.), *War and Peace in Outer Space: Law, Policy, and Ethics*, Oxford University Press 2021, p. 233

undermine investor confidence in commercial space ventures and increase insurance premiums for satellites.

Solutions to these kinds of space hybrid operations involve the following:

- Increased SSA capabilities providing global coverage in all orbits. Greater transparency in Earth's orbits can detect nefarious and suspicious activity as it occurs;
- A lower threshold for “deterrence by detection”, where governments publicly reveal the nefarious and suspicious activity of those countries carrying them out, either prior to their occurrence based on threat intelligence or in real-time;
- Increased resilience of all government and commercial constellation architectures, contributing to a greater deterrence by denial. Resilience blunts the intended effects of space hybrid operations, whereby confidence and predictability prevail over attempts at disruption;
- Formal threat intelligence sharing mechanisms between governments and commercial satellite operators to facilitate unity of action, confidence building, and timely action to avoid unnecessary incidences, unintended responses, or inadvertent escalatory actions.

SPACE SECTOR CAPTURE

On another level, certain states – particularly China – engage in what is increasingly being recognised as “space sector capture”. Similarly to Beijing's tactics in other domains, space sector capture involves providing a target nation with space-related equipment, services and financing to a point where the recipient state's own space sector becomes highly intertwined and dependent on Chinese space technology.⁴⁶ Implemented on an incremental basis, such a strategy is ultimately designed to limit the freedom of action and independence of the recipient state in the space domain.⁴⁷

⁴⁶ See U.S. China Economic and Security Review Commission, “2019 Report to Congress,” Section 3, p. 368-374, November 2019, URL: [https://www.uscc.gov/sites/default/files/2019-11/2019 Annual Report to Congress.pdf](https://www.uscc.gov/sites/default/files/2019-11/2019%20Annual%20Report%20to%20Congress.pdf); Vidya Sagar Reddy, “China's Design to Capture Regional SatCom Markets,” ORF Sepcial Report No. 70, 15, July 2018, URL: https://www.orfonline.org/wp-content/uploads/2018/07/ORF_SpecialReport_70_China_SatCom.pdf; Jevans Nyabiage, “China boosts its soft power in Africa while launching African space ambitions,” *South China Morning Post*, 11 October 2020

⁴⁷ Jana Robinson, “Prominent Security Risks Stemming from Space Hybrid Operations,” in Cassandra Steer and Matthew Hersch (eds.), *War and Peace in Outer Space: Law, Policy, and Ethics*, Oxford University Press 2021, p. 237,

Alongside from the sharp practices of space hybrid operations, the issue of space sector capture is a form of economic warfare that also impacts commercial satellite operators and can lead to a form of orbital exclusion and requires a different set of responses. Space sector capture occurs in a number of countries, primarily in Africa, Central, and Southeast Asia, as well as in Latin America. China and Russia provide countries with satellite technologies at a steep discount in return for favourable trade and resource concessions. The satellite technologies provided to target countries create dependencies that extend to everything from telecommunications and broadcasting through to national space policies and strategy – including obligations to support Chinese and Russian positions in international space regime negotiations at the UN for example.

Countries that find themselves locked in space relationships of this nature with Beijing and Moscow are, to a large extent, out of commercial reach for satellite services – and generally better technology – offered by Western space companies.⁴⁸ This leaves a growing number of countries with inferior satellite technologies, transactional dependencies on unreliable powers, and an inability to reliably acquire satellites and satellite services from other countries without completely reorienting their entire foreign policies.

Space sector capture is effectively an inverted form of orbital exclusion. The bottom line economic results are the same, as Western commercial satellite operators can find themselves cut off from potentially lucrative sources of revenue for their deployed constellations.

Addressing space sector capture by China and Russia in key developing markets requires a government-led long-term political and economic counter-strategy with close support from commercial satellite operators. Such a strategy should seek to include satellite technologies and services as part of foreign aid policies that are already in place; in every case, this “space package” should be designed to demonstrate the technological advantage and reliability gained by using Western satellite capabilities. This counter-strategy should also aim to limit the influence of Chinese and Russian space interests in these countries through more open engagement and debate on national space policy issues at the non-governmental level – for example, through specialist NGOs such as the Secure World Foundation.

Whether it be monopolistic practices by some satellite operators that threaten to stifle competition and innovation, the sharp practices of space hybrid operations, or the predatory strategy of space sector capture, orbital exclusion is a growing phenomenon that

⁴⁸ See the discussion in *ibid.*, pp. 236-241.

undermines efforts to create the conditions required for space sustainability. While specific actions and strategies can be adopted by national governments and commercial satellite operators immediately, a more long-term mindset is also required to ensure that space sustainability principles take hold and become the norm.

THE CASE FOR SPACE ENVIRONMENTALISM

Humankind has been operating spacecraft in Earth's orbits for 65 years. From the launch of Sputnik I in October 1957 through to the launch of the James Webb Space Telescope in December 2021, the rate of technological progress and ability to make use of space for the betterment of life on Earth has been astounding.

Yet there is still so much about space, and how we use it, that we do not fully understand. Despite our exploitation of space over the decades for greater connectivity and better understanding of our planet, we have also managed to trash the space environment. Only now are we starting to understand the consequences of this.

The past decade has seen a radical turning point in our use of space with the highly accelerated rise of the number of satellites in orbit driven by commercial megaconstellation projects. The other major development has been the return of geopolitical tensions between great powers which is playing out in orbit, with increased investments in national security space capabilities. Further unintended consequences may yet turn up, whether an uncontrolled chain of collisions; a reversal of market growth and innovation trends as LEO megaconstellations stifle competition; or even a scenario where thousands of satellites that re-enter the Earth's atmosphere over time create large enough deposits of aluminium and other metal particulates in the upper atmosphere to aggravate the global climate crisis on Earth.

Until very recently a working assumption among many in the space community has been that environmental challenges in outer space are completely separate and insulated from the environmental problems on Earth. There is emerging evidence to suggest that this may no longer be the case for much longer if the various megaconstellation projects currently in progress or planned go ahead to completion.

ALUMINIUM PARTICULATES

If all of the known LEO megaconstellation projects were to be built out as planned, it is estimated that there will be approximately 100,000 satellites in low-Earth orbit by 2030 – this

is compared to the approximately 4,000 active satellites in that orbital belt as of early 2022.⁴⁹ It has been posited that with tens of thousands of satellites in LEO, each with an average operational lifespan of five years, the sheer number of satellites that will de-orbit and decay into the Earth's upper atmosphere⁵⁰ will deposit more aluminium particulates there than all of the meteorites that have entered the atmosphere:

"[A]nthropogenic deposition of aluminum in the atmosphere has long been proposed in the context of geoengineering as a way to alter Earth's albedo [i.e. the overall reflectivity of the Earth]. These proposals have been scientifically controversial and controlled experiments encountered substantial opposition. Mega-constellations will begin this process as an uncontrolled experiment."⁵¹

Further research on this matter is required, but on the existing evidence alone there is ample cause for concern that satellites from megaconstellations that re-enter the Earth's atmosphere over time will also contribute to unpredictable climate effects because of the particulates they deposit in the upper atmosphere. Regulators should therefore consider tying environmental assessments – under existing national legislation, for example the US National Environmental Protection Act – to satellite licensing.

FROM SPACE DEBRIS TO SKY JUNK

An additional risk, not only to the environment more generally, but to human life and property in particular is the projected number of satellites – or large parts of them – and spent launcher components that will not burn up as they re-enter the atmosphere and fall to the Earth's surface, to include populated areas as well as fragile ecosystems. There is always a slight risk of this occurrence given the relatively small percentage of satellites and rocket boosters that do not disintegrate upon re-entry.⁵²

But as the number of satellites placed into LEO increases exponentially, so will the likelihood that a significant number of them will not fully burn up and potentially cause damage and

⁴⁹ Union of Concerned Scientists, "UCS Satellite Database," updated 01 January 2022, URL: <https://www.ucsusa.org/resources/satellite-database>

⁵⁰ It has been estimated that of the 200 to 600 orbital reentries each year, about 20 percent may be large enough to have partially survived reentry and dropped at least some fragments on the Earth's surface.

⁵¹ Aaron Boley & Michael Byers, 'Satellite mega-constellations create risks in Low Earth Orbit, the atmosphere and on Earth', *Nature Scientific Reports*, 10642 (2021), 20 May 2021, URL: <https://www.nature.com/articles/s41598-021-89909-7>

⁵² It has been estimated that of the 200 to 600 orbital reentries each year, about 20% may be large enough to have partially survived re-entry and dropped at least some fragments on the Earth's surface.

even loss of life on Earth's surface. This risk might be compounded not only by the kinetic impact of a falling satellite or rocket component but also by the often-dangerous chemicals on board these objects such as hydrazine, presenting a significant public health and environmental hazard.⁵³

A further risk is that of spent rocket boosters left in the lower reaches of LEO, which can collide with other objects – especially space junk – that are accumulating in the same orbital regime as they decay over time. This can cause cascading clouds of space debris. In 2019 one orbital debris expert noted that the largest space debris risk at the time was not from increased numbers of satellites in LEO but from approximately 20 spent rocket boosters, primarily from Russia, that still linger in that orbit.⁵⁴ Today, with many more satellites launched into LEO since 2019 and tens of thousands more expected to be launched by the end of the decade, the risk of collision with spent rocket boosters will only increase.

The launch cadences required to deploy the tens of thousands of megaconstellation satellites over the coming decade and beyond will involve thousands of satellite launches from various launch providers around the world. Even with the increased use of reusable first-stage rocket boosters, the second and third-stages of these launchers (depending on design and make of launcher) can stay in LEO for up to several years. This increase in the number of spent rocket boosters in LEO will further compound risks of catastrophic collisions and cascading clouds of space debris.

IMPACT ON ASTRONOMY

Lastly, there is the growing problem faced by the astronomy and wider scientific community due to megaconstellations in LEO. Scientists and astronomers have submitted numerous complaints and objections, including an amicus brief in US courts, against LEO megaconstellation operators and the national regulators that grant their operating licences.

The scientific community state that the increased number of satellites in LEO create inordinate amounts of light pollution that cause “smearing” of images captured by telescope. This light pollution is caused by sunlight reflecting off the solar panels and other surfaces of these satellites.

⁵³ See *ibid.*, and also Andy Lawrence, *et al.*, “The case for space environmentalism,” in *Nature Astronomy*, Volume 6, April 2022, pp. 433-434.

⁵⁴ See Jeff Foust, “Clusters, not constellations, pose biggest orbital debris risk,” *Space News*, 22 September 2019, URL: <https://spacenews.com/clusters-not-constellations-pose-biggest-orbital-debris-risk/>

Some operators, such as Starlink, have agreed to darken the surfaces of their satellites to mitigate glare, but such measures are voluntary and given the vast numbers of planned satellites to be placed in LEO and the cost of their manufacture and launch, it is unlikely that operators will take similar measures unless required by national regulators.

Even radio telescopes have registered increased incidences of interference due to LEO satellites infringing upon the radio frequency spectrum used by these instruments.⁵⁵ It should be noted that this is not simply a marginal issue of interference with amateur astronomy. What is happening is that megaconstellations are having a drastic impact on invaluable scientific work that cost billions of dollars, most of which is funded by governments. The fact that government scientific funding and national satellite regulatory bodies appear to be inadvertently at odds with each points, again, to the need for better policy coordination and space governance at national and international level.

CULTURAL CHANGE

We need to do much better if we are to sustain a space environment that can continue to provide the benefits of connectivity, precise navigation and timing, and remote sensing for humanity in the decades and centuries to come. While there might well be specific solutions to many of the risks outlined above, a more comprehensive and long-term approach is required. It must centre on changing our collective mindsets: the way in which we view space and its relationship to Earth.

Scientists are gradually learning, for example, that there is a complex relationship between the Earth and the Moon which goes beyond just gravity and orbital mechanics. Research suggests that much of the water deposits believed to be on the Moon have been siphoned off from the Earth's atmosphere for millennia.⁵⁶ It should come as little surprise, then, that human activities in Earth orbits might well have implications for the climate and environment below the upper reaches of the atmosphere.

A large part of this mindset or cultural change involves adopting a more comprehensive perspective on space environmentalism. The larger case for space environmentalism rests not as much on love and respect for “nature” (whether terrestrial or extraterrestrial), but on

⁵⁵ See Lawrence, et al., *op.cit.*

⁵⁶ Gunther Kletetschka et al., “Distribution of water phase near the poles of the Moon from gravity aspects,” *Nature Scientific Reports*, 12, 4501 (2022), 16 March 2022, URL: <https://www.nature.com/articles/s41598-022-08305-x#citeas>

a rational recognition that the Earth-Moon system and our exploitation of it is inherently complex. It entails emergent behaviour that is difficult, if not impossible, to discern at a very early stage of interacting with it, as we do now.

Space environmentalism also means treating the Earth-Moon system as we would the environment on Earth. As researchers and space professionals are increasingly recognising, the evolving space domain has “a close similarity with other environmental issues such as climate change, or plastics in the ocean”.⁵⁷ In the words of German astronaut Matthias Maurer, “Space is like the ocean – a resource you cannot claim for one country. People think space is so big, if I leave my trash here no one cares. But there is only so much debris the planet can afford.”⁵⁸

A space environmentalist mindset, therefore, entails a wholesale cultural change within the wider space community: from commercial satellite operators to manufacturers and launch providers, as well as government policy makers and regulators. It requires an integrated, contextualised perspective that shifts the way we view each proposal for very large or mega-constellations.

We need to part with the current narrow, incremental model where these projects are considered one satellite at a time within a framework that does not take account of what is happening in other countries. The ethos of next-generation orbital management must be grounded in an international approach coupled with a long-term perspective of the sustainability of space operations.

As things stand now, with separate regulatory bodies and frameworks, and an essentially laissez faire behaviour by competing companies, we are moving toward a possible scenario where low-Earth orbit and beyond becomes unusable.

⁵⁷ Lawrence, *et al.*, *ibid.*, p. 429.

⁵⁸ Peggy Hollinger and Sam Learner, “How space debris threatens modern life,” *Financial Times*, 08 June 2022, URL: <https://ig.ft.com/space-debris/>

CONCLUSION

Space sustainability is not incompatible with commercial and geopolitical competition, but it does require actors to avoid a zero-sum approach to space activities – especially in LEO – for everyone’s sake.

To be clear, however, even the GEO orbital regime necessitates further improvements in sustainable practices and thinking, but at least GEO operators are subject to stricter national and international regulation and coordination by the ITU than those in LEO.

The race to be the first or biggest in a new market promises great rewards for the winners in the short term. But space is global, interdependent and extremely varied in terms of space operations. In addition, there is a complex interplay between the environments of Earth and space, with unpredictable emergent environmental behaviour starting to gain increased recognition.

When the line is drawn under all this, the idea of “winning” by cutting corners on sustainability starts looking like fool’s gold. It is in fact in the long-term interests of all actors to step back and take in the bigger picture of how we can and should exploit the space domain and our potential impact on the challenges already existing on Earth.

This is not just something for us all to mull on in our leisure time. It is something that we can begin to understand now through commissioning comprehensive impact studies on how we use, and propose to use, the space domain and the complex interactions that will result along with possible emergent contingencies.

It can begin now by creating a multilateral working group between national regulators to coordinate and prioritise filings from operators. It can begin now with regulators rigorously enforcing regulations already in place and developing new regulations that are more in line with the principles of space sustainability rather than just the bottom line of any one company’s balance sheet. It can begin now by incorporating space sustainability principles into international standards and in all space-related science, technology, engineering, and mathematical (STEM) educational programmes, to include the design of satellites and launch vehicles and in architecting satellite constellations.

It begins now by acknowledging that there is much about the space domain and how we use it that we simply do not know – but we can commit ourselves to understand it better.




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