FROM THE HOOVER TECHNOLOGY POLICY ACCELERATOR

Space Safety and Sustainability

Part I: Past and Present Practices

by Simone D'Amico, Tycho Bogdanowitsch, and Rebecca Wang

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Executive Summary

Space is the invisible backbone of modern society, with space technologies enabling worldwide navigation, precise timing, communication links, weather forecasting services, natural disaster mitigation, and much more. As such, it is essential to maintain access to space for present and future generations. However, the exponential growth of human-made objects in space, including rockets, spacecraft, and debris, threatens this vital and finite resource.

Space safety and sustainability are essential for national security as satellites power critical capabilities such as geospatial intelligence, surveillance, and early-warning systems for missile launches. A proliferation of space debris and a lack of coordination among operators could disrupt military satellites and increase geopolitical tensions.

Given the high-stakes societal, economic, and national security considerations associated with maintaining a sustainable orbital environment, the Hoover Technology Policy Accelerator has launched the Leadership for Responsible Space Policy Initiative led by Hoover Science Fellow Simone D'Amico. This research is the prelude to a full report that will address both the technological and policy aspects of maintaining space as a global commons. These two areas are mutually dependent on one another and jointly essential for ensuring space sustainability. This working paper represents part I of the report and focuses on the state of the art in space operations, relevant domestic and international policies, and emerging technologies related to space safety and sustainability. Part II will explore areas for improving current technology and practice in more depth and make recommendations for further developments in both technology and policy to address the important challenges identified in this paper.

The working paper focuses on defining the "space safety and sustainability paradox," which highlights how expanding space activities that support Earth's safety,

sustainability, and security can also jeopardize sustainable access to space. As the orbital environment grows more congested, the detection, tracking, and characterization of space objects and activities that could impact security, safety, and operational stability—known broadly as space situational awareness (SSA)—becomes increasingly important for civilian and national security purposes.

Currently, the US Space Force and other international entities track and publish the orbital data of over 36,000 objects that are larger than ten centimeters in size. If a potential collision or conjunction (near miss) is detected, operators of the affected satellites are notified and are then responsible for coordinating collision avoidance maneuvers via independent and direct communication, often through email. Space traffic coordination (STC) is the cooperative planning, coordination, and on-orbit synchronization of activities to enhance the safety, stability, and sustainability of operations in the space environment. The existing STC system has operational limits that make it unable to cope with the tens of thousands of satellites that are expected to be launched in the coming years.

Part of the space safety and sustainability challenge lies in addressing significant technological gaps—including improving the accuracy and persistence of space object tracking, enhancing the sharing and consolidation of data across government and commercial sources, refining orbit determination methods, and advancing the understanding of how the activity of the Sun affects the Earth's atmosphere. Potential solutions include new ground-based tracking architectures, innovative space-based sensors, and upgraded space environment models. On the mitigation side, fully reusable launch systems and multiuse satellites can limit future debris generation, while active debris removal (ADR) technology offers a pathway to reduce the amount of existing debris in space.

Another part of the challenge stems from shortcomings in international and US domestic space policy. These include insufficient coordination among operators of satellites and other space vehicles, failure to share data that could help mitigate risks, and ineffective enforcement of existing regulations and governance frameworks. At the international level, the 1967 UN Outer Space Treaty remains the foundation of space law. Since its adoption, various organizations have been established to manage certain aspects of space activities, such as allocating communication bandwidths. However, the geopolitical climate of the past few decades has complicated efforts to implement and enforce new sustainability policies, including collision avoidance standards and deorbiting requirements. Nevertheless, there are many ongoing international policy efforts to mitigate space debris and encourage sustainable practices, including the European Space Agency's Zero Debris Charter and the UN's Pact for the Future.

Similarly, in the United States, two significant domestic programs on the horizon are the Orbital Sustainability (ORBITS) Act of 2025 and the Traffic Coordination System for Space (TraCSS) supported by the Situational Awareness of Flying Elements in Orbit Act, or SAFE Orbit Act, of 2025. Both the ORBITS Act and the SAFE Orbit Act are still draft legislation, but they are expected to be reintroduced and potentially passed in 2025 or 2026. The ORBITS Act aims to establish an ADR demonstration program to reduce the amount of high-danger orbital debris. TraCSS is the next-generation STC system that will integrate commercial data with government data, support data-sharing between operators, streamline conjunction analysis, and facilitate collaboration with international partners. TraCSS is currently under development, and the SAFE Orbit Act has been introduced to fully authorize the system.

New space policy approaches could be modeled on existing frameworks for aviation, maritime, and ground transportation governance, each of which offers insightful analogies. Getting all countries fully aligned on how to tackle the sustainability paradox in the near future is unlikely, but there are feasible steps that the United States and its allies can take. These include improving the sharing of SSA data, coordinating with other international STC systems, establishing international norms for collision avoidance, and investing in emerging technologies—including, but not limited to, those that can clean up the orbital environment or enhance the accuracy and coverage of space object tracking. Together with Russia and China, the United States could, for example, create capabilities that allow all countries to distinguish between a debris impact on a space vehicle and an adversarial strike, reducing the risk of unprompted escalation. Overall, the United States could lead by example and collaborate with international partners to establish an effective future approach to tackling the challenge of space sustainability.

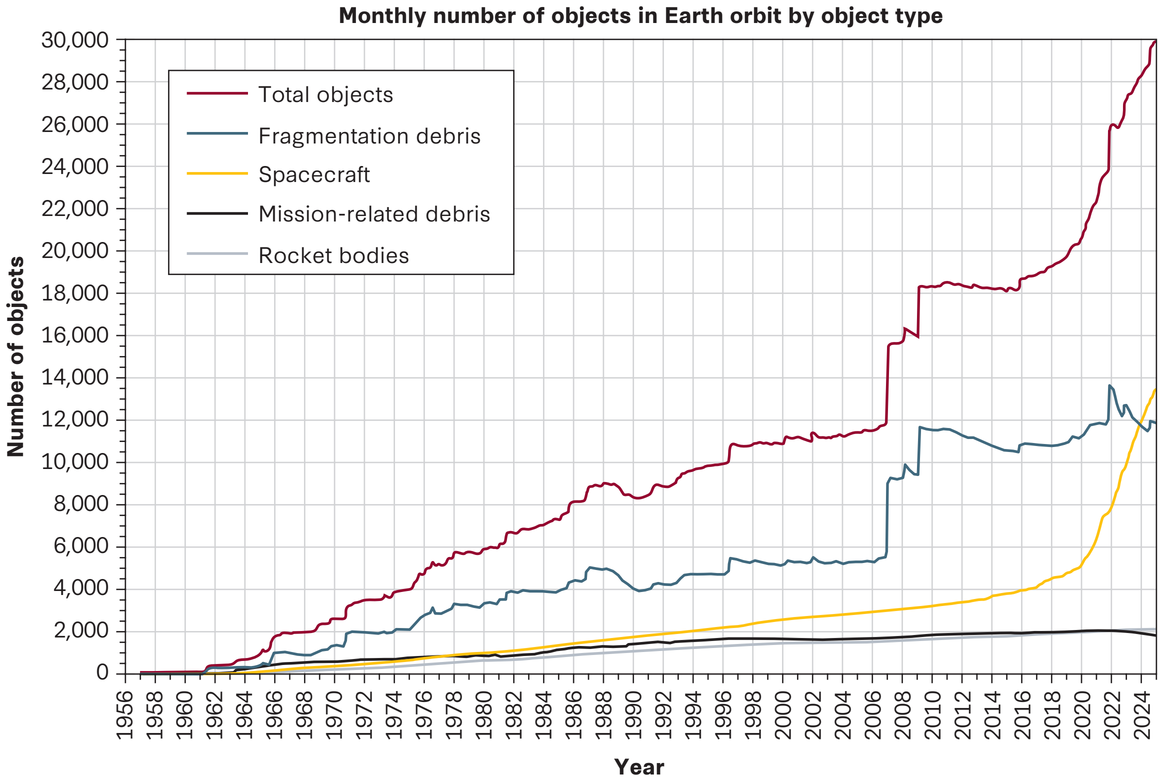
INTRODUCTION: THE SPACE SUSTAINABILITY PARADOX

In 1987, the United Nations (UN) Brundtland Commission defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs."[1] Established in 2015, the UN's Sustainable Development Goals aim to improve the lives of people on Earth while mitigating the hazardous effects of climate change and environmental degradation.[2] "Sustainability" can also be applied to outer space, as maintaining unfettered access to space is essential for the needs of current and future generations.

The modern world is relying ever more heavily on satellites for critical applications like navigation and timing services through the Global Navigation Satellite Systems (GNSS), space-based internet such as SpaceX's Starlink for communication, and the creation of virtual "digital twins" of Earth. These digital twins are a virtual representation of the planet built using satellite observations, or "remote sensing," to monitor humans' impact on the environment, forecast the weather, and manage responses to natural disasters. All these technologies are crucial to sustainability and safety on Earth while also being invaluable for national security and defense purposes, including communications, navigation, surveillance, and missile early-warning systems.[3]

However, these benefits come with an ever-increasing number of assets launched into space. As shown in figure 1, the growth of objects orbiting Earth, known as resident space objects (RSOs), has been exponential over the past decade and driven by

FIGURE 1 The number of objects orbiting Earth has grown substantially over the past decade



Source: Adapted from *Orbital Debris Quarterly News* 29, no. 1 (February 2025): 8.

increasing numbers of satellite launches. As of June 2025, more than 42,000 objects larger than ten centimeters are being actively tracked in Earth's orbit. These include about 12,000 active or functioning satellites, spent rocket bodies, and other debris. Approximately 85 percent of the active satellites are in low Earth orbit (LEO), which is a region below 1,000 kilometers in altitude, and around 9 percent are in geostationary Earth orbit (GEO), which is an orbit with an altitude of 35,786 kilometers that allows for satellites to remain fixed above a certain location on the Earth's surface.[4] By 2033, the number of satellites launched annually is expected to reach 3,700, contributing to a total of over 35,000 active satellites.[5] Additionally, statistical models estimate there are over one million RSOs between one centimeter and ten centimeters in size that are difficult to track with current technology.[6] Even small objects like these can cause catastrophic damage in the event of a collision because orbital speeds in LEO are up to 7.8 km/s or 17,500 mph, which is almost ten times faster than a bullet.[7]

The ownership of active satellites is dominated by the United States and China. As of November 2024, the US government and private US organizations have over 9,000 active satellites in orbit, including 7,500 Starlink satellites, while China and its commercial companies have over 1,000.[8] Additionally, both countries have plans to build mega-constellations with tens of thousands of satellites.[9]

For the United States, China, and every other country in space, many satellites support critical national security and defense capabilities. As a result, they are prime military targets, which has led to the development of various antisatellite weapons (ASATs) for defensive measures and conflict deterrence. There are two types of ASATs: kinetic versions that destroy satellites through a collision, and non-kinetic versions that disrupt satellites through cyberattacks, jamming, and blinding lasers.[10] The United States, China, Russia, and India have all conducted kinetic ASAT tests in the past 20 years.[11] Each of these tests destroyed a defunct satellite with a missile and created significant amounts of debris, with a recent Russian one in 2021 creating over 1,500 pieces of debris large enough to be tracked.[12] The United States banned ASAT tests in 2022 out of concern for the long-term sustainability of space; however, there has been no such commitment from China, Russia, or India.[13] As the number of satellites in orbit multiplies, space is becoming increasingly congested and contested.

Although space is vast, near-Earth space is a finite resource that is being threatened by the proliferation of satellites and debris. Similar to space, Earth's oceans were once considered infinite and suitable for the disposal of trash and plastic, but now the adverse environmental effects of many tons of waste in them are well understood.[14] Space debris, which is anything in orbit that is manmade and no longer in use, is analogous to trash in the oceans.[15]

To help assess what constitutes sustainable space activity, some researchers have developed the concept of "orbital carrying capacity," which is a set of bounds determining where satellites can make use of orbital volumes, how they can make use of them, and how densely they can be packed into them.[16] It is a complex metric that not only takes into account the number of objects in an orbit, but also satellite maneuverability and operator behavior. There is no consensus on what constitutes a sustainable orbital carrying capacity; however, experts agree that the current situation in near-Earth space is problematic.[17]

If orbital carrying capacity is exceeded, the result could be a worst-case scenario known as Kessler syndrome, which involves a cascade of collisions in LEO. This chain reaction could generate a dense cloud of debris, rendering entire orbits unsafe for decades or even centuries, and severely limiting access to space for humanity.[18]

The space sustainability paradox recognizes that the very growth of space activities that support Earth's sustainability may simultaneously threaten sustainable access to space. In the current absence of international collaboration, the risk of collisions in Earth's orbit is rising, which threatens the long-term usability of space for future generations.[19] (The paradox can also be extended to incorporate the environmental effects of rocket launches and satellites burning up in the atmosphere, but that is not the focus of this report.[20])

If the space sustainability paradox is not resolved, several significant consequences, including Kessler syndrome, could impact humankind within the next few years to several decades. Increased space debris directly threatens satellites used to observe Earth and provide communications to remote areas.[21] Without reliable satellite infrastructure, the ability to predict and manage natural disasters such as hurricanes, wildfires, and floods would be hampered, increasing the human and economic costs of these events. Weather forecasting, financial transactions, shipping routes, power grids, agriculture, and much more could also be significantly impacted.[22]

Similarly, national security and defense systems rely on space-based assets for surveillance, communication, and precision navigation. For instance, Starlink has provided vital communication services to Ukraine in the war against Russia.[23] Unchecked space debris and a lack of agreed-upon international traffic management guidelines could lead to the disruption of military satellites and increased geopolitical tensions as countries vie for control of safer orbital regions with relatively little or no debris.[24] There are also other significant risks. For example, a debris strike could be misinterpreted as an adversarial attack, triggering potential escalation between superpowers.[25] To avoid these disastrous consequences, it is imperative to address the space sustainability paradox.

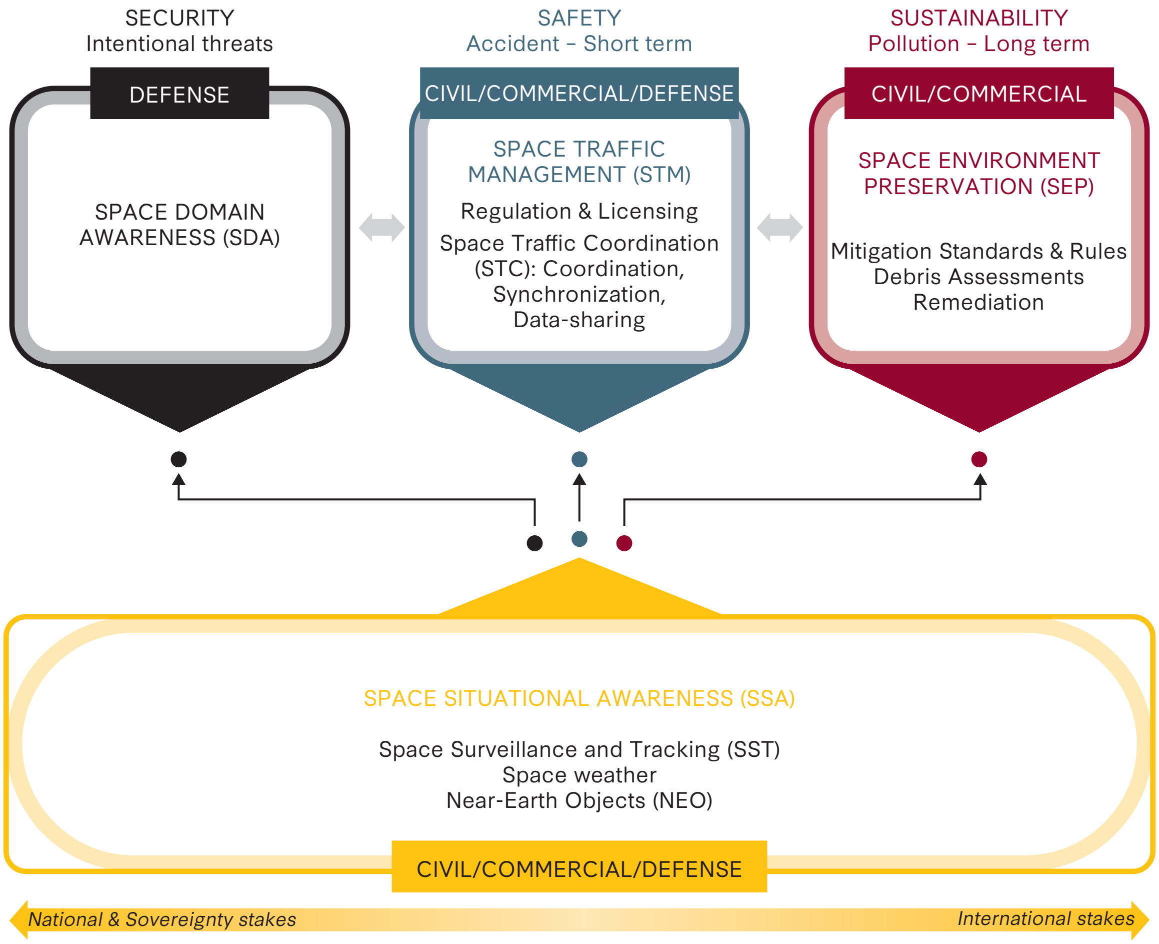
INTRODUCTION: KEY TAKEAWAYS

1. Space is the invisible backbone of the modern economy as it powers worldwide navigation, timing, communications, and weather monitoring
2. National security is heavily dependent on space-based assets for geospatial intelligence, surveillance, communication, navigation, and early warning systems for missile launches
3. The **space sustainability paradox** recognizes that the very growth of space activities that support Earth's safety and sustainability may simultaneously threaten long-term access to space
4. Potential collisions in space could significantly impact weather forecasting, financial transactions, shipping routes, power grids, agriculture, and many other areas

OPERATING IN SPACE

Space situational awareness (SSA) is essential for operating in space and refers to keeping track of objects in orbit and predicting where they will be at any given time. This requires an accurate understanding of the space environment, knowing what objects are in it, characterizing those objects, and maintaining awareness of their movements. These objects include manmade ones such as spacecraft and natural objects such as asteroids. The space environment also includes space weather such as solar activity and radiation that affect the movement of space objects.[26] As shown in figure 2, SSA can be split up into three broad categories: space domain awareness (SDA), space traffic management (STM), and space environment preservation (SEP). SDA is the effective identification, characterization, and understanding of any factor, passive or active,

FIGURE 2 SSA definitions from the Center for Space Policy and Strategy



Source: Mark Skinner, "Space Traffic Management Terminology," Aerospace Corporation Center for Space Policy and Strategy, October 2022, https://csps.aerospace.org/sites/default/files/2022-10/Skinner_STMTerminology_20221018.pdf.

associated with the space domain—the area surrounding the Earth at altitudes greater than 100 kilometers—that could affect space operations and thereby impact the security, safety, economy, or environment of a nation. STM refers to the regulatory frameworks, technical standards, and oversight mechanisms established by national and international authorities to govern the safe and sustainable use of orbital space. SEP is the activity of preserving and sustaining the space operations environment through space debris mitigation and remediation.[27]

Space traffic coordination (STC) is a key component under the broader umbrella of STM. It refers to the cooperative planning, coordination, and on-orbit synchronization of space activities to enhance the safety, stability, and sustainability of operations. The term STC is more commonly used in both national and international forums because it is less politically sensitive than STM, which often implies regulatory control. As such, throughout the rest of this working paper, the term STC will be used.

Security, safety, and sustainability are interconnected across all aspects of SSA. However, security is most closely associated with SDA, safety is primarily linked to STM/STC, and sustainability is predominantly aligned with SEP. Security issues could arise when any number of active spacecraft pose a threat to another spacecraft. Safety concerns encompass interactions between operational spacecraft as well as a spacecraft's interaction with space debris. Sustainability refers to mitigating the long-term effects of active satellites and space debris on the space environment.[28] In this report, the term "sustainability" will be primarily used, but in most cases "safety" and "security" are closely related as well.

The orbits of objects around Earth fluctuate over time due to natural effects and active orbital maneuvers by spacecraft. Absolute orbital velocities in LEO—the speeds of objects relative to Earth—are at least 7.3 km/s and at most 7.8 km/s (22,000 mph), while relative impact velocities—the speeds between two colliding objects—are typically around 14 km/s for space debris.[29] At these hypervelocity impact speeds, any projectile larger than one centimeter can lead to mission-ending damage.[30] For example, the impact of a one-centimeter piece of aluminum traveling at a relative velocity of 14 km/s releases energy equivalent to thirty grams of TNT, which is comparable to a small hand grenade. A ten-centimeter projectile would be comparable to seven kilograms of TNT.[31] This immense destructive potential of hypervelocity impacts highlights the importance of understanding the space environment and avoiding collisions.

A high-level overview of the role of SSA in mission operations is given in figure 3. Radar, optical, and radio frequency (RF) measurements from the ground are used to determine the orbits of trackable space debris, including active and inactive satellites, in a process called "orbit determination." Active satellites transmit and receive radio signals to and from a ground station.[32] Inactive satellites are no longer transmitting and receiving signals. For active satellites, ground-based measurements can be augmented by onboard measurements from GNSS or Global Positioning System (GPS) receivers and rarely other sensors on the satellite.

Orbit determination is used to find an object's state in orbit, which is the complete set of parameters needed to fully define its position and velocity at any given time and allow for the prediction of its motion. There are many different types of state representations, but the most widely used are two-line element (TLE) sets that describe an object's state in mean Simplified General Perturbations 4 (SGP4) elements. Astrodynamic models, such as SGP4, propagate or predict satellite orbits from an initial state by computing dynamic forces acting on satellites, including gravity, drag, solar radiation pressure, and other perturbations.[33]

In the United States, the Space Surveillance Network (SSN), operated by the United States Space Force (USSF) and the North American Aerospace Defense Command (NORAD), detects, tracks, catalogs, and identifies all manmade objects orbiting Earth larger than ten centimeters using ground-based sensors.[34] The USSF's next-generation SSA sensor, known as the Space Fence, was declared operational in March of 2020 and can track some objects smaller than ten centimeters.[35] The US Space Force also recently awarded Anduril a $100 million contract to modernize the data handling and communications of the SSN.[36] Today, the SSN spans the globe with a suite of sensors to continuously track tens of thousands of active satellites, inactive satellites (considered space debris), and other debris objects in orbit. NORAD maintains the freely available, authoritative Space-Track catalog.[37] Other publicly available catalogs and visualizers that build off Space-Track include CelesTrak, Heavens-Above, the European Space Agency's Database and Information System Characterising Objects in Space (DISCOS), and the Union of Concerned Scientists (UCS) Satellite Database.[38] It is stressed that usually these freely available catalogs do not carry crucial information on the orbit knowledge uncertainty.

The USSF uses the Space-Track catalog to perform conjunction assessments multiple times each day. In a conjunction assessment, volumetric regions around each cataloged object are analyzed to determine whether any of the other cataloged objects penetrate them, which constitutes a conjunction or close approach.[39] If a potential conjunction is predicted and the probability of collision is assessed to be above a certain threshold, then operators are notified via conjunction data messages (CDMs) on Space-Track. Coordination between operators involved in a conjunction is then performed through independent and direct communication. There is currently no comprehensive international standard for conjunction assessment or collision avoidance procedures.[40]

As the commercial space industry has grown, several organizations have developed and maintained their own SSA catalogs through sensing technologies. Examples include next-generation phased-array radars from LeoLabs, electro-optical telescope networks from ExoAnalytic Solutions and Slingshot Aerospace, and passive RF sensing from Kratos Space.[41] Other companies, such as COMSPOC and Kayhan Space, are creating their own operations centers and advanced software capabilities to fuse data from multiple sources and offer commercial SSA services, including automated STC platforms.[42] As depicted in figure 3, another promising technology area is optical and RF sensors that are deployed in orbit instead of on the ground and are known as space-based sensors. Companies such as NorthStar Earth & Space, HEO Space, and True Anomaly plan to use these space-based sensors to offer higher fidelity characterization of space objects, which is valuable for SDA and STC.[43] These commercial SSA providers utilize NORAD's Space Object Catalog and enhance it with their own commercial measurements to create commercial catalogs and visualizers, such as Kayhan Space's Satcat, Privateer's Wayfinder, and LeoLabs' Visualizer, which is shown in figure 4.[44]

As of April 2024, the US Space Command (USSPACECOM) had more than 185 SSA information-sharing agreements with partners from the commercial sector, academia, and intergovernmental and foreign organizations.[45] SSA sharing agreements enhance spaceflight sustainability and safety for all parties by improving space object catalogs, promoting the use of existing international data standards and integrity measures, and distributing tracking information.[46]

FIGURE 3 The role of SSA in mission operations; the arrows show the currently prevalent data flow space-ground-space; ephemeris is orbital parameters representing position and velocity

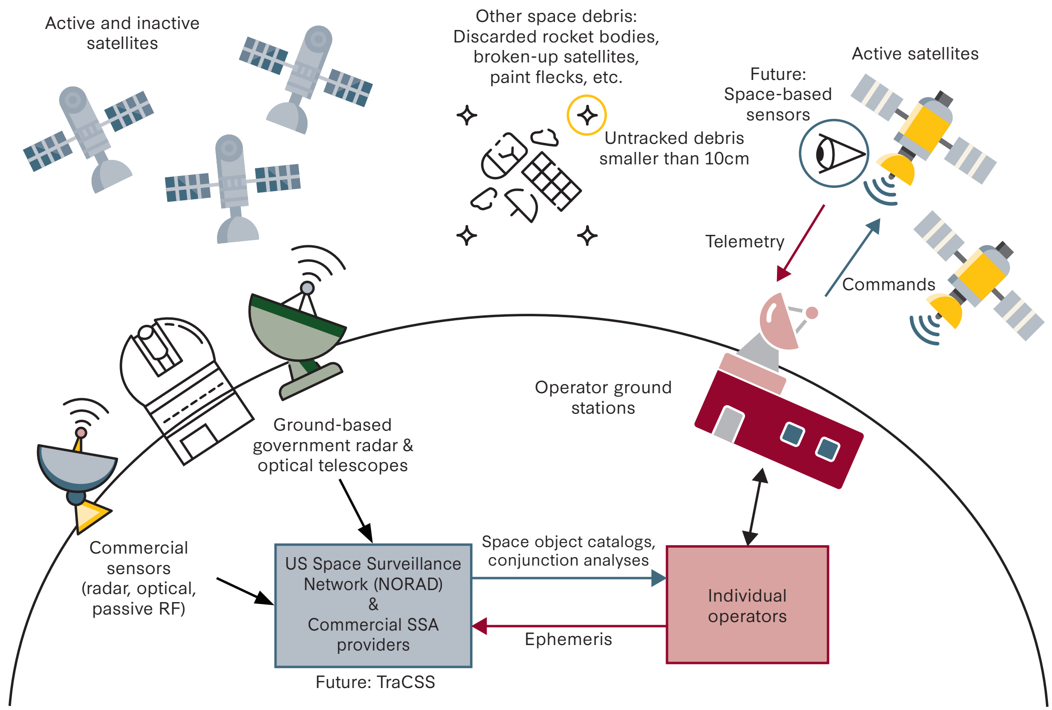
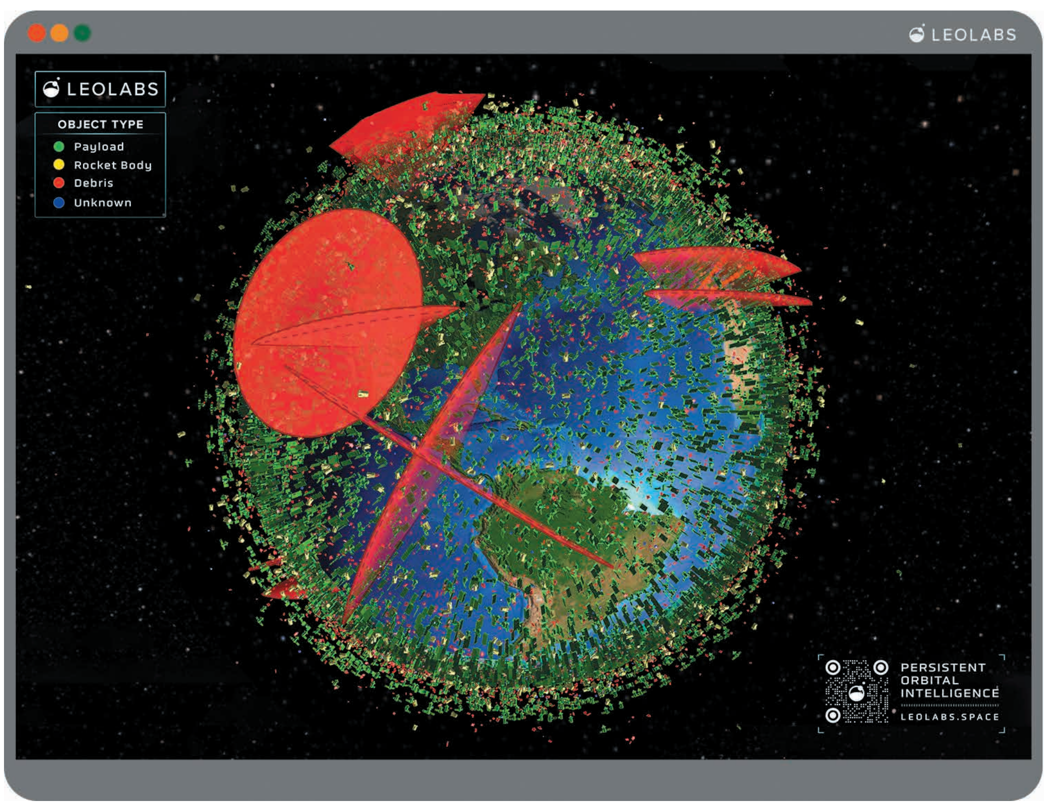
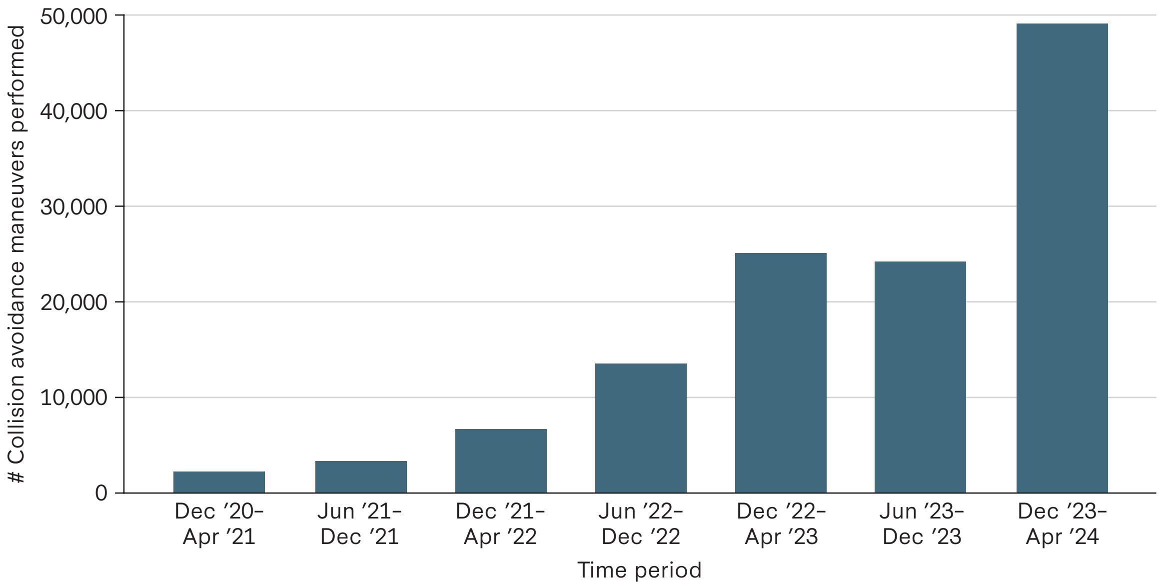


FIGURE 4 LeoLabs' Space Object Visualizer



Source: LeoLabs, accessed July 31, 2025, https://platform.leolabs.space/visualization.

FIGURE 5 Starlink collision avoidance maneuvers performed from 2021 to 2024

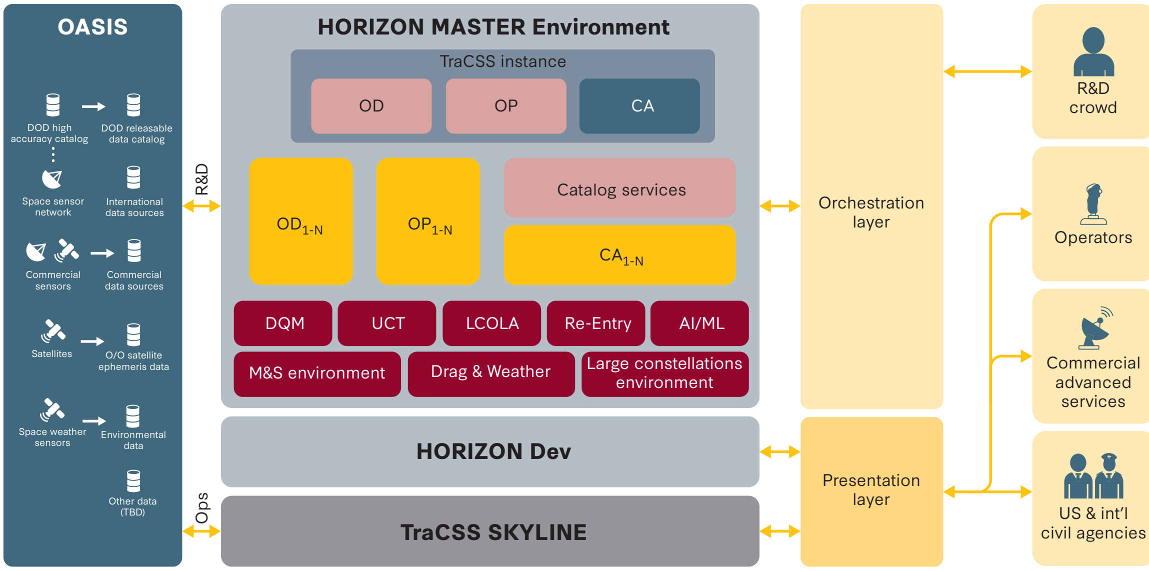


Source: Federal Communications Commission, "International Communications Filing System," accessed July 31, 2025, https://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/reports/related_filing.hts?f_key=-443498&f_number=SATMOD2020041700037.

Operators of active satellites utilize both government and commercial catalogs as well as SSA services to verify the orbital state of their vehicles and carefully plan orbital maneuvers, both of which reduce collision risks. Responsible operators typically use ground stations to track, receive data from, and send commands to their own satellites. Although not commonplace, operators can also share their orbit data, known as ephemeris, and planned maneuvers with the SSN and other SSA providers to improve the predictions of future spacecraft locations and thus the accuracy of conjunction analyses.[47] For example, the National Aeronautics and Space Administration's (NASA's) Conjunction Assessment Risk Analysis (CARA) program uses data from—and shares data with—the SSN to evaluate collision risks with NASA-operated spacecraft and to plan collision avoidance maneuvers.[48]

Such maneuvers are increasingly common. As shown in figure 5, Starlink performed over 49,000 collision avoidance maneuvers from December 2023 to April 2024 and has reported an average of twenty-seven maneuvers per satellite per year.[49] The substantial increase from the second half of 2023 to the first half of 2024 is due to SpaceX's decision to lower the collision avoidance threshold that it is willing to tolerate. The company's Starlink satellite constellation accounts for over 60 percent of active satellites, with over 7,500 satellites in orbit and plans to launch a total of 12,000 satellites into orbit by 2026. SpaceX also has requested permission to launch 30,000 more satellites on top of this original 12,000.[50] As such, Starlink has a vested interest in the sustainability of LEO and holds itself to very conservative collision avoidance thresholds. Starlink satellites maneuver when the probability of collision is greater than 1 in 1,000,000, which is two orders of magnitude more sensitive than the industry standard of 1 in 10,000.[51] SpaceX

FIGURE 6 TraCSS post-production release architecture



Source: Office of Space Commerce, "TraCSS Post-Production Release Architecture," accessed July 31, 2025, https://space.commerce.gov/traffic-coordination-system-for-space-tracss/tracss-schedule-roadmap/.

was also the first company to publish its satellite ephemeris as well as predictions of future Starlink locations via Space-Track and has called for the US government to require similar transparency from all other satellite operators.[52]

The new Traffic Coordination System for Space (TraCSS) operated by the Office of Space Commerce (OSC) at the Commerce Department aims to replace and significantly improve upon the existing SSN and Space-Track system by integrating commercial data through enhanced data fusion, supporting data-sharing and communications between operators, and streamlining conjunction analysis. The Department of Defense (DOD) will maintain the authoritative catalog of space objects, but the OSC will now be responsible for public space safety. Figure 6 lays out the planned architecture of TraCSS and how operators will interface with it. Multiple SSA data sources will be fused together in a data repository called TraCSS OASIS. Users will then access this data and basic safety services such as risk analysis through the TraCSS SKYLINE User Portal. Additionally, TraCSS HORIZON will provide a modeling, simulation, research, and test environment for users.

Phase 1.0 started to be rolled out in September 2024 to a beta set of users. In November 2024, the OSC chose Slingshot Aerospace to provide the website and user experience, or presentation layer, for TraCSS.[53] Phase 2 is planned to begin in 2026 and focuses on launch collision avoidance, while Phase 3 focuses on reentry assessment/management and other priority areas.

Overall, SSA is critical to all space operations. As such, the need for a robust, international STC system is immense. Other countries such as Russia, China, and the European

Union maintain similar capabilities to those of the United States, but there is currently no international STC system.[54] The most promising development has been TraCSS collaborating with the EU's Space Surveillance and Tracking (EU SST) to compare their services and plan future developments together.[55] Experts from many countries have called for greater international collaboration on space sustainability policy to help address this important issue.[56]

OPERATING IN SPACE: KEY TAKEAWAYS

1. Space situational awareness (SSA) is essential for operating in space and refers to keeping track of objects in orbit and predicting where they will be at any given time
2. Space traffic coordination (STC) refers to the cooperative planning, coordination, and on-orbit synchronization of space activities to enhance the safety, stability, and sustainability of operations
3. The current SSA architecture is primarily powered by the US Space Force's Space-Track catalog, but it is significantly outdated with large measurement uncertainties and poor latency
4. In the past decade, many commercial companies have launched efforts to close SSA and STC gaps by deploying their own sensors and improving on the services offered by Space-Track
5. The new Traffic Coordination System for Space (TraCSS) operated by the Office of Space Commerce (OSC) aims to replace Space-Track by integrating commercial data through enhanced data fusion, supporting data-sharing and communications between operators, and streamlining conjunction analysis

INTERNATIONAL POLICY

After the Soviet Union launched the first artificial satellite, Sputnik I, in October 1957, the UN General Assembly established the Committee on the Peaceful Uses of Outer Space (COPUOS) in 1959 to promote cooperation in the peaceful use of space for the benefit of all humanity, including for peace, security, and development.[57] To support this work, the UN also created the Office for Outer Space Affairs (UNOOSA), which serves as the secretariat for COPUOS. UNOOSA provides administrative and technical support, organizes meetings, prepares official documentation, facilitates the implementation of UN space treaties and guidelines, and promotes capacity-building in space activities for developing countries. In 1966, COPUOS drafted the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, commonly known as the Outer Space Treaty (OST).[58] Soon after, in 1967 the OST was approved by the UN General Assembly and subsequently ratified by 115 countries.[59]

The OST is considered the "Constitution" of space and is the foundational framework for international space law and policy, as it is a legally binding agreement. Key principles include the right of all nations to freely explore space, the use of space for the benefit of humanity, the prohibition of weapons of mass destruction in space, and the accountability of states for any damages caused by their space objects.[60] Shortly after the OST was implemented, four additional UN treaties were formed that serve as extensions of it: the Rescue Agreement (1968), the Liability Convention (1972), the Registration Convention (1975), and the Moon Agreement (1979).[61] These address obligations such as rescuing astronauts in distress, accepting liability for damages, providing transparency about space objects, and extending international law to the Moon and celestial bodies. However, these treaties were not ratified by as many nations as the original OST, with the Moon Agreement, in particular, having only eighteen signatories, reflecting limited international consensus around its provisions. Despite such issues, the OST and its extensions collectively serve as the basis for all space policy, both international and domestic.

Enforcing the principles of the Outer Space Treaty (OST) presents significant challenges, as the treaty does not establish a centralized international authority or direct enforcement mechanism. This is because it was designed to promote broad consensus among sovereign states during the Cold War, prioritizing high-level principles over the creation of a centralized enforcement authority that would have required nations to cede some level of control over their own space assets. Instead, compliance is maintained through a combination of international law, diplomatic engagement, and national implementation. Article VI of the OST holds states internationally responsible for all national space activities, including those conducted by private entities. As a result, each country is expected to regulate its space actors through domestic legislation that reflects the treaty's principles. In the United States this responsibility is carried out through a system of licensing and oversight managed by agencies such as NASA, the Federal Aviation Administration (FAA), and the Federal Communications Commission (FCC).

Potential violations of the OST are typically addressed through diplomatic means, such as other states raising a formal protest in COPUOS. For instance, in 1978 the Soviet Cosmos 954 satellite crashed in Canada, scattering radioactive debris. Under the Liability Convention, Canada filed a formal diplomatic claim, and the USSR paid the country a settlement of $3 million.[62] More recently, the United States and others issued strong diplomatic condemnations of the Russian ASAT test in 2021.[63] Later in that same year, the UN General Assembly passed a resolution calling for more responsible norms of behavior in space.[64] In the absence of an international "space police," enforcement of the OST relies on diplomatic pressure, multilateral norm-setting, and the deterrent effect of reputational damage or international condemnation.

Since the formation of UN COPUOS, several international organizations within and outside the UN have been established to address various elements of spaceflight and space policy, as outlined in figures 7 and 8. Figure 7 details the primary organizations with international governance and governmental participation:

- **UN COPUOS:** intergovernmental forum that develops international space laws and norms

- **UNOOSA:** secretariat for COPUOS and runs other programs, such as the Platform for Space-Based Information for Disaster Management and Emergency Response (UN-SPIDER) and the ICG (see next entry)
- **UN International Committee on Global Navigation Satellite Systems (ICG):** facilitates cooperation and interoperability between the multiple GNSS providers
- **International Telecommunication Union (ITU):** specialized UN agency that uses its binding legal authority over the global radio frequency spectrum and satellite orbital slots to ensure interference-free communication
- **Inter-Agency Space Debris Coordination Committee (IADC):** voluntary forum of the world's major space agencies that develops technical guidelines for mitigating

FIGURE 7 Primary international space policy organizations with participation of national governments

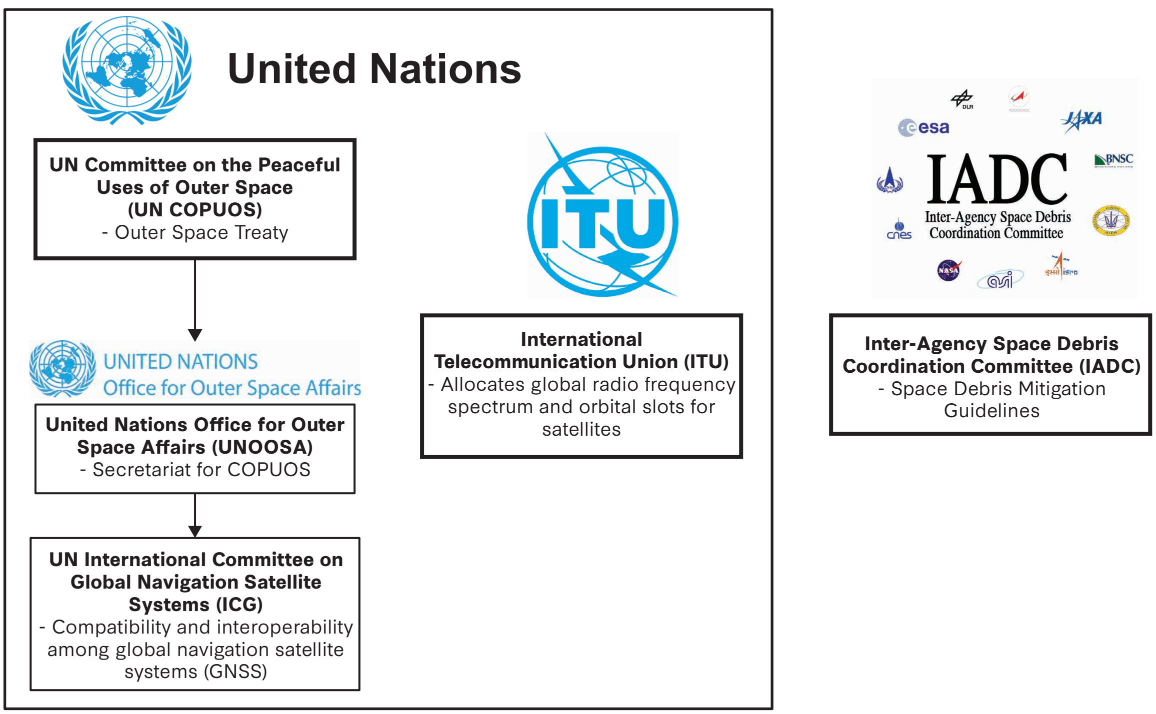


FIGURE 8 Leading nongovernmental and multistakeholder organizations supporting global space governance

space debris across all orbital regimes. While it operates independently of the UN, its recommendations have strongly influenced international norms, including the UN COPUOS Space Debris Mitigation Guidelines.

As depicted in figure 8, several international organizations complement formal intergovernmental bodies by advancing practical coordination, technical standards, and policy dialogue in space governance:

- **Group on Earth Observations (GEO):** coordinates international access to satellite data to support climate monitoring, disaster response, and sustainable development
- **International Academy of Astronautics (IAA):** creates expert-driven studies and independent policy recommendations that support long-term international cooperation in space
- **International Organization for Standardization (ISO):** develops widely adopted technical standards, including those for debris mitigation and spacecraft reliability
- **International Astronautical Federation (IAF):** hosts major forums like the International Astronautical Congress, bringing together space agencies, companies, and researchers
- **Secure World Foundation (SWF):** promotes space sustainability by conducting policy research, convening global stakeholders, and advocating for responsible on-orbit behavior
- **Space Data Association (SDA):** industry-led group that facilitates operational coordination and collision avoidance through voluntary data-sharing among satellite operators

Although no new, legally binding international space treaties have been adopted since the Moon Agreement in 1979, the international community has developed numerous nonbinding guidelines at the UN level, along with multilateral agreements led by a diverse range of stakeholders. While these initiatives all aim to promote the long-term sustainability of space, they are often hampered by a lack of broad agreement among nations on their provisions and how these are to be applied. In the absence of a centralized international authority, efforts to develop a unified governance framework remain fragmented. As a result, overlapping proposals from various international organizations have contributed to a complex and sometimes convoluted policy landscape. For example, multiple international bodies, including the UN COPUOS, ISO, and the IADC, have developed space debris mitigation guidelines, each with a slightly different technical emphasis and scope.

At the UN level, space sustainability is supported by both high-level political frameworks and more practical, technical guidelines. Adopted by the General Assembly in 2021, the UN Space2030 Agenda outlines a strategic vision for ensuring that space contributes to sustainable development and remains a peaceful and accessible domain for all humanity.[65] Building on this foundation, the Pact for the Future, adopted by 193 countries at the 2024 UN Summit of the Future, expands global commitments to include peace, sustainable development, climate change, and outer space governance.[66] It emphasizes preventing an arms race in space, ensuring equitable access to orbits, and preserving space as a sustainable and peaceful global commons through strengthened frameworks and new cooperative measures.[67]

More technically focused, the UN Guidelines for the Long-Term Sustainability (LTS) of Outer Space Activities, developed by COPUOS and endorsed in 2019, consist of twenty-one voluntary measures that promote responsible behavior in space.[68] These include recommendations on collision avoidance, information sharing, spacecraft design, and the long-term preservation of the space environment. The LTS guidelines draw heavily from the IADC Space Debris Mitigation Guidelines, which represent a widely accepted technical consensus among major space agencies. First issued in 2002 and updated most recently in 2025, the IADC guidelines provide specific mitigation strategies, such as post-mission disposal timelines, passivation of spent rocket stages (the removal or depletion of residual energy sources like fuel or batteries to prevent explosions), designing satellites to avoid accidental fragmentation, and limits on mission-related debris.[69]

Outside of the UN, the European Space Agency's (ESA) 2022 Zero Debris Charter builds on the principles outlined in the UN COPUOS LTS Guidelines and the IADC Space Debris Mitigation Guidelines by setting concrete operational goals and timelines. The charter promotes responsible on-orbit behavior by calling on industry and institutional actors to minimize debris generation throughout mission life cycles.[70] It encourages improved collision avoidance capabilities, robust satellite health monitoring, and strict end-of-life disposal measures such as reentry or deorbiting. To further reduce long-term orbital debris, the charter also sets a goal of demonstrating active debris removal (ADR) technologies in orbit by 2030. It calls for nations and companies alike to voluntarily commit to these goals and already counts over one hundred signatories.[71]

Likewise, the Artemis Accords, launched by the United States in 2020, are a set of nonbinding international principles designed to guide civil space exploration and use, particularly in support of NASA's Artemis program to return humans to the Moon. The Accords support space sustainability by promoting responsible behavior and international cooperation in lunar and deep space activities. While not solely focused on sustainability, they include commitments to transparency, interoperability, debris mitigation, and avoidance of harmful interference through safety zones. As of May 2025, the Accords have been signed by fifty-five countries.[72]

In addition to political frameworks like the Artemis Accords, technical standards are essential to advancing space sustainability in practice. For instance, ISO 24113: Space Debris Mitigation, developed by the International Organization for Standardization (ISO) in 2011 and revised most recently in 2023, sets stringent requirements for minimizing the risks associated with space debris.[73] It covers key areas such as post-mission disposal, collision avoidance, and satellite design for end-of-life deorbiting. Notably, ISO 24113 is directly based on the IADC guidelines and translates the broad international technical consensus among major space agencies into formal, certifiable engineering requirements that can be adopted by national regulators and spacecraft manufacturers.

In summary, international space sustainability policy operates across multiple levels, with each one serving a distinct role in shaping global behavior. UN guidelines, such as the LTS Guidelines and the Space2030 Agenda, establish broad political norms and principles for responsible space activity. At a more detailed level, IADC and ISO space debris mitigation guidelines provide technical best practices for countries and companies to implement these norms. Meanwhile, frameworks like the ESA Zero Debris Charter and the Artemis Accords are commitment-driven initiatives that rely on voluntary participation to promote concrete actions and shared operational standards. Each of these initiatives presents different dimensions of space sustainability, and future efforts should focus on bridging the gap between global aspirations and on-the-ground implementation.[74]

International space policy is inevitably deeply intertwined with geopolitics, as space capabilities are closely linked to national power, security, and strategic influence. This geopolitical context presents significant challenges, chief amongst which is the absence of a centralized enforcement mechanism to ensure that states act sustainably in space. Due to the current geopolitical climate, the likelihood of new binding international space treaties emerging in the near future is low. Nevertheless, meaningful progress can still be achieved by strengthening broadly accepted norms and promoting more widespread voluntary adherence to guidelines. Nonbinding international frameworks, such as the IADC guidelines, continue to play a critical role by informing domestic space regulations and operational standards around the world.

INTERNATIONAL POLICY: KEY TAKEAWAYS

1. The Outer Space Treaty (OST) is considered the “Constitution” of space and is the foundational framework for all international space law and policy, as it is a legally binding agreement

2. The OST does not include a centralized international authority or direct enforcement mechanism, which makes creating new and binding space policy challenging

3. The UN Committee on the Peaceful Uses of Outer Space (UN COPUOS) and other UN bodies are the central hub for international space policy today

4. There are a wide variety of nonbinding agreements and initiatives from international stakeholders such as NASA and the European Space Agency (ESA)

DOMESTIC POLICY

At the national level in the United States, space policy can play an essential role in supporting, enhancing, and enforcing international policy. In the United States, domestic space regulation and licensing for all space activities are split between three different agencies, as outlined in figure 9:

- **National Oceanic and Atmospheric Administration (NOAA):** agency within the Department of Commerce (DOC) that houses the Office of Space Commerce (OSC)
  and oversees remote sensing licenses
- **Federal Aviation Administration (FAA):** agency within the Department of Transportation (DOT) that oversees launch and reentry licenses
- **Federal Communications Commission (FCC):** independent agency in charge of communications licenses

Other major stakeholders in domestic space policy are presented in figure 10:

- **NASA:** premier government space agency in the United States that focuses on science and exploration missions
- **DOD:** many branches are directly involved in space, especially the Space Force
- **Department of State:** ensures that aerospace organizations abide by export controls as required by the International Traffic in Arms Regulations (ITAR). Also released the first-ever Strategic Framework for Space Diplomacy in 2023.[75]

FIGURE 9 US domestic space regulators

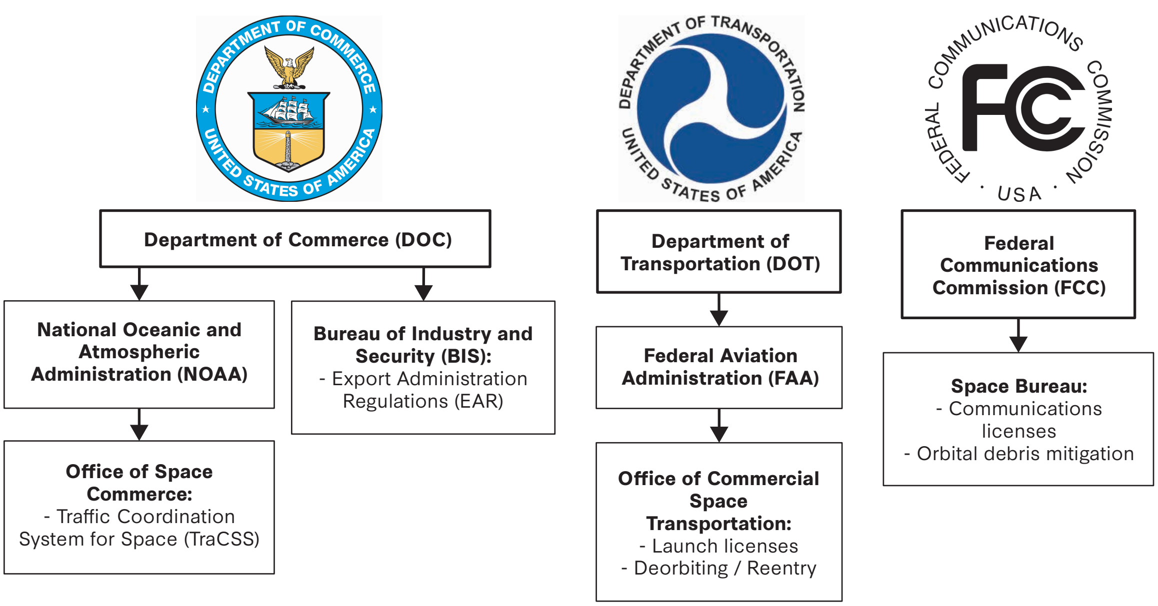
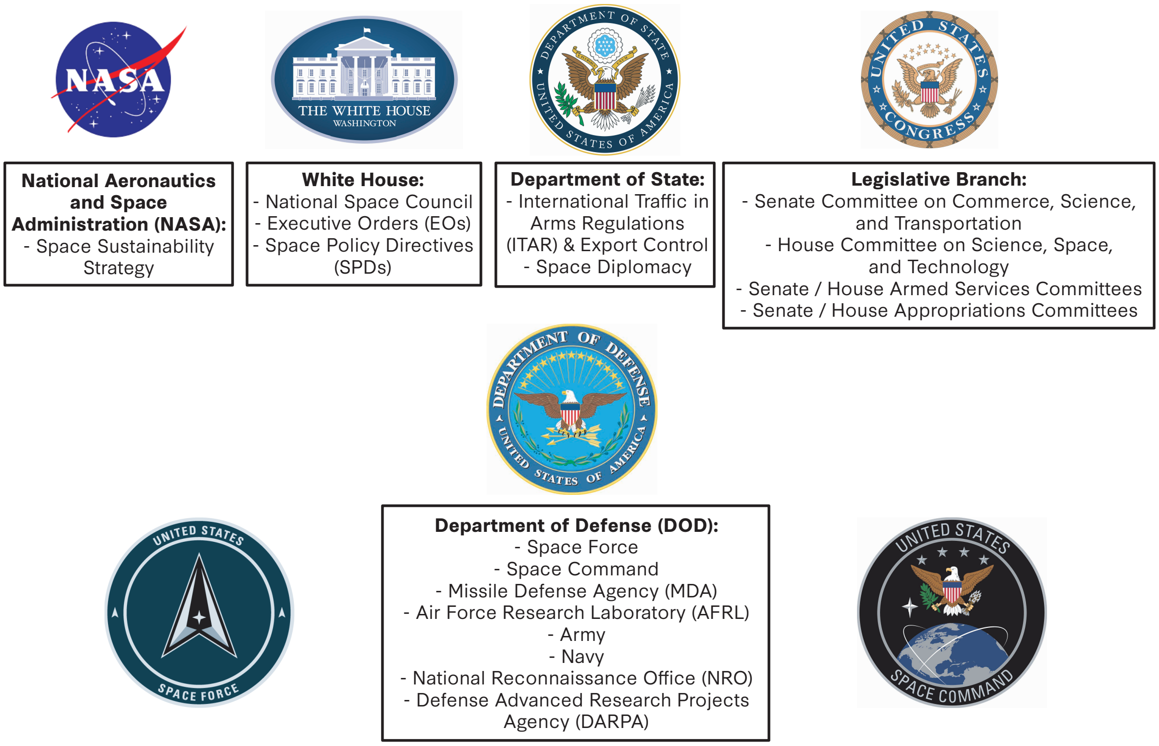


FIGURE 10 US domestic space stakeholders



Other government entities are involved in space through policymaking and legislation, such as the White House's National Space Council and congressional committees concerned with space.

Historically, long-established regulatory categories were sufficient for covering all space use cases, but this is now changing with the growing commercial space economy. It is unclear, for instance, who oversees new use cases that do not neatly fit into the three categories represented by the FAA, the FCC, and NOAA. One recent example of this was SpaceX's Polaris Dawn mission, which performed the first-ever commercial spacewalk. Before this mission, all American human spaceflight was conducted by NASA. Now there are questions as to who should oversee commercial human spaceflight. The Commercial Space Act of 2023 aims to address this by establishing a mission authorization system within the DOC for all commercial space activities not currently licensed elsewhere, but it has yet to be passed.[76]

For space sustainability specifically, it is unclear which agency is responsible for oversight. As part of its launch licensing process, the FCC imposes orbital debris-reducing requirements, including guidelines for the maneuverability of spacecraft, their ability to deorbit, and their capacity to disintegrate safely on reentry (known as "demisability").[77] In September 2022, the FCC shortened the time limit for satellite operators to deorbit LEO satellites from twenty-five years to five years to address growing debris.[78] The agency has so far issued only two substantial fines for violating its space operations requirements: Swarm Technologies agreed to a $900,000 settlement after it launched four unauthorized satellites in 2018, and Dish Network had to pay a $150,000 fine after failing to properly decommission and retire its EchoStar-7 satellite to a graveyard orbit in 2023.[79] The FCC labeled the latter event as the "first space debris enforcement action."[80] There is ongoing debate about whether the FCC is the appropriate agency to enforce space debris regulations—especially in light of the Supreme Court's recent decision to overturn the "Chevron doctrine," which had allowed federal agencies to interpret vague laws.[81] Without that deference, courts may decide that the FCC lacks authority over space debris, in which case Congress would need to take explicit legislative action to resolve the issue.

Leaving aside the question of who has authority over space-related issues, there are many efforts within domestic policy that address space sustainability, both directly and indirectly. Indirect efforts include the FAA's revamping of federal launch licensing regulations, known as Part 450—an effort that has faced criticism from commercial companies, including SpaceX, for not doing enough to streamline the licensing process.[82] NASA has also published a Space Sustainability Strategy that sets out its goals for tackling challenges in orbital debris research and providing a framework for space sustainability.[83]

The two main programs that deal directly with space sustainability are the proposed Orbital Sustainability (ORBITS) Act of 2025 and the recent development of TraCSS under the OSC.

The ORBITS Act is a bipartisan bill that would establish an ADR demonstration program to reduce the amount of extremely dangerous orbital debris. ADR is an acronym for active debris removal, which refers to a spacecraft's ability to collect debris, which can range from a few millimeters to a meter in size, and then remove it through either deorbiting the debris and having it burn up in the atmosphere or moving it to a graveyard orbit where it will not pose a threat for hundreds of years. The proposed legislation would also direct the DOC, the National Space Council, and the FCC to develop, update, and promote standard practices for avoiding near misses and collisions between spacecraft in orbit. Additionally, it would direct NASA, in collaboration with other agencies, to publish a list of debris objects that pose the greatest risk to spacecraft safety and on-orbit activities. The ORBITS Act was passed by the Senate in November of 2023 and introduced in the House in July 2024.[84] The Senate referred it to the Committee on Commerce, Science, and Transportation in May 2025.[85]

The other major domestic space sustainability initiative is the establishment of TraCSS in the OSC. TraCSS was created by President Trump's Space Policy Directive-3, which shifts responsibility from the DOD to the OSC for providing basic SSA data and STC services to commercial and civil space operators. TraCSS, which is described earlier in this report, is designed to provide a next-generation SSA system while also leaving room for more advanced services to be developed by the commercial industry. Senators reintroduced the SAFE Orbit bill to fully authorize TraCSS in February of 2025.[86] The bill would also elevate the OSC from an office within NOAA to a bureau reporting directly to the Secretary of Commerce. As a bureau, it would have more autonomy and be led by an assistant secretary, who would require Senate confirmation.[87]

With ORBITS and TraCSS, the United States is actively working toward a sustainable future in space. However, to achieve this vision, it must collaborate with international partners to integrate its domestic programs into a global space sustainability solution. For inspiration as to how to do this, it can be useful to look to previous instances of fostering international frameworks in critical Earth-based domains.

DOMESTIC POLICY: KEY TAKEAWAYS

1. The Federal Aviation Administration (FAA) oversees launch and reentry licenses, the Federal Communications Commission (FCC) is in charge of communications licenses, and the National Oceanic and Atmospheric Administration (NOAA) oversees remote sensing licenses
2. Other domestic stakeholders include NASA, the DOD, the National Space Council, and congressional committees
3. The ORBITS Act is a bipartisan bill that would establish an ADR demonstration program to reduce the amount of extremely dangerous orbital debris
4. The SAFE Orbit Act is a bill that would fully authorize the establishment of TraCSS in the OSC
5. There is ongoing debate about whether the FCC is the appropriate agency to enforce space debris regulations

AVIATION, MARITIME, AND GROUND ANALOGS

Although space is unique in many respects, there are some significant similarities with other Earth-based domains: namely aviation, maritime, and ground transportation. In each domain, collision avoidance requires diverse sensing approaches and a mutual understanding of international protocols. The aviation, maritime, and ground sectors all have mature and successful international governance frameworks, collision avoidance procedures, and environmental protection policies. They therefore offer some helpful analogs that could be used to inform space policy.

There are some key differences between space and these other domains, as outlined in table 1. For instance, objects in space are moving at absolute and relative speeds that are around 1,000 times faster than the average car or boat and 300 times faster than a cruising plane. As a result, the destructive energy of a collision of small

TABLE 1 CROSS-DOMAIN COMPARISON OF SPACE WITH AVIATION, MARITIME, AND GROUND

	Aviation	Maritime	Ground	Space
Absolute Speeds	>900 km/h	30–100 km/h	30–50 km/h	>28,000 km/h
Relative Speeds	900–1,800 km/h	30–200 km/h	30–100 km/h	28,000–56,000 km/h
Object Size Range	1–80 m	5–400 m	1–20 m	0.1 cm–100 m
Collision Energy	High	Low	Moderate	Extremely high
Collision Avoidance Systems	ATC system	Vessel traffic service	Traffic lights, GPS	SSA systems
Collision Avoidance Approach	Sensing / autonomy at the edge (Pilots)	Sensing / autonomy at the edge (Captains)	Sensing / autonomy at the edge (Drivers)	Remote control
Measurement Modalities	GPS & ADS-B, human eye	AIS, human eye	GPS, human eye	Radar, optical, RF, GPS
Update Frequency / Response Time	Seconds	Minutes	Seconds	Hours
Position Uncertainty	10–50 m	5–20 m	1–10 m	1–10 km (debris), <10 m (precise tracking)
Uncertainty Propagation	Low	Low	Low	High
Tolerance for Uncertainty	Low	Moderate	Low	Very low (due to high relative speeds)
Impact of Uncertainty	May trigger false alarms or missed alerts	Allows manual corrections	Critical for autonomous systems	Overly conservative collision avoidance maneuvers

centimeter-sized objects in space is extremely high. Another key difference is how measurements are taken to avoid collisions. In space, ground-based sensors, algorithms for data association, and orbit determination are used to detect potential collisions. If a risk is identified and reaction measures are technically possible, responsible operators communicate with their satellites hundreds of kilometers overhead to ensure a collision does not occur. This process typically means reaction times of several hours. In the other domains, there is sensing and autonomy at the edge, usually in the form of human pilots, captains, or drivers, which produces reaction times on the order of seconds. A third difference involves the significant uncertainties of ground-based measurements of space objects arising from their very high speeds and limited observability. As a result, spacecraft operators must be very conservative in their collision avoidance maneuvers, which cost precious fuel. These differences can help identifying ways to improve space traffic coordination, especially with the advent of new technology. The following sections provide useful parallels and a cross-comparison between the different transportation domains.

ORGANIZATIONAL FRAMEWORK AND GOVERNANCE

Successful international governance frameworks in the aviation and maritime domains offer useful models. In aviation, the International Civil Aviation Organization (ICAO) governs global standards for air traffic management, aircraft design, and environmental protection under the 1944 Chicago Convention.[88] Member states incorporate these standards into national regulations and ICAO's regional offices help adapt them to local needs.[89]

In the maritime domain, governance is anchored by the UN Convention on the Law of the Sea (UNCLOS) and the International Maritime Organization (IMO).[90] UNCLOS defines legal responsibilities in maritime zones such as territorial waters, exclusive economic zones, and the high seas. The IMO sets technical standards for safety, security, and environmental protection through conventions like the International Convention for the Prevention of Pollution from Ships (MARPOL) and the International Convention for the Safety of Life at Sea (SOLAS).[91] Together, they provide a coherent legal and operational framework for international maritime activity.

Finally, while ground transportation governance is more fragmented, with national governments taking the lead this domain can serve as a template for space governance once there are enough participatory states with substantial space activities. Currently, space operations lack a centralized governing body, with existing frameworks such as the Outer Space Treaty and the Moon Agreement providing only broad principles.[92] The absence of detailed, enforceable international standards creates challenges for managing issues like orbital debris, collision avoidance, and resource utilization. The frameworks of ICAO and IMO could provide guidance on how to govern areas such as space where there is no national jurisdiction. The following sections provide examples of how useful lessons from these domains can be applied to space.

COLLISION AVOIDANCE

Collision avoidance is a critical aspect of operations across the maritime, aviation, ground, and space domains. ICAO maintains standardized air traffic management systems and onboard collision avoidance technologies like the traffic collision avoidance system (TCAS).[93] TCAS provides pilots with real-time advisories about how to avoid midair collisions, while ground-based air traffic control (ATC) ensures safe distances are kept between aircraft. Another crucial technology is the Automatic Dependent Surveillance-Broadcast (ADS-B), which uses aircraft and ground infrastructure to provide real-time information about aircraft locations to the ATC.[94] Furthermore, ICAO Annex 11 outlines global standards for airspace organization and the coordination of ATC systems, emphasizing interoperability across nations.[95] Similarly, the International Regulations for Preventing Collisions at Sea (COLREGs), established by the IMO, provide a globally recognized set of navigation rules.[96] These rules include right-of-way hierarchies, signaling procedures, and safe speed guidelines to minimize collision risks. For example, COLREG Rule 5 mandates continuous lookout, while Rule 15 establishes crossing rules to determine which vessel must yield.[97] Also, Maritime Traffic Separation Schemes designate lanes for inbound and outbound traffic in congested waters to further enhance safety.[98] For tracking, the IMO supports and regulates the usage of the Long-Range Identification and Tracking system, which enables global tracking and identification of ships, and Automatic Identification System (AIS) transponders, which transmit a ship's position, identification, and more to other ships and authorities.[99]

For human-operated ground vehicles, collision avoidance occurs through traffic lights, road signs, and right-of-way hierarchies. For autonomous vehicles, the Society of Automotive Engineers J3016 Standard defines levels of autonomy in driving and sets out collision avoidance responsibilities at each level.[100] Currently, the National Highway Traffic Safety Administration maintains the Federal Automated Vehicles Policy, which provides guidelines for manufacturers and states on how to report crashes involving autonomous driving systems and stress safety considerations during development and testing.[101] Advanced Driver Assistance Systems, such as blind-spot detection and lane departure warnings, are based on the ISO 26262 standard and Automotive Safety Integrity Levels, which measure the risk level of automotive systems and equipment.[102] Collision avoidance methods for autonomous vehicles on the ground could act as blueprints for autonomous vehicles in space once they are developed. Likewise, standardized rules for satellite maneuvers and right-of-way in orbital encounters could be adopted from IMO regulations, specifically COLREGs, and the establishment of automated collision-avoidance and data-sharing systems for satellites could be iterated from TCAS policies.[103]

ENVIRONMENTAL PROTECTION

Space sustainability policies could be modeled after environmental protection policies that have been implemented across the aviation, maritime, and ground domains. The ICAO maintains the Carbon Offsetting and Reduction Scheme for International Aviation, which requires airlines to monitor, report, and offset their CO_2 emissions for international flights.[104] Additionally, ICAO's Annex 16 to the Chicago Convention establishes international standards for noise and gaseous pollutants emitted by aircraft engines.[105] Similarly, the IMO has developed robust frameworks to regulate pollution from ships. The International Convention for the Prevention of Pollution from Ships (MARPOL) serves as the cornerstone of these efforts. For instance, MARPOL Annex VI addresses air pollution by limiting sulfur oxide and nitrogen oxide emissions from ships, requiring vessels to use low-sulfur fuels or alternative technologies.[106] MARPOL Annex V regulates the discharge of garbage, including a complete prohibition on the disposal of plastics into the ocean.[107] The Ballast Water Management Convention mandates specific treatment measures to prevent the spread of invasive aquatic species through ballast water discharge.[108]

Although ground transportation differs slightly in that emissions standards are largely governed at the national level, there is a strong desire by governments to reach internationally set climate goals.[109] For instance, the US Environmental Protection Agency includes limits on nitrogen oxide, particulate matter, and greenhouse gas emissions from light-duty vehicles, while the EU's Euro 1-7 standard imposes stringent limits on vehicle emissions, significantly reducing air pollution from cars and heavy-duty trucks.[110] These practices highlight the potential for similar regulations in space to prevent the proliferation of orbital debris and contamination of celestial bodies, as well as to minimize the environmental impacts of rocket launches. As more and more countries participate in space activities, international environmental regulations could be supplemented increasingly by ones from national governments that reflect international norms.

AVIATION, MARITIME, AND GROUND ANALOGS: KEY TAKEAWAYS

1. Space governance must overcome the unique challenges of a non-terrestrial environment—one that lacks physical boundaries and is shared by a growing number of actors
2. Both the maritime and aviation domain have established systems for ensuring safe passage
3. The successful governance of other domains reflects centuries of diplomacy, tensions, and deliberations[111]
4. Universal principles of safety, cooperation, and environmental stewardship form a common thread across all these domains, offering valuable lessons for creating a global framework for space governance

LOOKING UP AND TOWARD THE FUTURE

KEY ISSUES

As this working paper has shown, the challenges of ensuring sustainable use of space by nations on Earth are both numerous and complex. While these issues will be explored in greater detail in the next working paper in this series, at a high level they include:

First, space sustainability, especially space traffic coordination, is a global problem; thus, a global solution is required. The United States and the EU are collaborating on the development of their respective STC systems, but there also needs to be data-sharing and coordination with China and Russia, especially as China is in the process of sending up thousands of satellites as part of its larger space agenda. Space and geopolitics are deeply intertwined, and as such, building toward a global solution will necessitate intermediate stages. As a first step, the United States should continue to work with like-minded nations to establish international norms in data-sharing and coordination. It can also build wider international confidence by exchanging technologies that can be used for detection of orbital debris strikes and collision avoidance between spacecraft. Commercial companies could play a pivotal role in facilitating these collaborations as they are less burdened by the intricacies of international diplomacy.

Second, developing commercial incentives for innovation in space situational awareness will be essential for progress to be made in space sustainability. As shown in the past decade by companies such as SpaceX, the commercial space industry is capable of developing and maturing revolutionary technologies at a breakneck pace. Now that there are tens of thousands of satellites in orbit, that same spirit must be harnessed to prevent catastrophe. Commercial companies need to be involved in the development of new solutions, such as the next-generation STC system, while at the same time ensuring these solutions are commercially viable. Today, there are relatively few business cases for coordinating space traffic and improving SSA for non-defense-related applications. Additionally, some commercial players see TraCSS as encroaching upon their opportunities to build STC systems. The right policy or regulatory framework could provide such incentives.

Third, effective enforcement is imperative for any space sustainability regulation or policy to have a meaningful impact. The first-ever space debris fine issued by the FCC in 2023 sets an encouraging precedent, but stricter regulations and enforcement actions will be needed in the future. Mega-constellation operators such as Starlink, Kuiper, and OneWeb have an inherent interest in caring about space sustainability in order to protect their multitude of vehicles. Starlink is a leader in collision avoidance and SSA, holding itself to collision avoidance and deorbiting standards that are much more stringent than those required by law.[112] Other operators who only have one or a few assets in orbit may be less inclined to take sustainability seriously. Today, the American space licensing system requires operators to commit to deorbiting within five years of mission completion and prove they meet reliability standards; however, there is not much follow-through on these requirements once a spacecraft is in orbit. Furthermore, the question of responsibility for—and ownership of—space objects is largely unanswered, especially when it comes to debris cleanup. It will be impossible to achieve true sustainability in space until there are frequent and comprehensive checks on companies' handling of their space assets and rigorous enforcement of current regulations and licenses.

Fourth, today's space technology has limitations, and policies should do more to encourage the development of solutions that address them. Current ground-based sensors cannot track any object smaller than a few centimeters, and the vast majority of space debris is below this observability threshold.[113] As such, millions of untracked objects pose significant risks to operational satellites, raising the question of how to prevent collisions with uncatalogued objects. Additionally, ground coverage of space is limited in certain areas, especially polar regions, which degrades tracking capabilities.

As a result of the large uncertainties associated with current tracking resources, reaction times for avoiding potential collisions can be many hours, leading to unnecessary evasive maneuvers and waste of fuel. Space-based SSA capabilities may be able to help address these technical challenges and others by augmenting ground-based systems, which have some important limitations. Optical telescopes on the ground, for instance, can only observe spacecraft during a clear night and all ground-based sensors can only observe space objects in LEO for a few minutes at a time as they pass overhead. Space-based sensors can offer persistent global coverage and more favorable viewing geometries, enabling them to observe objects that may be hidden or poorly tracked from the ground, such as satellites in GEO or over polar regions. Unlike ground-based systems, they are not constrained by weather, daylight, or atmospheric distortion, allowing for more consistent and timely observations.

PROMISING TECHNOLOGIES

Efforts to address the challenges of space traffic coordination and space debris mitigation increasingly focus on developing and deploying advanced technologies. With significant progress in the past decade, these innovations are now paving the way for sustainable orbital operations.

STC underpins SSA by monitoring orbital objects and predicting potential collisions. Key SSA technologies include the US Space Surveillance Network (SSN), which operates radars like the AN/FPS-85 and telescopes like the Ground-Based Electro-Optical Deep Space Surveillance system.[114] The SSN tracks over 36,000 objects currently in orbit, with an accumulated number of space objects tracked at roughly 60,000.[115] Similarly, private companies like LeoLabs have developed ground-based phased-array radars, such as the Kiwi Space Radar in New Zealand, which enable precise tracking of LEO debris as small as a few centimeters.[116]

Advances in space-based sensors also play a critical role. For instance, commercial companies such as NorthStar Earth & Space and Scout Space are currently developing and deploying space-based vision sensors for SSA.[117] NASA's Starling mission is currently demonstrating capabilities to track space objects using star trackers to better refine on-orbit navigation.[118] The mission also demonstrated autonomous collision avoidance coordination with SpaceX's Starlink constellation.[119] Artificial intelligence (AI) and machine learning (ML) can further enhance these capabilities by enabling spacecraft to process more data onboard, increasing autonomy and accelerating decision making.

Space debris mitigation combines preventive and reactive measures to address the growing orbital population of defunct satellites and fragments. Preventive technologies include satellite propulsion systems for controlled deorbiting at the end of a mission's life and on-orbit refueling, as demonstrated by Northrop Grumman's MEV-1 spacecraft, which successfully refueled a GEO satellite and kept it in service for five additional years.[120] The increasing adoption of low-cost electric propulsion systems enhances spacecraft maneuverability, reducing the risk of collisions. Reactive measures, such as ADR technologies, are also advancing. The European Space Agency's ClearSpace-1 mission plans to deploy a robotic arm to capture and deorbit debris.[121] Similarly, the Japanese company Astroscale has tested magnetic docking technology on its ELSA-d mission, demonstrating precision debris capture.[122] NASA is currently exploring the feasibility of using ground-based laser systems to deorbit small pieces of debris by gradually slowing them down.[123]

The convergence of emerging technologies with new governance frameworks marks a pivotal moment for space policy. By leveraging cutting-edge solutions like AI-enhanced collision avoidance, ADR, and robust data-sharing platforms, the space community can foster sustainable orbital operations. These efforts not only mitigate immediate risks but also lay the foundation for a safe, collaborative, and equitable space environment.

PATHWAYS TO A GLOBAL SOLUTION

Global coordination and cooperation in space is challenging. The last international space treaty to be ratified was the Moon Treaty in 1979—and the signatories do not include any state that has the capability to self-launch humans into space (i.e., the United States, Russia, or China).[124] Since then, the geopolitical climate has limited international space policy to voluntary guidelines, such as the UN's Guidelines for the Long-Term Sustainability of Outer Space Activities.[125]

However, international space law still has indirect enforcement mechanisms. The Outer Space Treaty requires states to conduct all their activities in space with "due regard" to the interests of all other states.[126] This provision necessitates national governments to oversee and regulate all space activities from their nation, including commercial actors. As the interpretation of "due regard" evolves with the expanding space population, national governments will need to consider how their regulatory responsibilities also evolve. Through this mechanism, international guidelines and best practices could serve as the basis for enforceable domestic policies.

While a truly global STC solution will be infeasible in the near future, there are attainable steps that can be taken at the domestic and international levels with allies and others. The United States is on the right track in developing TraCSS; however, there is still room for improvement. As more and more satellites are launched into space, autonomous spacecraft operations will become ever more important, which TraCSS will need to adapt to in order to be effective. Additionally, while some operators are fully committed to responsible data-sharing and coordination, there is not yet widespread adoption of these essential practices. On the regulatory side, the United States still needs to formally designate an agency responsible for regulating orbital debris as there are open questions about whether the FCC—which has currently assumed responsibility—is in fact the right organization to do so.[127]

Internationally, data-sharing and coordination with other national SSA systems, such as the EU SST, is a promising avenue. While each national system might operate on different data sources with varying analysis standards, combining insights from more sources will contribute to a more complete understanding of the space environment. Furthermore, operators within each nation need the ability to collaborate across borders to address collision risks and be aware of each other's planned maneuvers. There has already been progress in this direction with the US Office of Space Commerce releasing its "Vision for Global SSA Coordination" document in April 2024.[128] Moreover, the chairman of the EU SST program recently suggested that national SSA and STC systems could be federated through an approach similar to the International Committee on Global Navigation Satellite Systems (ICG), which is a forum for voluntary cooperation among countries possessing their own satellite navigation systems.[129]

Collaboration with other nations, such as China and Russia, has proven to be more difficult. While there have been conversations between US and Chinese operators, mostly on the commercial side, they have been limited in scope. However, as China launches more of its planned tens of thousands of satellites, coordination will become even more necessary as Chinese constellations will operate in similar orbital regions to American ones. The United States should lead the way in transparency and data-sharing to facilitate future cooperation between all major space actors. Another encouraging possibility is to develop and share capabilities to distinguish between a debris impact and an ASAT strike, reducing the risk of unprompted escalation from one superpower against another. More generally, improvements in SSA and STC are especially relevant for national security as militaries seek to avoid collisions and better understand the capabilities and actions of adversaries in space.

Equally important as advancements in policy is sustained US investment in emerging technologies for SSA and STC. Developing a next-generation space tracking architecture by integrating improved ground-based systems with novel space-based modalities is essential to achieving continuous and accurate custody of space objects throughout their orbits. Enhanced modeling of space weather and the increasing space object population is critical for generating reliable predictive capabilities that can inform effective policy decisions. Moreover, the deployment of advanced STC platforms can facilitate more efficient coordination among operators, thereby reducing the risk of orbital collisions. ADR initiatives also play a vital role in enhancing the long-term safety and sustainability of the space environment by targeting and eliminating high-risk debris.

Overall, there are feasible steps toward a global solution to address space safety and sustainability issues on the domestic and international levels. The next working paper in this series will explore these issues and potential solution pathways in more depth, providing specific policy proposals and technology development recommendations.

FUTURE OUTLOOK: KEY TAKEAWAYS

1. There are feasible steps toward a global space sustainability solution that the United States can first take with its allies and then other countries
2. International data-sharing and collaboration are critical to ensuring a sustainable and secure future in space
3. Investing in emerging technologies like space-based sensing and active debris removal (ADR) is vital to resolving the space sustainability paradox
4. US space licensing regulations should be modernized to incorporate industry best practices and keep pace with the accelerating proliferation of space objects

LIST OF ABBREVIATIONS

ADR	Active debris removal
ADS-B	Automatic Dependent Surveillance-Broadcast
AI	Artificial intelligence
AIS	Automatic Identification System
ASAT	Antisatellite weapon
ATC	Air traffic control
CARA	Conjunction Assessment Risk Analysis
CDM	Conjunction data message
COLREGs	International Regulations for Preventing Collisions at Sea
COPUOS	Committee on the Peaceful Uses of Outer Space
DISCOS	Database and Information System Characterising Objects in Space
DOC	Department of Commerce
DOD	Department of Defense
DOT	Department of Transportation
ESA	European Space Agency
ESPI	European Space Policy Institute
EU SST	European Union Space Surveillance and Tracking
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
GEO	Geostationary Earth orbit
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
IADC	Inter-Agency Space Debris Coordination Committee
ICAO	International Civil Aviation Organization
ICG	International Committee on Global Navigation Satellite Systems
IMO	International Maritime Organization
ITAR	International Traffic in Arms Regulations
LEO	Low Earth orbit
LTS	Long-term sustainability
MARPOL	International Convention for the Prevention of Pollution from Ships

ML	Machine learning
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Aerospace Defense Command
ORBITS Act	Orbital Sustainability Act of 2023
OSC	Office of Space Commerce
OST	Outer Space Treaty
RF	Radio frequency
RSO	Resident space object
SAFE Orbit Act	Situational Awareness of Flying Elements in Orbit Act
SDA	Space Data Association
SDA	Space domain awareness
SEP	Space environment preservation
SGP4	Simplified General Perturbations 4
SOLAS	Safety of Life at Sea
SSA	Space situational awareness
SSN	Space Surveillance Network
STC	Space traffic coordination
STM	Space traffic management
TCAS	Traffic collision avoidance system
TLE	Two-line element
TraCSS	Traffic Coordination System for Space
UCS	Union of Concerned Scientists
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNOOSA	United Nations Office for Outer Space Affairs
USSF	United States Space Force
USSPACECOM	US Space Command

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