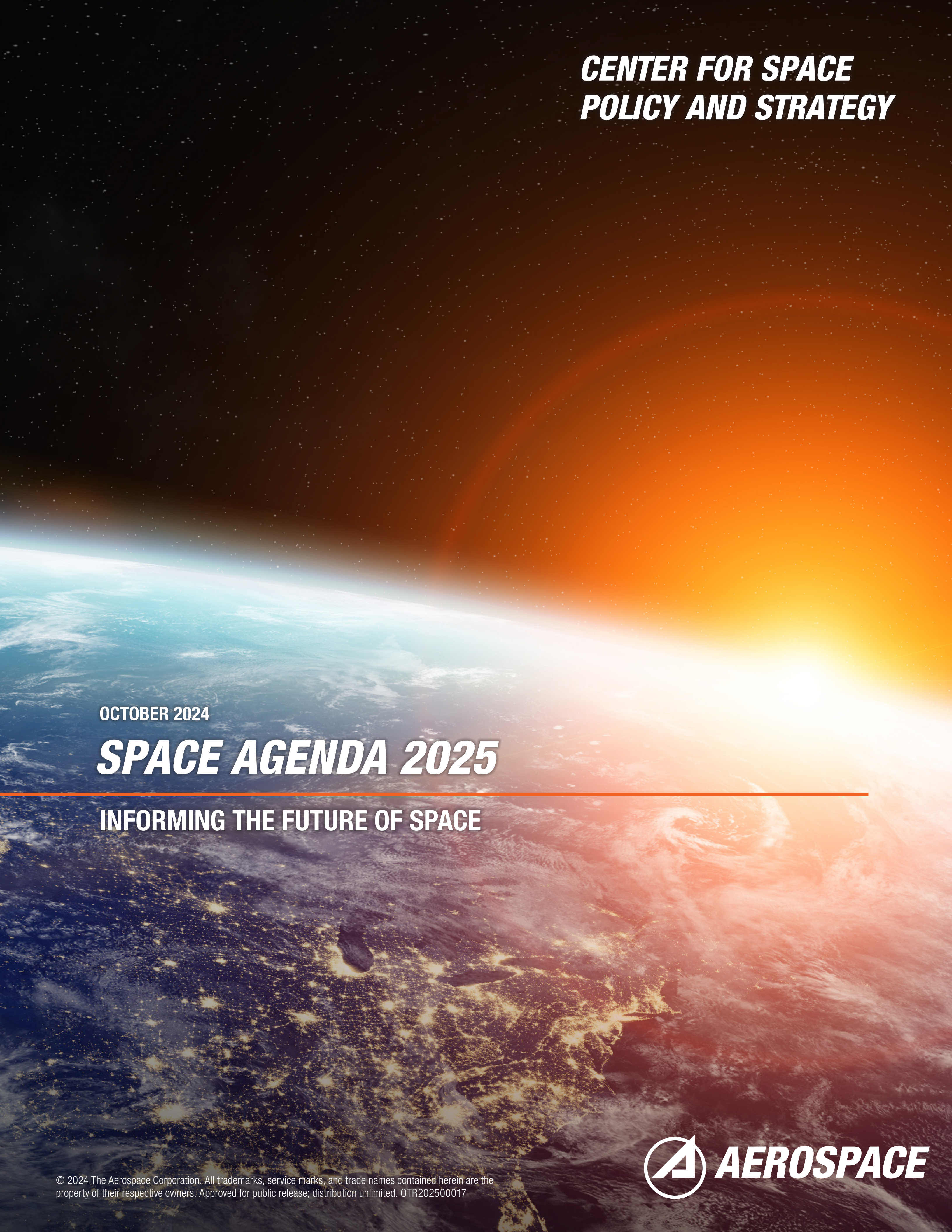

CENTER FOR SPACE POLICY AND STRATEGY

OCTOBER 2024

SPACE AGENDA 2025

INFORMING THE FUTURE OF SPACE

AEROSPACE

Space today is a transformed domain. Cutting-edge technologies and emerging commercial capabilities are creating new opportunities for space operations and exploration. At the same time, our nation faces serious challenges that must be addressed, from rapidly evolving adversary capabilities that threaten our security to complex issues involving things like space sustainability and the industrial base.

Four years ago, The Aerospace Corporation's Center for Space Policy and Strategy released the inaugural *Space Agenda 2021* in recognition of the critical time we found ourselves at in space. This series of papers highlighted the pressing trends and issues that would shape U.S. space policy in the years ahead.

As the pace of change across the space domain continues to accelerate, we are pleased to share *Space Agenda 2025*, which builds on our previous work and offers forward-looking perspectives on the most important topics affecting how our nation and its allies are approaching leadership and competition in space.

The in-depth research and informed insights provided in the pages ahead span defense, intelligence, civil, commercial, and international space, highlighting the growing interdependence and opportunities for integration across the space enterprise. We offer them freely as a resource to aid U.S. leaders and policymakers, including the next presidential administration and Congress, as they navigate critical decisions and deepen strategic partnerships over the next four years.

Steve Isakowitz
President and CEO
The Aerospace Corporation

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Introduction

Angie Bukley

Space Agenda 2025 is an effort by the Center for Space Policy and Strategy (CSPS) at The Aerospace Corporation to highlight and provide insights into some of the major space challenges facing policymakers. Written primarily for U.S. government and space sector leaders, this compendium of 16 chapters offers an accessible introduction to space policy issues affecting national security, civil space, and commercial space developments.

CSPS published a previous edition of *Space Agenda* in 2020. In the four years since, there has been significant progress on space-based applications, including improved communications capabilities as well as increased use of remote sensing, to understand and address climate change. Today, space technology brings us closer together and gives us more understanding of our world than ever before. The myriad services enabled by space technology offer new opportunities to strengthen national security and improve the human condition. Moreover, an infusion of commercial space capabilities into the civil and national security space sectors has caused a rethinking of government space systems architectures. But these trends are not yet fully consolidated and U.S. space leadership remains under challenge, making this a critical time for policymakers to shape the future.

While the *Agenda* does not cover every major space-related challenge, CSPS has analyzed and described 20 of the most pressing space issues across three broad categories: *strengthening leadership and competitiveness, catalyzing commercial space,* and *charting future value.* An issues map in the following introductory chapter, *Framing Space Agenda through Strategic Foresight,* provides a visual framework of these issues and adds a temporal dimension (*behind the curve; emerging and urgent*; and *planting seeds*). The chapter lays out these three categories along with the associated issues, critical questions, and descriptions. The chapter also points to the *Space Agenda 2025* chapters that align to each issue and references previously published CSPS work that is relevant to the topics. The intent is for *Space Agenda 2025* to provide a framework to support and inform sound policy development across the space enterprise.

Framing Space Agenda Through Strategic Foresight

Kara Cunzeman

The Changing Global and Space Environment

The United States stands in a different environment than it did when *Space Agenda 2021* was published. While the memory of the pandemic and resulting economic crisis grows faint, the scars linger. The proliferation of artificial intelligence (AI) and social media, along with the ongoing energy transition, has pushed multinational technology companies to the top of stock markets ahead of even the world's largest oil company, and the world continues to grow more interconnected even as some individuals feel even more isolated. Around the world, the nation's adversaries continue to create disruption. Ongoing conflicts in Ukraine and Gaza serve as a reminder of the volatile and uncertain world we live in, especially as we look ahead to how potential future conflicts might unfold. Against the backdrop of simultaneous worldwide conflicts and rapid innovation, and despite rising challenges for the Chinese economy, the post–Cold War world order is being challenged. Access to geographic areas (to include space) of strategic importance, rare earth minerals, and novel technologies continue to be arenas of global competition and are likely to define the upcoming years.

However, the future holds bright spots amidst the uncertainty. As the United States rebuilds its industrial capacity for semiconductors, advancing capability in AI promises new applications and efficiencies, cutting-edge approaches in medicine herald new ways to serve patients, and the desire to scale renewable energies grows, there is immense opportunity on the horizon for the American people.

Shaped by this ever-changing global landscape, space continues to be an embedded part of American lives and a strategic arena of great national importance. The role that space plays across diplomatic, intelligence, military, and economic elements of national power is growing, which makes defense by, to, and through space increasingly important to advancing U.S. interests worldwide. America's adversaries are growing their space capabilities, including with novel threats, and they are demonstrating emboldened actions that require vigilant action by our national security apparatus. To adapt to this changed world within fiscal constraints, the Space Force, along with broader Department of Defense and intelligence space organizations, will rely increasingly on commercial partnerships and capabilities. Currently, shifts are underway toward more distributed architectures that can be more resilient to offensive attacks. The Space Force is also working to update the aging infrastructure of the United States' spaceports, which, if left unfixed, may hinder potential growth of the space economy.

A little farther from home, the United States is also aiming to return astronauts to the Moon and build a moon base in the next few years via the Artemis program, although there is increasing recognition that initial timelines for the missions were unrealistic. As of October 13, 2024, NASA had 45 signatories for the Artemis Accords, which promote a nonbinding common vision for peaceful, sustainable, and transparent cooperation in space. China, joined by 13 nations (including Russia), is leading the development of an International Lunar Research Station (ILRS). The ILRS is intended to be a permanent lunar base established in the 2030s, a process that begins with reconnaissance missions in the next few years. China is also on track to land an astronaut on the Moon before the end of the decade. Beyond the Moon's surface, cislunar space is also becoming an area of interest.

Space debris and orbital traffic coordination continue to be pressing problems with the increased usage of low Earth orbit (LEO) and fielding of satellite megaconstellations. While several companies are developing active debris removal technology, in-space servicing, assembling, and manufacturing (ISAM) technologies are not yet mature enough to address potential collision unless more intentional policy and regulatory approaches are pursued, such as international space traffic coordination, reusability, and life extension. In February 2024, a collision nearly occurred between two nonmaneuverable satellites, one of many to come if preventative measures are not taken. Each collision between orbiting objects can create thousands of pieces of debris and make it significantly more difficult and dangerous to operate satellites. With the continued development of satellite megaconstellations, the number of objects in space is increasing at an unprecedented rate, and other nations will likely ramp up their own megaconstellations in the next several years, increasing the need for international coordination.

The commercial space market saw a major influx of capital beginning in 2020, but now has seen a rebalancing, with investors taking a more critical eye to their investments. While there has been a cooling of the markets and several companies have failed, the large private investments supported significant growth and large strides in technical and operational space capability across data analytics and services, launch, on-orbit servicing, and manufacturing in the past several years. Just one of many examples is that NASA and its partners are planning to deorbit the International Space Station at the end of 2030 and numerous companies are developing their own stations or modules and are betting on a growing demand for microgravity research platforms and space tourism.

Like other areas of U.S. government-shaped endeavor, the space enterprise has suffered due to delays in congressional enactment of key budgets and policies, which have had wide-ranging implications across national security, civil, and commercial space programs and activities. While we tend to address the enterprise through stovepipes, space is already part of a bigger national web of strategic value and must be treated as such. The continued activities of the National Space Council help to enhance executive branch coordination on these complex topics, but continued delays in funding and decisionmaking for space infrastructure and capabilities will have negative impacts on the country in a time of rapid change.

The Space Agenda 2025 Issues Map

The environment that decisionmakers need to navigate is fast moving, complex, and unpredictable. In an attempt to contextualize, but also simplify and focus on the highest-impact and most critical issues that policymakers should address for the space enterprise in the coming four years, the Strategic Foresight Team in the Center for Space Policy and Strategy (CSPS) developed a *Space Agenda 2025* issues map, shown in Figure 1. This map is divided into three key themes:

1. **Strengthening Leadership and Competitiveness.** Acknowledging that being a leader requires proactive shaping across all facets of national power and ongoing development of meaningful collaboration and cooperation with like-minded partners and allies.
2. **Catalyzing Commercial Space.** Stimulating and ensuring a vibrant commercial sector, now and into the future, to advance America's economic, scientific, technological, and national security interests.
3. **Charting Future Value.** Designing and leading in policies that will yield viable economic growth and environmental stewardship of the space industry and deliver greater benefits to the American people and future generations.

Across these 3 categories, the team identified 20 critically important issues to address over the next 4 years. These 20 issues were selected based on the determination that action on them needs to be taken over the next presidential administration. While there are hundreds of other highly important topics and policy areas across different scopes and time horizons, these were carefully selected as a blueprint for the incoming administration to best navigate issues that will have the biggest impact for U.S. leadership writ large. Each issue is described below and accompanied by a set of further reading material published in the last 4 years from CSPS, including the 16 chapters in this volume.

Furthermore, the issues map is divided into three decision categories: the issues where we are behind the curve and immediately need to address, the issues that are emerging and urgent, and the issues that require planting seeds in the near term for the future. These decision categories are meant to serve as a binning construct to prioritize efforts to address the 20 identified issues. While the issues are numbered to ease navigation, those numbers do not represent a further prioritization beyond the binning across the three decision categories.

The Strategic Foresight Team leveraged its expertise in applied strategic foresight and insights from several of its recent cross-enterprise futures studies to assess what we believe are the highest-impact, critical pathways for action that the next administration must address over the next four years. These themes and issues are all connected, as one would expect from the complex domain that is before us. However, it is our hope that this framework offers policymakers a basis to identify, discuss, formulate ideas, and debate strategy on the most critical topics for the nation to address to chart a future for U.S. leadership in space.

Figure 1. Space Agenda 2025 issues map.

Core Theme

Issue 1: Enabling Space for National Prosperity

Key Question: Why is space in the national interest?

Description: Space provides critical services, inspires through discovery and advancement in science, and protects through critical communications and network systems that defense and rescue staff readily use around the globe. Potential future value, both intrinsic and extrinsic, awaits as the United States further grows, expands, and explores uncharted paths, near Earth and far beyond. Space serves as both a critical function to Americans and a reminder that much of its potential to bring value has yet to be uncovered. Novel medicines, new discoveries about the universe and our place in it, and advancements in food science that could save lives could all await in the future story that unfolds in the space enterprise. The next four years will play a crucial role in laying the foundation for unlocking the future value that space can bring to Americans.

Space Agenda 2025 Chapter:

- Introduction: Framing Space Agenda Through Strategic Foresight (Kara Cunzeman)

Additional Reading from CSPS:

- Space Leadership in Transition (November 2019)
- Strategic Foresight for the Space Enterprise (November 2021)
- Project North Star: Strategic Foresight for U.S. Grand Strategy (July 2023)

Theme 1. Strengthening Leadership and Competitiveness

Issue 2: Strategic Supply Chains

Key Question: Are our supply chains resilient "enough" now and for the future?

Description: Since the rise of globalization, there has been a drive toward maximizing efficiency in supply chains. For the United States, this often meant relying on raw materials and manufacturing capabilities overseas, even for national security and defense products. The coronavirus disease (COVID-19) pandemic elucidated the fragility and challenges this approach has introduced. Reports are also abundant about force technology transfer and the security concerns around manufacturing critical technologies abroad. Ensuring supply chain resiliency, visibility, and security is thus essential for national security purposes (e.g., ensuring access to materials, manufacturing capabilities, and workforce availability). Additionally, as the space enterprise shifts toward proliferated architectures, the ability to quickly ramp up production and reconstitute may be determined by deep supply chain resiliency and affordability.

Space Agenda Chapter:

- Strengthening the Industrial Base to Deliver Proliferated Defense Space Systems (Andrew Berglund)

Additional Reading from CSPS:

- Supply Chain Risk Management (SCRM) Organizational Maturity Model (May 2020)
- The Green Circularity: Life Cycle Assessments for the Space Industry (April 2023)
- STAR: Shining Light on Space Supply Chain Risk (July 2023)
- Mine Games: Securing America's Critical Mineral Supply (January 2024)

Issue 3: Awareness and Management of Space Traffic

Key Question: What are the risks if the United States does not lead in space traffic management, in setting the rules and norms, and adequately coordinating across the international community?

Description: Space-faring nations are currently facing the importance of setting policies and standards related to space traffic. As nations start to implement rules, it is important for the United States to be aware of the regulations and, in some cases, work in cooperation and coordination with like-minded countries. The U.S. commercial space industry will be impacted by regulations put in place in other countries in which they do business. In some cases, it is possible that the regulations will be stricter than U.S. regulations, resulting in the possibility of high fines for noncompliance. For example, the upcoming European Union Space Law on space traffic may impose certain restrictions or standards on U.S. commercial space companies. Anticipating and understanding upcoming regulations is critical to staying ahead of fines and other consequences. Additionally, the United States must be a leader in setting space traffic standards and regulations to ensure its position as a leader in space is maintained.

Additional Reading from CSPS:
- Building Normentum: A Framework for Space Norm Development (July 2021)
- Space Traffic Management Terminology (October 2022)
- No Haven for Misbehavin': A Framework for Verifying Space Norms (March 2022)
- (Space) Ships Passing in the Night: Translating Maritime Rules of the Road for the Space Domain (December 2023)

Issue 4: Closing the Resiliency Time Gap

Key Question: Are we overoptimizing for the near-term?

Description: The military elements of the operational U.S. space enterprise have been aimed for several years at achieving resilience against known threats and projected operational environments. Several innovations and investments in technology, policy, and process have been intentionally accelerated to achieve resiliency quickly. Despite the significant progress made, there remain significant challenges—less related to known threats and more related to anticipating the attributes of resilient architectures deployed for the long run.

Additional Reading from CSPS:
- The Hypersonic Missile Debate (January 2021)
- Designing for Principles: Implementation Steps for the United States Space Force (September 2021)
- Enabling a New Space Paradigm: Harnessing Space Mobility and Logistics (January 2023)
- Debate Series: Should the Space Force Have a Warfighting-Centric Culture? (May 2024)
- FY 2025 Defense Space Budget: Continued Emphasis on Proliferation Under a More Constrained Top-Line (June 2024)
- The Space Development Agency and the Future of Defense Space Acquisitions (July 2024)

Issue 5: Space's Role in Strengthening Deterrence

Key Question: What actions can policymakers take in the next administration to ensure both that deterrence holds, and if that deterrence fails, that the United States is positioned to restore it swiftly and at minimal cost to the United States, its allies, and its partners?

Description: Since the signing of the Outer Space Treaty of 1967, the space domain has been kept free from the threat of nuclear weapons. In an era of increasing great power tension and changing geopolitical norms, however, whether it remains so is an open question. Policymakers should take steps now to ensure both that our approach to deterrence remains sound in a changing world and that the nuclear complex is prioritized accordingly.

Space Agenda Chapters:

- 'Our Most Vital Assets': Space Ground Infrastructure and U.S.–Foreign Relations (Robert Wilson)
- Space-Enabled Capabilities for Connecting and Collaborating in the Arctic (Karen Jones and Lina Cashin)

Additional Reading from CSPS:

- Partnering Not Bossing: Better Leveraging International Capabilities for Space Domain Awareness (August 2021)
- Charting a Path Through the Space Arms Control Verification Challenge (August 2024)

Issue 6: Leadership in Space as an Instrument of National Power

Key Question: How should the United States boldly lead in space to secure its interests writ large?

Description: To be consistent with existing policies from the national level down to individual agencies and services, the United States should leverage all instruments of national power in its relationships with other nations to promote the common defense and general welfare of its people. As the number of global players invested in space increases in an increasingly uncertain world, the United States will continue to have new opportunities to lead and shape global space norms, especially in collaboration with allies and partners; however, these opportunities could become weaknesses if squandered. Even within the next administration, the United States, for the first time since the 1960s, may be facing near-peer competitors challenging U.S. leadership in lunar exploration. The United States must be ready with a multifaceted strategy that leverages a range of diplomatic, intelligence, military, and economic power to achieve its objectives.

Space Agenda Chapters:

- The Next Space Security Norm (Robin Dickey)
- Strengthening a Solid Foundation: U.S. Advantages from Commercial Space (Geoff Reber)

Additional Reading from CSPS:

- Commercial Normentum: Space Security Challenges, Commercial Actors, and Norms of Behavior (August 2022)
- No Haven for Misbehavin': A Framework for Verifying Space Norms (March 2022)
- Building Normentum: A Framework for Space Norm Development (July 2021)
- Developing Foundational Spacepower Doctrine (October 2020)

Issue 7: Making National Security Space "Affordable"

Key Question: Why isn't space getting cheaper?

Description: Much of the rhetoric of budgetary policymakers around national security space is that it's expensive from the beginning and does not always deliver the capability needed to the integrated mission set. Many current initiatives are justifying shifting from traditional architectures for cost and resiliency reasons. The U.S. government (USG) must consider options to more systematically assess what end-effects are needed to ensure national security and deterrence, what potential solutions are (both leveraging space and terrestrial options), what opportunities exist to scale affordability, and how to ensure that public dollars are being spent in an efficient manner.

Space Agenda Chapter:

- Why Transforming the Budget Structure Would Benefit Defense Space (Jamie Morin, Lara Sayer, and Robert Wilson)

Additional Reading from CSPS:

- Issue Brief: FY22 Defense Space Budget Request Analysis (August 2021)
- FY 2023 Defense Space Budget Brief: Missile Warning and Tracking Looms Large (September 2022)
- FY 2024 Defense Space Budget Brief: New Priorities and Long-Term Developments Toward a New Architecture (June 2023)
- FY 2025 Defense Space Budget Brief: Continued Emphasis on Proliferation Under a More Constrained Top-Line (June 2024)
- Lessons from the Cloud: Outsourcing and Integrating Commercial Space Services (April 2024)

Theme 2. Catalyzing Commercial Space

Issue 8: Ensuring Health of the Space Market

Key Question: What is the role that the USG wants to take in ensuring the commercial space market succeeds?

Description: Across the USG space enterprise, organizations are increasingly looking to leverage "commercial space capabilities" to ensure mission success and sustain the nation's competitive advantage. This is driven by increased investment in space technologies over the past couple years, with some reports claiming as high as a $1.1 trillion market size by 2030. However, the path to commercialization and business case closure remains murky for many end applications. A balanced understanding of the benefits and potential risks (e.g., risks to the enterprise if a company dissolves, risk of ending up reliant on a single vendor if that is all the market can support), as well as potential levers to foster the market, is crucial for the USG to understand prior to relying on these capabilities.

Space Agenda Chapters:

- Anticipating the New European Union Space Law (Michael Gleason and Catrina Melograna)
- Leverage and Preserve: Need for DOD to Strengthen Support for U.S. Commercial Space (Wei Chen, Mindy Han, Sarah Georgin, and Robert Wilson)

Additional Reading from CSPS:

- Issue Brief: The Future of Civil and Commercial Space Authorization and Oversight (September 2021)
- Assessing Commercial Solutions for Government Space Missions (February 2022)
- Policy Compliance Roadmap for Small Satellites (September 2022)
- Striking a Balance Between Safety and Scrubs (August 2023)

Issue 9: Communicating the Value of Space

Key Question: How does the space enterprise effectively communicate the value of space to the American people and policymakers?

Description: Space is a critical national asset—critical to national security, communications, and the everyday way of life of the America people. Communicating this value of space is required for obtaining citizen buy-in necessary for USG investment and prioritization of space. The space enterprise is responsible for educating and engaging the American people and their representatives in government on the importance of space, including business opportunities and ensuring the American people understand space's critical role in U.S. leadership. Likewise, U.S. leaders are responsible for ensuring the prioritization of the protection of U.S. space assets and investment in space capabilities.

Space Agenda Chapter:

- Russia's War in Ukraine: Key Observations About Space (Michael Gleason)

Additional Reading from CSPS:

- The Value of Space (May 2020)

Issue 10: Bolstering Innovation

Key Question: Is our innovation ecosystem healthy enough to sustain our competitive advantage and is the U.S. government poised to actually leverage innovative ideas?

Description: The incentive structures within both the commercial and government markets push companies away from routine early-stage innovation. Private equity, excess capital, and government funding drive innovation as they allow their recipients the freedom to explore, fail, and rework industry problems. In the space economy where timelines are long, capital requirements are intensive, and opportunities for demonstrating success are scarce, the government must ensure the innovation ecosystem (including academia, corporations, nongovernment organizations, and capital) remains healthy and drives U.S. innovation forward for continued competitive advantage.

Space Agenda Chapters:

- Space Regulatory Reform Is a Wicked Problem Still Worth Tackling (Brian Weeden and Victoria Woodburn)
- Rational Exuberance: Understanding Value and Performance in the Space Economy (Karen Jones and Brian Weeden)

Additional Reading from CSPS:

- Space Game Changers Driving Forces and Implications for Innovation Investments (October 2020)
- Leveraging Digital Engineering for Space Guardians and Space Explorers (December 2021)
- Game Changer: A Breath of Fresh Air: Air-Scooping Electric Propulsion in Very Low Earth Orbit (March 2021)
- Game Changer: In-Space Servicing, Assembly, and Manufacturing for the New Space Economy (July 2022)
- Game Changer: The Great Convergence and the Future of Satellite-Enabled Direct-to-Device (September 2023)

Issue 11: Investing in America's Future Through Space

Key Question: How do we seed future opportunities for America through space?

Description: Investments in space have helped yield GPS, Tang, and even the modern-day cell phone. Almost every significant advancement in modern society has required an ecosystem of innovation and investments to make what didn't exist possible. What future value will space bring to Americans in the future due to its investments? What policymakers do today to invest in both the infrastructure and the people (through science, technology, engineering, and mathematics [STEM] education, upskilling, and innovation ecosystems that power the future) is critical for seeding future opportunities for America.

Additional Reading from CSPS:

- Developing Future Space Workers: Leadership Needed Today (April 2021)
- Clearing Skies in the Forecast for Nation's Weather Satellites (June 2021)
- Charting a Course Through Cislunar Master Planning (June 2022)
- Strategic Foresight: Addressing Uncertainty in Long-Term Strategic Planning (November 2020)

Issue 12: Normalizing Space as a Part of Every Industry

Key Question: How do we make space approachable and bring "non-space" industries into the space ecosystem?

Description: The success of the "space industry" is contingent upon commercial and government markets seeing the value in the domain. However, the community often falsely separates the terrestrial and space markets. In reality, the space domain is part of the overall market space and has the potential to bring value that can be exploited by players to achieve their end goals. Until the space community shifts toward bringing space into the conversation as a key part of every industry, many will continue to not see the value in space and not be interested in investing or working in the arena. Policymakers can help the community create these connections through collaboration ecosystems and investments that bridge the divides that exist today.

Additional Reading from CSPS:

- Global Communications Infrastructure: Undersea and Beyond (February 2022)
- The Green Circularity: Life Cycle Assessments for the Space Industry (April 2023)

Theme 3. Charting Future Value

Issue 13: Building a Best-in-Class Workforce

Key Question: What is the responsibility of policymakers today to ensure a diverse workforce of tomorrow?

Description: Space has a place for everyone, and space needs everyone. A diverse space workforce not only provides opportunities for underrepresented groups, but it is also critical for yielding innovation in the space economy. Policymakers must take steps today to ensure equitable access to education across the United States as well as encouraging other nontraditional industries and skill sets to pursue jobs in the space industry. A robust space workforce that includes multiple disciplines (e.g., farmers, artists, doctors, engineers, designers, welders, technicians, construction workers and builders, psychologists, and teachers) is required to build and maintain the U.S. space enterprise. These efforts must start today to ensure we are prepared for a strong space infrastructure tomorrow. Policymakers are responsible for fostering the ecosystem for the space economy to grow and to catalyze the great ideas and diversity that the American potential offers.

Additional Reading from CSPS:

- Developing Future Space Workers: Leadership Needed Today (April 2021)

Issue 14: Environmental Stewardship

Key Question: Why and how should the United States lead in environmental stewardship?

Description: From protecting Earth's atmosphere to protecting the surface of Mars, being a leader in space-related environmental stewardship ensures that U.S. values are carried into space. As we scale our space activities, whether in the exploration of celestial bodies or commercializing activities, being responsible stewards becomes more complex. If environments are not greatly considered, space activities have the potential to significantly alter or damage existing ecosystems, resulting in consequences we cannot reverse, including economic viability for space and the United States.

Space Agenda Chapter:

- The Invisible Link: Key Spectrum Issues for Space (Audrey Allison)

Additional Reading from CSPS:

- The Green Circularity: Life Cycle Assessments for the Space Industry (April 2023)
- Implications of a Growing Spaceflight Industry: Climate Change (June 2022)
- Toward Environmental Accountability: Transforming Satellite Data into Action (August 2021)
- Issue Brief: A Short Guide for Understanding and Assessing U.S. Space Sustainability Initiatives (April 2021)

Issue 15: Tackling Orbital Debris

Key Question: Why is it critical for the United States to act now to ensure a safe, secure, and operationally viable orbital environment and safe Earth surface in the future?

Description: Space debris is a hot topic today with an increase in the number of satellites in low Earth orbit and space objects reentering. While a Kessler Syndrome scenario may not be in the immediate future, being proactive allows us to start addressing this future possibility now. Waiting for a catastrophe will make reaction and remediation much harder. The United States must put policies in place now to protect the space environment for everyone from the possibility of detrimental effects from a space debris incident.

Space Agenda Chapter:

- Space Sustainability in the Context of Contested Space (Marlon Sorge and Greg Henning)

Additional Reading from CSPS:

- Active Debris Removal: Policy and Legal Feasibility (April 2021)
- Game Changer: Triggers and Effects of an Active Debris Removal Market (January 2021)
- (Space) Ships Passing in the Night: Translating Maritime Rules of the Road for the Space Domain (December 2023)

Issue 16: Preventing a Day Without Space

Key Question: What choices can policymakers make to strengthen resilience within and across essential space architectures, both on orbit and on the ground?

Description: Space is essential both to national security and to the daily activities of hundreds of millions of Americans, yet space is also increasingly crowded, congested, and contested. What's more, adversarial actors continue to develop space power for their own interests and to contest American access to and freedom of action in this vital domain. Therefore, the next administration must take action to ensure Americans retain the benefits provided by space.

Additional Reading from CSPS:

- A Framework for Resilience (April 2019)

Issue 17: Proactive Policymaking for AI in Space

Key Question: What are the opportunities and risks involved with integrating AI systems both on orbit and across the space enterprise at large?

Description: Recent advancements in AI—particularly in machine learning, autonomous systems, and data processing—offer significant opportunities for enhancing space missions. However, while fields of AI have already demonstrated value and others promise value in the future, policymakers must also temper expectations given the hype surrounding tools such as generative AI. In a world of increasingly capable, yet increasingly misunderstood, AI systems, how swiftly, how effectively, and how safely we integrate these capabilities into our on-orbit systems are crucial to the nation. Building upon existing policy frameworks, the administration should focus on making strategic investments that can foster value-added AI innovations applicable for space, to include infrastructure, as well as advancing standards and policies that promote U.S. leadership, security, and responsible use of AI across the space enterprise.

Additional Reading from CSPS:
- The Future of Ubiquitous, Real-Time Intelligence—A GEOINT Singularity (August 2019)
- A Framework for Developing Trust in Artificial Intelligence (July 2021)

Issue 18: Inspiring the Next Generation

Key Question: How do we leverage space to catalyze big thinking in America?

Description: While the space community harkens back to its heyday in the 1960s when the nation had full alignment to go to the Moon in a space race against the Soviets, today our interests and investments remain far more varied. Space is also not at the forefront of American minds as it was during the Cold War. We live in an era where a substantial amount of America’s workforce is disengaged in the workplace. Additionally, much of Generations Z and Alpha look to the future with fear, rather than hope and excitement. America is missing a huge opportunity to engage these minds to imagine and create better futures and to leverage emerging advancements in space to catalyze these discussions. Space today is on the verge of some very exciting future possibilities for Americans: offering new solutions to food and water scarcity, critical minerals, sparse internet access, power generation, pharmaceuticals, and discoveries we can't yet imagine! Policymakers have the opportunity to engage, inspire, and involve Americans on this incredible ride, and should be creating policies, making investments, and delivering communication campaigns to support inspiring the future.

Additional Reading from CSPS:
- Pathfinder’s Guide to the Space Enterprise (September 2020)
- Space and Art: Connecting Two Creative Endeavors (February 2021)

Issue 19: Designing Space for Humans

Key Question: How do we design for space so that humans can not only survive, but thrive?

Description: From the beginning of the Space Age, special care has been taken to protect human life in the especially dangerous environments associated with human spaceflight; however, vital components of normal, everyday human life have not been preserved as mission needs have supplanted them. If space is to truly become home for large numbers of people beyond specialized or novel missions off the surface of Earth, then a holistic approach to the design and implementation of human spaceflight systems and frameworks must start with a focus on us humans and the societies we build—from the ground up. The space elements of the economy won't be able to scale until humans can survive and thrive in space successfully, and those seeds should be planted now if we want that future to be a reality.

Space Agenda Chapter:

- Mind the Gap: Commercial Space Stations and the ISS (Colleen Stover and Angie Bukley)

Additional Reading from CSPS:

- Human Spaceflight Safety: Regulatory Issues and Mitigating Concepts (November 2020)
- Avoiding Costly Delays in Human Space Exploration: Historical Perspectives on NASA Programs (November 2021)
- The In-Space Rescue Capability Gap (July 2021)

Issue 20: Off-Planet Governance

Key Question: What norms do we want to exist as we expand into cislunar space, the Moon, and beyond and how do we ensure we establish and evolve them successfully?

Description: The United States needs to build up enforcement mechanisms when someone violates norms and/or laws such as the Outer Space Treaty. As China and others look toward tangibly testing the ambiguous governance landscape with upcoming missions to the Moon and beyond over the next four years, the United States has the opportunity to get ahead or react. Policymakers should be planning and assessing a range of choices based on not only what has been done, but what could be done and how that might fundamentally challenge what the United States wants governance and norms to look like off world.

Space Agenda Chapter:

- Moonstruck! International Aspirations in Cislunar Space (Angie Bukley and Colleen Stover)

Additional Reading from CSPS:

- Debate Series: High Ground or High Fantasy: Defense Utility of Cislunar Space (May 2024)
- Pack It In, Pack It Out: Updating Policy and Standards for Cislunar Sustainability (September 2023)
- Commercial Normentum: Space Security Challenges, Commercial Actors, and Norms of Behavior (August 2022)
- Building Normentum: A Framework for Space Norm Development (July 2021)
- Singapore: Country Brief (February 2023)
- South Korea Country Brief (August 2023)

Charting a North Star Vision

The breadth of issues listed above requires more than just a litany of individual solutions. As the emerging environment is evolving, so too must our policymaking to keep pace and ensure our leadership and relevancy. The next four years will be critical to U.S. leadership in space and far beyond. Our ability to lead in space can be a key component of our broader national leadership.

A largely stovepiped space domain has created numerous obstacles from slow acquisition and integration to classification to evolutionary (not revolutionary) solutions. Without a clear integrated vision for where the country wants to go, the United States risks its competitive advantage and could be giving up opportunities to advance the nation and deliver benefits to its people. A whole-of-nation vision and a compelling picture for how space should support it will put America in a stronger position, now and in the future.

The incoming administration has the opportunity to set such a bold new vision. It can articulate the aspirations for where we want to go, why we want to go, and how space contributes, encompassing the full space enterprise—civil, commercial, and national security. Such vision is not solely about space but how space can serve. It's about how it improves American lives, helps chart U.S. leadership in the 21st Century and beyond, and inspires the next generation along the way. To do so, our vision requires not only clarification about what America wants for space, but more broadly what America wants of its future. We have the tools and approaches to manage uncertainty and imagine these futures, but we need leadership to help the nation trailblaze a collective course to get there.[1]

The future is made in the present. The incoming administration has the opportunity to chart a bright American future in the coming years. It is our hope that this *Space Agenda 2025* issues map and collective chapters in this body of work can play a role in helping decisionmakers bring that to fruition for the nation and its people.

Special Acknowledgments

Many thanks to the following individuals for their contributions to *Space Agenda 2025* issues map and to the Strategic Foresight Team.

Kara Cunzeman	Paul Frakes
Catrina Melograna	Caleb Bailey
Sarah Georgin	Maya Harris
Zachery Tyson Brown	Will Vasquez

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This paper was published as a chapter of *Space Agenda 2025*, with Angie Bukley, Colleen Stover, and Victoria Woodburn serving as editors in chief. *Space Agenda 2025* is an effort by the Center for Space Policy and Strategy (CSPS) at The Aerospace Corporation to highlight and provide insights into some of the major space challenges facing policymakers. You can find the complete list of individual *Space Agenda 2025* papers at http://csps.aerospace.org/SA2025, as well as download the combined set of 16 chapters in the *Space Agenda 2025 Compendium* at https://csps.aerospace.org/papers/space-agenda-2025-compendium, all available to you with our compliments.

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Section 1
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STRENGTHENING THE INDUSTRIAL BASE TO DELIVER PROLIFERATED DEFENSE SPACE SYSTEMS

Andrew Berglund

Executive Summary

The Department of Defense's (DOD's) plans to transition to a more proliferated space architecture will not be achieved without robust supply chains and a ready defense industrial base. Resourcing and executing this transition will be challenging, as the DOD seeks to use dozens to hundreds of satellites to support missions historically reserved for a few large satellites. Besides the greater numbers of satellites, these systems must be delivered on a shorter, more consistent schedule and at a scalable, sustainable unit-cost level. To be successful, the DOD will need to rebalance priorities to focus on resiliency over efficiency, taking steps to ensure that the United States has reliable and secure sources for raw materials, parts, and components. This chapter examines several issues at the intersection of proliferated DOD space systems, the defense industrial base, and supply chains, including:

- Factors motivating the DOD's transition to more proliferated space systems
- Implications of the transition for the defense industrial base and supply chains
- Challenges and early signs of stress resourcing and executing the transition

Given that proliferated space systems are a key component of the DOD's plans to improve resilience and deliver space warfighting capabilities, the DOD should reinvigorate its support to the defense industrial base. This should include steps across several categories: planning and visibility, stockpiling and using commercial technologies, and financial support. This chapter identifies a few specific actions the DOD, and industry in some cases, could pursue under each category:

- **Planning and visibility:** incorporating defense industrial base and supply chain assessments into the newly created Space Futures Command to better evaluate industry readiness to implement future force designs
- **Stockpiling and encouraging commercial technologies:** procuring and stockpiling certain long-lead items prior to contract award, reducing vendor risk and ensuring that parts are available to meet short acquisition timelines
- **Financial support:** continuing to identify opportunities to use Defense Production Act authorities and other mechanisms to invest in U.S. manufacturing capabilities for key components

The DOD should soon derive operational benefits from its initial proliferated space systems. If successful, these systems are likely to accelerate the department's plans to transition more of its missions and acquisitions to similar approaches. The DOD's actions over the next several years to support the defense industrial base will be critical to these efforts.

Introduction

The Department of Defense (DOD) plans to field multiple proliferated satellite constellations to improve resilience and more quickly field new technologies. These systems will employ dozens to hundreds of relatively small, highly networked satellites to support missions historically reserved for fewer large and less networked satellites. In the next several years, proliferated systems are expected to make significant contributions to critical missions, from missile warning and tracking to low-latency data transmission. If these early efforts prove successful, calls for expanding the number and types of missions that proliferated systems could support will likely grow louder.

Robust supply chains and a ready defense industrial base are essential to the DOD's success transitioning to a more proliferated space architecture. Resourcing and executing this transition will be challenging. The COVID-19 pandemic and Russia's further invasion of Ukraine have revealed a fragility within our most basic defense supply chains. Moreover, the defense industrial base must deliver greater numbers of satellites on a much faster timeline than traditional space system acquisitions while holding the cost of each satellite at a sustainable level. This will require careful planning as well as rebalancing the department's priorities to focus more on supply chain resilience over efficiency, including steps to ensure that the U.S. has reliable and secure sources for components, parts, and raw materials.[1]

Both the DOD (with broader U.S. government support) and industry are taking steps to advance the transition to more proliferated defense space architectures. These steps include efforts to improve planning and visibility, stockpiling key inputs, and financial supports and business practices. However, early signs of stress within the defense industrial base indicate that sustained attention and action to strengthen supply chains is vital, as these new types of space systems will increasingly support some of the DOD's most important warfighting capabilities. The department will also need to take steps to ensure warfighters are prepared to operate these systems and adapt to more frequent hardware and software refresh cycles. During this time of proliferated constellations, fast delivery, and stressed supply chains, a multipronged approach is needed, including improving planning and visibility, strategic stockpiling (upstream and downstream), and various levers for financial support. As a customer, the DOD can work to ensure transparent and fair mechanisms to achieve government mission success and commercial performance expectations.

Planning for Current and Future Missions

Several DOD acquisition efforts are underway to deliver proliferated satellite constellations to serve both existing and future space missions. These efforts vary in important ways, including constellation size, composition, and planned orbit, but they all borrow from commercial space innovations and practices. A number of other missions could also be served by proliferated constellations, including positioning, navigation, and timing; tactical communications; and weather services.[2]

The Space Development Agency (SDA), one of three Space Force acquisition organizations, is executing a series of acquisition programs, known as tranches, to field several layers of proliferated satellites. These efforts, organized under the SDA's Proliferated Warfighting Space Architecture (PWSA), are intended to support specific missions, including missile warning and tracking, as well as to provide a space-based data infrastructure that can serve a broad range of missions. As of August 2024, SDA has launched 27 satellites to low Earth orbit (LEO) for the initial demonstration of capability phase, Tranche 0. The operational PWSA capability of Tranche 1 and beyond is planned to total more than 500 satellites.[3] For the acquisition efforts under contract, Tranche 1 and Tranche 2, a total of 7 different vendors are building between 10 and 132 total satellites.[4] Once fully populated, the constellation will need to be regularly replenished with satellites to maintain coverage.[5]

Space Systems Command (SSC), another Space Force acquisition organization, is also pursuing a proliferated medium Earth orbit (MEO) constellation. The Resilient Missile Warning/Missile Tracking/Missile Defense program plans to field a constellation of about 27 satellites through a series of acquisition programs known as epochs.[6] This constellation will provide capabilities similar to some of SDA's satellites, but from a more distant altitude to provide additional resilience against some types of threats. Also, because these MEO satellites operate at a higher altitude than SDA's LEO satellites, fewer are needed to provide global coverage.[7] For the acquisition effort under Epoch 1, one contractor is building six satellites.[8] Space Force awarded another vendor a contract to continue maturing its design, strengthening competition within the program for future production contract awards.[9]

For all missions that will utilize proliferated space systems, there will likely be a learning curve for the warfighting community as they adjust to operating larger constellations. New technologies as well as changes to tactics, techniques, and procedures will likely be critical to fully utilizing these new space capabilities.[10]

Space Supply Chains and Implications for the Defense Industrial Base

Supply chains can be analyzed in a number of different ways, including viability, security, logistics, and quality, each of which can be further decomposed into subcategories. The demands of proliferated space systems will add pressure to supply chains across all these dimensions. However, in the early stage of the transition to more proliferated constellations, viability deserves careful consideration. The DOD cannot deliver and sustain its future defense architecture without diverse, resilient, and reliable supply chains. Traditional defense contractors will need to adjust their design and production processes to account for increased satellite quantities, smaller satellite sizes, and reduced timelines between contract award and delivery. While small satellites require many of the same raw materials, parts, and components as large satellites, there are important scale differences. For example, lithium-ion batteries designed for a several-ton satellite would overwhelm a several-hundred-kilogram satellite, yet both satellites may require the same material inputs or production lines.

As prior research has shown, practices used to effectively produce large quantities of goods in commercial markets, such as automobiles and consumer electronics, are relevant for space systems.[11] At the most basic level, success requires shifting the mission assurance focus from individual units to the overall process, applying proven commercial principles of high-volume production. Once the design and production processes are qualified, data analytics and statistical controls are used to evaluate each finished unit and ensure that it meets specifications.[12] In addition to supporting increased production quantities, this approach improves efficiency and timeliness by reducing unit-level reviews and rework.

Orbits and Quantities

The number of satellites required to populate a proliferated constellation is partly a function of the system's orbit. Historically, defense space systems have mostly operated in geosynchronous orbit, at an altitude of roughly 36,000 kilometers. At that distance, each satellite has line-of-sight access to up to a third of Earth's surface, such that a few satellites can provide global coverage for Earth observation, communications, or other missions. Proliferated satellites in lower orbits have line-of-sight access to a much smaller portion of Earth, so many more are needed to provide the same level of coverage.

The shift to more proliferated space systems is not just a matter of producing more satellites more quickly. These new systems also require different types of technologies and support infrastructures, in large part to enable many satellites to function as a coherent system. For example, proliferated constellations are now being designed with laser communications systems for both space-to-space (optical intersatellite links) and space-to-ground connections. Among other benefits, these systems are able to more securely and more quickly transmit large amounts of data compared to radio frequency communications systems. A single satellite may carry several laser communications terminals, allowing simultaneous connections to other satellites and facilitating a mesh network of efficient and resilient data routing throughout the constellation. The Space Force is investing in a number of vendors to advance laser communications terminals and related capabilities, including networking between different orbital altitudes.[13] These steps help enable multiple vendors to deliver interoperable systems, providing redundancy that strengthens acquisitions and capabilities. Maturing these technologies is vital for achieving the goal of robust, resilient space networks that use automation and advanced onboard processing capabilities to efficiently route data and recover from outages.

The DOD's future space systems also depend on hardware and software modularity, which are strategies that enable interoperability through the use of common interface and data standards. Modular designs are required for some types of DOD weapon system acquisition programs and are an increasing point of emphasis across all programs.[14] Among other things, modularity can help to lower costs for suppliers, since they can avoid building different versions of a system or subsystem to meet different customers' needs. The strategies also encourage resilience and strengthen competition, diversifying the number and range of subcontractors that can contribute to the overall system. At the architecture level, interoperability and modularity can take the form of constellations designed to operate with diverse generations or types of satellites, which can facilitate more rapid, smoother technology insertion, even when a constellation comprises several vendors' solutions.[15]

Benefits to the Industrial Base. More proliferated DOD space architectures offer several benefits for the defense industrial base. First, they provide industry a more consistent demand signal. Satellites in a proliferated LEO constellation are replaced more frequently, often on a predetermined schedule every few years. Vendors can have greater confidence in both how many satellites are needed to populate the constellation as well as the number and timing of replacement systems. This is contrasted against more irregular demand for traditional satellite systems, which involve longer periods of research and development with intermittent spikes in production demand. Among other things, companies are using the DOD's demand signal for proliferated systems to make capital investments that will increase production capacity, though there will, of course, be lags between investment and actual capacity.[16] Second, vendors do not have to do extensive development efforts, which can be both risky and costly under certain types of contracts, because proliferated systems are prioritizing relatively mature designs and components, in part to reduce the risk of schedule delays. Third, vendors are able to leverage their commercial product offerings for government customers and vice versa, reducing the number of distinct research efforts and production lines that must be maintained. This is because proliferated government systems are more often modeled after commercial space constellations and commercial technologies rather than government-unique requirements. This also benefits the government. Combined with the increased emphasis on hardware and software modularity, the DOD can more easily and quickly benefit from and integrate new commercial products.

Challenges for the Industrial Base. Proliferated national security systems also create challenges for the defense industrial base. First, they will compete more directly with commercial space systems for source materials, both domestically and internationally. In addition to SpaceX's Starlink system, which has more than 6,000 operational satellites on orbit as of September 2024.[17] Several other large commercial constellations will begin launching in the next few years, including Eutelsat OneWeb's combined GEO and LEO satellite constellation (France/United Kingdom) and Telesat's Lightspeed LEO constellation (Canada).[18] Second, a consistent DOD demand signal comes with an increased emphasis on timeliness. Traditionally, space acquisitions composed of a few large, exquisite satellites routinely missed scheduled delivery milestones.[19] Yet these delays could often be tolerated because fielded systems often outlasted their intended design lives by years. For proliferated constellations, delays to replacement systems will have a greater impact. Among other things, satellites in a proliferated constellation have much shorter lifespans, driven primarily by limited propellant capacity and the need to more frequently use thrust to maintain orbit. Third, vendors might be limited in the full benefits and efficiencies of high-volume production because the DOD's current demand for satellite quantities is fairly modest compared to similar commercial systems, and this demand is divided among several vendors to promote competition and diversity. In fact, only three of the vendors across the DOD's current proliferated space acquisitions have DOD contracts to produce close to or more than 100 satellites. While there is no defined threshold count that separates low and high production volumes, companies are more likely to benefit from production efficiencies as they approach 100 satellites.[20] The DOD's emphasis on fixed-price contracts for proliferated satellite acquisitions means that vendor profits will largely be driven by consistent awards of large numbers of satellites that drive production efficiencies. In other words, while the DOD is emphasizing competition and diversity, vendors have a strong incentive to capture as large a share of the satellite quantities as possible.

Prime Contractor Business Models

Vendors that have been awarded a prime contract under a proliferated space system acquisition appear to be adopting one of two business models. In the first model, the prime contractor subcontracts most of its major systems and components but relies on its own systems engineering, testing, and assembly expertise to deliver an integrated system. This is the approach taken by traditional defense contractors like Lockheed Martin, L3Harris, and Northrop Grumman. [21] In the second model, the prime contractor leverages an existing competitive advantage in satellite bus design and production, and then seeks to acquire other companies to establish direct control over much of its supply chain for critical subsystems and components. This vertical integration approach, championed in the sector by SpaceX, continues a trend among newer commercial space companies as well as defense contractors like Millenium Space Systems, Sierra Space, Rocket Lab, and York Space Systems.[22] Vertical integration is expensive, so not all companies can afford to pursue this approach, and to be successful, a vertically integrated company will still need to understand how to design and build its products at scale and cost-effectively. More broadly, vertical integration within the space sector may reduce competition and diversity if a vertically integrated company chooses not to make its components available to competitors.

One explanation for these diverging business models is that newer defense contractors are seeking to specialize in smaller satellites and proliferated systems, whereas traditional defense contractors have and will likely continue to build large, traditional defense satellites in addition to their other defense product lines. Because it is costly, vertical integration is more likely to deliver cost, performance, and schedule efficiencies when it is closely aligned to a company's core product lines. Vertical integration allows a company to set the standard for price, performance, availability, and delivery of key technologies. In announcing its SDA contract, Rocket Lab's chief technology officer explained that the contract " is the culmination of a thoughtful and deliberate investment in our space systems business. It's why we either acquire key space technologies or invest in them organically."[23] Jason Kim, at the time chief executive officer of Boeing's Millenium Space Systems, said that the company has vertically integrated about 80 percent of its supply chain, with the remaining 20 percent being commoditized parts and components that are widely available.[24] While it is not clear whether vertical integration in this market improves long-term profitability, it has enabled these nontraditional vendors to compete effectively for the DOD's proliferated space acquisition contracts.

In the past few years, traditional defense contractors have had mixed success with vertical integration. Raytheon recently announced that they would no longer pursue space prime government contracts and instead focus on opportunities supplying components.[25] This shift occurred despite the fact that only a few years ago the company acquired Blue Canyon Technologies, a small satellite manufacturer and mission services provider, in a move to vertically integrate its small satellite business.[26] In 2023, a senior Raytheon official explained that "being in a mission prime position hasn't yielded the results that we were looking for."[27] One important trend to watch is the extent to which the remaining traditional defense contractors active in proliferated space acquisitions—Northrop Grumman, L3Harris, and Lockheed Martin—continue to pursue prime contracts for proliferated system acquisitions or follow a strategy like Raytheon, more focused on acting as a key supplier, which likely reduces profit margins but also financial risk.

Whether both business models prove effective for these types of acquisitions will have important implications. If more vendors choose not to pursue prime contracts, there may be less competition for future awards, potentially resulting in less innovation and higher costs. Similarly, if vertically integrated vendors are successful at executing their acquisitions, it may be difficult for the DOD to select other, less proven, and less specialized vendors for prime contracts. Finally, vertical integration can raise concerns about diminished competitiveness and is part of the government's evaluation of whether mergers violate antitrust law.[28]

Early Signs of Stress

Even though the Space Force's proliferated space acquisitions are still relatively new and have not yet reached full production rates, there are concerns about the defense industrial base's ability to meet current and future demand. In particular, these concerns reflect the challenges both traditional and newer defense contractors will face securing necessary supply chain inputs and meeting both production and timeliness requirements. Recent examples of these challenges include:

- **Missed subcontractor deliveries.** One prime contractor, which has contracts with both the SDA and SSC to support proliferated space systems, did not finish satellite production in time to meet its launch window.[29] The company, which was able to launch its satellites several months later, blamed the delay on the subcontractor responsible for delivering satellite buses, claiming that it missed scheduled delivery dates and had defective hardware.

- **Backlogs.** A company that is a key subcontractor for several acquisition efforts is facing funding and production challenges as it tries to scale up to meet government and commercial demand.[30] While recording record revenues, the company has a significant production backlog, and it has not yet been able to realize efficiencies from investments to increase production capacity and drive down costs.

- **Shifting business models.** One contractor was a late addition to an SDA's acquisition program after Congress added $250 million to accelerate capability delivery. That contract now appears to have been cancelled, as the vendor has shifted its business model to no longer pursue prime contracts, despite the fact that in the last several years that vendor had taken steps to vertically integrate its supply chains to better compete for prime contracts.[31]

Beyond these specific examples, there have been many broad reports of space supply chain challenges. For example, attendees at the 2022 and 2023 State of the Space Industrial Base workshops—supported by the Space Force, the Air Force, Defense Innovation Unit, and the Air Force Research Laboratory—rated the space supply chain as one of the least healthy parts of the space industrial sector.[32] The fact that space supply chains are considered so fragile is concerning given the expected increased demand for proliferated space systems. For several years, just as the DOD's proliferated space acquisition programs were starting, supply chain disruptions were largely attributed to the COVID-19 pandemic. However, by early 2024, Frank Calvelli, Assistant Secretary of the Air Force for Space Acquisition and Integration, stated that supply chain disruptions and the pandemic were not valid reasons for missing schedule deadlines: "Buy your parts early, get your orders in, be organized, be effective."[33] Similarly, the SDA has encouraged its vendors to diversify their supply chains to avoid single points of failure.[34] However, diversification is only possible if there is more than one source available, and the trend toward vertical integration could limit the available supply of subcontractors for some components.

The DOD's shift toward more proliferated space systems may also contribute to other, long-standing challenges related to supply chain, such as cybersecurity and counterfeit parts. The increased emphasis on rapidly delivering space hardware and software must be counterbalanced with a strong security imperative emphasizing processes to guard against these risks.

Strategies for Addressing Supply Chain Risk

The DOD and industry have each taken steps to address risks to supply chain viability. However, across the following categories, more action is likely needed to deliver and support proliferated space systems. The DOD should reinvigorate its support to the defense industrial base, helping ensure production capacity and component availability to support future space missions. While the following strategies are largely independent of one another, a combined approach is likely to be most effective.

Planning and Visibility

Incorporate supply chain risk assessments into planning functions. Space supply chains would be improved if the Space Force fully incorporated supply chain assessments into its planning functions. Over the past several years, the Space Force has improved its long-term planning through force design exercises led by the Space Warfighting Analysis Center (SWAC). The SWAC's recommendations have had a discernable impact on the service's budget requests, shaping the future of missile warning and communications capabilities.[35] In 2024, the Air Force announced plans to move the SWAC under a newly established Space Futures Command that would "develop and validate concepts, conduct experimentation and wargames, and perform mission area design."[36] The command's new responsibilities should include risk assessments or other processes to assess the readiness of the defense industrial base to support the SWAC's force designs.

Improve understanding of supply chain strengths and constraints to support acquisition decisions. A persistent challenge to planning for and building supply chain resilience is the lack of reliable data to inform decisions and investments. Proposed approaches to this problem include systems for aggregating and dynamically updating supply chain information "to better understand component availability, cost adjustments, quality measures, and security risks."[37] For proliferated space system acquisitions, implementing such an approach or similar commercial tools would greatly improve the DOD's ability to get ahead of supply chain constraints. The DOD should consider more explicitly building supply chain visibility into its acquisition decisions and employing strategic sourcing principles to evaluate the strength of a vendor's supply chain before contract award.

Consolidate orders across programs. One way the Space Force could utilize more effective planning and supply chain visibility is to coordinate purchases across acquisition programs. This approach would be particularly useful for certain types of common, specialized parts, such as radiation-hardened electronics, for which the commercial market does not have a compelling need. Coordinating purchases would strengthen the DOD's purchasing power and help support a more viable market for these inputs. To avoid wasting resources, this activity would need to be guided by the other planning functions, including an understanding of commonalities between vendors' designs.

Stockpiling and Encouraging Commercial Technologies

Consider strategically stockpiling certain components downstream to meet the timelines for proliferated constellations. The DOD and industry can take steps to proactively address supply chain contracts by strategically stockpiling parts and components downstream in the supply chain. While acquisition programs often use various mechanisms to procure long-lead items, the short timelines between contract award and launch may require keeping some parts in inventory or procuring those long-lead items even before contract award. Such actions help buy down schedule risk, increasing the likelihood that a vendor can meet its development and production timelines. The head of one vendor for a government acquisition program told us that the company had chosen to pre-order some specialized parts prior to contract award, which enabled them to execute the contract more quickly.[38]

Third-party vendors may also play a role in strategic stockpiling. One company we spoke with analyzes space supply chains and assembles kits of critical satellite parts. The company can then contract with vendors to provide these kits as a way of accelerating schedule and reducing supply chain risk. The DOD can play a similar role. The Defense Logistics Agency could stockpile some critical long-lead components and then provide them directly to vendors that secure a contract. This would create some risk for the government but could help ensure a more competitive solicitation since no single contractor would have a stockpile, and thus schedule, advantage. Several other challenges to stockpiling will also need to be addressed. For example, if the DOD or industry choose to preorder a part of component rather than place orders as needed, the supplier of that part or component may experience large demand fluctuations rather than a smoother, more predictable demand. Government or third-party stockpiling also requires knowledge of a vendor's design in order to procure the correct parts or components in advance. Vendors may be reluctant to share this information.

The DOD should look for ways to stockpile materials upstream in the supply chain, such as critical minerals. Upstream in the supply chain, stockpiling can include critical minerals that are valuable for a range of industrial applications. For example, in April 2024, the DOD used Defense Production Act authority to strengthen the supply chain for germanium, a critical mineral used to produce space-qualified solar cells.[39] This and similar actions, including recycling efforts that preceded China's 2023 export controls, helped shore up the DOD's access to critical minerals, countering China's efforts to monopolize these minerals, including germanium.[40] Given the DOD's focus on China as a "pacing threat" in the context of an emerging great power competition, critical minerals deserve a central place in supply chain policy. Beyond stockpiling, industrial policy studies indicate the need for more expansive international partnerships, financial support, and other incentives to strengthen U.S. access to critical minerals that support the aerospace industry.[41]

Continue to emphasize the use of commercial off-the-shelf (COTS) parts where technically feasible. The use of COTS, or alternate-grade parts, holds the promise of significantly reducing costs and streamlining the cycle time for part qualification. Parts that come off commercial production lines, including specialized electronics, are less expensive than high-reliability parts made to meet military specifications. COTS parts also rely on statistical data when making determining qualification decisions, eliminating redundant qualification testing. In addition, specialized and lower-volume parts, and components, such as integrated circuits and field-programmable gate arrays, are two or three generations behind state-of-the-art commercially available parts that may allow for greater performance capability gains.

Financial Support

The third set of strategies to strengthen supply chains for proliferated space systems are various kinds of financial support. These may be particularly useful for nontraditional contractors that do not have access to significant capital, which inhibits their ability to take advantage of strategies like vertical integration and stockpiling.

Consider stabilizing a contractor's revenue stream by funding payments at regular intervals instead of performance-based payments. Both the DOD and industry can also utilize different reimbursement mechanisms to help vendors receive a more consistent cash flow. For the DOD, one such mechanism is the use of progress payments, whereby funding is released on a set time interval, rather than performance-based payments, which are tied to the accomplishment of contractual milestone. For fixed-price contracts, the total amount paid to the prime contractor is the same, but progress payments provide more consistent revenue. Similarly, at least one prime contractor used accelerated payments with its subcontractors during the COVID-19 pandemic to support small and at-risk businesses.[42]

Consider government direct payments that support key technologies or components in the space supply chain. The government's recent efforts to strengthen the U.S. manufacturing and industrial base provides another type of financial support through direct payments. For example, in June 2024, the Biden-Harris administration announced a nearly $24 million award to support expanded production of space-grade solar cells.[43] The DOD has used the Defense Production Act to make several similar investments.[44] As the DOD executes more proliferated space acquisitions and expands its understanding of the fragility within supply chains, it is likely to discover additional areas where such direct payments could increase defense industrial base resilience.

Conclusion

The DOD will soon derive operational benefits from its initial proliferated space systems. If successful, these systems are likely to accelerate the department's plans to transition more of its missions and acquisitions to similar approaches. Therefore, it is essential that the DOD and industry take steps to strengthen the supply chains that will be needed to resource this transition. Most importantly, this requires a more comprehensive and dynamic understanding of risks and fragility to guide solutions, including stockpiling and financial support.

Acknowledgments

The author would like to thank several colleagues for reviewing and providing feedback to improve this paper, including Robert Samuel Wilson, Jeff Juranek, Donald Sather, Yao Y. Lao, and Karen Jones.

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[4] These figures only include contracted quantities under the Tranches 1 and 2 of the Transport and Tracking layers, as of September 2024. The high end of this range is Northrop Grumman, which is on contract for 116 transport satellites and 16 tracking satellites. Two other vendors, York Space Systems and Lockheed Martin, are on contract for 114 and 96 total satellites, respectively. The other remaining vendors are on contract for fewer than 50 total satellites each. There are additional awards for classified or experimental efforts that are not included in this list.

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About Space Agenda 2025 Publications

This paper was published as a chapter of *Space Agenda 2025*, with Angie Bukley, Colleen Stover, and Victoria Woodburn serving as editors in chief. *Space Agenda 2025* is an effort by the Center for Space Policy and Strategy (CSPS) at The Aerospace Corporation to highlight and provide insights into some of the major space challenges facing policymakers. You can find the complete list of individual *Space Agenda 2025* papers at http://csps.aerospace.org/SA2025, as well as download the combined set of 16 chapters in the *Space Agenda 2025 Compendium* at https://csps.aerospace.org/papers/space-agenda-2025-compendium, all available to you with our compliments.

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'OUR MOST VITAL ASSETS': SPACE GROUND INFRASTRUCTURE AND U.S.–FOREIGN RELATIONS

Aaron Bateman

Executive Summary

Allies and partners are critical to achieve and maintain U.S. military and intelligence advantages in space. Although national security space experts often focus on satellites and launchers, satellite ground infrastructure hosted on foreign territories has been a core element of U.S. national security space partnerships since the Cold War. This infrastructure has been used to track satellites, carry out intelligence collection, and employ space-based nuclear command and control, among other functions.

During the Cold War, these missions required the United States to build relationships with states that possessed suitable territories for hosting ground infrastructure. But this need for land in specific locations abroad created significant foreign policy challenges for Washington. In the 1960s and 1970s, varied political issues, including apartheid in South Africa, unrest in Ethiopia, and a shift in Australia's domestic politics, all affected U.S. satellite infrastructure hosted in those locations. Fundamentally, these examples underscore that space operations are deeply embedded in terrestrial politics.

Securing access to real estate for hosting satellite ground infrastructure has emerged as a critical element of intensifying U.S.–China rivalry in space since both countries depend on overseas territories for projecting spacepower. This is a longstanding issue for the United States and an emergent one for China that stems from its growing investment in military space systems. The United States has the advantage in this arena as it did during the Cold War because its alliances and partnerships are global. Nevertheless, Beijing has been successful in cultivating space relationships, particularly with countries in the Global South, that have enabled its overseas satellite ground infrastructure to grow. In these circumstances, the United States should use diplomacy to frustrate Beijing's attempts to bolster its military capacity in orbit by establishing space partnerships with countries that are in prime locations to host satellite ground infrastructure.

Introduction

During the Cold War and today, analyses of spacepower tend to focus on systems in orbit, while overlooking the extensive ground infrastructure that is a critical component of space operations. Satellites allow the United States to overcome the tyranny of distance, but they are very much dependent on terrestrial hardware. Since the dawn of the Space Age, the United States has maintained a vast network of tracking stations for monitoring the spacecraft of friends and foes alike. Moreover, multiple countries around the globe host sites for sending and receiving data from U.S. satellites. This vast infrastructure on Earth that makes both civil and national security spaceflight possible underscores the importance of alliances and partnerships for American spacepower. During the Cold War, having allies in nearly every corner of the world that were willing to host U.S. space facilities helped tip the superpower space balance in favor of the United States.

James Webb, the head of NASA, told President John F. Kennedy in 1961 that "We feel there is no better means [than cooperative space efforts] to reinforce our old alliances and build new ones."[*] The placement of U.S. civilian and military space infrastructure in Australia, Zanzibar, Iran, Japan, Ethiopia, and South Africa (among many other places) underscores the international character of Cold War-era American space activities. Neil Armstrong's first steps on the Moon in 1969 became a symbol of resounding American technological achievement, but his famous statement, "…one giant leap for mankind" would not have been broadcast to the world without a communications dish located near Canberra, Australia. Around this same time, a base located in Asmara, Eritrea (then under Ethiopia's control), became the home of a large array of U.S. government antennas for collecting signals from Soviet spacecraft that provided U.S. intelligence agencies key insights into the Soviet space program. In return for hosting U.S. space infrastructure during the Cold War, foreign governments secured a stake in American space activities as well as bargaining leverage, in some cases.

The importance of satellite ground infrastructure has only grown in the post-Cold War era. The marked expansion of systems in orbit has precipitated the proliferation of space domain awareness (SDA) sensors across the globe as well as satellite ground systems, which creates opportunities for the United States. Certainly, having access to more data concerning what is taking place in orbit has both economic and security benefits. But the United States is not alone in seeking international partners to expand the reach of its terrestrial space infrastructure; China is also making inroads in Latin America and Africa for the very same reasons. But China's historic lack of expansive alliance relationships abroad limits its access to foreign territories, in stark contrast to the United States during and after the Cold War. To mitigate this problem, Beijing has used the promise of scientific and technological collaboration with countries, particularly in the Global South, to get access to territories that can house terrestrial space infrastructure. In these circumstances, it is vital that the United States continues to establish space partnerships with countries around the world as both a means of achieving its national objectives in orbit and frustrating China's attempts to do the same.

Allies, Partners, and U.S. Space Infrastructure During the Cold War

Even before the Soviet Union launched Sputnik in 1957, multiple U.S. efforts were underway to develop infrastructure for tracking artificial satellites. As part of the 1957 International Geophysical Year (IGY), the Smithsonian Astrophysical Observatory (SAO) began fielding Baker-Nunn optical cameras that could be used to determine the position of satellites in orbit. SAO built tracking sites in Argentina, Australia, Curacao, India, Iran, Japan, Peru, South Africa, Spain, and at three locations in the United States. In establishing agreements with foreign countries to host Baker-Nunn cameras, SAO leaders stressed the civilian nature of the program. Particularly in India and Japan, sensitivities arose concerning even the perception that the space tracking sites might be associated with U.S. military activities. Nevertheless, several foreign countries viewed their hosting of SAO cameras as a way to strengthen their ties with the United States. At the end of the

[*] Presentation by the Administrator of the National Aeronautics and Space Administration (Webb) to President Kennedy, March 21, 1961, *Foreign Relations of the United States* (*FRUS* hereafter), 1961-1963, Vol. XXV, Organization of Foreign Policy; Information Policy; United Nationals; Scientific Matters.

1957 IGY, NASA began funding the SAO Baker-Nunn network and established data standardization across the different tracking sites to ensure the network acted as a unified whole rather than a loose confederation of independent stations.[†]

Around the same time that SAO was establishing its Baker-Nunn network, the Department of Defense and intelligence community were devising plans for a national security space tracking network. In a letter to the head of the Advanced Research Projects Agency, Central Intelligence Agency Director Allen Dulles stressed that the surveillance of foreign space vehicles "demands immediate and complete attention by the U.S. intelligence community."[‡] To address this issue, the U.S. Air Force erected its own Baker-Nunn cameras and the U.S. Navy created a radar system that could detect satellites transiting overhead. Combined, these resources formed the basis of the early U.S. Space Surveillance Network. In March 1964, the Pentagon established a Space Defense Center located in North American Aerospace Defense Command's (NORAD's) Cheyenne Mountain complex in Colorado to oversee the Department of Defense's space surveillance operations. The civilian Baker-Nunn camera network supplemented data from U.S. military space tracking sensors.[§]

Placing space tracking sensors on foreign territories created both opportunities and challenges for the U.S. government. The infrastructure served as a mechanism for more closely linking U.S. interests with the hosting nation, but dependence on foreign territories also created a liability when foreign policy agendas clashed. In 1960, the U.S. Air Force had established a space tracking facility in South Africa that created complications for the U.S. policy on apartheid. Shortly after the site became operational, officials in Washington considered reducing some military support for South Africa out of concern that not doing so might lead to an impression that the United States accepted apartheid. But the importance of the tracking station had a restraining effect on U.S. discussions about tempering engagement with South Africa. The State Department observed in a 1961 memorandum to the White House that maintaining the tracking station necessitated a cautious attitude toward Praetoria until an alternative site could be found.[**] This South African case study underscores the reality that the requirement to maintain space tracking infrastructure in particular locations had a spillover effect on broader U.S. foreign policy objectives. To mitigate this situation, the United States began looking for alternative space tracking locations.

The need to capture telemetry signals that contain valuable information about the performance of Soviet spacecraft drew unexpected countries into the superpower space competition. As the Soviet Union began launching deep space probes in the early 1960s, the U.S. intelligence community needed to fill its gap in technical collection on these satellites. Consequently, in 1965 the U.S. government established a covert space surveillance site at Kagnew Station (codenamed "Stonehouse") in Asmara, Eritrea, which was then under the control of Ethiopia. This location was perfect for intercepting telemetry from Soviet space probes because it was located on the same longitude as a Soviet spacecraft command and control facility in Crimea (present-day Ukraine). Fortuitously, the Pentagon already had a communications facility at Kagnew Station that could provide a cover for the clandestine intelligence activities taking place.[††]

When civil war broke out in the vicinity of Asmara in the mid-1970s, the site's future was called into question. At one point, insurgents attacked the facility and heavily damaged communications equipment located on the base, thereby degrading all U.S. defense communications in the Middle East, Africa, and South Asia. The deteriorating security situation in Ethiopia ultimately prompted the Carter administration to close down operations at Kagnew Station and evacuate the site.[‡‡] Some U.S. officials feared that an American withdrawal from Kagnew might result in an increased Soviet presence

[†] Teasel Muir-Harmony, "Tracking Diplomacy: The International Geophysical Year and American Scientific and Technical exchange with East Asia," in *Globalizing Polar Science: Reconsidering the International Polar and Geophysical Years*, ed. Roger Launius et al (New York: Palgrave Macmillan, 2011), 74.
[‡] Brief for DCI, "briefing memorandum on space vehicle surveillance," undated, CREST, CIA-RDP80B01676R003800100005-7.
[§] Rick Sturdevant, "From Satellite Tracking to Space Situational Awareness: The USAF and Space Surveillance, 1957-2007, *Air Power History*, vol. 55, no. 4 (winter 2008).
[**] Letter from the Under Secretary of State (Bowles) to McGeorge Bundy," September 21, 1961, *FRUS*, 1961-1963, Vol. XXI, Africa.
[††] Mark Nixon, "The Stonehouse of East Africa," *Cryptologic Quarterly*, vol. 38 (2019), 29-39.
[‡‡] Aaron Bateman, "The Weakest Link: The Vulnerability of U.S. and Allied Global Information Networks in the Nuclear Age," *Journal of Strategic Studies* (2024), https://www.tandfonline.com/doi/abs/10.1080/01402390.2024.2360724.

in the Horn of Africa. Emperor of Ethiopia, Haile Selassie, worried that a U.S. exit from Ethiopia would reduce American military aid to his country and thus looked for alternative partners, including Moscow.[§§] In the end, however, U.S. officials maintained that the risks of keeping the site outweighed the potential benefits.

Even before the White House decided to close Kagnew Station, defense and intelligence officials were already looking for an alternate location due to the instability in the region. U.S. leaders considered moving some of the hardware at Kagnew to U.S. sites in Iran, but access to those facilities would be cut off in the wake of the 1979 revolution.[***] The Kagnew Station closure created greater momentum in favor of placing vital terrestrial infrastructure only in countries that were deemed politically stable and reliable U.S. partners. However, international political shifts that might affect U.S. access to vital foreign territories were very difficult to predict.

American policymakers worried how changing political agendas could affect their overseas bases even among their closest allies. In 1966, the U.S. and Australia governments signed an agreement to establish a Joint Defense Space Research Facility at Pine Gap near Alice Springs, Australia, which both governments acknowledged was home to national security activities that were critical for the defense of their mutual interests.[†††] In 1971, as the United States began launching Defense Support Program (DSP) satellites that are designed to detect missile and space launches, Australian leadership agreed to host one of the DSP ground sites near Woomera (which was moved to Pine Gap in the 1990s) for processing DSP data collected in the Pacific region. This ground facility made Australia a key node in the American space-based nuclear command and control infrastructure.

U.S. anxieties about the future of the sites in Australia were aroused when Australian Labour Party leader Gough Whitlam came to power in December 1972. In the lead up to the election, Whitlam signaled his intent to take Australian foreign policy in a more independent direction and he expressed overt hostility toward American bases in Australia. Pine Gap had become a topic of significant domestic political controversy in Australia due to the public perception that the Australian government exercised only limited control over activities at the site, further fueling animosity toward the United States. Complicating matters even more was the growing fear among a section of Australian society that the presence of American bases could make Australia a target for Soviet nuclear weapons.

All these factors prompted U.S. officials to assuage Australian anxieties about the U.S. defense presence in their country. A 1974 National Security Council staff memorandum stressed that the White House needed to take whatever action necessary to "prolong the life of our most vital assets (like Pine Gap)."[‡‡‡] Ultimately, the governor general of Australia sacked Whitlam in 1975, which cooled U.S. concerns about the tenure of the American sites. But tensions resurfaced in the late 1980s concerning the lack of Australian control over operations at the DSP ground site. To calm Australian leadership, senior U.S. officials modified longstanding policy that restricted the management of strategic systems to U.S. personnel only and permitted the DSP ground site deputy commander, an Australian national, to take control in the absence of the U.S. commander. Air Force Space Command supported this shift in light of what it described as a "special relationship" between Washington and Canberra.[§§§] Although these episodes never became a serious threat to the U.S. space presence in Australia, they reminded policymakers that U.S. space hardware situated in foreign territories, even in allied countries, was subject to domestic political whims outside of Washington's control.

[§§] Information memorandum, "Ethiopia-US Relations," November 1, 1973, CREST, CIA-RDP85T00875R001100160069-4.
[***] Letter from the Deputy Secretary of Defense (Nitze) to the Under Secretary of State (Katzenbach), September 6, 1968, *FRUS*, 1964-1968, Vol. XXIV, Africa.
[†††] Statement by the Hon. Richard Marles, "Securing Australia's Sovereignty," February 9, 2023, https://www.minister.defence.gov.au/statements/2023-02-09/securing-australias-sovereignty.
[‡‡‡] Memorandum from W. R. Smyser to Henry Kissinger, "Where do We Stand in Asia," July 18, 1974, *FRUS*, 1969-1976, Vol. E-12, Documents on East and Southeast Asia, 1973-1976.
[§§§] "Missile Warning," Air Force Space Command, 1990, National Security Archive, https://nsarchive2.gwu.edu/NSAEBB/NSAEBB235/21.pdf.

Improvements to U.S. space surveillance infrastructure were urgently needed in the 1970s due to the massive growth of space objects. Between 1967 and 1970, the number of objects in orbit more than doubled from 1,200 to just over 2,400. Monitoring Soviet satellites took on even greater importance as Moscow reinvigorated testing of its anti-satellite (ASAT) weapon designed to attack satellites in low Earth orbit. Senior NORAD officials stressed that better sensors were required for timely detection of a Soviet ASAT attack against U.S. reconnaissance satellites that provided the majority of American and allied intelligence on the Soviet Union and China. More sophisticated sensors for tracking Soviet satellites were also needed to transmit targeting data to the U.S. ASAT program initiated in 1977.

To remedy the inadequacies of the U.S. space monitoring network, in 1978 the Pentagon contracted TRW to develop a new optical surveillance capability called the Ground-Based Electro-Optical Deep Space Surveillance (GEODSS) system. TRW used advances in solid-state electronics to design an electro-optical telescope that could transmit data nearly instantaneously, rather than rely on the slow film processing method associated with Baker-Nunn cameras. In addition to speed, GEODSS would allow the U.S. space surveillance network to more accurately monitor satellites in geostationary orbit.[****]

To be effective, GEODSS required a global footprint. Two sites would be situated in U.S. territory, in Hawaii and New Mexico. A third site would be placed in South Korea, though the Pentagon closed it in 1993 due to financial considerations.[††††] Finding a place for the fourth site would become a complicated diplomatic exercise. In the summer of 1976, U.S. Air Force technical experts concluded that Morocco would be an ideal location for a GEODSS site. The U.S. Navy already had two communications facilities in the country that could host the telescope, but the Air Force insisted that a new facility be built farther inland solely for the space tracking facility.[‡‡‡‡]

King Hassan of Morocco initially approved the U.S. request to place GEODSS on Moroccan territory in exchange for arms sales, but deteriorating U.S. relations with government officials in Rabat stalled construction. After three years, the U.S. embassy in Rabat described the GEODSS deal as “effectively shelved” due to Hassan’s frustration with a lack of U.S. support for his fight against the Polisario Front in the Western Sahara.[§§§§] Once again, broader U.S. foreign policy considerations were affecting the placement of critical space tracking infrastructure abroad. With the failure of the Moroccan GEODSS site, the United States turned to its British ally and struck an agreement to place the space tracking facility on the island of Diego Garcia in the Indian Ocean.

To mitigate some of the difficulties associated with securing access to foreign territories for space surveillance, Air Force leaders have long considered the development of a *space-based* system for tracking satellites. In fact, a 1967 Air Force study advocated moving all surveillance and warning sensors into space, thereby replacing the ground-based systems,[*****] but moving all this infrastructure into space turned out to be impractical. In 1982 Air Force Systems Command laid down the requirements for a Space-Based Surveillance System (SBSS) that could detect and track foreign space objects and warn of attacks on U.S. and friendly space systems. Though it was slated to be operational in 1993, multiple programmatic delays would prevent SBSS from reaching orbit until 2010. Thus, through the end of the Cold War and for years afterward, the United States continued to depend on radar and optical surveillance sites spread across the world to surveil objects in space.

[****] Chapter III, “Space Defense,” in Military Uses of Space, 1945-1991, National Security Archive.

[††††] “Space Surveillance Sensors: GEODSS (Ground-based Electro-Optical Deep Space Surveillance) System,” August 20, 2012, https://mostlymissiledefense.com/2012/08/20/space-surveillance-sensors-geodss-ground-based-electro-optical-deep-space-surveillance-system-august-20-2012/

[‡‡‡‡] Memorandum from Poor to Clements, “U.S. Military Facilities in Morocco,” March 8, 1977, *FRUS*, 1969-1976, Vol. E-9, Part I, Documents on North Africa, 1973-1976.

[§§§§] Telegram from U.S. Embassy in Morocco to the Department of State, “Long-Term Planning for US Military Access and Overflights in a Southwest Asian Contingency,” January 31, 1980, FRUS, 1977-1980, Vol. XII, Part III, North Africa.

[*****] “Surveillance and Warning: A Master Plan,” in Military Uses of Space, 1945-1991, National Security Archive.

Space Infrastructure and Alliances After the Cold War

In the post-Cold War era, alliances remain a critical element in U.S. space strategy. Although anxieties about superpower military space competition receded with the dissolution of the Soviet Union and the so-called peace dividend of the 1990s, space quickly reemerged in the 21st century as a domain of potential conflict. The 2007 Chinese ASAT test was a watershed moment in post-Cold War space security that reminded U.S. and allied defense planners that space systems were attractive targets because of their role as enablers of global power projection. Concurrently, the growing number of government and non-government space operators was making space increasingly congested. In this rapidly changing space environment, enhancing space monitoring capabilities around the world took on even greater importance.

Even before anxieties about space security heightened with the 2007 Chinese ASAT test, the Department of Defense was already establishing mechanisms for international cooperation in SDA. In 2004, then-President George W. Bush designated U.S. Strategic Command as the lead agency for administering the Commercial and Foreign Entities (CFE) program aimed at bolstering U.S. SDA partnerships. The Pentagon intended for CFE to "encourage international cooperation and transparency with foreign nations and/or consortia on space activities that are of mutual benefit."[†††††] CFE entailed the United States sharing SDA data with foreign participants. As of September 2024,more than 100 SDA sharing agreements have been established with countries around the world.[‡‡‡‡‡] It is important to note that, until recently, the limited number of sensors owned by other countries has made CFE a primarily one-way information stream, with the U.S. government acting as the main SDA data provider.

Today, allied countries around the world possess sophisticated SDA sensors. Germany, Japan, Australia, France, and the United Kingdom have all established military space units that operate space tracking systems that enhance the United States' ability to monitor satellites. As such, hosting infrastructure is no longer the primary mechanism for U.S. military space cooperation with allies and partners—but this situation also creates challenges. The United States is rapidly adopting a coalition approach to outer space, meaning that allies and partners are playing a more prominent role. The Pentagon and key allies established the Combined Space Operations Initiative (CSpO) to ease coordination of space activities.[§§§§§] This shift toward combined operations requires data standardization and systems interoperability to ensure that SDA information can be quickly disseminated to end users. However, linking disparate SDA sensors spread across the world that were not designed to communicate with each other is a significant challenge.

Space-based sensors greatly enhance the U.S. ability to detect and monitor threats in orbit as well. In the past two decades, the United States has deployed SBSS in low Earth orbit as well as multiple Geosynchronous Space Situational Awareness Program (GSSAP) satellites that perform a "neighborhood watch" function in the geosynchronous orbital regime.[******] The United States is not alone in developing sophisticated sensors for in-orbit monitoring. Japan has announced its intention to launch a space-based surveillance capability to supplement its existing ground-based optical and radar space surveillance systems.[††††††] The growth of space-based SDA will enhance, but not replace, terrestrial sensors for monitoring the space environment.

Terrestrial space infrastructure has become a key element in recent U.S. efforts to strengthen its existing alliances in the Indo-Pacific and Europe. In 2023, the United States, Australia, and the United Kingdom announced a joint plan to field

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††††† Report of the Commission to Assess United States National Security Space Management and Organization, January 11, 2001, https://aerospace.csis.org/wp-content/uploads/2018/09/RumsfeldCommission.pdf.

‡‡‡‡‡ Karen Singer, "100th space sharing agreement signed, Romania Space Agency joins," April 26, 2019, U.S. Strategic Command Public Affairs, https://www.stratcom.mil/Media/News/News-Article-View/Article/1825882/100th-space-sharing-agreement-signed-romania-space-agency-joins/.

§§§§§ David Vergun, "More Nationals Need to Address Space Security, DoD News, December 7, 2023, https://www.defense.gov/News/News-Stories/Article/Article/3610656/more-nations-meet-to-address-space-security/.

****** "Geosynchronous Space Situational Awareness Program," U.S. Space Force, https://www.spaceforce.mil/About-Us/Fact-Sheets/Article/2197772/geosynchronous-space-situational-awareness-program/.

†††††† "Japan to put space situational awareness satellites into orbit to track debris and threats," Space Watch Asia Pacific, https://spacewatch.global/2018/08/japan-to-put-space-situational-awareness-satellites-in-orbit-to-track-debris-and-threats/.

more capable deep space radars for monitoring threats in geostationary orbit.[‡‡‡‡‡‡] These new capabilities will strengthen preexisting space cooperative partnerships, since both Australia and the United Kingdom have long contributed to U.S. SDA and satellite ground infrastructure.

International partnerships concerning satellite ground sites and SDA infrastructure are important for China to achieve its military, commercial, and civil goals in orbit as well. Space cooperation is an important element of China's Belt and Road Initiative (BRI). Furthermore, Beijing is using BRI to expand its terrestrial infrastructure that supports both civil and military space missions because countries in Latin America and Africa (among other places) are eager to strengthen scientific and technological ties with China.[§§§§§§] Therefore, it is increasingly important for the United States to continue establishing space cooperation partnerships in the Global South as a counterbalance to China's efforts.

Conclusion

Space competition during the Cold War could be easily misconstrued as having been a bipolar, superpower affair. In reality, U.S. space capabilities—both civil and national security assets—heavily depended on infrastructure hosted by allies and partners across the world. Being able to place hardware in foreign territories extended the reach of U.S. space systems but also became a source of vulnerability. The United States could not be certain that its access to space infrastructure located on the real estate of allies, even the closest ones, would be indefinite. When changing political conditions necessitated moving space infrastructure out of a particular overseas location, the geographic expanse of U.S. alliances and partnerships generally provided suitable alternatives.

Today, the terrestrial imperatives of spacepower remains an important factor in shaping U.S. engagement with allies and partners. Resiliency in orbit requires a vast infrastructure on the ground to monitor the space environment, launch satellites into space, and to transmit data to and from space systems. Even countries with limited assets in orbit can enhance coalition space operations through hosting support infrastructure. This situation underscores that international partnerships are the foundation of U.S. space security.

The United States is not alone in its dependence on overseas satellite ground sites and terrestrial SDA sensors. China's fast-growing military and civil space programs have required an expansion of Beijing's terrestrial space infrastructure. This reality has prompted Chinese officials to cultivate closer ties with countries, especially in the Global South, that are willing to host SDA facilities and satellite ground systems, which are oftentimes dual use. It is therefore vital for the United States to continue forging space partnerships with countries around the world to achieve its own space goals, and to also strengthen ties with states outside of its alliances. In some cases, this approach can help to deny China access to specific overseas territories for hosting terrestrial space infrastructure, thereby impeding its national space objectives. Fundamentally, U.S.–China competition in orbit is shaping the terrestrial geography of superpower competition.

[‡‡‡‡‡‡] Rebecca Connolly, "Space Surveillance and AUKUS: The Power of Awareness," January 19, 2024, Lowy Institute, https://www.lowyinstitute.org/the-interpreter/space-surveillance-aukus-power-awareness.
[§§§§§§] R. Evan Ellis, "China-Latin America Space Cooperation: An Overview," February 16, 2024, U.S. Army War College Strategic Studies Institute, https://ssi.armywarcollege.edu/SSI-Media/Recent-Publications/Display/Article/3680615/china-latin-america-space-cooperation-an-overview/.

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About Space Agenda 2025 Publications

This paper was published as a chapter of *Space Agenda 2025*, with Angie Bukley, Colleen Stover, and Victoria Woodburn serving as editors in chief. *Space Agenda 2025* is an effort by the Center for Space Policy and Strategy (CSPS) at The Aerospace Corporation to highlight and provide insights into some of the major space challenges facing policymakers. You can find the complete list of individual *Space Agenda 2025* papers at http://csps.aerospace.org/SA2025, as well as download the combined set of 16 chapters in the *Space Agenda 2025 Compendium* at https://csps.aerospace.org/papers/space-agenda-2025-compendium, all available to you with our compliments.

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SPACE-ENABLED CAPABILITIES FOR CONNECTING AND COLLABORATING IN THE ARCTIC

Karen L. Jones and Lina M. Cashin

Executive Summary

In the Arctic region, space capabilities that support navigation and timing, communications, and remote sensing will be vital in establishing persistent situational awareness while connecting and informing defense, commercial, and civilian interests.

The analysis in this chapter is structured around a more complex Arctic with:

- Increased geopolitical rivalry, overlapping territorial claims, shifting alliances, and growing polarization among and between major global powers.
- A strong need to achieve multinational interoperability and multistakeholder cooperation for shared Arctic missions.

Specific missions in the Arctic region, such as border security, sovereignty protection, vessel assistance, fisheries monitoring, environmental and oil spill response, search and rescue, and science and research, will demand greater cooperation and connectivity as activities continue to expand.

Over the past few years, a proliferation of existing and proposed commercial space capabilities in the High North have offered connectivity services across multiple orbits. The White House has taken notice and has included an objective in the *Implementation Plan for the 2022 National Strategy for the Arctic Region* to achieve broadband communications to increase reliability of communications for U.S. military personnel operating in Arctic regions."[1]

This chapter recommends sharing capabilities and flexible architectures that offer economy, security, and user flexibility. A strategic path forward could also leverage innovations in space such as multi-orbit, multi-mission capable terminals, hybrid (multi-orbit) architectures, and satellite networks with robust data transmission capacities to meet the future needs of an advanced Joint Force and allies.

Introduction

The polar region is developing at a time when the expanding commercial space industry can provide persistent space-enabled connectivity, navigation, and increased surveillance. A combination of satellites in various orbits can provide the coverage and resilience necessary to meet national security, industry, and environmental goals. However, the Russian invasion of Ukraine has ripped up the “High North, Low Tension” script, a common Norwegian adage during more peaceful times. Geopolitical tensions are rising in the Arctic as Russia wages unprovoked war against Ukraine, and China continues to ramp up High North investments and activities. Now more than ever, the United States and its allies must project power in the sub-Arctic and Arctic regions to strengthen security and protect economic and environmental interests.

Today, cooperation is challenging as international forums and organizations, such as the Arctic Council and the North Atlantic Treaty Organization (NATO), are undergoing shifting alliances and membership. Beyond organizational alignments, specific missions, such as border security, sovereignty protection, vessel assistance, fisheries monitoring, environmental and oil spill response, search and rescue, and science and research will demand greater cooperation and connectivity as activities in the High North continue to expand.

During this time of increased competition and tension, the United States can partner and share space capabilities with allies and trusted partners across a range of missions. Space capabilities are uniquely qualified to address this dynamic and geopolitically stressed environment in the High North. Operations will advance using open systems with resilient architectures that offer economy, security, and user flexibility, supporting unified governance structures. Within the broader context, existing and emerging space capabilities will allow the United States to assert its influence as an Arctic nation.

Background

The area north of the Arctic Circle (66.3° latitude) includes 14.5 million square kilometers of ocean, ice, and land masses (see Figure 1). Arctic marine systems are warming at two to four times the global average rate, and many scientists view the region as a sentinel for climate change impacts on the world’s oceans.[2] This rapid warming results in widespread permafrost thawing and negatively influences global carbon cycles, hydrology, and Arctic ecosystems. Additionally, melting sea ice is exposing two major sea routes for increased maritime traffic (see Figure 1), and harbors are becoming available year-round for shipping, resource extraction, and industrial development.

The Arctic is one of the most sparsely populated areas on the planet. Approximately four million people live above 65 degrees North, dispersed across eight Arctic countries, i.e., Canada, Denmark (via its autonomous territory, Greenland), Finland, Iceland, Norway, Russia, Sweden, and the United States (by virtue of Alaska). The following populations above the Arctic Circle include approximately:

- 400,000 Indigenous peoples from over 40 different ethnic groups
- 2,000,000 Russian inhabitants, or roughly half the Arctic population[3]
- 11,000 U.S. inhabitants on the north slope of Alaska[4]

The polar region is developing at a time when the growing commercial space industry can provide persistent space-enabled connectivity, navigation, and surveillance. A combination of commercial satellites in various orbits can provide the coverage and resilience necessary to meet national security, industry, and environmental goals. Fortunately, the U.S. government and other organizations, such as the Arctic Council, recognize the need to address connectivity and infrastructure gaps by encouraging greater use of commercial space services for civil and defense needs.

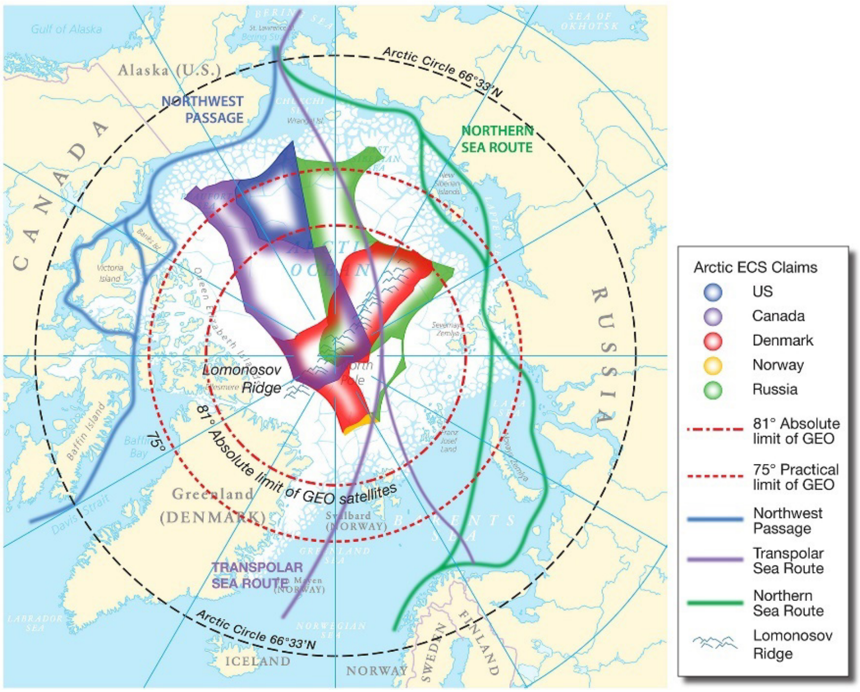

Figure 1: The Arctic Region – the area north of the Arctic Circle, 66°33' north latitude. *The areas intersecting over the North Pole illustrate that all five coastal Arctic States have made declarations of the extended continental shelf (ECS). The map shows areas of significant overlap between the countries, such as the Lomonosov Ridge, with Russia, Denmark, and Canada each claiming areas as extensions of their continental land mass.*

Governments and industry have historically optimized connectivity and satellite communications (or "satcom") for high population densities at mid-latitudes. Remote regions at extreme latitudes, such as the Arctic, struggle with adequate market demand, translating to higher network deployment costs per subscriber and escalating usage fees as connectivity providers seek a reasonable return on investment.[5] The result is that less populated areas are frequently overlooked, leaving residents without adequate access to broadband and communication services for distance learning, telemedicine, commerce, and general connectivity to the rest of the world. According to a nonprofit organization focused on Alaskan tribal members, small communities (estimated at 60,000 people) are unserved with no access to broadband, and an additional 200,000 people are "underserved" with low-end broadband download/upload speeds less than 10/1 Mbps.[6]

Arctic Governance and Cooperation

Arctic governance requires significant cooperation and relies on a foundation of various conventions and rules. The eight member countries of the Arctic Council and NATO (comprising 32 members in Europe and North America) are supranational governing bodies, with power and influence transcending national boundaries. In addition, the United Nations Convention on the Law of the Sea remains a prominent and binding framework for nations' maritime rights and responsibilities.[7]

Due to increasing commercial, civil, and defense activities in the High North, there is a pressing need among Arctic Council and NATO members to share data from space systems and collaborate operationally. However, both organizations have experienced recent changes, and the situation remains dynamic and geopolitically sensitive. Within this context, one must consider future space capabilities in the High North that allow for open systems with flexible architectures that offer economy, security, and user flexibility.

Arctic Council. The Arctic Council, established in 1996, is an intergovernmental forum that encourages cooperation, coordination, and interaction among the Arctic States, indigenous communities, and other inhabitants to address sustainable development and environmental protection issues.[8, 9] The council also looks to the United Nations' Sustainable Development Goals as a guiding framework for sustainability.

The United States is one of eight members of the Arctic Council, along with Canada, Denmark, Finland, Iceland, Norway, the Russian Federation, and Sweden. These eight Arctic States,[10] with land inside the Arctic Circle, are permanent members of the Arctic Council. In addition, mid-latitude countries typically not associated with the Arctic, such as China, India, and Singapore, are accorded observer status.[11] Importantly, any issues related to national or international security are excluded from the mandate of the Arctic Council.

Russia is the largest geographical stakeholder in the Council, comprising 45 percent of the Arctic territory. The Kremlin continues to prioritize the Arctic due to strong vested economic interests, military, environmental, and national security goals; and historical ties to the region as part of its national identity.

Despite the council's 28-year history of cooperation, it comes as no surprise that following Russia's invasion of Ukraine, Russia was "iced out" of various international forums, including the Arctic Council, after seven member countries boycotted Russia's chairship. Conveniently, in 2023, Russia's chairship rotated out of the Arctic Council in a two-year planned cycle, making way for Norway's chairship from 2023 through 2025. After Norway's rise to the council chairship, the Biden administration acknowledged the need for scientific and practical cooperation. A senior White House official emphasized that "the Arctic Council should continue to serve as the premier forum for cooperation among Arctic states, including collaboration on sustainable development, protecting the environment, addressing the impacts of climate change, scientific research, and on other issues of importance to member countries."[12]

North Atlantic Treaty Organization (NATO). NATO, also referred to as the North Atlantic Alliance, remains strong and aligned with the Russian invasion of Ukraine driving expansion and an increased focus on NATO member defense budgets and burden sharing. Jens Stoltenberg, secretary-general of NATO, points out that as the organization celebrates its 75th birthday in 2024, NATO "is the strongest, most successful alliance in history because we have been able to change."[13] Adapting and changing also includes expanding the roster of NATO nations, most recently with two historically neutral countries, Finland and Sweden, joining in 2023 and 2024, provoked in part by Russia's military aggression in Ukraine.

NATO has years of experience exercising and training with allies and partners in the High North to prepare and respond to complex situations and crises that go beyond border defense.[14] U.S. Marine Corps Maj. Gen. Robert Sofge, commander of U.S. Marine Corps Forces Europe and Africa, stressed, "...now is the time to get our systems connected, our doctrine aligned, and to share our tactics to ensure we can sense and make sense in a complex battlefield, in the harshest of conditions, against a capable opponent."[15]

The North Atlantic Alliance relies heavily on space infrastructure to support its collective guarantee of freedom and security for member states. The Alliance has highlighted the criticality of space capabilities in multiple areas, "from weather monitoring, environment, and agriculture to transport, science, communications, and banking."[16] Space assets, both commercial and nationally owned, enable a strong backbone for deterrence and defense—in part due to satellite activities, including intelligence, surveillance, and reconnaissance (ISR); navigation; tracking forces; and missile launch and tracking.

To organize and manage these capabilities, the Alliance has dedicated a new organization called NATO SATCOM Services 6th Generation (NSS6G), which combines space resources and capabilities from France, Italy, the United Kingdom, and the United States to support NATO.[17] NATO Communications and Information (NCI) manages NSS6G and provides NATO with network core enterprise services, operational and exercise support, and program management. Due to advances in space technology and greater global participation, NATO increasingly relies on space and must ensure it can operate despite the growing emergence of Russia and China counter space-enabled threats.[*,18,19] As a result, U.S. allies and partners, supported by NATO NCI, must be prepared to operate in a contested environment to collaborate, connect, and share resources and capabilities.

U.S. Policy Responses. The United States has defined its strategic and commercial interests through a series of policy statements. Across four U.S. administrations, the policies have been mutually supportive and consistent. National and economic security, international cooperation, and environmental sustainability are enduring objectives from President Bush in 2009 to President Biden in 2022 (see Table 1).

Table 1: National Arctic Policies Across Four U.S. Administrations

Policies build on common themes of national security, cooperation, and environmental sustainability.

Bush 2009	*National Security and Presidential Directive/Homeland Security Presidential Directive*
Obama 2013	*National Strategy for the Arctic Region*
Trump 2019	*Department of Defense Arctic Strategy*
Trump 2020	*Memorandum on Safeguarding U.S. National Interests in the Arctic and Antarctic Regions*
Trump 2020	*The Department of the Air Force Arctic Strategy*
Biden 2022, 2023	*National Strategy for the Arctic Region*, and *Implementation Plan for the 2022 National Strategy for the Arctic Region*
Biden 2024	*U.S. Department of Defense Arctic Strategy*

Need for Domain Awareness and Connectivity – From Seafloor to Space. In January 2023, a high-altitude Chinese balloon appeared to float aimlessly into the United States from Canada. Aside from the humorous press coverage, the incident sparked a more serious debate about why the U.S. Northern Command (NORTHCOM) did not spot the balloon earlier, despite awareness of China's balloon program.[20] Later, in March 2023, the commander of U.S. NORTHCOM and North American Aerospace Defense Command (NORAD) testified before Congress, stressing that "it is imperative that the United States and Canada move quickly to improve domain awareness from the seafloor to space and cyberspace for all approaches to North America." General VanHerck added that, as part of all domain awareness, over-the-horizon radars funded by the United States and Canada would improve the ability of USNORTHCOM and NORAD to detect threats to North America from "the Earth's surface to space." Additionally, U.S. Space Force investments in advanced space-based missile warning sensor capabilities are promising for the detection of hypersonic and advanced missile threats.[21]

Further, to increase domain awareness, more efforts are needed to "link existing platforms and sharing data with multiple commands, interagency and international partners" through existing innovative programs and new initiatives.[22] The Arctic presents unique security challenges as supranational organizations—NATO and the Arctic Council—hold key positions of trust and power. This type of organizational cooperation underscores the need for open and shared systems (for space, air, land, or marine-based data) to improve domain awareness and inform decisions.

[*]Various public media sources have indicated that electromagnetic pulses (EMP) may be used to disable communication systems by radiation and electronic damage and upsets.

The DOD's *2024 Arctic Strategy* goes further than platform connectivity and emphasizes the need for "robust transmission capacity" to support cooperation with U.S. allies and partners. Looking to the 2030s, the strategy suggests that large amounts of data will be needed for Joint Force demands and operation of "over 250 advanced multirole combat aircraft that could be deployed for Arctic operations."[23]

A National Call for Improved Satellite Services in Northern Latitudes. Until recently, Arctic policies lacked clear plans directing activities and steps. However, following the release of the *National Strategy for the Arctic Region* (NSAR) in 2022, the White House released the "NSAR - Implementation Plan" (NSARIP) in October 2023 to provide operational articulation.[24,25] The plan details more than 30 objectives and 200 discrete actions that advance the four mutually reinforcing pillars of the National Strategy, which are security, climate change and environmental protection, sustainable economic development, and international cooperation and governance. The 2023 NSARIP also outlines an objective to "improve communications, positioning, navigation, and timing (PNT) capabilities by developing communications and data networks capable of operating in the northern latitudes." According to Dr. David W. Allen of The Aerospace Corporation, the United States has a "close relationship with our allies to ensure we are in sync on radio frequency compatibility and interoperability between our GPS constellation and Japan's Quasi-Zenith Satellite System and Europe's Galileo PNT systems. We provide notification for any modifications to our GPS constellation." These multiple layers of cooperation between the United States and its allies remains important, particularly with signs of space-related cooperation between Russia, which has its own PNT system known as GLONASS, and China with its more modern and accurate BeiDou PNT network.[26]

Consistent with the NSAR, the DOD's *2024 Arctic Strategy* also underscores both the need for the DOD to pursue "technology through commercial partners and agreements with NATO Allies and partners" and to enhance command, control, communications, computers, cyber, intelligence, surveillance, and reconnaissance (C5ISR) capabilities with a "particular focus" on satellites providing Arctic coverage.[27] In short, both the White House and the DOD are encouraging greater consideration of commercial satellite capabilities for civil and defense activities.

Satellite Options: Commercial, Multi-orbits, International Cooperation

The 2023 NSARIP calls for maintaining "worldwide Satellite Communications for Presidential and DOD command and control over strategic forces."[28] In the future, such a system could include a secure mesh network of commercial solutions using satellites in numerous orbits to close the capability gap in the Arctic. Such a network could harness the strengths of each type of satellite orbit to optimize coverage, speed, resolution, latency, and cost trades for any one mission.

A satellite known as geostationary, a particular type of geosynchronous Earth orbiting (GEO) satellite that orbits at an altitude of 35,786 km (26,199 m), sits above the equator and is synchronized to the Earth's rotation. As a result, a GEO satellite can appear as a fixed point and provide persistent coverage for communications and sensing across a large swath of Earth. However, many parts of the Arctic are beyond line of sight for GEO coverage (see Figure 1). Due to the curvature of the Earth, 81 degrees is the maximum latitude beyond which a GEO is below the local horizon. Operationally, a GEO satellite's practical limit is approximately 75 degrees.[29] However, both low Earth orbit (LEO) and medium Earth orbit (MEO) satellites with adequate orbital inclination can provide polar coverage. A highly elliptical orbit (HEO) satellite also offers advantages for the Arctic region. From a spatial and temporal resolution perspective, two HEO satellites can provide continuous coverage. The oval-shaped orbit allows the first satellite to hang or "loiter" over the North Pole area before it tags the second satellite and returns to a much shorter time over the South Pole. Combined, the two satellites are optimized for coverage above 65 degrees north.[30]

Increasing LEO Popularity. More recently, due to technological advancements such as satellite cross-links, miniaturized parts, and high-volume satellite production, proliferated LEO constellations using small low-cost satellites are now introducing resilient global coverage and improved economies of scale. Over the past 10 years, the number of LEO satellites has increased dramatically from approximately 1,200 (before 2010) to almost 8,125 (June 2024), driven in part by the increasing demand for global internet coverage and other services.[31] Some of these LEO satellites occupy high-inclination orbits, thus contributing to polar region coverage, including some LEO satellites in sun-synchronous orbits, which provide consistent, daylight imaging conditions by synchronizing or maintaining a "fixed" position relative to the Sun. The popularity of high inclination and polar orbits provides a plethora of space sensors to monitor and observe dynamic areas of interest such as the Arctic Ocean, permafrost/land, cryosphere, infrastructure, and shipping traffic.

A Shift to Multi-orbit Networks. Accelerated in part by recent mergers of operators and the ability to cross-link between LEO, MEO, and GEO satellites, there is a strong shift toward multi-orbit networks. These hybrid networks offer perhaps the best method for providing resilient, fast, and affordable connectivity in the Arctic region. LEO satellites offer low latency, which is critical for remotely controlled sensors and unmanned platforms, while, at higher altitudes, MEO and GEO satellites can provide backbone connectivity and greater coverage with longer lifespans. Key space research and acquisition organizations such as the Defense Advanced Research Projects Agency (DARPA), the Space Development Agency, the Air Force Research Laboratory, and other government organizations are recognizing the benefits and need for hybrid constellations.

Commercial Connectivity: Proliferation of LEO and Emerging Hybrid Constellations. Historically, simple store and forward constellations, such as Gonets (Russia) and Argos (France), have served the polar regions using narrowband, unidirectional communications for scientific and meteorological purposes since the 1970s. By the late 1990s, Iridium Communications introduced global satellite communications, which provided coverage to both poles. Few new satellite services to the region were introduced until the past seven years or so, when a flurry of new commercial satellite offerings across LEO, GEO, and HEO emerged. The White House has taken notice and has included an implementation objective in the 2023 NSARIP to "[p]artner with the growing commercial space industry, Allies, and partners to achieve broadband communications to increase reliability of communications for U.S. military personnel operating in Arctic regions."[32]

LEOs with Arctic Coverage. While established constellations, such as Orbcomm, Iridium, and Globalstar, continue to operate, new proliferated LEO (pLEO) operators have emerged. SpaceX's Starlink has introduced the world's largest constellation, including satellites in polar or near-polar orbit. Meanwhile, Eutelsat's acquisition growth strategy has led to a hybrid GEO and LEO constellation. A future constellation to watch will be Telesat's (Canada) Lightspeed constellation, which will launch in 2026 with plans to cover the polar region. Current and future commercial satellite connectivity providers in the High North include:

- **Orbcomm** (USA). One of the first commercial LEO constellations offering services in 1996. Orbcomm operates 31 LEO satellites at 750 kilometers (km) altitude and a ground station network of 16 gateways in 13 countries to track and establish two-way satellite communications.[33] Its business focus is on Internet of Things (IoT), asset tracking, and monitoring systems across a range of industrial vertical markets. [†]

- **Iridium** (USA). Operates 66 satellites in polar orbits at 778 km altitude; uses inter-satellite links (ISLs) to route network traffic. Although Iridium replenished its first generation in 2019, it does not offer broadband speeds up to 25 Mbps and higher, as defined by the Federal Communications Commission. It offers commercial voice and data, IoT data, broadband, and hosted payload services.

- **Globalstar Inc.** (USA). Unlike Iridium with ISLs, Globalstar operates a "bent-pipe" constellation, with 48 satellites in a LEO at 1,414 km, inclined at 52 degrees to the equator. The constellation covers over 80 percent of the Earth's surface but does not cover areas above 70 degrees north latitude.[34] In 2022, a partnership was

[†]Iridium and Orbcom do not provide broadband speeds as defined by the FCC as 25 Mbps.

established with Apple, enabling Apple's iPhone to send distress signals using Globalstar's satellite network. Apple will spend $450 million, the majority to Globalstar, for satellite network capacity.[35]

- **Eutelsat Group** (France).[‡] Recently completed the deployment of its LEO constellation in 2023, with 634 satellites operating at 1,200 km. In September 2023, Eutelsat (France, focused on GEO) acquired OneWeb (the United Kingdom, focused on LEO). Existing customers must use different user terminals for each GEO and LEO network, but Eutelsat OneWeb plans to introduce a ruggedized hybrid GEO/LEO terminal with a phased-array antenna to allow connectivity to either a GEO or LEO satellite network.[36]

- **SpaceX – *Starlink*** (USA). Over 6,200 active satellites operating at 550 km altitude. The satellites use ISLs to connect to each other, forming a mesh network in space. SpaceX intends to serve the Arctic region and has invested in ground stations across Alaska (e.g., Nome, Fairbanks, and Kuparuk) for high-speed backhaul using terrestrial fiber optic cables.[37]

- **Telesat – *Lightspeed*** (Canada). Planning 198 satellites to be launched in 2026, from 1,315 to 1,335 km altitude in two orbital inclinations for complete global coverage, including polar areas,[38] while concentrating capacity over regions of highest demand. The constellation will use optical ISLs to create a mesh network in space and will use on-board data processing and routing for dynamic capacity delivery in regions with high demand.[39] The satellites will offer space relays for hosted government satellite missions.[40]

- **Amazon – *Project Kuiper*** (USA). New constellation. Under the terms of its FCC filings, Project Kuiper will be required to launch and operate half of its 3,236 satellites no later than July 30, 2026, and must launch and operate the remaining satellites no later than July 30, 2029.[41] Amazon Kuiper intends to provide internet to "tens of millions of people who lack basic access to broadband internet,"[42] but the constellation's coverage over the Arctic region is not yet known.[43]

Far North GEO Coverage. The current generation of GEO high throughput satellites (HTS) can also support high latitude regions, including a significant portion of the Arctic, with large amounts of capacity concentrated in small areas, using high power, multiple spot beams, and frequency reuse. The practical northern limit for GEO coverage is 75 degrees north (see Figure 1), well above the northern slope of Alaska. Therefore, assuming an unobstructed view, satellite dishes in Alaska can point at an angle of 10 degrees or higher to connect to a GEO satellite. Pacific Dataport (Anchorage, Alaska), for instance, launched their HTS satellite named *Aurora 4A*, a small GEOsat or "microgeo," designed to provide backhaul capacity in rural Alaska between last mile coverage options.[§] Despite the technical problems, this effort demonstrates the commercial sector's interest in solving a key challenge in the High North: fast and reliable satellite backhaul capacity.[44]

International and Commercial Cooperation Across Flexible Architectures. International partnerships are the key to U.S. deterrence and power projection by unifying global actions toward a common goal. Further, commercial space capabilities provide agility and connectivity to accomplish shared goals. The U.S. Space Force and trusted NATO and Arctic partners can collaborate, along with commercial partners, to deliver value. Beyond working across international partnerships, commercial space is also finding ways to deliver enhanced capabilities using the advantages of different orbits: LEO, MEO, GEO, and HEO. Two examples of leveraging space capabilities—the Arctic Satellite Broadband Mission (ASBM) and the Commercial Services for the Warfighter—are described below.

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‡During a September 2023 merger, Eutelsat combined its GEO satellite business with OneWeb's LEO constellation after shareholders voted on September 28 in favor of the all-share deal.

§The Aurora 4A satellite suffered a solar array drive malfunction, limiting its operations to 6 and 12 hours per day. The satellite will be replaced with UtilitySat 1 until a full replacement is available (source: Gunter's Space Page).

Arctic Satellite Broadband Mission (ASBM). Space Norway's[**] new HEO 2 satellite constellation launched in August 2024. The Arctic Satellite Broadband Mission (ASBM) intends to close the Arctic connectivity gap to provide continuous broadband coverage north of 65 degrees north latitude. Northrop Grumman built two large satellites, each weighing approximately two tons, to "speed up when over the South Pole and slow down above the North Pole, tagging each other to deliver persistent coverage of the northernmost region of Earth."[45,46] Both satellites are designed to operate for at least 15 years and will allow users to switch between GEO and HEO satellites.[47] Space Norway plans to cooperate with commercial satellite operator ViaSat and the Norwegian Ministry of Defense to offer mobile broadband coverage to civilian and military users in the Arctic.

Notably, a precedent has been set as Space Norway now claims the first operational U.S. DOD payload ever hosted on an internationally procured and operated space vehicle.[††] The following civilian and military payloads, are included:

- **Viasat.** A high-speed global network extension across the Arctic region with Ka-band payloads.[48]
- **U.S. Space Force – Enhanced Polar System Recapitalization (EPS-R).** A stopgap communications system using an extremely high frequency (EHF) extended data rate payload to fill a vital gap for defense operations in the Arctic region.[49,50]
- **Norwegian Ministry of Defense.** X-band payload.
- **European Commission.** A Norwegian radiation monitor payload.

Commercial Services for the Warfighter. Network convergence across GEO, MEO, LEO, HEO, and even terrestrial 5G cellular networks is happening now and will depend on interoperability standards and various existing spectrum regulations to ensure that there is no harmful interference. An emerging direct-to-device (D2D) market is also proving that unmodified cell phones can connect directly to orbiting LEO satellites for emergency services, texting, and, eventually, wider bandwidth applications.[51]

It comes as no surprise that military users seek to benefit from this connectivity convergence wave. In response, the Air Force Research Laboratory (AFRL) is prototyping and testing future satellite communications equipment so that warfighters can connect to a range of satellites that are in their field of view at any given time. AFRL's Defense Experimentation Using Commercial Space Internet (DEUCSI) contract, also known by the program name "Global Lightning," is now evaluating how hybrid SATCOM terminals can work across multiple constellations or satellite orbits with "highly capable, affordable antennas." In 2023, Global Lightning users conducted iterative tests across the globe, and the results are now being integrated into underserved areas such as the Arctic.[52]

Leveraging international partnerships and expanding commercial satellite capabilities can provide reliable and ubiquitous connectivity. These space capabilities can increase data-sharing to improve operations, provide greater transparency and accountability, and can be the means to "uphold international law, rules, and standards globally" as articulated in the *National Strategy for the Arctic Region*.[53]

Multi-missions Across a Range of Orbits and User Groups. In the future, SATCOM users can expect to see multi-orbit SATCOM operations working seamlessly to share information with a range of users.[54] Nowhere on the planet are these advantages more applicable than in the High North, where openness, flexibility, and interoperability are key to meeting

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[**]Space Norway, owned by the Norwegian Ministry of Trade, Industry and Fisheries, is a key part of the Norwegian Government's activities and assets in the space sector (source: https://spacenorway.no/en/about-us/).
[††]The pioneering commercially hosted infrared payload (CHIRP) mission was the first DOD-hosted payload on a foreign-owned satellite bus, SES (Luxembourg). The payload launched in 2011 and operated for 27 months.

mission requirements ranging from national security, to border protection, fisheries monitoring, search and rescue, and more (see Table 2).

Table 2: Arctic Missions ***Persistent satellite imaging, continuous connectivity, and open data sharing will enable cooperation and magnify transparency in the Arctic region, to support various missions.***	
Arctic Missions	**Benefits to Interoperability, Connectivity, and Data Sharing**
National Security	Sharing satellite data with both allies and adversaries during military exercises, and detection of trespassing and other potential threats. Data sharing can mitigate mistrust and misperceptions among countries.
Border Security and Sovereignty Protection	Allows observation and border security enforcement, and territorial and natural resource protection. Includes responding to emergencies and safeguarding the free flow of commerce. Responsive communications can mitigate misunderstandings and support contingency operations.
Vessel Assistance and Management	Supports safe passage for ships in the Northern Sea Route, Northwest Passage, and other maritime routes.
Fisheries Monitoring	Supports and encourages compliance for fisheries management bodies and fishing moratoriums, and ensures ocean sustainability.
Environmental and Oil Spill Response	A multilateral treaty ratified by Canada in 2014, *Marine Oil Pollution Preparedness and Response in the Arctic* aims to increase cooperation and coordination among Arctic countries. Commitments include mutual assistance and information exchange to improve oil spill response success.
Search and Rescue	Supports coordination, cooperation, and response between Arctic nation coast guards called for in the 2013 *Arctic Search and Rescue Agreement*.
Science and Research	Supports the 2017 *Agreement on Enhancing International Arctic Scientific Cooperation*, which facilitates Arctic government data access by scientists, to support research, education, career development, and training opportunities.[55]

Recent mergers, such as the Eutelsat–OneWeb and Viasat–Inmarsat mergers, and agreements between Intelsat and SES with LEO operators OneWeb and Starlink are all pointing to a future where hybrid GEO, MEO, and LEO space networks will harness the strengths of each orbit to optimize utility for commercial, civil, and defense purposes.[56] Moreover, increasing the use of software-defined platforms can provide the levels of adaptability needed to work across multiple satellites and networks.

Next Steps and Key Decisions over the Next Four Years

The fallout from Russian aggression introduces increasingly urgent security challenges in the Arctic, particularly as the Arctic Council must reorganize itself around this new reality. During this new era of tension in the High North, the U.S. and NATO allies will need to assert their territorial, economic, and military interests. It is, therefore, a crucial time for satellite systems to support affordable and persistent connectivity, navigation, and observation by emphasizing open, available, and shared systems with trusted Arctic partners, to achieve multi-national interoperability and multi-stakeholder cooperation. Supranational alliances, such as the Arctic Council and NATO, have experienced recent changes, and the ongoing situation remains dynamic and geopolitically sensitive. Within this context, one must consider future space capabilities above 65 degrees north, including commercial services that allow for:

- Support and implementation of Arctic policies.

- Innovative collaboration with allies to share capabilities. The partnership between Space Norway and the U.S. military to bring broadband and other space capabilities to the Arctic region is a potential pathfinder for these types of partnerships.

- Incentivizing and use of open systems with flexible architectures that offer economy, security, and user flexibility.

- Development of multi-orbit, multi-mission capable terminals and hybrid solutions, which allow connections across various satellite constellations, including establishing interoperability standards for hybrid satellite architectures.

- Satellite networks that can handle robust data transmission capacities to meet the future needs of an advanced Joint Force.

These recommendations are structured around a more complex and less friendly Arctic with increased geopolitical rivalry, overlapping territorial claims, and growing polarization between major global powers. However, these same recommendations offer solutions for technical cooperation for search and rescue, environmental response, and other cooperative missions. Whatever the scenario in the High North, the United States and its allies will benefit from the enduring strategic value of space enabled capabilities.

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About Space Agenda 2025 Publications

This paper was published as a chapter of *Space Agenda 2025*, with Angie Bukley, Colleen Stover, and Victoria Woodburn serving as editors in chief. *Space Agenda 2025* is an effort by the Center for Space Policy and Strategy (CSPS) at The Aerospace Corporation to highlight and provide insights into some of the major space challenges facing policymakers. You can find the complete list of individual *Space Agenda 2025* papers at http://csps.aerospace.org/SA2025, as well as download the combined set of 16 chapters in the *Space Agenda 2025 Compendium* at https://csps.aerospace.org/papers/space-agenda-2025-compendium, all available to you with our compliments.

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THE NEXT SPACE SECURITY NORM

Robin Dickey with Michael P. Gleason (Editor)

Executive Summary

The U.S. government has led in the development of new space security norms, such as a commitment to not conduct destructive direct-ascent anti-satellite (DA-ASAT) missile tests. While it may seem incongruous to expand norm-building efforts at a time when Russia is reportedly close to launching an orbital weapon that would violate its legally binding commitments under the Outer Space Treaty, it is not too soon to consider the next major space security norm effort. This chapter summarizes the norms discussions in various United Nations (UN) bodies and proposes a set of criteria that are then applied to a series of potential norm options that the United States and like-minded nations could champion.

The selected criteria (comprising the acronym FOUR) are:

1. **Feasible.** Relevant space actors have to believe that the benefits of applying the norm proposal outweigh the costs.
2. **Observable/Attributable.** States must be able to observe and attribute behaviors related to a norm proposal.
3. **Understandable.** A norm must be understandable and definable to an appropriate level of detail.
4. **Relevant.** Security-focused norms that align with the Department of Defense (DOD) tenets of responsible behavior.

These criteria, when applied to the most commonly discussed norms topics raised at the UN open-ended working group on reducing space threats through norms, rules, and principles of responsible behaviors, lead to four candidates for the next space security norm. Each candidate shows some promise for addressing the FOUR criteria, and the next administration should pick one, or several, of these options to pursue:

- Do not intentionally produce debris (may be qualified by “significant amounts” or “long-lived”).
- Do not make physical contact (or rendezvous) with another state’s space object without consent.
- Do not interfere with critical civilian services.
- Establish security-related transparency and communication methods.

Introduction

Norms of behavior have become a major focus of space diplomacy efforts across the last decade, accelerating and increasing in intensity since 2020. Space security norms have been particularly important and challenging as more militaries develop space capabilities and a widening range of commercial space services are made available for national security activities. As tensions rise, so too does the risk of miscommunication and miscalculation that could lead to conflict in space. Norms can help alleviate some of the pressure and provide paths for deconfliction and deterrence of irresponsible or threatening behaviors. While there is ongoing debate on the merits of establishing norms through voluntary guidelines versus through binding treaties, an increasing number of countries agree that some level of common understanding needs to be built over what behaviors in space are acceptable or unacceptable from a security perspective.[1]

The U.S. government has begun efforts to lead in the development of new space security norms. In particular, the United States has championed a potential norm in the form of a commitment to not conduct destructive DA-ASAT missile tests. The commitment, which started as a unilateral announcement led by Vice President Kamala Harris, has spread to numerous other countries and to a widely supported United Nations (UN) resolution. Now, it is time to consider what the next major space security norm effort should be. This chapter discusses the history of space security diplomacy and norms discussions, explores the development of the destructive DA-ASAT test commitment, and proposes a set of criteria that are then applied to a series of potential norm proposals that the United States could champion. Although this chapter does not pick a winner from the short list of options, it provides insights and metrics that could be used to form a foundation for turning one of these norm ideas or others into a broadly accepted and internationally implemented norm of behavior.

Evolution of the Space Security Norm Discussion

Diplomatic discussions on security-related norms or treaties for outer space have long been fraught and stalemated. In the 1980s, the UN Conference on Disarmament (CD) found that discussions on the topic of Preventing an Arms Race in Outer Space (PAROS) exacerbated significant differences in the positions of the United States, Europe, and other partners and allies on the one hand, and the Soviet Union (now Russia), the People's Republic of China (China), and many developing states on the other.[2] For four decades the CD accomplished nothing of substance on PAROS, with the debate after 2000 mainly revolving around a draft treaty proposed by Russia and China on the prevention of placement of weapons in space, known as the PPWT. The United States and several of its partners and allies have continuously objected to the PPWT on the grounds that its terms are undefinable, unverifiable, and leave out key threats to the space environment such as the testing of DA-ASAT missiles.[3]

Several spinoff efforts from the Conference on Disarmament have attempted to break the deadlock and develop space security provisions of substance, such as the Group of Governmental Experts on Transparency and Confidence-Building Measures for space and the Group of Governmental Experts on Further Measures for PAROS. The former effort reached consensus in 2013 but had mixed implementation of recommendations, and the latter failed to reach consensus in 2019.[4] A new effort began in 2020, when the United Kingdom (with U.S. support) proposed and passed a resolution calling for states to submit their views on how to reduce space threats through norms, rules, and principles of responsible behavior.[5] After numerous states submitted their responses, the UN General Assembly voted in 2021 to create an open-ended working group (OEWG) on the same topic.[6]

The OEWG on reducing space threats met four times for week-long sessions in 2022 and 2023, ultimately failing to reach a consensus. The same disagreements dividing the Conference on Disarmament for decades appeared again in the OEWG, with Russia and China arguing that discussions should focus only on legally binding agreements banning placement of weapons in space, while most of the OEWG participants maintain that a focus on nonbinding norms of behavior in space would be more pragmatic and effective, at least as a first step. Other divisions and disruptions have included Russia's attempt to prevent discussion on the applicability of the Law of Armed Conflict to space and Iran's argument that the very concept of "responsible behavior" is discriminatory.[7] These disagreements ultimately prevented the group from reaching the level of consensus needed to produce a report, despite many concepts and proposed norms earning support from a majority of the participants.

Regardless of the formal outcome, the OEWG generated unprecedented discussion on potential space security norms. The findings from these discussions could be carried on in the future as the United States looks to lead and collaborate on further development of space norms.

Destructive DA-ASAT Missile Testing

Since 2022, the United States has led efforts to develop a particular norm through a combination of unilateral statements, public discussions, and multilateral engagements at the UN and the OEWG on Reducing Space Threats. The U.S. commitment to not conduct destructive DA-ASAT missile tests was announced by Vice President Kamala Harris on April 18, 2022. While encouraging other nations to join the commitment and help establish it as a norm, the vice president indicated that the commitment was the first initiative under the broader effort to "develop proposals for national security norms that advance U.S. interests and preserve the security and sustainability of space."[8] In the months following the announcement, U.S. diplomats promoted discussion on the subject at the UN OEWG on Reducing Space Threats. Many countries have since made matching commitments, including Canada, New Zealand, Japan, the United Kingdom, South Korea, Switzerland, Australia, Norway, Costa Rica, and all 27 European Union states.[9]

Beyond states directly joining the commitment, broader demonstrations of support have helped put the commitment on the path toward becoming a clear norm. On December 7, 2022, the UN General Assembly passed a U.S.-proposed resolution calling for states to refrain from destructive DA-ASAT missile testing, with 155 states voting in favor, 9 against, and 9 abstaining.[10] Three of the states that have previously tested destructive DA-ASATs did not vote in favor of the resolution: Russia and China voted against it and India abstained.[11] China, Russia, and Iran have been vocal critics of the commitment, claiming it is insignificant or a cynical attempt by the United States to block other states from developing a capability the U.S. already has, but an increasing range of international actors have indicated support. The commitment is largely recognized as a positive "first step" and not the end to the process of developing space security norms. Over 30 companies from around the world have also signed an industry statement in support of international commitments to not conduct destructive DA-ASAT tests, although many major commercial space actors have refrained from joining the statement.[12]

At the December 20, 2023, meeting of the National Space Council, Vice President Kamala Harris announced that she has directed the U.S. government to continue outreach to build further support for the commitment.[13] As this commitment builds toward the critical mass of support needed to become a norm, it is time to consider what the next major U.S. space security norm effort should be.

Selection Criteria for the Next Space Security Norm Effort

As noted above, the initial White House announcement of the U.S. commitment to not conduct destructive DA-ASAT testing said the commitment was meant to be the first initiative of a wider range of norm development efforts. So, what behaviors should be the next focus for a space security norm? Numerous states, civil society organizations, and UN reports have proposed possible criteria for norms or related concepts like transparency and confidence building measures (TCBMs). For the specific case of potential norms that the United States could champion, this chapter proposes "FOUR" criteria could be used to narrow down and compare the options:

1. **Feasible.** In order for any norm to have a chance, the relevant actors have to believe that the benefits of applying the norm proposal outweigh the costs of allowing normative constraints. So, a norm cannot be so restrictive that states feel it harms their national interests or that it would strongly motivate others to violate it, either openly or in secret. In today's context, it also means that the most likely proposals to succeed are those already featuring in discussions such as those at the OEWG on reducing space threats. Although it is rare to find overlap between

concepts that have been mentioned favorably by both the United States and its allies on one side and Russia and China on the other, those few cases where convergence seems possible have the highest potential for global political feasibility.

2. **Observable (and attributable).** If there is potential for agreement that certain behaviors are acceptable or unacceptable, states must be able to observe and attribute those behaviors in order to be able to enact incentives and deter norm violations. This metric has two parts because space actors must be able to identify (a) that the norm has been violated and (b) who was responsible for the violation. If it is impossible or highly difficult for an actor to attribute violations of the norm, states will not have the confidence to support that norm proposal for fear that others will violate it in secret in order to gain asymmetric advantage.[14]

3. **Understandable.** A concept cannot become an effective norm unless it is understandable and definable to an appropriate level of detail. This does not mean that a norm necessarily requires a highly technical or quantitative definition but that each actor participating in the norm must be able to recognize which behaviors would uphold or violate the norm. A norm proposal is doomed to fail if it revolves around a controversial or poorly defined term, where states might have strong disagreements on what the term means or nefarious actors could use ambiguity to "cheat" on the spirit of the norm while arguing that they had done nothing wrong and had remained within the letter of the norm. As a non-legally binding commitment, assessing compliance with a norm should not require lawyerly reading of terms.

4. **Relevant.** Finally, while many concepts could be ripe for development as space norms in general, for the next space security norm concept, consideration should be given to what is "in scope." Recognizing that all the major powers have now either explicitly stated that they see space as a warfighting domain or are conducting themselves as if they believe that, this analysis will only focus on norm proposals aimed at resolving security concerns during peacetime, competition, or crises in space, contexts which would feature a very different set of norms from those used if an actual war in space were to occur. The norm should also be relevant to the operations and behaviors in which the DOD is interested, and a useful metric for such a measure would be to assess whether the norm concept aligns with one of the five "Tenets of Responsible Behavior" outlined by the Secretary of Defense in 2021 and codified in the Department of Defense Space Policy. The tenets are meant to guide responsible DOD space operations but also can serve as a benchmark for the categories of potential norms in which the DOD and the U.S. government may be interested. The five tenets are:

    a. Operate in, from, to, and through space with due regard to others and in a professional manner.

    b. Limit the generation of long-lived debris.

    c. Avoid creating harmful interference.

    d. Maintain safe separation and safe trajectory.

    e. Communicate and make notifications to enhance the safety and stability of the domain.[15]

Norm proposals that fall within the scope of these tenets would be more likely to align with existing U.S. government and DOD discussions and interests, easing the path to lead norm development. Therefore, alignment with the DOD tenets is a useful measure of "relevance" for the analysis in this chapter.

Assessing Norm Options Based on the Criteria

The documents and statements submitted to the UN OEWG on reducing space threats provide a foundation for identifying space security norm options that could satisfy the "feasibility" criterion. The author reviewed nearly 200 documents in the OEWG's archive, searching for state proposals and indications of support for different norm concepts.[16] The following norm options received support from a large number and range of states relative to other concepts discussed in the OEWG:

1. Do not deliberately or intentionally produce space debris.
2. Do not make physical contact (or rendezvous) with another state's space object without consent.
3. Do not disrupt or interfere with the provision of critical space services for civilians.
4. Establish a range of communication and transparency measures.

These four norm options are analyzed below to explore how well each matches up with the FOUR criteria of feasible, observable, understandable, and relevant.

Norm Option 1: Do Not Intentionally Produce Debris. The most popular norm concept discussed in the OEWG on reducing space threats was based around the concept "**Do not deliberately or intentionally produce space debris**" or, in a more security-focused framing, "**Do not physically destroy space objects**." This would, as a norm, be an expansion of the current destructive DA-ASAT test commitment, broadening it to include all activities that produce significant amounts of long-lived debris. It also lines up with the DOD tenet "Limiting the Generation of Long-Lived Debris." Beyond the United States, nearly as many states have voiced support for this broader norm proposal as have expressed support for the specific test commitment, with almost 40 states indicating in the OEWG that states should refrain from intentionally creating debris in space. Many proponents of this concept focus specifically on the debris-producing effects agnostic to how those effects are created. Others are more technologically focused and frame the concept more narrowly and potentially more controversially internationally as being against any testing or use of destructive ASATs.

This norm proposal would be relatively easy to attribute due to the observability of many kinds of debris using current space situational awareness technologies. However, there may be challenges with defining the norm. The phrasing of the norm concept described here is written to reflect the phrasing used by states in norm discussions at the OEWG. This phrasing is quite broad and would be difficult to implement consistently as-is because some normal operations in space, such as deployment of satellites from second-stage rockets, can predictably produce some amounts of debris. This could be interpreted as "deliberate creation" of debris and lead to a number of contentious disagreements about norm application.

Finding ways to minimize or mitigate debris in normal operations is a task for space safety and sustainability norm efforts such as those articulated in the Inter-Agency Space Debris Coordination Committee (IADC) and the Committee on the Peaceful Uses of Outer Space (COPUOS) debris mitigation guidelines or the Long-term Sustainability of Outer Space Activities (LTS) guidelines. So, a more evolved phrasing of this norm would need to reflect the objective of preventing states from destroying satellites and creating indiscriminate debris as a main product or byproduct of a hostile action. One option would be to imply quantitative thresholds in the definition, such as by using the terms "long-lived" or "significant amounts" to characterize the debris. Another could focus on the production of debris through destructive acts, which is already paralleled in language such as the fourth COPUOS debris mitigation guideline: "Avoid intentional destruction and other harmful activities." Those qualifications, while narrowing the scope of a norm, may be needed to persuade states that they would not be harshly penalized for small accidents or for producing small amounts of debris during space operations.

In terms of feasibility, China and Russia have not actively opposed this specific norm idea, but they do oppose the related effort to end destructive DA-ASAT testing. That, combined with Russia's deliberate production of debris in its 2021 ASAT test does not bode well for the prospects of active Russian or Chinese support for a space security norm on debris production. However, the breadth of states and non-state actors highlighting debris as one of their main concerns in space security discussions means that this concept could achieve a critical mass of support even without Russia and China.

Norm Option 2: Do Not Make Physical Contact (Rendezvous) with Another State's Space Object without Consent. Rendezvous and proximity operations (RPOs) were a commonly targeted topic for potential norm development. While many states raised the idea of a general norm that RPOs should be conducted in a safe, transparent, and consensual fashion, the variation most in line with the norm evaluation criteria was the proposal: "**Do not make physical contact (or rendezvous) with another state's space object without consent**." This option is relevant to U.S. interests, such as the DOD tenet of "maintain safe separation and safe trajectory," but does so in a relatively narrow fashion to make it more feasible.

The concept of rendezvous—which in this context means the act of physically making contact with another satellite—is easier to define and to attribute than the concept of proximity. This is because the physics of orbital motion make it extremely difficult to reach common agreement on a quantitative definition of a "minimum safe distance" or spherical "keep-out zone" around satellites.[17] The difficulty of defining proximity means that satellite operators could get stuck in endless debates over potential norm violations and who got too close to whom, or nefarious actors could claim that their own close approaches are responsible while others' are not. On the other hand, it is much easier to observe and attribute events where one satellite approaches and makes contact with another. Current space situational awareness technology and the processes of tracking and registering satellites should make it relatively simple to identify a violation of a "no physical contact/rendezvous" norm and to determine who owns the satellite conducting the violation.

At least 33 states, including Russia, the European Union, Nigeria, the Philippines, Turkey, and the United Kingdom, mentioned grappling, physical contact, active debris removal, or rendezvous in the context of consent, while numerous other states argued for RPO consent in general that would be inclusive of rendezvous consent. This makes the proposal one of the small number of concepts that could theoretically gain support from a wide range of states with typically adversarial perspectives.

Norm Option 3: Do Not Interfere with Critical Civilian Services. Interference can be a tough topic in space security norm development. Although the DOD tenets of responsible behavior, the Outer Space Treaty (OST), and the Constitution of the International Telecommunication Union (ITU) all mention avoiding creation of harmful interference, interference of many kinds occurs frequently in space. States have long struggled with enforcing obligations related to harmful interference, raising the possibility that a norm has developed that allows activities like jamming without a strong response or condemnation.[18] One international norm proposal could fit under the category of harmful interference: "**Do not disrupt or interfere with the provision of critical services to civilians**." This focuses on prohibiting or discouraging specific targets of interference instead of regulating interference methods themselves.

A common topic of discussion at the OEWG on reducing space threats has been the potential for catastrophic effects of disruption to critical space services on which civilians rely. An example of such consequences was on public display in April 2024 when an airline had to suspend flights into Tartu, Estonia, because the airport relied solely on GPS signals for approach and landing coordination, and those signals were being disrupted.[19] The concept of prohibiting or limiting such interference with critical services was mentioned in the OEWG by 37 states, including the United States. The biggest obstacle facing this potential norm is that, in the OEWG, Russia has already been laying the groundwork to argue that satellites providing critical civilian services are a legitimate target if those satellites are also providing services to military forces in combat. Russia acknowledged that disruption to critical infrastructure for civilians is bad but blamed the companies supporting Ukraine for any interference or attacks Russia may initiate against those companies.[20] Incidentally, Russia was the state accused by Estonian officials of causing the interference affecting takeoff and landing navigation at the airport.[21]

In terms of definition, there is not universal acceptance of what constitutes a critical civilian service but neither is it as controversial as some of the other topics up for discussion. For example, positioning, navigation, and timing and other space services that enable disaster and emergency response were mentioned frequently in the OEWG as needing protection from interference. The actual behavior may not be difficult to observe since the norm hinges on noticeable disruption to key services, but it can be challenging to attribute the source of covert means of interference such as electronic and cyber.

Norm Option 4: Establish Methods of Transparency and Communication. Besides debris-producing activities, the category of norms proposals that had the most support across a wide range of states was the collective set of three proposals aimed at improving transparency and communication. Some of the norm ideas discussed in the OEWG, particularly the popular concepts of **sharing space situational awareness (SSA) data**, have crossover with norm concepts discussed in safety- and sustainability-focused organizations such as COPUOS. Others are based on existing proposed transparency and confidence building measures (such as discussions of **pre-launch notifications based on the Hague Code of Conduct** relating to missile launches and proposals that **states share national security space policies, doctrines, and strategies**) derived from the report of the 2013 Group of Governmental Experts on Transparency and Confidence-Building Measures.[22] This collective set of transparency and improved communication proposals had well over 30 states voice support, and the SSA and policy-sharing proposals were supported by both the United States and China. The DOD tenets of responsible behavior in space also feature a category dedicated to "[c]ommunicating and making notifications to enhance the safety and stability of the domain."

While those three proposals focus on the content of communications (SSA data, upcoming launch information, and policy and strategy descriptions), another important discussion revolved around how communications should be made. Because satellites are operated remotely from control stations around the world, it can be difficult to contact operators of another state's satellites in a crisis or high-intensity security concern. Therefore, numerous states have proposed **national or operator points of contact and direct channels of communication designated to address specific space security challenges**. These channels of communication and consultation could help deconflict disputes over space behavior and provide peaceful off-ramps to avoid escalation. Although these proposals were not the most popular—14 states mentioned points of contact, channels of communication, or both—they also were not particularly controversial as even the states prioritizing a legally binding arms control treaty acknowledged the benefits of some confidence-building measures. So, these norm proposals might have less momentum, but they also face fewer obstacles.

Attribution is less of a challenge for these proposals than others because it is easy to recognize whether a state is sharing information or participating in a channel of communication. Instead, the biggest challenge is getting sufficient diplomatic interest and political will. Because these norms would require states or operators to invest time and resources to establish the information-sharing or communication mechanisms, participants are needed who are willing to put in the effort and take the initiative. This means that, unlike many of the other norm proposals listed in this chapter, mere acceptance is not enough to implement communication and transparency norms. Positive action needs to be taken.

Table 1 summarizes the analysis of the four norm options and how they meet the four criteria of feasible, observable, understandable, and relevant.

Table 1: FOUR Criteria Analysis for Space Security Norm Options				
Norm Option	Feasible	Observable/Attributable	Understandable	Relevant (DOD Tenets)
Do Not intentionally produce debris	No active opposition, but Russia and China oppose related proposal	Typically observable with current SSA capabilities, often attributable	Straightforward but may need qualifiers: "long-lived" and "significant amounts"	Limit generation of long-lived debris
Do Not make physical contact (or rendezvous) without consent	Wide support, including related conceptual interest from Russia.	Typically observable and attributable with current SSA capabilities	Clear delineation using "physical contact" threshold	Maintain safe separation and safe trajectory
Do Not interfere with critical civilian services	Broad support and represents major state concern, but some opposition from Russia	Effects easy to observe, but may be difficult to attribute	Would require more discussion/definition of "critical civilian service" but not outright controversial	Avoid creating harmful interference
Establish Methods of Transparency and Communication	Broad support but requires action and resources to implement (not just refraining from specific behavior)	Easy to identify whether states or operators are following the norm.	Most terms nontechnical and straightforward to define or categorize.	Communicate and make notifications

Honorable Mention

Numerous other potential norm proposals could be worthy of investigation and discussion. Some interesting norm concepts were proposed but had fewer supporters than the four concepts analyzed in this chapter, or they appear more difficult to define or implement. However, any of the following could become the foundation of a norm development effort by the United States or other states (or even commercial space actors):

- Do not conduct operations that foreseeably or negligently produce debris (in contrast from *intentional* production of debris mentioned above).
- Do not conduct proximity operations that would impair the safe operations or force a maneuver of another satellite.
- Do not interfere with a satellite in a way that causes loss of control or permanent loss of functionality.
- Do not interfere with military satellites playing a role in nuclear deterrence and stability (missile warning, national technical means of treaty verification, nuclear command and control, etc.).

The other major category of proposals includes variations of "[d]o not develop, deploy, threaten to use, or use space weapons." This is the catch-all for the proposals led by Russia and China, mostly related to their PPWT treaty proposal. While several states expressed interest in various facets of the discussion on banning different types of space weapons or activities related to deploying or using them, the category as a whole did not receive particularly broad support in the OEWG relative to other norm proposals.

However, many of these topics will likely be raised in the Group of Governmental Experts (GGE) on further measures of preventing an arms race in outer space that started meeting in 2023.[23] This might lead to a further bifurcation of space security diplomatic discussions, with China, Russia, and their partners promoting their preferred approach in the GGE and the group of states interested in norms of responsible behavior convening in the OEWG or other follow-on efforts.

Conclusion

This analysis did not focus specifically on which of the four potential norm proposals would be in the best interest of the United States to promote. A wide range of factors would go into such an assessment, and ultimately the United States does not need to pick a single option. Many norms will be needed to ensure the security and stability of the space domain, and each norm proposal may need to be approached in a different manner or use different diplomatic mechanisms.[24]

However, each of the four concepts has the potential to both make a positive impact and to be accepted by enough of the international community to constitute a norm. A norm against intentional production of long-lived debris could help reduce activities that would make the space environment unusable, and a norm requiring consent for rendezvous operations could set a baseline for minimizing behaviors that could be interpreted as highly threatening or escalatory. A norm against interference with critical civilian services could help ensure that security-related actions in space do not have catastrophic consequences on Earth. Any number of the transparency and communication norm concepts could help build confidence and reduce miscalculation and misunderstanding. If the U.S. government wants to take a strategic approach to norm development, looking at multiple steps into the future, senior leaders should consider now whether these ideas should form the basis for the next space security norm development effort.

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This paper was published as a chapter of *Space Agenda 2025*, with Angie Bukley, Colleen Stover, and Victoria Woodburn serving as editors in chief. *Space Agenda 2025* is an effort by the Center for Space Policy and Strategy (CSPS) at The Aerospace Corporation to highlight and provide insights into some of the major space challenges facing policymakers. You can find the complete list of individual *Space Agenda 2025* papers at http://csps.aerospace.org/SA2025, as well as download the combined set of 16 chapters in the *Space Agenda 2025 Compendium* at https://csps.aerospace.org/papers/space-agenda-2025-compendium, all available to you with our compliments.

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STRENGTHENING A SOLID FOUNDATION: U.S. ADVANTAGES FROM COMMERCIAL SPACE

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Executive Summary

The commercial space economy is growing and increasingly driving new space-based capabilities. U.S. government (USG) actions, during the Cold War and after, created a vibrant commercial space industry that still leads internationally. However, the space domain is undergoing rapid changes and great power competitors seek to overtake the United States and/or threaten the nation's space capabilities. This chapter describes the current competitive state:

- Revenue from commercial space activity exceeds global government space spending, though it is still sustained by government demand
- The U.S. industry is leading in global market share
- Commercial innovations underpin/drive many new space capabilities
- The People's Republic of China (China) is fusing its military and civil efforts to rapidly grow its domestic space capability
- The Russian space industry is in comparative decline, and Russia may seek asymmetric advantages
- The European Union competes for a global market share and is generally a security ally

Using a strategic planning framework, this chapter examines several current or potential USG strategic actions. The analysis explains the value of leveraging the domestic commercial industry for national security. Strategic actions the United States might take that build on existing strengths, like domestic capacity and innovation pipelines, appear particularly advantageous going forward. The U.S. Space Force's commercial space strategy, for example, can create a positive feedback loop likely to outcompete rivals. Potential actions to reform import and/or export controls require more careful consideration; depending on how they are implemented, they can either strengthen or weaken the current U.S. position. The framework and initial analysis provide a starting point for more robust strategic planning to sustain future U.S. leadership in space.

Introduction

Space capabilities in the United States today are created primarily by the labors of the private sector, even if substantially funded by the government. While the share of government space funding that goes to private contractors has declined since the 1990s, the private sector role has expanded beyond just contracted research and production to include private sector-led capabilities developed and sold on a commercial basis to both government and private customers. As a result, private industry investments are growing drivers of new space capabilities. While total private financing for space activities is volatile, the long-term trend suggests that in this new Space Age, commercial capacity and innovation will be linchpins of enduring U.S. space power.

Seeing this trend, in 2014, the People's Republic of China (China) began fostering private space companies, including to fulfill military contracts.[1] Other militaries, including Russia's, have moved beyond dual use to direct buys of commercial space capability.[2] Based on recent public assessments, Russia[3] and China[4] recognize and are looking to counter the United States' commercial space industry advantage,[5] while the U.S. government (USG) is looking for opportunities to increase it.[6]

This chapter will use a long-standing strategic planning framework to explain the importance of several current USG strategic actions in the context of great power competition in the space domain. Starting from a deeper understanding of the growing importance of commercial space capability and U.S. competitor responses to that condition, the framework creates a context for evaluating the utility of USG actions. In this chapter, only an initial analysis is made. Future work should evaluate a broader set of competitive factors and alternative actions and regularly monitor for critical changes in the circumstances assessed.

Current U.S. Space Leadership by the Numbers

Estimates for the size of the global space economy in 2023 range from $400 billion to $630 billion.[7] To be clear, global government spending on space capability still underpins the space economy. The data and trends show that the commercial markets expanded from that base are an accelerating force. The United States captures the single largest share of the global space market, which, in one previous estimate for 2023, was 37 percent ($148 billion).[8] Among other areas, U.S. industry leads in revenue from:

- Manufacturing of spacecraft (46 percent of global market)
- Launch services (54 percent of global market)
- Ground equipment (32 percent of global market for antennas, networking, system operations, user equipment, and 2 of the 5 leading equipment makers)[9]

How Did the United States Get Here?

Prior USG policies and funding fostered the U.S. space industry leadership. High levels of investment in the context of Cold War competition left the United States in a strong global position after the collapse of the USSR. Through the 1990s, the USG continued to be a heavy space buyer, mostly from domestic sources. Meanwhile, a second factor was at work: the USG increasingly pursued policies that expanded the domestic space industry and markets, likewise encouraging robust private investment. While companies seeking to go further and faster were often dissatisfied with USG positions and processes, some key USG decisions include the licensing of radio-frequency (satellite) spectrum to commercial entities, competitive (at least dual source) national security launch, public provision of Global Positioning System (GPS) signals, relaxation of remote-sensing rules, commercial crew and cargo contracts, and research/development contracts to diverse suppliers (especially using flexible contracts* such as Other Transaction Authorities[10]).

Threat, Opportunity, Weakness, Strength (TOWS): A Framework for Analysis of Future Strategies

Given the ongoing growth of the global space economy and the success of the United States so far, both competitors and allies are reacting by taking strategic actions to improve their domestic space capability. This includes smaller nations outside the G20.[11] The USG would be unwise to rest on its laurels and should develop a forward-looking strategy to maintain its advantages.

In that U.S. endeavor, a simplified TOWS analysis can aid strategic planning. As proposed in 1982,[12] the TOWS approach looks at how extrinsic factors can be addressed by intrinsic (existing) strengths or weaknesses. Figure 1 illustrates how a TOWS matrix is used to identify potential actions. A strategy is built selecting several actions, not a single entry nor using only one quadrant. Some readers might be more familiar with Strengths, Weakness, Opportunities, Threats (SWOT).† Beyond putting intrinsic factors first, SWOT analyses tend to focus on identifying and categorizing factors of importance for a strategy without considering the dynamic interaction of internal decisions and external conditions (or decisions).[13] The TOWS approach illustrated here, derived from the 1982 paper, moves from brainstorming to a structured analysis.

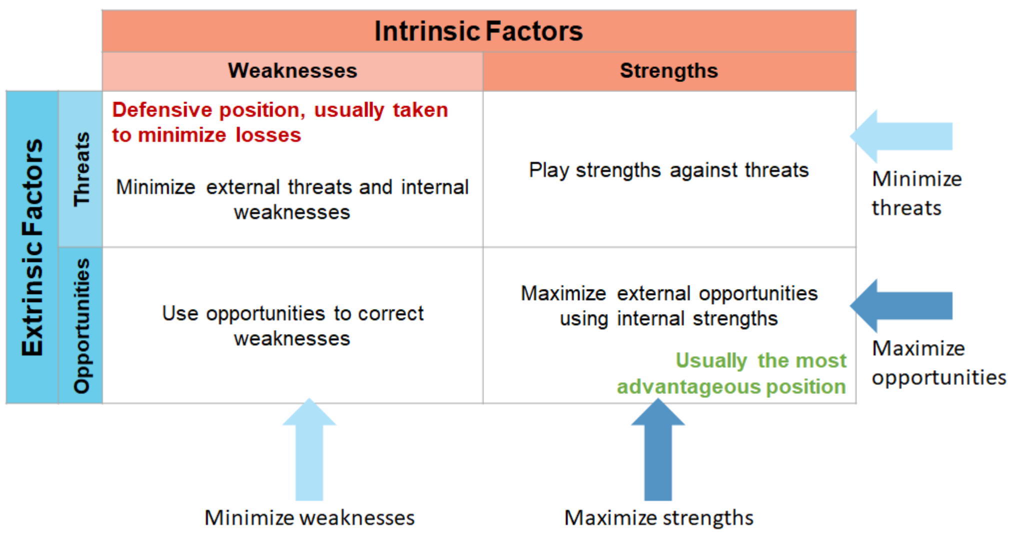

Figure 1: The general structure of a TOWS analysis.

It should be emphasized that TOWS is useful for analyzing options at a moment in time. The transforming space domain is characterized by volatility, uncertainty, complexity, and ambiguity. Additional tools, such as foresighting, should be used to know when a TOWS analysis needs to be reevaluated.[14]

Development of a fulsome U.S. competitive strategy is beyond the scope of this chapter, but it is feasible to look at a few current or potential U.S. strategic actions. Generally, the most advantageous actions are found in the lower right quadrant of Figure 1 (maximizing strengths and opportunities) and the least advantageous in the upper left (minimizing weaknesses and

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*From the DOD guidebook on the subject (2023): "The OT authorities were created to give DoD the flexibility necessary to adopt and incorporate business practices that reflect commercial industry standards and best practices into its award instruments. When leveraged appropriately, OTs provide the Government with access to state-of-the-art technology solutions from traditional and non-traditional defense contractors (NDCs)."

†Strengths, Weakness, Opportunities, Threats (SWOT) is a reordering of the same items evaluated in a TOWS matrix.

threats). This chapter will review at least one action in each quadrant, beginning with the most advantageous, as shown in Table 1.

Table 1. Strategic Actions Considered Herein

		Intrinsic Factors	
		Weaknesses	**Strengths**
Extrinsic Factors	**Threats**	◆ **Possible Action F:** tighten controls to mitigate innovation theft and supply chain threats *[minimize T, minimize W]*	◆ **Current Action D:** deter by increasing combat readiness ◆ **Possible Action E:** intermingle global supply chains with foreign competitors *[minimize T, maximize S]*
	Opportunities	◆ **Current Action C:** improve acquisition processes to better leverage commercial capacity *[maximize O, minimize W]*	◆ **Current Action A:** accelerate use of commercial solutions by USG ◆ **Current Action B:** expand use of modular open systems approaches (MOSAs) for space *[maximize O, maximize S]*

A full analysis of these actions, including their placement in Table 1, requires an enumeration of the TOWS factors. For the purposes of an initial analysis, two U.S. strengths are critical and have already been mentioned: U.S. firms globally lead in space innovation and the U.S. space industry leads in production capacity. One opportunity has also been mentioned: growth in global, commercial space demand. Validating those factors and identifying other important factors requires a more detailed assessment of the global landscape.

Opportunities Created by the Growing Commercial Space Industry

Today, commercial space activity generates more revenue ($261 billion from satellite services and consumer equipment) than twice the global government space spending combined ($114 billion).[15] Private investment in space has accelerated; venture capital investments across the space sector ($30 billion within the United States since 2021)[16] are outstripping USG space technology investments. And increasingly, engineers are introducing non-space innovations to spacecraft, such as graphics processing units, lithium-ion batteries, and 3D-printed parts.

The growth of the commercial space industry was driven by the creation of markets and provision of value-added services. The first commercial space activity was Intelsat 1, which launched in 1965[17] and created a global telecommunications market in the space domain (though Intelsat remained owned, managed, and subsidized by governments until 2001).[18] Fully commercial satellite operators arrived in the 1980s, with PanAmSat in 1984 being the first fully commercial satellite telecommunications provider. Orbital Sciences, now Northrop Grumman, launched the "world's first privately developed space launch vehicle" in 1990.[19] And the first non-communications commercial spacecraft, IKONOS, launched in 1999.[20] Today, mobile wireless devices using satellite position and timing services are pervasive, and commercial space services have become central to the ongoing conflict in Ukraine.[21]

The accelerating importance of commercial space capabilities can be summarized by looking at changes in space activities over time, as shown in Figure 2, using the three "ages" articulated by former U.S. Space Command Deputy Commander Lt. Gen. John Shaw.[22] The first age roughly corresponds to the Cold War period (1957 to 1991). The second age saw large growth in satellite communications revenue and U.S. space agencies initiating use of commercial fiber networks. Today, a third age has begun, wherein commercial enterprises lead throughout space system lifecycles. The size of the circles roughly corresponds to the size of the global space market, adjusted for dollar inflation.[23]

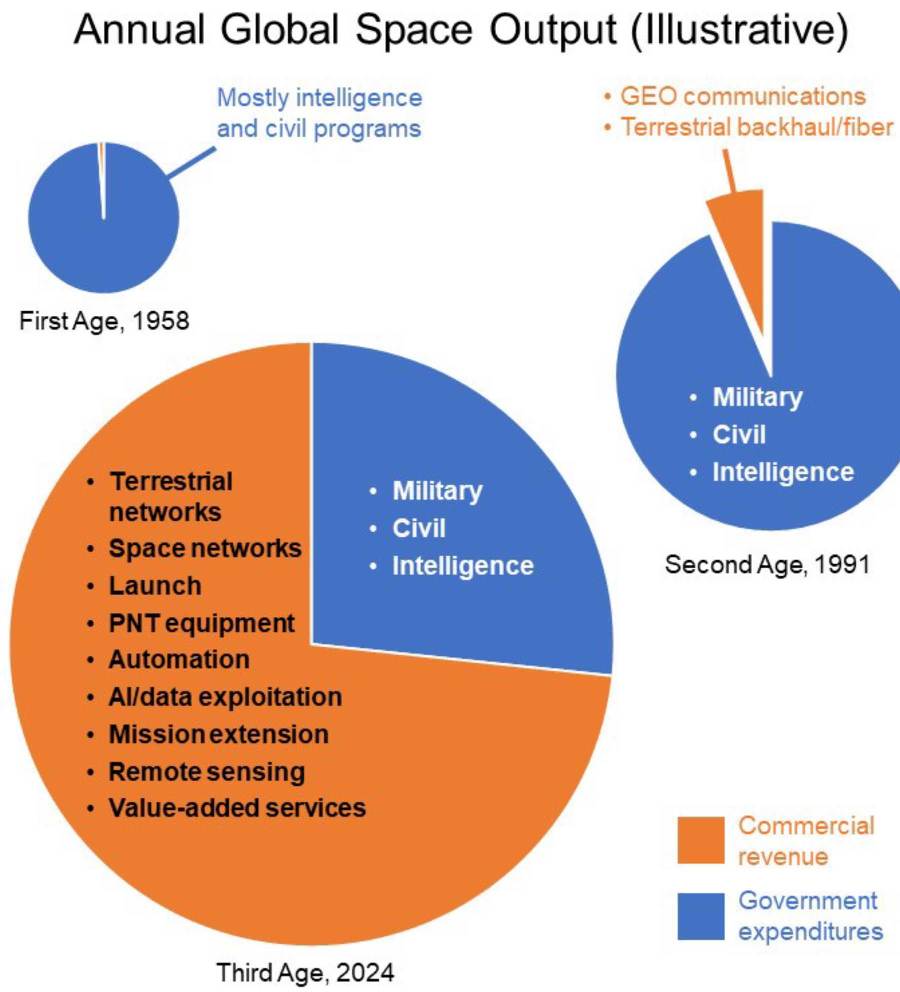

Figure 2: Rough illustration of changes in global space activity.

Figure 2 also provides a visual validation of two key opportunities: first, that the global space demand for commercial space capability is significant and growing, and second, that the growth was in part created by commercial innovations satisfying government needs. The accelerating trend is to be expected as growing demand fuels more innovation. Consider, for example, that commercial tools for cyber monitoring are state-of-the-art, Intelsat has bought the first orbital mission extension service from SpaceLogistics LLC, and private/venture capital is speculating on future markets from mining to disposal services.

In this context, the U.S. Space Force's strategy is to "wherever possible, … leverage the use of commercial space solutions and integrate them into its architectures and force offerings,"[24] including to create decision-quality operational planning products for combatant commands.[25] This is what was referred to as Action A, an accelerating use of commercial production, services, and innovation in USG space activities. Similar actions are seen in NASA's ongoing commercial crew and cargo procurement programs, and the National Reconnaissance Office's (NRO's) Electro-Optical Commercial Layer contracts. These actions play foremost to the opportunity presented by ongoing growth of the commercial space industry, enticing further private investment. They also leverage commercial progress up the value chain, including innovations created by commercial interests. Using these opportunities to increasingly satisfy USG space needs further incentivizes domestic commercial innovation and strengthens the United States' ability to outproduce competitors, creating a positive feedback loop.

USG Challenges in Leveraging Commercial Opportunities

Despite success in building up the world's leading space industry, the USG occasionally struggles to leverage commercial opportunities. Obviously, there are many space-based capabilities for which governments are the only consumers; for example, there is no commercial market for nuclear attack warning sensors or survivable communication systems. Conversely, the commercial space industry will not idly innovate solutions for which the government has not signaled a need. Historically, the USG has had to direct many developments and establish elaborate monitoring and contracting processes to sustain a competitive supplier base. But, even when commercial solutions might directly suffice, the USG is known for effecting slow budget, planning, and development processes that can challenge even established USG suppliers.[26] These challenges can be weaknesses in international competition.

There are several USG actions underway attempting to better leverage opportunities. One such action is expanded use of the modular open systems approach (MOSA) for space procurements (see Table 1, Action B). In 2019, each of the service secretaries identified MOSA use as a warfighting imperative.[27] It has been challenging to adopt the MOSA in the space domain, but the Space Development Agency's (SDA's) acquisition plan is an active example. The SDA's spirals are incremental developments, with its cycles moving faster than several USG planning processes. To shape development and sustain competition, the SDA manages interoperability standards across its procurements to create interchangeable architecture modules: tranches of spacecraft that can fuse data into ground support systems or end users.[28] The MOSA also eases the path for inserting new innovations, whether developed directly by the SDA or coming from elsewhere. In this way, the SDA's MOSA harnesses growing commercial opportunities and the strength of the U.S. commercial space sector while working within (and/or despite) existing weaknesses.

The USG is also acting to directly reduce weaknesses. For example, the Office of the Assistant Secretary of the Air Force for Space Acquisition and Integration has published space acquisition tenets[29] to mitigate weaknesses in current U.S. Space Force practice (Action C). While the tenets do not specifically call for usage of commercial capability, they include use of existing technology, shorter development timelines, effective contracting, avoiding overclassification, and holding industry accountable for the contract. Those first two items are enabled by commercial opportunities and strengths; the other items seek to correct slow or inefficient USG activities.[30]

International Responses

How China Is Responding to the New Space Age. Seeing the strategically significant results of U.S. actions to improve and leverage the U.S. domestic space industry, China is working to build its own commercial capability. In 2017, the People's Republic of China State Council made the strategy explicit, identifying a need to "accelerate the overall planning of space infrastructure according to the needs of the military and civilian sectors."[31] Reportedly, "[Chinese] State-media often cites data showing that in the United States 85% of the military's core technology comes from the private sector and 80% of firms that supply the U.S. military also sell commercially."[32]

The U.S.–China Economic and Security Review Commission assessed in 2019 that "China seeks to become a peer in technology and status of the United States in space."[33] Further, the Commission points to sources arguing that China's 2014 decision to open its space industry to the private sector was "part of Beijing's push for military–civilian fusion, a strategy to leverage key dual-use industries such as aerospace, aviation, and automation to give China an edge in its competition with the United States." The 2020 Commission report highlighted that, "As a reflection of China's military–civil fusion policy, PLA [People's Liberation Army] end users work closely with SASTIND [State Administration of Science, Technology and Industry for National Defense] and defense industrial enterprises in managing space systems RD&A." China's consolidated military space organization "rely upon state-owned defense industrial establishments for research, development, and manufacturing of space systems."

China's strategy is not just about using commercial companies to build dual-use capability in case of a conflict. China's strategy also leverages governmental capabilities to open the door to commercial investment as part of its broader geopolitical strategy. The BeiDou Navigation Satellite System, for example, is an integral part of its Belt and Road Initiative of international outreach and market development. China has regularly sought to partner with other nations on civil/crewed space projects. China's national security has directly benefited from the growth and success of companies like Huawei and ZTE Corporation.

China still has a way to go in its military–civil fusion. In a survey of China's nascent commercial space industry, the Institute for Defense Analysis found, "When queried about their future, the companies in the database indicated a desire to be Chinese versions of American space companies. They believe their customers will be those that American companies cannot serve or are not interested in serving."[34] The same report notes, "Most companies do not even have business plans or a strong sense of who their customers might eventually be." However, a Council on Foreign Relations author observes, "Chinese leadership has long used market forces to reform state-owned defense conglomerates with mixed results… Nevertheless, China's leadership has marshaled an enormous amount of organizational energy to turn China's military into a technologically advanced fighting force through civil–military fusion—it would be unwise to write this effort off."[35] A 2023 report to Congress stated, "China is already a world leader in missile and space technologies, and tighter U.S. export controls are unlikely to have an effect on future Chinese innovation in these areas."[36]

China's response highlights one key threat for a TOWS analysis (see Table 1): competitors are growing their domestic space capabilities, and they will seek to exploit global commercial space opportunities. It also suggests another competitor threat: increasingly effective attack vectors against U.S. space capability (non-lethal, lethal remote, kinetic, nuclear, and cyber). China's civil-military fusion strategy could be considered a third threat: competitors using centrally managed space development and planning. This third threat is notable when contrasted with the United States' strength in using competitive market forces to obtain innovation.

How Russia Is Responding to the New Space Age. In stark contrast with China, Russia's strategy for benefiting from domestic space activities and countering the United States' commercial space industry advantage is unclear. One prominent Russian researcher believes, "Russia has inevitably chosen an asymmetric approach to countering U.S. space capabilities."[37] Russian domestic space capability is in decline. During the decades of the Cold War, the Soviet Union regularly launched more than 100 spacecraft a year.[38] But in 2023, Russia launched only 19 spacecraft in total (across all orbits and missions). More recently, Russia was the global leader in space launch capability;[39] today, Western sanctions for Russia's invasion of Ukraine have left Russia out of Western launch contracts, and other nations are increasingly flying on native or non-Russian vehicles.

Russia reorganized its space industry with the re-creation of ROSCOSMOS in 2015, in what some consider a widescale nationalization.[40] Russia's space economy appeared profitable on the basis of launch sales alone prior to 2014, but ROSCOSMOS has had a net loss of $1.6 billion from that reorganization through 2023.[41] Apparently feeling the initial nationalization was insufficient, the agency's director in 2022 called for further national control and ownership of critical satellite component manufacturers.[42] Later that same year, the director was replaced with a deputy from the Ministry of Defense, annual budget reductions of more than 10 percent were introduced, and "funding for scientific research and development was zeroed out entirely."[43] A 2023 assessment concluded that Western sanctions (financial and technical) were further eroding Russian domestic space capability, leading to "a quicker shift towards self-isolation" and "deeper and more integrated incorporation [of its space industry] into the military program."[44, 45]

Russia retains deep technical capability in space, a legacy of its Cold War prowess and ongoing strategic investment synergy with nuclear and tactical force needs (i.e., technology and production for Russian missiles, drones, or terrestrial electronic warfare has high crossover with that needed for space systems). Russia is engaged in several international partnerships leveraging those strengths. For example, in 2019, President Vladimir Putin announced that Russia was assisting the Chinese in developing early missile warning systems, including a $60 million software contract.[46] Russian leadership statements on the need to improve domestic space supply chains and organization of its industry under ROSCOSMOS' leadership suggest that Russia is focused on leveraging its legacy space strengths with a *limited* commercial market.

If this chapter is correct in its assessment that integrating commercial innovation forces is a technology-accelerating approach, Russia is likely to fall further behind each year. Nonetheless, Russia can clearly threaten U.S. space capability, and it clearly believes that central organization of its space industry under ROSCOSMOS has advantages.

European Responses to the New Space Age. A look at the United States' allies in Europe provides further insight. In the 1980s, the European Space Agency coordinated investments that helped create globally competitive space and launch system prime contractors. Today these contractors directly compete with manufacturers in the United States, Russia, China, Japan, India, and a growing number of other nations. European manufacturers are global leaders in some technology sectors. In 2019, the European Investment Bank published a report on the future of the European space sector, which argued for "fostering investments and an entrepreneurial space ecosystem in Europe."[47] Among other steps, the report focused on market demand and recommended deployment of "innovative pull mechanisms from the public sector," (i.e., following the United States' lead of leveraging commercial capability for government space needs). In 2020, the European Space Policy Institute (ESPI) largely matched those recommendations in assessing Europe's strategy in a global context.[48] Notably, the ESPI report identifies three goals that collectively emphasize the importance of Europe's commercial space capability: "maximise the integration of space into European society and economy … foster a globally competitive European space sector… ensure European autonomy in accessing and using space." That third goal ties commercial space capability back into national security. Most significantly, the 2023 "European Union (EU) Space Strategy for Security and Defense" states:

> "The European Commission will stimulate New Space to scale up in the EU with the support of the CASSINI programme‡. This will include a more systematic development of anchor-customer contracts, further mobilization of grants-loans-equity with the support of the European Innovation Council, the European Investment Bank, the European Investment Fund, synergies with the EU Defence Innovation Scheme, and the organisation of space/defence hackathons and challenges on a yearly basis. The Commission will incentivize more collaborative work between space, security and defence start-ups in the areas of research and development."[49]

The European example further validates the threat of direct competition for leadership. Europe is already a peer competitor in the global space economy. Adding information for the lower half of Table 1, U.S. allies also see opportunities created by space demand growth and by commercial innovation. The short discussion above also identifies a third opportunity: as "compete-mates" (market competitors but security allies), allied space capability is growing, and they are willing partners in addressing shared security concerns.

How Do Current U.S. Actions Address Competitive Threats?

Central to understanding Chinese, Russian, and European responses to the third Space Age has been a comparative evaluation of the U.S. commercial space sector against those nations' commercial space sectors. This emphasizes the identified U.S. strengths of domestic commercial innovation and leading production capacity, but also identifies several threats to ongoing U.S. leadership. The global space economy also provides opportunities for the United States to become

‡CASSINI is the European Commission's 2021 to 2027 initiative to support entrepreneurs, startups, and subject matter experts in the space industry, including New Space.

stronger but alternatively, to be surpassed by its competitors. Actions A, B, and C focused on seizing opportunities, but the United States is also taking actions against competitive threats.

Most apparent, the United States seeks to deter competitor aggression by increasing combat readiness of U.S. military systems (Action D). Based on both dollars appropriated[50] and rhetoric from national security leadership, this appears to be the main thrust of the USG's current strategy. Within combat readiness, one could separately consider U.S. system resilience and U.S. counterspace capability. In either case, the United States' current strong, innovative commercial space industry is providing advantages from reliable low-cost launch capacity to innovative data processing and network resilience. However, combat-ready space systems must incorporate elements that are not of commercial interest. Thus, to keep the United States' strengths in play, preferred resilience strategies[51] for space have been disaggregation, distribution, diversification, and proliferation through inclusion of dual-use capability.

To mitigate competitive space threats, the USG has long pursued export controls. The TOWS framework suggests two divergent paths forward in this regard. One path could be to continue with a focus on competitive threats, from import (supply chain) attack vectors to export of capability, shoring up U.S. weaknesses to those threats (Action F). The alternative path (Action E) could be to lean into domestic strengths by *relaxing* import/export restrictions. This novel, alternative action might seem infeasible to casual observers of U.S. foreign relations in recent years. Over the last decade, U.S. administrations have consistently tightened restrictions on trade with both China and Russia, especially for high technology and space equipment. However, decisions focused merely on rising competitive threats ignore domestic strengths that can undermine competitors and/or strengths that can be weakened by a purely reactionary strategy. For example, a recent article in *International Security* argues, "Structural incentives to cut off a rising power's access to global supply chains can trigger a process that ultimately accelerates the dominant power's decline overtime."[52]

Given that the United States' current space capabilities are often superior, especially in the commercial sector, availability of U.S. products could undermine competitor commercial development strategies. And while U.S. exports could help competitors rapidly copy/match U.S. capabilities, they can also be targeted (and monitored) to specific ends. Copying globally available capability keeps competitors constantly one step behind the United States, while the nation's innovation engine is primed by expanded demand. Specifically, if targeted in areas where technology is globally mature but Chinese competitiveness lags, the action could protect critical U.S. capability while undercutting Chinese private/local production investment, creating dependencies and/or disrupting China's development. Pursuing Action E would require significant changes to export/import regulations and law (e.g., the Wolf Amendment), which themselves are often identified as a U.S. competitive weakness. Steps in this direction are already underway. In October 2024, building upon responses to proposed rule-making announcements in 2019, the Commerce Department's Bureau of Industry and Security announced completion of a rule-making action reducing export controls on space technology for the closest U.S. allies, as well as preliminary action to relax rules for a much broader range of countries and the movement of responsibility for many space-related technologies from the State Department to the Commerce Department. Action E can also be an effective competitive strategy on its own. In the development of "5G" communication technology, China appears on a course much like Action E.[53] Circumstances seem well aligned for the United States to pursue a similar path in the space domain.

Other Considerations

The discussion to this point has primarily used the TOWS matrix as a framework, or lens, through which to understand the interaction of USG actions with their strategic context. A few actions have been characterized with broad strokes, but their analysis is limited to only a few, first-order considerations. The framework provides for a more thorough evaluation through consideration of additional TOWS factors and by consideration of the interplay of multiple potential actions. Moreover—volatility, uncertainty, complexity, and ambiguities (VUCA) are inherent in this dawning third Space Age. The VUCA aspects can be addressed by repeating the analyses over a range of factors and using tools like foresighting to identify and monitor conditions that necessitate reconsideration.

Conclusion

The United States' commercial strengths and opportunities are a significant advantage economically and in great power competition in the space domain. Prior decisions by USG space agencies have placed the U.S. industry in a leadership position today. And because of ongoing commercial space economy growth, industry can be expected to drive many new capabilities and underpin or provide dual-use national space power. Strategic actions that the United States might take that build on its existing strengths, such as domestic capacity and innovation pipelines, appear particularly advantageous going forward. There is a mix of actions that the United States can take that both leverage opportunities and are directly aimed at competitive threats or apparent weaknesses.

The United States' great power competitors are clearly aware of the advantages the United States already has in space. They seek to counter them while building up their own industry. A few current U.S. actions were evaluated using a simple framework (TOWS), which also aids in identifying other options. Three current actions all play to U.S. strengths: (Action A) increasing commercial usage/integration; (Action B) applying MOSA; and (Action D) deterrence through building resilient and counterspace systems. A fourth current action (Action C), described as improving acquisition practices, seeks to minimize USG weaknesses. A novel action (Action E) would be to target expansion of U.S. space industry into foreign markets, especially in China. This could play to U.S. strengths and opportunities and potentially undermine several of their threat vectors. In contrast to Action E, a sixth (Action F) was considered to further tighten import and export regulations, focused on perceived U.S. weaknesses.

Further strategic actions, or the same actions in more detail, could be considered and in combination with each other. This chapter provides only an initial analysis. Adding more TOWS factors and expanding the evaluation of competitive actions would yield a fulsome strategy. Any strategy should be paired with ongoing foresighting to ensure that the analysis remains relevant in today's rapidly changing space domain and global competitive environment.

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This paper was published as a chapter of *Space Agenda 2025*, with Angie Bukley, Colleen Stover, and Victoria Woodburn serving as editors in chief. *Space Agenda 2025* is an effort by the Center for Space Policy and Strategy (CSPS) at The Aerospace Corporation to highlight and provide insights into some of the major space challenges facing policymakers. You can find the complete list of individual *Space Agenda 2025* papers at http://csps.aerospace.org/SA2025, as well as download the combined set of 16 chapters in the *Space Agenda 2025 Compendium* at https://csps.aerospace.org/papers/space-agenda-2025-compendium, all available to you with our compliments.

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WHY TRANSFORMING THE BUDGET STRUCTURE WOULD BENEFIT DEFENSE SPACE

Robert S. Wilson, Jamie Morin, and Lara Sayer

Executive Summary

The Department of Defense (DOD) uses a top-level budget structure no longer befitting of how complex systems are developed and produced. Although industry has largely evolved to fluid development and production, the DOD's Planning, Programming, Budgeting and Execution (PPBE) process still categorizes defense acquisitions as either (1) research, development, testing, and evaluation (RDT&E) or (2) procurement. This division poses challenges for acquiring space capabilities, particularly as the department transitions to larger numbers of iteratively designed systems and commercially owned assets and services.

In March 2024, a congressionally directed commission on the PPBE process recommended that the DOD work in consultation with Congress to transform the defense budget structure to favor major capability areas over lifecycle phases. The DOD has endorsed many of the near-term recommendations of the commission but is still exploring the longer-term ideas like budget transformation. For space, this could look like requesting and receiving funding in categories such as missile warning and tracking, narrowband satellite communications, or positioning, navigation, and timing instead of RDT&E and procurement.

Table 1: Current and Proposed Budget Structure

Current Structure	Proposed Structure
Lifecycle Phase (e.g., RDT&E or Procurement)	Service/Component
Service/Component	Major Capability Activity Areas
Budget Line Item	System/Program (Budget Line Item)
Project	Lifecycle Phase

Source: "Defense Resourcing for the Future," Commission on Planning, Programming, Budgeting, and Execution Reform (March 2024).

Such a change would offer significant benefits for national security space systems, including giving Congress better insight into how much funding is going toward specific capability areas and aligning budgetary decisions with force structure analyses. As noted often by Congress and the DOD, the United States is in a period of intense global competition, and improving defense acquisition would better prepare the nation to defend its global interests.

Introduction

The Department of Defense (DOD) requests and receives funding through a top-level budget structure that has largely remained intact for more than 60 years, albeit with increasing segmentation at lower levels. Although the DOD's acquisition processes and practices for technology and product development have undergone many changes over those decades, the two primary budget categories used for defense acquisitions have been remarkably consistent: research, development, testing, and evaluation (RDT&E) and procurement.[1] The DOD's reliance on these two appropriation categories continues, even as the private sector has largely evolved to a more fluid, iterative approach to development and production.

While drawing precise distinctions between RDT&E and procurement can be difficult for many types of defense acquisitions, it has been a particular challenge for space acquisitions. The RDT&E/procurement distinction quickly breaks down when applied to complex, expensive development projects that result in small numbers of systems, especially when the system design changes from one unit to the next. Few of the DOD's spacecraft programs have entailed large-scale production runs, and it is common for even satellites with the same name in the same constellation to differ from one another at a component level. In contrast, acquisition programs that result in high production volumes of similar or identical units fit more neatly within the existing appropriations categories. For munitions acquisitions as an example, RDT&E appropriations buy 10 percent of the total expected purchase as test assets, and—once the design is finalized—procurement appropriations buy hundreds, thousands, or millions of rounds to complete the remaining purchase.

The department is changing the types of space capabilities and services it seeks to acquire. Instead of relying on a small number of custom-built satellites mostly in high-altitude geosynchronous Earth orbits, the department is seeking to buy large numbers of cheaper and smaller space assets across a diversity of orbits. A central principle of these programs is to rapidly iterate on designs, further blurring the lines between how they should be funded. Further, given the maturity of some commercial space providers, the DOD is aiming to leverage commercial services to a greater extent. These changes are valuable and necessary, particularly given the threat environment for space; however, they will further stress the existing budget structure even beyond the challenge of navigating the RDT&E/procurement divide. To enable, among other things, faster delivery of military capabilities and more flexibility for meeting defense needs, policymakers should consider transforming the DOD's budget structure, which will deliver specific benefits for future space acquisitions.

How the Current Budget Structure Challenges DOD Space Acquisitions. The Fiscal Year 2022 National Defense Authorization Act directed the establishment of an independent commission to "conduct a comprehensive assessment of the efficacy and efficiency of all phases and aspects of the planning, programming, budgeting, and execution [PPBE] process."[2] In March 2024, the PPBE Commission released its final report with 28 recommendations.[3] Among these recommendations, the commission recommended transforming the DOD's budget structure. Although this change would be beneficial for many parts of the department, it would produce a particularly powerful effect for national security space.

As noted, determining when RDT&E ends and procurement begins has been a persistent challenge for defense space acquisitions. For space systems, the DOD's Financial Management Regulation states that when satellites are launched individually, the "first two satellites may be financed with either RDT&E or Procurement appropriations" and the "third and subsequent satellites shall in all cases be financed with Procurement appropriations."[4] However, for programs in which a single rocket launches multiple satellites, all of the satellites on that launch may be financed with "either RDT&E or Procurement appropriations depending upon which budgetary approach is most consistent with the contract structure."[5] Accordingly, a launch vehicle's capacity and the size of the spacecraft would weigh heavily on whether they are funded through procurement or RDT&E.

This separation between the first two satellites and the subsequent satellites, along with the high cost of nonrecurring engineering for redesigning large, monolithic satellites, has limited the DOD's ability to change designs for satellite programs in acquisition. Satellites in programs such as Advanced Extremely High Frequency, Space-Based Infrared

System, and Global Positioning System remained mostly static due in part to PPBE rules. Only in recent acquisitions has the DOD been able to return to more incremental design changes, bending rules to address changing threats.

The department's plans to modernize its military space capabilities will further test the limits of the current budget structure. A priority within the department, as reflected in the statements from leadership and in the budget, has been the transition to large numbers of smaller satellites.[6] For example, the Space Development Agency's budget has increased significantly over the five years since it was created.[7] Although the Space Development Agency is not only the acquisition center trying to acquire lots of space assets, it is perhaps most emblematic of the transition towards proliferation. The agency's top priority, as an example, is the Transport Layer, which it says will comprise 300 to 500 communication satellites in low Earth orbit. On its face, a transition from handfuls of satellites to hundreds of satellites could be taken to make the distinction between research and procurement sharper. However, spiral development, a systems development lifecycle method that relies on iteration and incremental improvement, has guided the agency's acquisition approach, and under this approach, hardware and software design will continuously evolve and development and procurement efforts will happen concurrently.[8] As evidence, although the agency has launched dozens of satellites and is funded to launch hundreds more over the next several years, it does not have a procurement funding line for its spacecraft.

Agile and fluid development is becoming more of the norm for space systems, even outside the Space Development Agency. Digital engineering allows for virtual modeling and testing of different hardware and software configurations to streamline acquisition, and new development methodologies enable faster capability deliveries and user feedback loops. Collectively, defense space acquisition benefits from these developments and models, and their ascendance shows that research, development, testing, evaluation, and procurement are more circular rather than linear processes.

The department's aspirations in space also show problems beyond simply the RDT&E and procurement divide. A common talking point among DOD and Space Force leadership with respect to space has been the importance of the DOD using commercial space services. Typically, commercial services would be purchased using operations and maintenance appropriations, which are available for only one year. Space Systems Command leaders have adopted the motto "exploit what we have, buy what we can, and build only what we must."[9] In 2024, the DOD released a commercial space integration strategy and Space Force released its newest commercial space strategy.[10] Despite the attention on commercial space capabilities, industry and Space Force leaders have pointed out the lack of available DOD funds to spend on commercial space. In May 2023, Jeremy Leader, acting deputy director of the Commercial Space Office in Space Systems Command, attributed part of the problem to the absence of line items in the budget for commercial services: "If folks don't have their own dedicated line item for commercial capabilities within their mission area, it makes it kind of convoluted to try to find where that commercial money is actually available."[11] Even with commercial budget lines, the current budget structure does not lend itself to easily weighing the trades between buying commercial services for a mission area or using traditional DOD acquisition. A typical acquisition program will cut across multiple appropriations accounts, and the senior official responsible for reviewing and approving the acquisition program may not be the same person responsible for a commercial services budget line, especially if it is in the operations and maintenance budget. Moreover, the DOD submits budgets with five-year spending plans, and the fast pace of change in commercial innovation complicates the department's ability to appropriately plan for commercial services in its budgets or make trades between commercial services and traditional acquisition programs.

The Benefits of a Transformed Budget Structure for Space. The PPBE Commission's recommendation for a transformed budget would alter the hierarchical structure of the budget, as laid out in Table 1.

Table 1: Current and Proposed Budget Structure

Current Structure	Proposed Structure
Lifecycle Phase (e.g., RDT&E or Procurement)	Service/Component
Service/Component	Major Capability Activity Areas
Budget Line Item	System/Program (Budget Line Item)
Project	Lifecycle Phase

Source: "Defense Resourcing for the Future," Commission on Planning, Programming, Budgeting, and Execution Reform (March 2024).

The most important part of this change would be appropriating the budget using major capability activity areas. For space, this could look like requesting and receiving funding in categories such as missile warning and tracking, narrowband satellite communications, or positioning, navigation, and timing instead of RDT&E and procurement. Congress would have better insight on how much funding is going toward capability areas and what systems and programs cost. Further, major capability activity leads could more easily weigh trades among systems and programs within their major capability area. The PPBE Commission's proposal would still require such trades to undergo reprogramming procedures or to have prior approval, but it would give leads in capability areas comparable information about its programs and mechanisms to try to reroute money. Such change would be valuable for commercial space services because it would allow major capability activity leads to assess, for example, narrowband satellite communications services with custom-built narrowband satellite communications acquisition programs. Commercial services could be considered within the context of meeting capability needs, and, for some missions, commercial services could be chosen in lieu of traditional acquisition.

Transforming the budget along these lines would also better align it with how force structure decisions are being made. Over the past several years, the Space Warfighting Analysis Center (SWAC) has had tremendous influence shaping capability decisions for the Space Force. As an example, in the fiscal year 2023 budget request, the Space Force unveiled plans for fundamentally changing its approach to missile warning and tracking, including large amounts of funding for missile warning and tracking satellites in low Earth orbit and medium Earth orbit. The budget noted that these changes were in response to a SWAC force design on missile warning and tracking.[12] More recently, in the fiscal year 2025 budget request, the largest new budget line was for a capability that the budget documents indicate was in response to a SWAC force design for protected satellite communications.[13] If the Space Force is adapting its thinking to mission level assessments of capability, this modified budget structure would integrate decisions on the budget and force structure.

Additionally, this budget transformation would mitigate issues between delineating lifecycle categories (e.g., RDT&E and procurement). Although the DOD would still present the lifecycle categories, it would be within the amount listed for the system or program and the service could move money in and out of these categories without the need to go through reprogramming procedures or consume general transfer authority, as is required under the current budget structure. The budget construct would better align with how space capabilities are developed and acquired.

Changes Short of Transforming the Budget Structure. Importantly, the PPBE Commission recognized that the budget structure transformation is a long-term project, a fundamental change to how the DOD and the military space community organizes and presents its budget, and recommended a multi-year process of socialization and adoption. In the interim, or if there is limited or no political appetite to fully transform the budget, the commission included several recommendations that would benefit military space and give needed agility to provide emergent technology and deliver capability more quickly.

- **Review and Consolidate Budget Line Items (BLI):** There are 113 BLIs within the Space Force budget structure and 75 Program Elements (PE) in the RDT&E appropriation alone. The sheer number of line items makes it difficult for the DOD and Congress to manage and have sufficient oversight; it also impacts the agility needed for changing threats and evolving technology. Consolidating these budget line items would streamline the allocation and execution processes and support more fluid realignment of funding to support warfighter requirements. This review and consolidation would be a collaborative effort between the executive and legislative branches, and it would increase transparency for Congress and end unnecessary duplication or redundancy in the existing budget structure. There have been several successful consolidations demonstrated by the Department of the Army and the United States Special Operations Command. Each was the result of many months of engagements and a strong partnership with defense committees prior to the president's budget submission.[14]

- **Mitigate Problems Caused by Continuing Resolutions (CR):** Unfortunately, CRs have become a regular way of life for the DOD and the rest of the federal government. The Office of the Under Secretary of Defense (Comptroller) estimates that five out of the last 15 years have been spent operating under CRs, which delay the department's ability to implement new or growing programs. This recommendation strives to mitigate some of the adverse impacts of CRs by allowing the department to proceed with new starts and increased program quantities and development ramp-ups under CRs when those items have been included in the president's budget request, and all four defense committees have supported them in their corresponding bills. Execution of these and all requirements will be limited by the total CR funding authority, so decisions on funding priorities will be necessary.[15]

- **Update Thresholds for Below-Threshold Reprogramming (BTR):** BTRs are one of the most important tools available to the DOD for handling changing threats, requirements, and technology. Unfortunately, these thresholds have not kept pace with historical budget increases. Increasing these thresholds in alignment with budget increases over the past two decades will give program managers and program executive officers the agility that today's environment demands. The proposed thresholds under the commission's report are: RDT&E - $25 million, Procurement - $40 million, Operations and Maintenance (O&M) - $30 million, and Military Personnel (MILPERS) - $15 million.[16]

- **Increase Availability of Operating Funds:** Year-end spending challenges for one-year funding remains a significant issue for all of the DOD. Allowing a small portion (5 percent) of operating funds (O&M and MILPERS) to be carried over into a second year of availability, a type of flexibility that is already available to some non-DOD federal agencies, will support more effective execution on high priority requirements. If Congress is willing to enact this change, it would allow the DOD to better handle late-breaking changes to requirements, unanticipated bills, contracting challenges, as well as provide for smoother execution in years with lengthy CR periods. Funds that remain unobligated at year-end could be expended through a thoughtful, deliberative process, rather than through compressed contracting processes. The result would be more productive expenditure of the funds, fewer deobligations (situations where the Department reduces the funding level previously set aside for a contract and often loses the ability to spend that money) and hence greater buying power for the department.[17]

- **Address Challenges with Colors of Money:** Although this recommendation would become unnecessary once the DOD's budget structure was transformed as proposed, the PPBE Commission also included alternative recommendations to address challenges managing different lifecycle-oriented appropriations accounts, often referred to as "colors of money."[18] These include:

    - **Allow Procurement, RDT&E, or O&M to be Used for the Full Cycle of Software Development, Acquisition, and Sustainment:** The capability of software-intensive or software-enabled programs takes place through a continuous cycle of development, prototyping, testing, fielding, troubleshooting, revision, and sustainment. The requirement to break down the funding for this cycle into different appropriations for research and development, procurement, and sustainment does not align with the reality of how this capability is created and maintained and results in arbitrary color of money budget and execution determinations. For example, while a single appropriation for software and digital technology pilot programs can be helpful, it adds yet another execution challenge for programs that are not solely software focused. Allowing software to be funded by any existing color of money available to an organization achieves the effect of "colorless" money, reducing delays and administrative burdens associated with realigning funds through BTRs or above threshold reprogramming (ATR) without creating additional budget segmentation or delaying program schedules. Implementation of this recommendation would require collaboration between the DOD and Congress, an update to the DOD Financial Management Regulation, and clarity in the narratives of program justification books.[19]

- **Use O&M for Hardware Improvements:** Many DOD weapon systems that are currently in sustainment have been in the inventory for an extended period and require periodic hardware updates due to obsolescence issues, part failures, and/or diminishing manufacturing sources. Updates incorporating more readily available components and more current technologies may reduce costs, increase capability, or both. In such cases, it has become increasingly difficult to differentiate between increased capability (which requires RDT&E and procurement funding) and form/fit/function hardware updates to maintain a capability (which can be made with O&M funding). Sustainment is generally executed with O&M funds, so a requirement for RDT&E or procurement funds may be difficult for sustainment activities to predict and obtain, creating a barrier to efforts to effectively address parts' issues.[20]

- **Align Program and Program Office Funding to the Predominant Activity of the Program:** While already a practice in DOD labs and many program offices, allowing a program office to use a single color of money for all activities would further streamline execution. This recommendation, which could act as an interim step to the more intensive effort to transform the budget structure, would allow program personnel to focus on executing the mission and adjusting to rapidly changing operational needs and technological advancements.[21]

In some regards, the Space Development Agency is a test case for some of the commission's recommendations. The Space Development Agency is using a single color of money (RDT&E) for all its acquisitions except launch, a small number of consolidated budget line items, and other approaches that enable flexibility and increased acquisition speed.[22] Although the agency is still in the early phases of fielding its architecture, it has received consistent praise for its execution speed and agility.[23] The agency's success in moving quickly reflects some of the advantages of pursuing the commission's recommendations for defense space writ large.

Feasibility of Altering the Budget Structure for Space. Although these changes, particularly the transformation of the budget structure, would represent a significant departure from how the DOD has requested and received appropriations, there seems to be at least some willingness on the part of the department and Congress for fundamental change. Prior to the PPBE Commission's final report, it released an interim report in August 2023. Kathleen Hicks, the deputy secretary of defense, directed the department to "adopt all actions that can be implemented now."[24] In December 2023, the DOD released an implementation plan for the interim report's recommendations.[25] Importantly, the budget transformation recommendation and most of the other recommendations discussed were listed as "potential recommendations" in the interim report. In August 2024, the department announced it was moving forward with 26 of the 35 initiatives recommended by the commission and is considering resourcing implications, while also noting, "our resourcing process must evolve in concert with the Congress."[26] Since the Fiscal Year 2024 Appropriations Act noted that the "House and Senate Defense Appropriations Subcommittees look forward to reviewing the recommendations of the Commission,"[27] it is clear that the department will need to continue to work collaboratively with the appropriate committees to define a future appropriations structure if major change is to be achieved.

Congress has shown an interest in modifying the budget structure specifically for space. The House Appropriations Committee, in its markup to the Fiscal Year 2024 budget, includes direction for the Space Force to prepare a "supplementary budget exhibit for Space Force programs that organizes and aligns the existing budget lines for programs, projects, and activities into mission area expenditure centers, such as missile warning, satellite communications, and position, navigation, and timing."[28] The FY 2024 Appropriations and the FY 2025 House Armed Service Committee budget markup also included this direction.[29] The budget exhibit could be a trial for how transforming the budget structure could look in practice. Space could serve as a forerunner for the rest of the department.

Conclusion

Given changing threats and pressing needs, the DOD should push for fundamental changes in its budget structure. Although changing the budget structure along the lines of the PPBE Commission's recommendation would be transformative and require real collaboration with Congress, it should not be viewed as surprising or extreme. Defense acquisition professionals and scholars have called for the department to revisit its budget structure for some time. The PPBE Commission, fitting within a rich history of analytical work on this topic, is simply the latest to make these recommendations.[30] Given the pivotal moment in the DOD's space program—including transitioning to proliferated assets and commercial services—and the release of the commission's report that it directed, Congress should also embrace these changes. As noted often by Congress and the DOD, the United States finds itself in a period of intense global competition, and improving defense acquisition would better prepare the nation to defend its global interests.

Acknowledgments

Thank you to Andrew Dawdy for reviewing the paper, and thank you to Andrew Berglund for serving as editor.

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About Space Agenda 2025 Publications

This paper was published as a chapter of *Space Agenda 2025*, with Angie Bukley, Colleen Stover, and Victoria Woodburn serving as editors in chief. *Space Agenda 2025* is an effort by the Center for Space Policy and Strategy (CSPS) at The Aerospace Corporation to highlight and provide insights into some of the major space challenges facing policymakers. You can find the complete list of individual *Space Agenda 2025* papers at http://csps.aerospace.org/SA2025, as well as download the combined set of 16 chapters in the *Space Agenda 2025 Compendium* at https://csps.aerospace.org/papers/space-agenda-2025-compendium, all available to you with our compliments.

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ANTICIPATING THE NEW EUROPEAN UNION SPACE LAW

Michael P. Gleason and Catrina A. Melograna

Executive Summary

The European Union (EU) expects to release a new EU Space Law in late 2024 or early 2025. It will likely require non-EU commercial space companies providing satellite services within the EU marketplace, including U.S. companies, to comply with the law and regulations it will impose. While the draft law is being closely held by the EU, analysis of its foundational documents and senior EU leader statements makes it possible to anticipate its objectives and priorities and to make a reasonable prediction of the types of requirements the law will impose on U.S. commercial space operators. Most significantly:

- Technical standards setting has become a pathway for EU economic, market, and political power, and the EU has identified the commercial space sector as an area of emphasis.

- The EU Space Law is likely to impose minimum requirements on commercial satellite operators related to cybersecurity, collision avoidance responsibilities, resilience, information sharing, and launch and reentry. Non-EU companies, including U.S. companies, that provide services within the EU and do not comply with the law could face significant fines.

The EU market is significant, and U.S. commercial space companies' future costs of compliance with the EU Space Law may affect U.S. companies' competitiveness. Therefore, the U.S. government should begin developing an approach to the pending EU Space Law—with thorough U.S. commercial space industry input.

Introduction

In January 2024, the European Union's (EU) commissioner for Internal Market outlined the EU's plan to harmonize 11 European national-level space laws with a single EU-level law. The stated purpose of the emerging EU Space Law is to protect EU space systems and EU Member State space systems through legal requirements, regulations, and obligatory standards that apply to "any space system operating in the EU (whether EU or non-EU)."[1] The EU commissioner specifically identified on-orbit collision avoidance and deorbiting standards while also stating:

> This law will reinforce the position of Europe as a space power, the attractiveness of our single market and our ability to shape norms and standards globally.[2]

The EU Space Law is expected to require U.S. commercial space companies providing satellite services within the EU market to comply with the law and regulations it will impose.[*] To understand the law's significance, the United States needs to look no further than the impact of several recent EU laws and regulation on U.S. companies in other sectors. One example is the EU's General Data Protection Regulation (GDPR), regulating consumer privacy and data security laws in the EU and requiring organizations, regardless of whether they reside within the EU's boundaries or not, to comply. Noncompliant U.S. companies can expect significant sanctions and fines from EU regulators. In similar fashion, U.S. commercial space companies could stumble into potential EU sanctions and fines if they are not cognizant of, or do not take seriously, emerging EU Space Law and regulations.

For these reasons, and because the potential EU law has substantial implications for space sustainability, the U.S. government and U.S. commercial space sector should be alert to what is happening within the EU marketplace, the world's largest single market.[3] The U.S. government should be ready to adapt to the challenges the law may present for the U.S. commercial space industry, the U.S. government in terms of DOD commercial integration, and U.S. space leadership.

Introducing the European Space Sector

Within Europe, space activities operate at three distinct levels: the European level, the intergovernmental organization (IGO) level, and the national level (individual countries).

The European Commission (the EU executive branch equivalent) is the primary actor at the European level. The **European Union Space Programme** is implemented by the European Commission's (EC) Directorate General for Defence Industry and Space (DG DEFIS) and is operated by **the European Union Agency for the Space Programme (EUSPA)**, established in 2021 and with its headquarters in Prague.

EUSPA is separate and distinct from the European Space Agency (ESA) and its space activities, which reside at the IGO level.[†] Importantly, the subject of this chapter is EU space ambitions as manifested in the European Union Space Programme, not ESA's space ambitions. ESA is not part of the European Union and is not subject to EU law.[4] ESA also has its own unique governance and funding mechanisms, and while there is overlap among the 27 EU member states and the 22 ESA member states, not all ESA member states are members of the EU (such as the United Kingdom and Canada).[5] Observers must not make the mistake of conflating the two organizations and their respective space activities. In fact,

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[*] Similarly, the U.S. Federal Communications Commission (FCC) requires that non-U.S. licensed systems meet the same orbital debris mitigation standards as U.S. licensed systems and may impose penalties and fines for noncompliance. The FCC imposed its first-ever penalty for noncompliance with the standards in October 2023 when it fined DISH (a U.S. company) $150,000.

[†] The other European space-related entity that resides at the IGO level is the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT).

significant friction often exists between the two organization even though they work closely together in many ways to advance European space activities.

Table 1: European Space Activities Levels	
Level	**Description**
European	EU as owner and operator of Galileo PNT constellation, the Copernicus Earth observation constellation, and EU Space Surveillance and Tracking (SST). Develop and oversee collective space policy, strategy, and activities for EU: ◆ European Commission ◆ Common foreign and security policy
Intergovernmental organization (IGO)	European multi-state organizations: ◆ European Space Agency ◆ European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)
National	State's individual civil and defense space activities and agencies: ◆ Examples: Belgium, France, Germany, Italy, Spain, the United Kingdom, Poland, Norway, Luxembourg, Sweden, and so forth

EU space activities are approved, directed, and operated by the EU to meet EU political, economic, security, and defense objectives and to ensure EU economic, technological, and political autonomy. EU space activities receive significant funding from various places within the EU budget.

> ***An EU Approach for Space Traffic Management defines STM as the means and rules to access, conduct activities in, and return from outer space safely, sustainably, and securely.***

The EU Space Programme's three flagship satellite programs, operated by EUSPA, are:

1. **Galileo.** A global satellite positioning, navigation, and timing (PNT) system similar to the U.S. Global Positioning System (GPS)
2. **Copernicus.** An Earth observation system
3. **The European Geostationary Navigation Overlay Service.** A regional satellite-based positioning, navigation, and timing augmentation system similar to the U.S. Wide Area Augmentation System.

In early 2022, the European Commission (EC) proposed two new flagship programs related to space. The first new initiative is development of IRIS,[2] an EU-funded, developed, and operated large low Earth orbit (LEO) constellation to enable high-speed broadband everywhere in Europe (and implicitly around the globe).[‡] The second program is to establish an EU space traffic management (STM) approach with the ambition to "be at the forefront of the development of STM guidelines and standards."

Foundations of EU Space Law

The 2022 *EU Approach for Space Traffic Management*[§] and the2023 *EU Space Strategy for Security and Defence* are driving and shaping the EU Space Law. First, articulated in February 2022, the EU STM approach notes the critical importance of STM for space safety, security, and sustainability. The approach calls for the EC to develop enabling

[‡]Infrastructure for Resilience, Interconnectivity and Security by Satellite
[§]The 2022 EU STM approach has many similarities to the 2018 U.S. Space Policy Directive-3, *National Space Traffic Management Policy*.

legislation for STM-related nonbinding measures and binding obligations on satellite operators. Most interestingly, the approach includes the possibility of imposing future EU STM legal requirements and mandatory standards on **any satellite operator** providing services within the EU.[6]

Second, recognizing space threats and the importance of resilient space assets to security, the EU released its inaugural *EU Space Strategy for Security and Defence* in March 2023. The strategy's goal is to allow the EU to protect its space assets, defend its interests, deter hostile activities in space, and strengthen its strategic posture and autonomy.[7] Building directly on the EU STM approach, the strategy calls for the EC to propose an EU Space Law that provides a common framework within the EU for security, safety, and sustainability in space. The *EU Space Strategy for Security and Defence* explains that a standard approach across the EU is needed to share information across EU Member States, to protect space systems from threats, and to enable EU-wide cooperation during space security incidents.

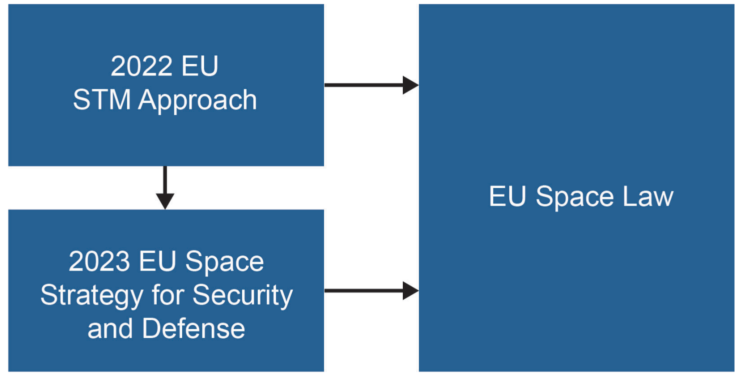

Figure 1. EU space law drivers.

Due to the EU's current lack of a common legal framework for space activities, national-level space laws and regulations create a fragmented regulatory landscape within the EU, putting it at a competitive disadvantage in the global marketplace. In fact, eleven EU Member States have their own unique national space laws, and more Member States are in the process of adopting national space laws. Besides putting the EU at a competitive disadvantage, the EU judges that such fragmentation in space law weakens its autonomy and strategic posture.[8]

In the EU's State of the Union 2023 Letter of Intent, EU President Ursula von der Leyen indicated that an EU Space Law is a key priority for 2024.[9] At the time of this writing, the draft EU Space Law is expected to be released in late 2024 or early 2025, after new EU leadership takes its place following the 2024 EU parliamentary elections. In the meantime, the draft law is being closely held by the EC with few details publicly revealed. However, close examination of the 2022 *EU Approach for Space Traffic Management* and the 2023 *EU Space Strategy for Security and Defence*, as well as statements from senior EU officials, provide a general sense of the areas the law may cover and what the law may include. Also, based on the precedents set by EU laws affecting other economic sectors, the EU will likely delegate licensing of space activities and monitoring and enforcement of the EU Space Law to the EU member states. From this analysis, U.S. observers may anticipate what features of the EU Space Law may have an impact on the United States and the U.S. commercial sector in the coming years.

Analysis and Key Findings

The analysis, detailed in the appendix herein, identifies several relevant objectives, priorities, features, and actions called for in the EU STM approach and the *EU Space Strategy for Security and Defence*. The analysis also includes statements from senior EU leaders, and predictions from media and other observers. From a synthesis of the information in these sources, we can reasonably forecast that the EU Space Law could require the following measures:

- Cybersecurity requirements
  - Increased cybersecurity hardening requirements and standards across the supply chain.
  - Increased cyber incident monitoring, assessment, information sharing, and reporting.

- Collision avoidance requirements
  - Establishment of minimum requirements.
  - Use of active tracking devices on satellites.
  - Systemized notifications and warnings of any major incident or reentry.
  - Commercial satellite operators subscribe to a collision avoidance service at least to similar level of performance as the current EU Space Surveillance and Tracking partnership.
  - Commercial entities that provide collision avoidance services for satellite operators maintain communication mechanisms and contacts (i.e., operators' directory) for managing conjunction events with satellite operators and other collision avoidance service providers.
- Resilience requirements
  - Critical space services have a minimal level of resilience.
- Information sharing requirements
  - Increased information-sharing regarding threats and security incidents.
- Launch and reentry licensing requirements
  - Standardized EU criteria for launch and reentry licensing.
  - Licensing provided by individual EU Member States.
- Monitoring and enforcement of EU law
  - Provided by individual EU Member States.

Why It Matters

The emerging EU Space Law is likely to be more stringent on various points than current U.S. regulations. With 440 million consumers, the European Union is the world's largest single market and largest economy.[10] Such a large market may make it difficult for U.S. commercial satellite service companies to forego the opportunity to sell services within the EU in order to avoid the law, even if they would prefer to operate under the more lenient U.S. standards.

Even though the EC has revealed few details about the new EU Space Law, observers can anticipate several implications for U.S. industry and the U.S. government. First, based on previous EU rules like GDPR, it is not difficult to imagine a scenario in which the EU mandatory rules impose higher costs or restrictive requirements on U.S. commercial space enterprises providing services within the EU marketplace. Importantly, while large, well-established enterprises may be able to manage the costs of compliance, newer companies may struggle to absorb the additional costs.[11]

The GDPR, the Digital Markets Act (DMA), and the 2024 EU Artificial Intelligence Act (AI Act) serve as useful case studies for what U.S. commercial space companies, large or small, may expect.

- **General Data Protection Regulation (GDPR)**.
  Reacting to EU citizens' demand for privacy protections, in 2018, the EU implemented the General Data Protection Regulation (GDPR).[12] The GDPR is an extensive set of data privacy and security laws applying to EU and non-EU companies operating in or offering services in the EU. The overall intent of the laws is to protect the data of EU

citizens by imposing mandatory measures and hefty monetary fines for noncompliance.[13] Depending on the infringement, GDPR imposes a "maximum penalty up to €20 million or 4% of global revenue, whichever is higher" per incident.[14] EU regulators have fined U.S. companies hundreds of millions of dollars for not complying with EU law. In the past few years, the EU's Data Protection Commission fined Meta (Facebook and Instagram's parent company) more than US$410 million, Amazon US$888 million, WhatsApp US$267 million, and Google US$90 million.[15]

- **Digital Markets Act (DMA)**
  The DMA's intent is to prevent anti-competitive behavior from big digital technology players and make sure they do not have a monopoly in the EU by forcing them to open some of their services to competition. Currently, the DMA mainly impacts the U.S. technology giants Alphabet, Amazon, Apple, Meta, and Microsoft. To comply with the DMA and open the EU marketplace to more digital competition, these U.S. companies must change their platforms.[16]

  The DMA came into effect on March 7, 2024, and on March 25, 2024, the EU opened investigations on Apple, Google, and Meta for possibly violating the law. According to the DMA, violators could be fined up to 10 percent of the company's total worldwide annual turnover or up to 20 percent in the event of repeated infringements. If necessary, nonfinancial remedies can be imposed, possibly including forced divestiture of (parts of) a business.[17] In June 2024, Apple announced that due to the DMA, forthcoming iPhone 15 Pro, iPhone 15 Pro Max, and all iPhone 16 models that include Apple Intelligence features will not be available in Europe, resulting in the loss of millions of potential new iPhone customers for Apple.[18]

- **Artificial Intelligence Act (AI Act)**
  The recent 2024 EU Artificial Intelligence Act (AI Act) is part of a set of regulations aimed at creating a robust framework, not just for Europe but for the world in promoting trustworthy AI "by ensuring that AI systems respect fundamental rights, safety, and ethical principles and by addressing risks of very powerful and impactful AI models."[19] U.S. companies will have to comply with the laws if they are using data within their AI from EU customers.[20] The EU AI law will come into force in 2026 and, depending on the violation, companies could be fined on a scale of anywhere from €7.5 million (or 1.5 percent of annual turnover) to €35 million (or 7 percent of turnover) per violation.[21]

Understanding the forthcoming EU Space Law also matters for international STM standard setting. EU ambitions include demonstrating leadership in global STM standards development and promoting standards internationally that reflect EU values.[22] The 2022 EU STM approach calls for the EU to be proactive and at the forefront of international STM standard setting. To enable this ambition, the EU has established a forum called "The STM Stakeholder Mechanism," which aggregates EU Member State and other stakeholder requirements, synthesizes stakeholder views, coordinates external engagement, and promotes the EU STM approach internationally. [23] Underlining the EU's ambition, while emphasizing space cybersecurity standards, the 2023 *EU Space Strategy for Security and Defense*, says better EU representation is crucial in international standardization organizations.

The forthcoming EU Space Law likely will contain provisions to enable these ambitions. As the EU grows more experienced in aggregating the preferred standards of the EU Member States and those of other European stakeholders it is likely the EU will seek more influence in shaping the standards adopted by international standardization bodies such as the International Organization for Standardization (ISO). This implies that U.S. leadership in setting global standards may erode in some areas.

In that way, the EU Space Law also has implication for the U.S. ability to shape space-related standards. A telling example of why standard-setting matters is the EU's adoption of the Global System for Mobile (GSM) Telecommunications standard in the late 1980s. The EU passed laws at that time requiring GSM be the standard in Europe, which gave Europe an early advantage in the rapidly growing global mobile telecommunications market and made Europe the leader in mobile telephony.[24] Except for within the United States and a handful of other places, GSM became the *global standard*, severely impacting growth in the U.S. mobile telephony industry at the time.[25]

The EU Space Law could also impact the U.S. Department of Defense (DOD) strategy to integrate commercial space capabilities into DOD space architectures. If U.S. space companies want to provide services within the EU, they will have to bear the costs of complying with the EU Space Law, and those costs might be passed onto the DOD and other customers. If U.S. space companies, large or small, decide not to provide services within the EU so they can avoid incurring the costs of complying with the EU Space Law, they narrow their addressable market considerably and therefore will be more likely to rely on the DOD. Either choice may result in higher costs for the DOD.

Conclusion

Several recent examples of EU law impacting U.S. companies in non-space sectors provide analogies to a potential future with an EU Space Law. U.S. commercial space companies could be caught unprepared for future requirements and standards, and the burden of compliance may be unexpected and unwelcome. The U.S. government might be requested to help relieve some of the burden, or U.S. regulators may need to eventually follow suit, representing a loss of prestige and leadership for the United States. Moreover, the U.S. strategy to integrate commercial space capabilities into national security space architectures may be impacted in unexpected ways.

The U.S. space community should prepare for the forthcoming EU Space Law, including senior decisionmakers and other observers learning about the three levels of European space governance and space activities. The U.S. space community needs to understand the differences among major European stakeholders and appreciate the diverse interests, motives, priorities, and funding mechanisms of each, and recognize that each operates under different political and legal structures. Once understood, the U.S. interagency can begin developing an informed approach to the pending EU Space Law—with thorough U.S. commercial space industry input. As usual when it comes to the U.S.–EU relationship, a delicate balance between cooperation and competition is the only way forward.

Appendix

Table A-1 identifies several relevant objectives, priorities, features, and actions called for in the 2022 *An EU Approach for Space Traffic Management*. Table A-2 derives the same from the *EU Space Strategy for Security and Defence*. Table A-3 highlights what senior EU leaders have emphasized, and Table A-4 captures predictions from media and other observers.

Table A-1: 2022 EU STM Approach
Objectives
• Identify possible areas for an EU STM legislation and, by 2024, make a proposal for an EU STM legislation. • Preserve EU interests and autonomy. • Contribute to the security and defense dimension of the EU in space. • Contribute to the preservation of a safe, sustainable, stable, and secure outer space. • Enable emergence of a well-functioning EU internal market important to the development of EU goods and services associated with the use of space. • Aim to develop a common level playing field at the EU level, which would ensure that the most virtuous operators are not penalized. • Guarantee that EU operators do not suffer from distortion of competition by operators established outside the EU benefiting from less stringent standards by imposing equal treatment to EU operators and to any satellite operator intending to provide services within the EU (i.e., imposing legal obligations, rules, and regulations on any satellite operator providing services within the EU).
Ambitions

• European standardization organizations develop harmonized technical standards and guidelines for STM.
• Manufacturers and operators prove compliance with the technical standards and guidelines developed by European standardization organizations.
• Proactively ensure the development of international standards where feasible and needed.
• Make the best use of the EU's capabilities and innovation in the field of space surveillance and tracking (SST).
• Support EU-level STM standards and guidelines, for example:
  ▸ The use of active devices to facilitate the tracking of satellites.
  ▸ The warning of any major incident or reentry.
  ▸ Guidelines for special cases of STM, such as nonmaneuverable satellites or constellations.

Actions
• Establish an EU forum aimed at ensuring a holistic EU approach on STM in international standardization for dealing with STM. Member States and all other EU actors, such as the EU SST Partnership, EU industry, etc., will have the opportunity to participate. • Prioritize the most impactful standards and guidelines, and promote their implementation through a toolbox and recommendations. • Develop a toolbox based on identified STM standards and guidelines, which could help Member States when they grant licences for the provision of services requested by satellite operators over their territory.
Incentives
Establish incentives for satellite operators to comply with nonbinding guidlelines and standards, for example: • A "safe space" label based on award criteria. • Awards. • A list of companies and operators who implement STM guidelines or standards.
Highlights of Potential Legislation, Law, Regulations, Legally Binding Rules
• Legally compel satellite operators to register with a collision avoidance service that offers at least a similar level of performances as the current services offered by EU SST. • Legally compel entities in charge of collision avoidance services to maintain communication mechanisms and contacts (e.g., operators' directory) at their disposal for managing conjunction events with other service providers.

Table A-2: 2023 EU Space Strategy for Security and Defence

Objectives

- Build on the joint communication for *An EU Approach for Space Traffic Management*.
- Develop EU-wide security framework for the protection of space systems, information-sharing, and cooperation on space security incidents.
- Strengthen the technological sovereignty of the EU space sector:
  - Reduce strategic dependencies on countries outside the EU.
  - Boost the resilience of critical industrial value chains.
- Collectively enhance the level of resilience of space systems and services in the EU and ensure coordination between Member States.

Ambitions

- Ensure that EU competition rules and international trade instruments are fully applied to tackle challenges faced by the EU space and defense sectors, such as the risk of distortive foreign subsidies. This should include investigating certain acquisitions of EU companies active in these sectors, which may be facilitated by illegal foreign subsidies.
- Greater steering of the EU in the development of standards:
  - Better representation in international standardization organizations is crucial, in particular to protect the security interests of the EU and its Member States.
  - Coherence with North Atlantic Treaty Organization (NATO) standards will be encouraged.

Actions

- The EC will consider proposing an EU Space Law to ensure a consistent EU-wide approach and build on the joint communication for an EU Approach for Space Traffic Management.
- The EC will consider proposing an EU Space Law that enhances the level of security and resilience of space operations and services in the EU as well as their safety and sustainability.
- It will encourage the development of resilience measures in the EU and foster information-exchange on incidents as well as cross-border coordination and cooperation.
- The EC will assess the need to establish new industrial alliances related to technologies that are relevant for space and defense in compliance with the EU competition rules.
- More systematic integration of relevant security standards in the early design phase of these systems.
- The EC will consider establishing an Information Sharing and Analysis Center (ISAC), bringing together commercial entities and relevant public entities, including, possibly, the European Space Agency (ESA).
- The EC, with the support of the EUSPA, will establish an ISAC (EU Space ISAC) to strengthen the resilience of capabilities of the EU space industry (upstream and downstream), including New Space.

Incentives

- Incentivize the exchange of information on threats targeting space assets or their supply chain.
- Incentivize the development of standardized interfaces (covering security aspects) between satellites and responsive launch systems to ensure future satellites' interoperability and access to space solutions and to support the development of innovative in-orbit transportation solutions.

Highlighted Potential EU Legislation, Law, Regulations, and Legally Binding Rules

- Mandate cybersecurity requirements as part of the design of all space systems delivering essential services.
- Member States could be required to identify essential space systems and services, for example:
  - Identify major supply chain actors.
  - Define and implement a common minimum level of resilience for critical space services.
  - Develop coordinated national preparedness and resilience plans and emergency protocols.
  - Develop security monitoring centers to allow for the notification of security incidents in a systematic manner.
- Consider requirements to make sure that security, including cybersecurity, is part of the design of all space systems delivering essential services. The EU could propose the more systematic integration of relevant security standards in the early design phase of these systems.
- Consider specific cybersecurity standards and procedures in the space domain as part of the EU Space Law where relevant.
- Establish an EU information exchange network that would provide through EUSPA a comprehensive first level of analysis and reporting of satellite anomalies and security incidents that signal a space threat.

Table A-3: Statements from the EU and EU officials

- “The proposed EU space law will set rules on space traffic management and will provide a framework to ensure the safety of the critical space infrastructure.” EU Parliament commentary regarding Letter of Intent from the President of the Commission Ursula von der Leyen to the president of the European Parliament, and to the presidency of the Council of the EU.[26]
- “We need to build a true EU Single Market for space. This is the purpose of the upcoming EU Space Law.” Thierry Breton, commissioner for Internal Market of the European Union.” January 2024.[27]
- “The EU Space law will set common rules related to space activities, focusing on 3 aspects: safety, resilience and sustainability, bringing legal certainty and stimulating innovation.” Thierry Breton, January 2024.[28]
- “It is also a matter of security. In the current geopolitical context, the protection of our space systems from systemic security risks is a must, through minimum requirements for any space systems operating in the EU (whether EU or non EU). For instance on anti-collision, deorbiting standards but also on cyber security risks management….” Thierry Breton, January 2024.[29]
- “This law will reinforce the position of Europe as a space power, the attractiveness of our single market and our ability to shape norms and standards globally.” Thierry Breton, January 2024.[30]
- “To protect our space systems and increase their resilience, we need to be able to monitor our infrastructures and better detect potential threats in space to ensure timely reactiveness.” Thierry Breton, January 2024.[31]
- Non-attribution discussion, April 2024
  The EU Space Law is a set of mandatory measures. The push is for hard law and mandatory standard, not voluntary best practices.
  - The EU Space Law will harmonize across the EU Member States, all licensing for launch, collision avoidance, and reentry. Licensing will remain the responsibility of the Member States.
  - The Member States will be left to enforce the law, not the EU.
  - Non-EU entities will have to follow EU Space Law to provide services within the EU.
  - The EU considers collision avoidance services to be a government responsibility due to the strategic nature of the space domain.
  - The draft EU Space Law is 150 pages.

Table A-4: Media and Observer Predictions

- “According to documents seen by POLITICO, the bloc’s diplomats have been briefed on plans to create an EU Space Label that will be used to designate companies that play by the new rules on sustainability and security.”[32]
- “The EU Space Law will set standards to curb light pollution caused by growing satellite constellations and limit greenhouse gas emissions and pollution caused by rocket launches.” [33]
- “The Commission aims to use the lure of its single market as the muscle to make the new rules stick.”[34]
- “The Space Law will be a regulation.”[35]
- Euractiv reporter paraphrasing remarks by EC official, Guillaume de la Brosse, (EC Innovation and New Space Head of Unit).
  - The upcoming EU Space Law will focus on cybersecurity by design, hardening the security levels of space’s industry supply chain and applying (cyber)security measures proportionally to how critical certain products are deemed.
  - Companies will be required to mitigate their risks by conducting assessments and evaluating potential events threatening their infrastructure.
  - Companies will be required to prevent, detect, and protect themselves against cyber incidents. The upcoming EU Space Law will also provide a framework on how to handle these incidents. Eventually, the law will detail to whom and how to report cyber incidents.
  - Regarding sustainability, the “level of ambition [of the law] will be quite low,” said de la Brosse.[36]

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About Space Agenda 2025 Publications

This paper was published as a chapter of *Space Agenda 2025*, with Angie Bukley, Colleen Stover, and Victoria Woodburn serving as editors in chief. *Space Agenda 2025* is an effort by the Center for Space Policy and Strategy (CSPS) at The Aerospace Corporation to highlight and provide insights into some of the major space challenges facing policymakers. You can find the complete list of individual *Space Agenda 2025* papers at http://csps.aerospace.org/SA2025, as well as download the combined set of 16 chapters in the *Space Agenda 2025 Compendium* at https://csps.aerospace.org/papers/space-agenda-2025-compendium, all available to you with our compliments.

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LEVERAGE AND PRESERVE: THE NEED FOR THE DOD TO STRENGTHEN SUPPORT FOR U.S. COMMERCIAL SPACE

Wei W. Chen, Mindy R. Han, Sarah E. Georgin, and Robert S. Wilson

Executive Summary

Many U.S. commercial space companies have benefited from significant venture capital (VC) investment, including during the steady rise in VC investment beginning in 2008, which culminated in a spike in 2021. Since then, VC investment has fallen precipitously, dropping nearly 50 percent from 2021 to 2023. As U.S. defense space leadership seeks to use commercial space assets and services to a greater extent, the rise and fall in VC investment presents a dilemma and opportunity for the U.S. Department of Defense (DOD). The DOD can leverage commercial space assets and services that were paid for by other investors; however, given that some of the markets for commercial space services are immature, the DOD may need to serve as anchor tenant—being the biggest or main customer for a commercial capability—to ensure it can use these assets and services in the future.

For capability areas in which the market has not fully developed, such as remote sensing, space situational awareness, radiofrequency mapping, and alternative positioning, navigation and timing, the DOD should consider partnering with commercial firms that offer attractive defense solutions. In some cases, anchor tenancy may be a temporary approach to bridge the gap until a robust commercial market develops; in others, a commercial firm may be reliant on government revenue for many years. Government agencies may be reluctant to do this, but the DOD's costs in serving as anchor tenant should be weighed against the money that it would have needed to spend to build those capabilities itself. Additionally, the DOD's support for these firms would strengthen elements of the U.S. space industrial base that would be tenuous in the absence of government revenue. Leveraging U.S. commercial space assets and services to a greater extent could also mean preserving U.S. commercial advantages in space.

Introduction

The United States benefits from its accessibility to the largest commercial space sector in the world. Most of the active satellites in orbit are owned by U.S. companies, and the Satellite Industry Association's *2024 State of the Satellite Industry Report* estimates $105 billion in 2023 revenue from the U.S. satellite industry, more than 35 percent of the industry's global revenues.[1,2] U.S. companies span the spectrum of space capabilities—launch; ground services; satellite communications; electro-optical imagery; synthetic aperture radar; radio frequency mapping; weather; space situational awareness; and alternative positioning, navigation, and timing, among others.

The expansion and maturation of the U.S. commercial space sector has prompted the Department of Defense (DOD) to place greater emphasis on leveraging commercial space capabilities to meet the department's needs. Agencies and organizations within the DOD have developed commercial space strategies in recent years, including the first-ever DOD Commercial Space Integration Strategy and the U.S. Space Force's Commercial Space Strategy, both of which were released in 2024.[3] Even the DOD's 2022 National Defense Strategy notes the importance of the department's use of commercial space, the first-ever national defense strategy to reference commercial space.[4] While national space policy documents have endorsed the use of commercial space for decades, the DOD may be in the early stages of a step-function increase in both the breadth and intensity of actual utilization.

The DOD's push to leverage commercial space comes at a time when government demand may be particularly valuable for U.S. commercial space firms. A few years ago, commercial space companies benefited from significant public and private capital investment. However, that investment has fallen precipitously as a result of interest rate increases to tame inflation and the failure of several banks with significant venture portfolios, including Silicon Valley Bank, a leading source of venture capital (VC) funding. In aggregate, from 2021 to 2023, U.S. VC funding dropped nearly 50 percent.[5]

The current market conditions create compelling opportunities for the DOD. By making judicious and targeted decisions to sign long-term contracts for commercial services, the department can leverage past and future private capital and share the costs of supporting the continued development of the commercial space sector. This support could help ensure the DOD has access to a diverse, innovative set of commercial space capabilities when needed, while also help to position commercial space firms for sustained success amid changing market conditions.

Rise and Fall of Venture Capital

Over the last two decades, severe financial disruptions have led to significant U.S. government interventions in U.S. financial markets. In response to the global financial crisis in 2007-2008, the Federal Reserve and other global central banks supported the continued functioning of financial markets by dropping short-term interest rates to nearly zero. The Federal Reserve also bought mortgage-backed securities and other assets. This intervention led to a decade of historically low interest rates that made borrowing costs relatively low and investment capital broadly available, allowing companies with speculative business models to raise capital more easily. As a result, U.S. VC funding to startups rose steadily from 2009-2017, as reflected in Figure 1. These levels increased drastically between 2018-2020 before peaking in 2021 because of the government's large fiscal programs and a loosening of monetary policy in response to the pandemic.

This investment environment, along with other factors, converged to foster a rapid increase in the number of new U.S. commercial space companies. These companies benefited from increasing stock market performance and strong initial public offering valuations. The commercial space sector received additional capital through the use of special purpose acquisition companies (SPACs)—publicly traded vehicles that exist to acquire promising private companies, effectively providing those companies with access to public markets without going through an initial public offering, or IPO. SPACs have existed as niche financial vehicles for decades, but the low interest rate environment transformed them into significant fundraising vehicles beginning in 2020 (Figure 2). Several space companies that were founded just five to ten years prior

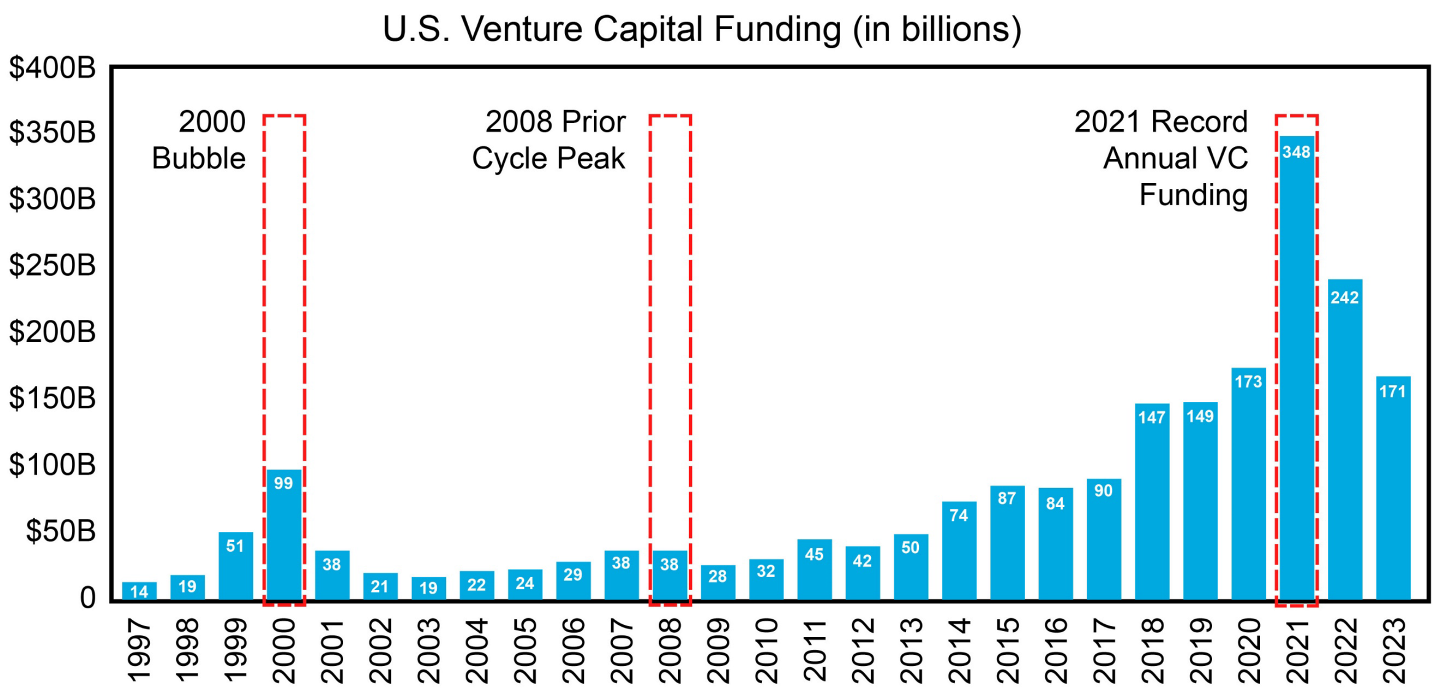

Figure 1: U.S. venture capital funding (in billions) from 1997–2023.
(Source: The Aerospace Corporation analysis using data from National Venture Capital Association, Pitchbook, Thompson Reuters, and PwC Moneytree.)

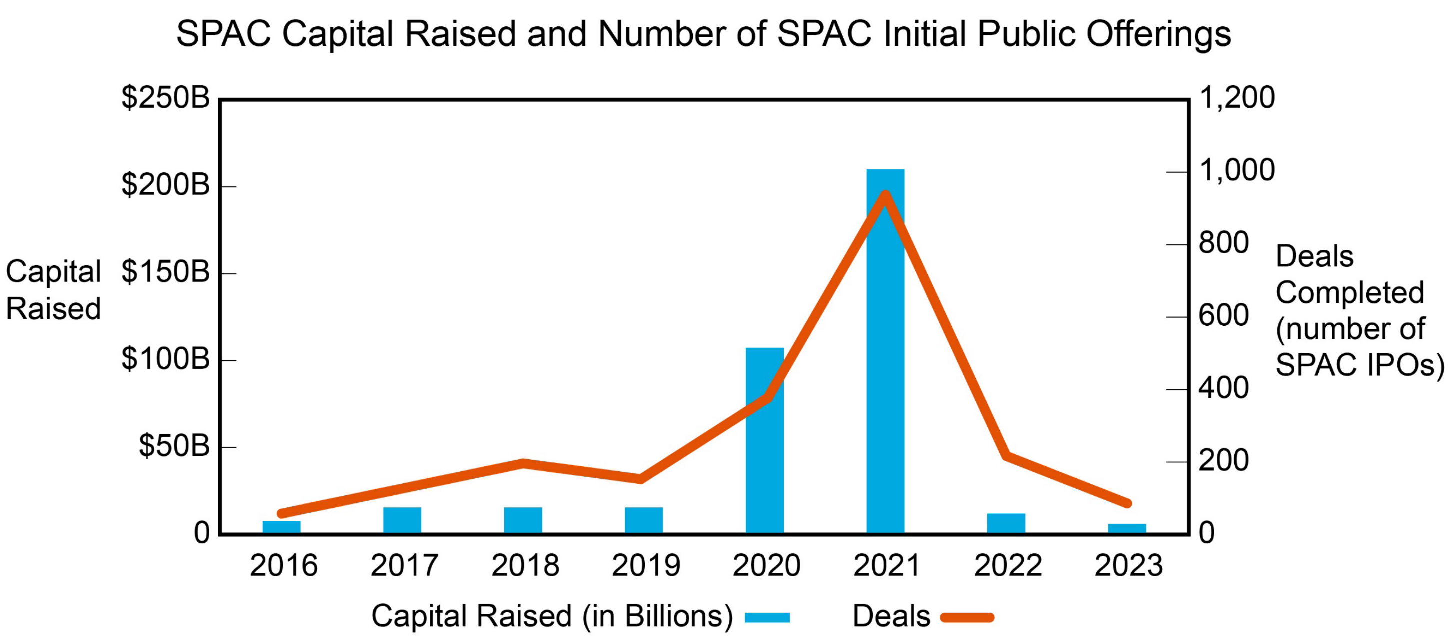

Figure 2: Special purpose acquisition company (SPAC) capital raising from 2016 to 2023.
(Source: The Aerospace Corporation analysis using data from Bloomberg Terminal.)

grew quickly and went public through SPACs, including Planet Labs (July 2021), Spire Global (August 2021), Terran Orbital (March 2022), and AST SpaceMobile (April 2021).

In 2021, inflation started to climb, which caused the Federal Reserve and other central banks to rapidly increase interest rates. Higher interest rates led to a cut in VC investment, exacerbated by the five bank failures that occurred during 2023.[6] As a result, as shown in Figure 1, VC funding dropped 50 percent from 2021 to 2023. Over this same period, SPAC funding dropped 97 percent, due to a combination of higher interest rates, poor performance of many companies acquired by SPACs, and regulatory scrutiny by the U.S. Securities and Exchange Commission. Collectively, these developments severely cut the amount of public and private capital available for space companies.

The challenge for space companies that received sizable VC investment is not simply that some of these investment sources have dried up but also the growing mismatch between what may be feasible for a space company and the expectations of VC investors. In a typical VC 10-year investment cycle, VC investors are looking for returns of 5 to 10 times their investment in that period. This demand for immediate returns does not lend itself to developing and manufacturing infrastructure or deploying satellites. As a result, many companies may be unable to deliver to their VC investors' expectations for returns and the timelines to achieve those returns, making it harder to rely on continued VC investment.

The Case for the DOD to Play a More Active Role

The rise and fall of public and private capital for commercial space companies presents both a pressing issue and an opportunity for the DOD. Based on DOD strategy documents and comments from U.S. defense space leadership, the department is poised to make commercial space capabilities an important component of how the DOD carries out its missions. To ensure that it can do this over the long-term, DOD will need to play a more active role in providing revenue for commercial space companies. Although taking such a position will pose tradeoffs and risks, the DOD should do this for principally three reasons:

1. Commercial space assets and services can provide valuable defense applications.

2. Paying for commercial space assets and services that exist, instead of building new custom-built space capabilities, will save the DOD money and time.

3. Many promising U.S. commercial space companies may not survive without significant government revenue.

Value of Commercial Space for Defense Applications. For DOD, commercial space assets can complement or replace custom-built defense systems, even if the commercial systems were designed primarily for commercial applications. The core function of many space systems is to collect and transmit information, which can be valuable for civil, commercial, and defense applications. For example, space-based electro-imagery companies can help oceanographers monitor the health of the seas, help farmers detect pests in their farms, and help military analysts track troop movements and other potential threats. Further, commercial companies have proposed intriguing models for particular missions. For example, for electro-optical imagery, commercial providers have focused on achieving excellent temporal resolution (rapid revisit rates) to be complementary to traditional systems that focus on achieving high spatial resolution (small pixel sizes).

Another advantage of commercial satellite capabilities and services is that the data can be shared more easily than data from government space systems. Electro-optical imagery, synthetic aperture radar collection, radiofrequency mapping, and space situational awareness companies (among others) all collect data, either on the Earth or in the space environment. It can be easier to disseminate commercial imagery or other data than information from government systems, whose capabilities may be sensitive. As seen in the war in Ukraine, this dissemination can be particularly powerful in certain circumstances. The first images that many people saw of Russia's military buildup on the border of Ukraine and subsequent invasion were from commercial satellites. Increasingly, commercially available satellite imagery is being used for intelligence relating to military activity, but it is also creating new dynamics in global transparency by potentially being more credible to global audiences than information from government-controlled systems.

Saving Money and Time. Perhaps most importantly, buying commercial space assets or services can save money and time. Defense acquisition is a time-intensive and expensive process.[7] To the extent that commercial space capabilities and services exist that can satisfy defense needs, buying those capabilities or licensing those services would likely be a much more efficient use of resources than developing them independently. In fact, the DOD already buys commercially available products (e.g., computers and passenger cars) for many of its needs. It also pays for services, such as potable water, electricity, and telephone services from commercial providers. Another example are iPads, of which the U.S. military buys plenty. Imagine how much more difficult it would be for the DOD to hire a contractor to develop a comparable tablet than to simply buy iPads that are already mass produced.

In the case of commercial space, the DOD can benefit from the high capital investments made in the lead-up to the VC investment spike in 2021. Public and private investors spent considerable capital to build commercial space companies and capabilities, and the DOD can access those capabilities without having paid for their development. Ensuring that it can use commercial space services for the long-term could be a bargain for the department compared to developing and acquiring its own custom-built systems.

Preserving Commercial Space. Another reason for the DOD to take a more active role in providing revenue for commercial services is to help sustain those companies. The decline in public and private capital has not had a drastic effect on *all* commercial space capability areas. The satellite communications market, in particular, remains strong. In April 2024, the World Economic Forum issued a report on the space economy, which includes revenue calculations for commercial space across different sectors. For commercial space services and end-user equipment, the report estimates that more than 98 percent of the direct revenue generated in 2023 came from satellite communications and positioning, navigating, and timing.[8] Satellite communications has been a mature market for several decades and one in which government is one of many customers; positioning, navigation, and timing—albeit a different type of market—has existed for decades as well.

In contrast, for other emerging capability areas, the decline in public and private capital *has* affected the financial viability of commercial space firms. Commercial demand for space-based remote sensing, for example, is not yet sufficient for many of these companies to become profitable. Researchers at The Aerospace Corporation analyzed approximately 150 commercial remote sensing companies to identify how many would be profitable in the absence of government (U.S. or foreign) revenue. The answer was very few, if any.[9]

For commercial remote sensing and other areas in which the market has not fully developed, such as space situational awareness, radiofrequency mapping, and alternative positioning, navigation and timing, the DOD should partner with commercial firms that offer attractive defense solutions that are less expensive than what the government could achieve by itself.[10] In addition to ensuring it can use these assets and services, the department's support for these firms would strengthen elements of the U.S. space industrial base that would be tenuous in the absence of government revenue.

Defending Anchor Tenancy

To fully benefit from the opportunity presented by the current state of the space industrial base, the DOD will need to be willing to serve as an anchor tenant, being the biggest or main customer for a commercial capability, when doing so serves the DOD's goals. Generally, there are several situations in which the government could reasonably decide to become an anchor tenant for a capability or a private firm:

- To invest in a technology or product that could provide far-reaching benefits.
- To avoid building a similar technology or product from scratch.
- To help mature that technology or product to advance national goals.

In the case of space, all of these rationales may exist for the DOD to support commercial industry. The early days of the aviation industry offers an example of the benefits of strategic investments and partnerships with industry. Prior to World War II, aviation companies relied on revenue provided by U.S. government air mail contracts, without which the airlines would have been unprofitable. As is the case with the airlines, government anchor tenancy may be a temporary approach to bridge the gap until a robust commercial market develops.

The DOD should also prepare itself in the event anchor tenancy is not a temporary or short-term condition. If the commercial market does not fully develop, a commercial firm may be reliant on government revenue for many years. Government agencies may be reluctant to do this, but the DOD's costs in serving as an anchor tenant should be weighed against the money that it would have needed to spend to build those capabilities itself. Further, in some cases, anchor tenancy may require the government to buy a service in order to avoid the burdensome requirements and acquisition processes associated with large-scale government development. The NASA Commercial Crew program was a case in which serving as an anchor tenant gave the agency more flexibility than a government-owned and -operated program would have.[11]

Serving as the main customer for a commercial capability area would also allow the DOD to help shape those assets and services. For example, in the case of semiconductors, the department served as the anchor tenant for integrated circuits in the 1950s and 1960s, which led to many of the products being built with defense applications in mind, even if the eventual intent was to reach broader commercial markets.[12] This is already happening to some degree in commercial space. The U.S. Space Force has introduced cybersecurity standards for commercial companies wanting to sell services to the DOD.[13] Further, the department has continuously coordinated with commercial firms on some of its needs, helping to shape commercial offerings. Thus, in places where the DOD establishes anchor tenancy, the department can more easily steer the direction of technology evolution and how responsive commercial firms are to these specific defense needs versus broader commercial needs.

Anchor tenancy should be considered as a middle ground between traditional acquisition and a fully mature market in which the government is simply one of many customers, as shown in Figure 3. Looking again at the semiconductor example, from 1962 to 1968, the average cost of integrated circuits went from $50 to $2. As these circuits became less expensive, their commercial appeal grew and the DOD had less influence over the semiconductor market.[14] The benefit of this for the DOD, however, was that the assets were far less expensive to buy. In the traditional acquisition process, the government hires a contractor to build a custom system designed to precise government

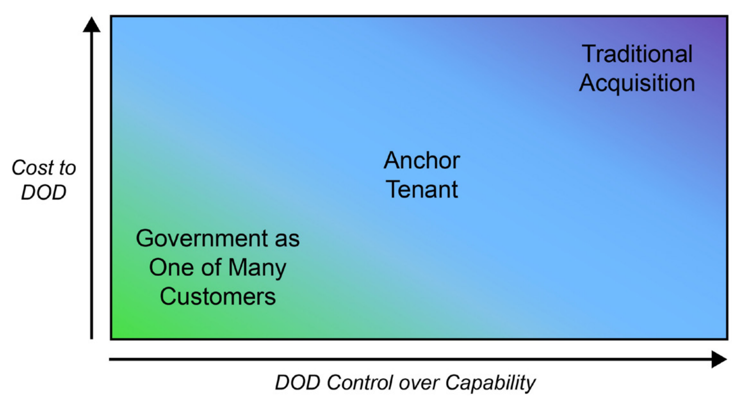

Figure 3: Anchor tenancy as a middle-ground approach to cost and capability.

Using Debt

Leveraging debt could be a creative approach for the DOD to support space firms. In traditional industries that require significant initial investment and infrastructure, debt is often the appropriate source of capital. Debt investors are compensated by interest and typically have less urgent deadlines for market development as long as the companies can pay their interest expense, pay off the debt at maturity, or rollover the debt into a new credit instrument. As noted, sustaining VC funding typically requires large and fast returns, which do not lend themselves to developing infrastructure and deploying satellites. Although the VC investment may have supported the invention of some of these commercial firms, debt may be more appropriate for scaling the companies.

The primary challenge with using debt for a commercial space firm is that debt investors do not typically want to take on significant market or technology risk. However, if the DOD were to provide loan guarantees and initial business for a space company, the risk would lessen. With the DOD as the guarantor, the company could more easily access credit markets with risk-free rates. The important question then becomes whether the company has enough cash flow to

- Support the debt, which would likely be less demanding than meeting VC expectations.
- Refinance as the debt reaches maturity.

In December 2022, the Secretary of Defense established the Office of Strategic Capital (OSC) to “attract and scale investment to national security priorities.”[15] In July 2024, OSC announced a request for information to receive public input as it prepares to issue loans and loan guarantees for “critical technology and supply chain components.”[16] Commercial space companies should be attractive options for OSC as it pursues this new loan program.

requirements; the government will have significant control over the design and operation of a system, but it will typically cost more than something that is commercially available. In contrast, serving as simply one of many customers, the government may not have much influence at all over the item’s capability, but will likely be able to buy the item much more cheaply. Bottom line, anchor tenancy offers the government some influence over acquisition capabilities, albeit at a higher cost than the same item developed within a broad commercial market—yet not as expensive as traditional DOD acquisition methods. The DOD’s preference is to serve as one of many customers of a commercial firm, but serving as anchor tenant—even for a long period time—may be preferable to traditional acquisition.

The DOD can also use its anchor tenancy to try to help commercial firms expand their commercial reach. Remote sensing companies have noted that clarification on future government revenue would help them raise private capital.[17] For the commercial firms that the DOD wants to partner with, it should discuss the contract mechanisms and terms that would benefit the commercial firms’ financial viability while using U.S. taxpayer money judiciously.[18] In cases where companies operating in this arrangement do experience long-term success, sustained profitability is a valuable industrial by-product of the DOD’s improved access to space capabilities.

Navigating Risk and Trust

Partnering more extensively with commercial players entails risk for the DOD. Even with additional government revenue, companies may struggle to become profitable. The department will need to make difficult decisions about where to invest and partner, recognizing that some of the companies that are left out will likely fail. In making these decisions, the DOD will want to consider financial variables, such as the company’s financial make-up, economic trends, and business model; technical variables, such as current capabilities, development roadmaps, and integration challenges; and operational variables, including the company’s management, workforce, supply chain, and strategy.[19] The DOD will need a robust framework to assess potential partner companies and understand the risk associated with these variables.

Another set of risks relate to the DOD’s potential distortion of commercial markets. As with the rise of VC funding stemming from low interest rates and easy access to capital, significant DOD spending on commercial space services could create inefficiencies. In 2023, RAND published a report on leveraging commercial space services in which it warns that investing in capabilities with an “immature market risks the Department of the Air Force’s long-term goals.”[20] The report expands, “If commercial demand for a service is not sufficient to support sustained revenue for more than one or two firms, adverse outcomes may result. A weak commercial market could result in higher costs to the DOD, vendor lock stemming from lack of competition, the consolidation of the industrial base, and reduction in the innovative potential that comes from meeting commercial demand." [21] Although the report does not say that the Air Force should not invest in immature markets, it does caution that the DOD's investment in capabilities with immature markets could leave it as the dominant customer, potentially eroding the market and limiting the "industrial base to a few commercial providers, or even one provider."[22]

There is validity to RAND's assessment that the DOD could be the dominant customer for some of the commercial space capability areas and that such investments could stymie competition. However, a greater risk is that, by being cautious and less active with these nascent sectors, some of them may not survive. In certain cases, particularly niche offerings or those that require heavy capital expenditures upfront, a weak commercial market may lead to a loss of capabilities and no addressable market without the initial presence of DOD investments. Many of these firms benefited from an exceptional VC environment that encouraged innovation and risk taking, resulting in new space capabilities and services valuable for the department. By taking a more active role, the DOD can leverage these capital-intensive space capabilities to strengthen U.S. advantages in space.

The DOD also faces risks related to foreign influence from within its suppliers and commercial partners. Identifying foreign influence can be challenging, particularly for start-up space companies that have received private capital. The department will also want to weigh risks of foreign control and influence to avoid partnerships in which potential adversaries could exploit the companies' critical technologies. Foreign influence could take the form not just in the leadership of the company but also in the private equity and VC firms giving it funding.

The complex task of identifying foreign influence should not dissuade the DOD from investing more heavily in commercial space. The department should be diligent in selecting partners, but it still should select partners. The DOD and the government have many organizations and mechanisms for making these assessments—including the Air Force Office of Special Investigations, AFWERX, Defense Innovation Unit, Office of Strategic Capital, Office of Commercial Economic Analysis, and the Committee on Foreign Investment in the United States (CFIUS)—and this would be a central element of any DOD program in this area.

Conclusion

The DOD should embrace partnerships with commercial space firms that offer attractive military capability. These partnerships can represent an efficient use of resources, helping to ensure the DOD's ability to use systems and services even though much of the capital and initial investment for them came from elsewhere.

This is not to say that taking a more active role in some commercial space firms and serving as an anchor tenant will not be free of costs. As noted previously, assessing the risks of foreign influence will remain a challenge, exacerbated by the complexity of the investor landscape. Further, as noted by RAND, the DOD's contribution to revenue in some companies could make it harder for other companies to compete. Additionally, some of these efforts and companies could fail, even with the department's added investment.

However, the risks of excess caution are greater. Without consistent government demand, many of the U.S. commercial space firms that offer valuable defense applications may not survive. In part, due to an exceptional VC and financial environment leading up to 2021, the United States has benefited from a bourgeoning commercial space industry that spans all space capabilities, resulting from high-capital investments made by other investors. With the right funding and approach, the DOD can ensure it can use these assets for defense purposes. Doing so will save the department the money and time that would otherwise be necessary to build additional custom systems and help preserve and leverage U.S. competitive advantages in space. If the DOD wants to ensure it can benefit from having the most expansive commercial space sector in the world, it may just have to pay more for it.

Acknowledgments

Thank you to Matt Swinehart, David Rader, Mike Dickey, and Ryan Conroy for their reviews. Thank you also to Andrew Berglund for serving as editor.

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About Space Agenda 2025 Publications

This paper was published as a chapter of *Space Agenda 2025*, with Angie Bukley, Colleen Stover, and Victoria Woodburn serving as editors in chief. *Space Agenda 2025* is an effort by the Center for Space Policy and Strategy (CSPS) at The Aerospace Corporation to highlight and provide insights into some of the major space challenges facing policymakers. You can find the complete list of individual *Space Agenda 2025* papers at http://csps.aerospace.org/SA2025, as well as download the combined set of 16 chapters in the *Space Agenda 2025 Compendium* at https://csps.aerospace.org/papers/space-agenda-2025-compendium, all available to you with our compliments.

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RUSSIA'S WAR IN UKRAINE: KEY OBSERVATIONS ABOUT SPACE

Michael P. Gleason

Executive Summary

The war in Ukraine offers lessons for the U.S. Department of Defense (DOD) and the U.S. Space Force (USSF). While focusing on the ground-based components of space systems and on the importance of integrating data from space capabilities at the battle-edge, this chapter highlights several lessons including:

- A key reason Russia has not been able to exploit its advantage in sovereign space capabilities compared to Ukraine is that Russian forces have not sufficiently integrated data from Russian space capabilities at the operational and tactical levels.
- In sharp contrast, Ukraine has successfully integrated data from space and disseminated it quickly to the warfighter using innovations in *ground-based* space system hardware, software, and applications.
- Ukraine shows that independent access to space and fleets of satellites is not sufficient for advantage in war. Innovations in ground-based technology have done just as much, if not more, than the satellite capabilities themselves to maximize the effectiveness and lethality of Ukrainian forces.

While Russia has attacked and continues to threaten commercial space ground systems and data networks, the war in Ukraine also warns that commercial satellites should not expect to be exempt from attack, including destructive attacks, in a war that extends into space. Moreover, Russian physical, cyber, and electronic attacks in Ukraine against commercial space systems' ground and link segments warn similar attacks will occur in future conflicts. Commercial ground and link segments, which are crucial for the warfighter, must be protected.

In addition, the vulnerability of commercial space systems should incentivize the United States to accelerate changes to regulations, policy, bureaucracy, systems, and operations to enable sharing data from hardened U.S. military space capabilities. Innovators must come up with new ideas to meaningfully improve data access for allies and partners.

Finally, the USSF should evaluate its priorities and investment decisions to see if they adequately reflect the importance of integration, networks, and other components of the ground-based segment of space systems.

Introduction

Prior to Russia's further invasion of Ukraine in 2022, most national security experts would have predicted that Russia would gain significant advantage from its outer space capabilities in the event of an intensified conflict between the two nations. After all, Russia has independent access to space, decades of experience using space for military purposes, and significant satellite and counterspace capabilities, while Ukraine had neither a space program nor any national satellites. As the war has unfolded, it is actually Ukraine that has been more effective utilizing space-based capabilities. Ukrainian forces have successfully leveraged commercial space services, including imagery, radar, and communications, to enable communications among their forces and to target Russian forces.

The war in Ukraine offers lessons for the Department of Defense (DOD) and the U.S. Space Force (USSF) on how future conflicts could extend to space. This chapter highlights three of those lessons.

First, Ukraine's innovative use of data and networks to provide actionable information to fielded forces has had a powerful effect on the battlefield. Although satellites tend to draw the most attention among strategists and policymakers, ground systems and data networks have proven vital to Ukrainian forces' ability to integrate the data from space into their operations and weapon systems. Effective data integration has strengthened Ukraine's defense against numerically superior Russian forces.

Second, Russia has attacked and continues to threaten commercial space ground systems and data networks in this war, suggesting Russia knows how critical these capabilities have been for Ukraine. This highlights the vulnerability of ground systems and data networks. These segments of space systems (whether commercial or military) will likely be targeted in future conflicts that extend to space. To date, Russia's attacks have consisted of temporary, reversible attacks against satellites or cyberattacks against ground infrastructure and not destructive attacks against the satellites themselves, signaling some level of restraint. Russia's attacks have raised questions about how, if at all, the United States should protect commercial space systems that come under attack in a conflict.

Finally, Russia's attacks on commercial space systems makes a case for the United States to make the data from hardened, jam resistant U.S. military space capabilities significantly more available to allies, partners, and other supported nations.

Ukraine's Use of Commercial Space Capabilities

In its fight against Russia's invasion and occupation of its territory, Ukraine has benefitted greatly from its access to global commercial space services. At the start of the war, a member of Ukraine's cabinet wrote a letter to eight space remote sensing companies asking for their support.[1] Commercial electro-optical imagery and synthetic aperture radar companies, which can detect movements at night and through clouds, have helped Ukraine's military forces target Russian assets and carry out battle damage assessments.[2] In March 2022, HawkEye 360, a commercial radiofrequency mapping company, publicly announced "the capability to detect and geolocate Global Positioning System (GPS) interference, with analysis of data over Ukraine revealing extensive GPS interference activity."[3] Even prior to Russia's invasion and during the early days of the conflict, commercial remote-sensing satellites helped monitor the Russian buildup of forces and troops within occupied Ukraine and in Russia and Belarus, providing observers around the world a compelling picture of what was happening on the ground.

Commercial satellite communications have also been fundamental to Ukraine's defense. The commercial companies that have provided information to Ukraine include Viasat, OneWeb, SES, Iridium, Inmarsat, Eutelsat, Avanti, and, most prominently, Starlink. President Zelensky has used Starlink to connect to Ukrainians, national parliaments, and international organizations around the world. Ukrainian forces have used Starlink for secure communication and situational awareness, connecting leadership to military units on the battlefield. The capability has also facilitated "tele-maintenance" of weapon systems in Ukraine. When something has broken, Ukrainian forces have used Starlink to connect with U.S. maintenance specialists at a base in Poland to diagnose and resolve the problem via video.[4]

Lesson 1: Prioritize Integration Between Satellites and Terrestrial Forces

A key reason Russia has not been able to exploit its advantage in indigenous space capabilities is that Russian forces have not sufficiently integrated data from their space capabilities at the operational and tactical levels. Analysis suggests there are several reasons for this, including inadequate doctrine, strategy, training, material investment, and a lack of priority on "getting space support to the warfighter," (as is said in U.S. military parlance).[5] An assessment of Russia's space capabilities from 2019 indicated that even its newest space-based ISR systems had issues: "In addition to the high failure rate of the satellites, the products and services that they do provide often fail to meet the requirements of end users and are not competitive with equivalent foreign capabilities."[6]

In sharp contrast to Russia's failures to integrate data from space, Ukraine has demonstrated that what matters is not only what satellite data or services are provided, but also how they are delivered to the warfighter. Innovations in ground-based satellite hardware, software, and applications allow Ukrainian units in the field to rapidly process and disseminate information from satellites. The networked, distributed approach to using and sharing information from space pursued by Ukraine and its allies has demonstrated the asymmetric advantages of this approach compared to the centralized, hierarchical structure used by Russia. Enabled by commercial telecommunication satellites (including Starlink among others), and while leveraging data from a wide variety of commercial remote sensing satellites, Ukrainian forces have been able to innovate and adapt with more decentralized command and control and more direct communications and coordination between tactical units.

One reason the impact has been so significant is the underlying environment that enabled or encouraged data to be shared quickly with key stakeholders. The ground-based hardware, software, and applications allowing units to rapidly process and disseminate information have proven invaluable to Ukrainian military efforts against Russia. Ukrainian forces have also benefited from receiving raw data, which enables customization, rather than processed data, along with requisite training on how to exploit the raw data flexibly. The timeline for transferring data from space to warfighters has dropped from days to hours or, in some circumstances, to fewer than 10 minutes.[7]

The "Uber for artillery" application, GIS Arta, allows units collecting information on potential targets, including from satellites, to share that information directly with units that could fire on the targets.[8] This application pairs sensors with shooters in a decentralized network instead of having to funnel specific information up and back down through centralized command nodes. As another example, Palantir software can draw imagery from a total of 306 commercial satellites. Soldiers in battle can use handheld tablets to request more satellite coverage if they need it.

Western military and intelligence services work closely with Ukrainians to facilitate this information sharing.[9] Cloud-based environments have also helped remove data stovepipes and minimize the need to translate between systems.[10]

Russia's inability to accomplish these tasks helps explain the underwhelming contribution of its superior space capabilities to its fight in Ukraine. While space power theory, doctrine, and strategy often stress the importance of satellites, Ukraine shows that independent access to space and fleets of satellites are not sufficient for providing an advantage in war. Accessing commercial innovations and implementing practices for sharing satellite information at the battle edge have done just as much, if not more, than the satellite capabilities themselves to maximize the effectiveness and lethality of Ukrainian forces in the war.

Applications to U.S. Doctrinal Concepts. Russia's war in Ukraine provides an opportunity to test some doctrinal concepts as espoused in the 2020 USSF document, *Space Capstone Publication: Spacepower, Doctrine for Space Forces*. The Space Capstone Doctrine asserts that space systems provide their greatest potential when *integrated* with other forms of military power and states a spacecraft provides little value if the data it provides cannot be exploited.[11] Underlining this doctrinal concept, in April 2023, then-Major General David Miller—who at the time was director of operations, training, and force development for the U.S. Space Command—observed that warning, surveillance, and targeting information coming from satellites ultimately had no value if it could not be delivered to the warfighter in a tactically useful time-frame.[12]

Disseminating data from space rapidly and then making that data useful tactically (for example, by integrating it into weapon systems) for warfighters in other domains is not a simple task. It took significant investment and many years for U.S. joint forces to become proficient at it, and there is still plenty of room for improvement.[13] Along with apt doctrine, strategy, and training, making data useful requires sophisticated networks, data processing software, automation, tailored applications, adequate spectrum, decentralized data-sharing processes, and requisite hardware (for example, antennas, modems, and user equipment suited to harsh environments). Assessing Russia's and Ukraine's different experiences in making use of data from satellites validates the doctrinal claim that a satellite's value is directly tied to the end user's ability to effectively use data from the satellite when and where they need it.

These observations underscore the importance of space doctrine, information-sharing processes, and ground-based enabling segments beyond the satellites, whether commercial or government owned. Russia's inability to exploit its space superiority relative to Ukraine and Ukraine's ability to exploit space even though it lacks satellites confirm USSF doctrinal assertions and senior leader statements that space systems provide little value if the data they provide cannot be exploited.[14]

However, Russia's war in Ukraine provides opportunities for analysts to test other aspects of USSF doctrine and organizational priorities. For example, current USSF doctrine (and space power theory in general) may not sufficiently account for commercial space services contributions to war at the strategic, operational, and tactical levels. Arguably, access to data from commercial satellites now provides a sound alternative to independent access to space and national space systems. In addition, analysts should evaluate if USSF investments reflect the importance of integration, networks, and other components of the ground-based segments of space systems. In light of the experiences in Ukraine, it would be prudent to assess USSF priorities and investments across the board to seek out areas for improvement.

Lesson 2: Prepare for Attacks Against Commercial Ground Segments and Satellites

Commercial space actors have come under attack in Russia's war on Ukraine. For example, in the hours before troops invaded Ukraine in February 2022, Russia conducted a cyberattack that disabled Viasat modems, including terminals used for Ukrainian command and control.[15] The attack produced international and strategic effects, disabling tens of thousands of ground-based terminals throughout Europe and disrupting wind turbines and internet services. In addition to highlighting a major cyber vulnerability in these ground systems, the event showed how many aspects of civilian infrastructure and communications in Ukraine and Europe relied on the terminals.

The nature of Russia's cyberattack was also revealing in that it demonstrated the vulnerability of terrestrial space systems. Cyberattacks on the ground segments of space systems can be effective and are more likely than destructive attacks on orbiting satellites, or even cyberattacks against the satellites themselves.[16] Several U.S. leaders across industry and the military have observed that ground systems and software, such as cloud environments, can be particularly vulnerable in conflict. U.S. Space Force Chief General Saltzman said in May 2022, "One of the observations that I would offer on that is that, if you think the only way to dismantle space capabilities is by shooting down satellites, you're missing the bigger picture…as these cyberattacks are on ground networks."[17] In addition to cyberattacks, commercial space actors are wrestling with continued jamming attacks against their link segments.[18]

Beyond cyberattacks, physical attacks can also manifest against commercial ground segments. Satellite control centers, terminals, or various communication nodes traveling with military units can be just as vulnerable to physical attack (for example, by cheap drones, artillery, bombs and missiles, and sabotage) as any other facility or capability on Earth. It is far less expensive and less challenging technologically to physically attack the ground segment compared to attacking orbiting satellites, which require high-tech space tracking systems and other exotic and expensive capabilities such as direct-ascent missiles or co-orbital weapons capable of reaching specific orbits.

While attacks on the ground, link, and data segments of space systems may be cheaper, easier, and similarly effective as physically attacking satellites, Ukraine indicates that orbiting commercial satellites should not expect to be exempt from attack, including destructive attacks, in a war that extends into space. [19] While U.S. government leaders have raised options for protecting commercial space systems, including indemnification and providing threat information to commercial actors, Ukraine demonstrates that it is an increasingly urgent issue. The hardening of ground systems, software, and cloud environments may be a key investment in securing space systems as a whole.

Lesson 3: Provide Easier Access to Data from Hardened U.S. Military Space Capabilities

Russia's attacks on commercial space systems likely increase the perceived value to allies and partners of access to data from hardened, jam resistant U.S. military space capabilities. These U.S. military space systems provide robust services that are more protected than other government or commercial space systems against cyberattack, jamming, electromagnetic energy, and other types of interference. However, the data and services from these U.S. systems is often difficult to share with allies and partners.[20] U.S. regulations, classification policy, bureaucratic barriers, and other practices often preclude effective data and network sharing with allies, partners, and other supported nations.[21] While the U.S. may seek to share capabilities in times of crisis, gaining access to these systems at a tactical level could be challenging due to the need for expensive terminals, and other specialized equipment, that have to be integrated with other military equipment on short timelines.

Russia's war in Ukraine should incentivize the United States to accelerate changes to regulations, policy, bureaucracy, systems, and operations to reduce barriers to sharing access to higher-end U.S. military space capabilities. Where commercial satellite services face persistent jamming, interference, cyberattack and physical threats, providing allies and partners access to data from protected satellite systems could quickly become a U.S. imperative; this imperative could grow if adversaries field even more aggressive capabilities to challenge commercial satellites.[22] While sensitive U.S. information needs to be protected and recipients need to have appropriate safeguards in place, there may be advantages to the United States if it can design and implement more accessible methods for allies and partners to get crucial data from and through U.S. space systems.

The United States has taken steps recently to make access to data from U.S. space systems easier, but there is plenty of room for further improvement and innovation. For example, in January 2024, the DOD lowered some classification barriers, making data from the space systems easier to share with allies and partners.[23] Other efforts to improve access to data from U.S. space systems include the DOD's combined space operations (CSPO) initiative, which facilitates satellite data sharing among key allies, including Australia, Canada, France, Germany, Italy, Japan, Norway and the United Kingdom.[24] In addition, military coalition exercises that practice space information sharing also contribute to lowering barriers to data sharing. In February 2024, 25 nations participated in the most recent Global Sentinel exercise, which began in 2014 and focuses on space security cooperation and operational collaboration. While many NATO and other close U.S. allies participated, less frequently involved partners such as Brazil, Colombia, and Peru also joined, with India and Mexico attending as observers. Other initiatives, such as personnel exchanges, combined education and training, exercises, and cooperative development, are incrementally trying to improve space data sharing with allies and partners.[25]

Given the sluggishness of current U.S. initiatives to lower classification, export control, and other barriers, innovative ideas are needed to improve partner access to the data that hardened U.S government space systems provide. One option would be to define a pre-set menu of approved U.S. military space services that can be provided to allies, partners, and other supported nations, which could allow allies and partners to better plan how to leverage U.S. space capabilities, lower barriers in a crisis, and enable quicker and more efficient access to data when time matters most.

These space services could accelerate information sharing and enhance alliance effectiveness in several ways. Identifying the user equipment needs, such as specialized modems, terminals, antennas, and other hardware and software, ahead of a crisis could lead to solutions that reduce delays caused by classification issues, export licensing requirements, and other barriers. Finding suitable ground sites, establishing necessary data links, procuring terminals, and provisioning requisite cybersecurity and local physical security require time and resources. The earlier these needs are identified and addressed, the quicker the access to data from U.S. space systems can begin in the event of crisis or conflict. In a more stable period, establishing such infrastructure could look more like traditional Foreign military sales. Financial contributions from partners could be prearranged. In the case of urgent situations like Russia's invasion of Ukraine, these factors could take the form of emergency security assistance.

Conclusion

In war, the state that possesses superior space systems is not guaranteed more effective space support for the warfighter. Instead, the ground and link segments that facilitate networked data dissemination methods and innovative application of the data from satellites have allowed Ukraine, with no satellites of its own, to make better use of space than Russia. Increasing opportunities to make use of space information and services developed by commercial space services have enabled Ukraine to close the gap in space capability while Russian forces have apparently struggled to provide sufficient space-derived information to their warfighters in a timely fashion. Ukraine has demonstrated that what matters is not only what satellite data or services are available but also how fast they are delivered to the warfighter and how well equipped the warfighters are with proper user equipment and training for integrating and using data from space. This dynamic indicates that policy, information-sharing structures, data-processing capability, and data-dissemination networks, while not always the most visible components of space strategy, can be the deciding factor in gaining a competitive advantage in war. Current USSF doctrine in this regard is on target, but USSF priorities and investments should be assessed given these observations.

In addition, while U.S. space strategy for several years has contemplated the vulnerability of commercial satellites and ground systems that the DOD relies upon for many missions around the globe, it is unclear how willing the department is to invest in protection of commercial space systems, in space, or on the ground. Competing priorities for scarce resources often leave these concerns unaddressed. The need to defend critical national security space systems takes priority, but Ukraine shows that protecting commercial space systems, especially the ground and link segments of space systems, is increasingly urgent. USSF strategy, priorities, and investment decisions should take these factors into consideration.

Importantly, Ukraine also shows that any country (allies, adversaries, or non-aligned) with sufficient access to data from commercial satellites has an alternative to developing costly independent access to space and national satellite systems. Ukraine provides them the incentive to focus investments on data distribution and ground systems. In addition to being concerned about the possibility of Russian attacks on commercial space systems, to defend U.S. troops in the field, the DOD and combatant commands may be called upon to deny access to space services from a third country's commercial space enterprise.

Finally, although Ukraine has leveraged the data from commercial satellites to a remarkable extent, Ukraine also demonstrates that important advantages may be available to the United States if it can make the data from hardened, jam-resistant U.S military space capabilities more readily available to allies, partners, and other supported nations.

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About Space Agenda 2025 Publications

This paper was published as a chapter of *Space Agenda 2025*, with Angie Bukley, Colleen Stover, and Victoria Woodburn serving as editors in chief. *Space Agenda 2025* is an effort by the Center for Space Policy and Strategy (CSPS) at The Aerospace Corporation to highlight and provide insights into some of the major space challenges facing policymakers. You can find the complete list of individual *Space Agenda 2025* papers at http://csps.aerospace.org/SA2025, as well as download the combined set of 16 chapters in the *Space Agenda 2025 Compendium* at https://csps.aerospace.org/papers/space-agenda-2025-compendium, all available to you with our compliments.

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SPACE REGULATORY REFORM IS A WICKED PROBLEM STILL WORTH TACKLING

Brian Weeden and Victoria J. Woodburn

Executive Summary

Rapid growth in U.S. commercial space has yielded important benefits for civil and national security space capabilities. Continued commercial space growth and innovation depends in large part on further modernization of the policy and regulatory environment that enables and promotes those commercial activities. As a result, presidential administrations and Congress have grappled with reforming the space regulatory regime many times over the last few decades, with some major successes but also many remaining challenges.

The breadth of space regulatory issues that need reformation is vast, each with its own unique set of stakeholders, existing regulations and policies, executive branch regulators, congressional authorizers and appropriators, and economics. Despite this complexity, the next U.S. administration must continue the good work that has been started by previous administrations and make the difficult decisions to resolve the seemingly perpetual debates that have persisted for decades. To that end, we offer several recommendations for the next presidential administration:

- Space regulatory reform is an urgent issue and should be pursued assiduously. The longer it takes to make key decisions, the likelier it is that there will be consequences for future U.S. commercial space sector viability and government programs and policy goals that rely on commercial space.

- While space issues are often cross-cutting, the next White House must decide which topics can be handled at the agency level and which ones require a full interagency process to resolve. Pulling everything up to the interagency level will reduce the available bandwidth to tackle the breadth of issues that need resolving.

- As much, if not more, political capital should be spent on implementation of policy decisions as on their formulation. It is easier to announce a decision than it is to actually implement change.

- Engage constructively with Congress early and often in the process. Very few of these problems can be resolved exclusively by the executive branch and many require the executive and legislative branches to reach an agreement.

Introduction

One of the consistent themes in the space world over the last two decades is the rapid growth in the activities of the commercial sector. While commercial space has been around in some form since the 1960s, it has expanded from satellite communications to remote sensing of Earth, space launch, and most recently, human spaceflight and in-space servicing, assembly, and manufacturing.

This growth in commercial space activities has accelerated over the last four years. For example, the United States hosted 36 launches in 2020.[1] By 2023, that number grew to 117 U.S. launch attempts, the vast majority of which was driven by an increase in commercial launches.[2] The variety of space activities has also grown, with commercial companies attempting or planning missions involving commercial space tourism, orbital debris removal, space-based manufacturing, and space resource extraction.

Multiple U.S. agencies have put in place policies and strategies to leverage the innovation, speed, and cost savings of the commercial space capabilities for government missions. The National Aeronautics and Space Administration (NASA) was an early adopter and today relies on commercial capabilities to transport people and cargo to and from the International Space Station and plans on using commercial capabilities for critical parts of the Artemis program to return to the Moon. Additionally, the Department of Defense (DOD) is also seeking to leverage commercial assets and services for a variety of national security missions. In April 2024, the DOD and U.S. Space Force (USSF) released commercial space strategies to guide increased partnerships and engagement with commercial space actors. Likewise, the National Oceanic and Atmospheric Administration (NOAA) is evaluating using commercial space-based data for weather forecasting.

To effectively leverage the advantages of commercial space capabilities, such capabilities need to exist in the first place, and their existence is heavily impacted by the policy and regulatory oversight framework put in place by the federal government. Currently, regulation of U.S. commercial space activities primarily falls under the jurisdiction of three agencies. The Federal Aviation Administration's Office of Commercial Space Transportation (FAA/AST) has authority for licensing launches and reentries as well as private spaceports. NOAA's Office of Space Commerce regulates private remote-sensing satellites. Lastly, the Federal Communications Commission (FCC) regulates non-federal use of the radio-frequency spectrum. In addition, the Department of Commerce (DOC) and State Department both play a role in licensing the transfer of controlled technologies to non-U.S. entities as part of the export control regime.

These existing authorities have developed over several decades and, as commercial space activities continue to diversify and increase, the limitations of this existing framework have become apparent. Commercial innovation has outpaced some of the existing regulatory processes, and there are planned activities that don't clearly fall under the existing authorities. There are long-standing tensions between the private sector and the national security community over the potential threat that commercial use of dual-use technologies could pose. There is also a lack of clearly refined processes or authority for supervision and authorization of so-called "novel" activities that fall outside the existing categories listed above. These challenges are complex and difficult enough that several past administrations have tried to address them, but many challenges still exist for the next administration to resolve.

As a result of these challenges, oversight and regulation of commercial space exemplifies what is known in public policy as a "wicked" problem. In this context, wicked problems are defined in distinction to tame problems: it is difficult to define all the necessary variables, there's not a clear stop condition when the problem is completely "solved," you can't test all possible solutions, and there are many different stakeholders with different interests or even definitions of what a good solution or outcome might be.[3] Many of the tools developed in math, science, and engineering to solve tame problems are unable to deal with wicked problems, yet wicked problems often involve some of the most critical public policy issues to address.

This paper provides an overview of the history and breadth of federal regulation and oversight of the commercial space industry and its enduring challenges. Additionally, it highlights potential actions that the next presidential administration could take to ensure continued U.S. leadership in commercial space activities. A clear and predictable regulatory regime can ensure U.S. leadership and safety while also promoting commercial growth and innovation. By contrast, ill-defined, opaque, slow-moving, or overly cumbersome regulations risk hindering the growth of the U.S. commercial space sector during a time when the U.S. government is becoming increasingly reliant on it.

Challenges to Commercial Space Regulation

The debate over how to modernize oversight of commercial space activities is largely a function of the complexity of the system. This complexity relies on a myriad of factors, some of which are unique to the space industry while others are common across emerging technology areas. Some of the challenges unique to space include the international treaty obligations that pertain and the diverse number of government stakeholders. Alternatively, tensions between both regulating and promoting industry and dual-use technologies can be found across multiple sectors. The convergence of these challenges, plus emerging political dynamics, makes regulating commercial space more challenging than many other sectors.

The most unique aspect of space regulation is the international obligation for the U.S. government to regulate its private sector space activities. Article VI of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (The Outer Space Treaty) states that "States Parties to the Treaty shall bear international responsibility for national activities in outer space... whether such activities are carried on by governmental agencies or by non-governmental entities" and such activities "shall require authorization and continuing supervision by the appropriate State Party to the Treaty."[4] As a party to this treaty, the U.S. government is responsible and liable for its space activities and those of its citizens, including commercial activities, and has created its oversight regime, including national space policies and regulations, as part of fulfilling its authorization and supervision responsibility. The biggest impact of this obligation is that governments must be more involved in oversight of space activities than many other areas.

Many additional challenges to regulating commercial space are not unique to the space sector. These shared challenges include the dual-use nature of the technologies that have both defense and non-defense applications, disparate and overlapping regulatory authorities across multiple federal agencies, significant links to national security and sovereignty, and growing international competition. Additionally, regulatory agencies are also tasked with competing priorities in both having to regulate the commercial space industry while also promoting its growth.

Public policy is still an exercise in balancing competing interests and priorities, and that balancing act is both shifting and getting more complicated when it comes to space regulation. National security and public safety have historically been among the most important priorities, but that is waning with the globalization of space technologies and the growing recognition of the socioeconomic benefits from wider access to space applications. Promoting and growing the commercial space sector is increasingly important for driving innovation but could undermine traditional actors and public safety if it happens too fast. All of the expansion and growth in space is also in tension with ensuring the long-term sustainability of space activities, for both current users and uses as well as those in the future.

Historically, the United States has taken a prescriptive approach to commercial space regulation, resulting in regulations that often are slow to adapt to evolving technology or the increased growth of the commercial space sector activities. As the pace of technological change within the commercial space sector is evolving faster than regulators can respond, a number of current and emerging commercial space activities fall into a regulatory gap outside of current regulations. This gap can cause delays in getting commercial activities approved, resulting in added costs and disproportionally impacting small companies and startups.

On top of these policy questions is a layer of political considerations. Regulation is a term that has a variety of political connotations and implications. The major U.S. political parties have different philosophies for the role of government in providing oversight of the private sector, such as what should be considered in that oversight and how light or heavy a regulatory touch the government should take. These philosophies can even differ within a political party, depending on the technology or sector, and are evolving over time. The political context adds yet another layer of complexity in making progress on this topic.

Additionally, comprehensive commercial space regulation will require a whole-of-government approach. While the FCC, FAA, and NOAA are the primary regulatory agencies when it comes to commercial space operations, a range of other agencies, including the DOD, NASA, Department of Energy, Department of State, and more, has a stake in the industry. Different agencies have their own missions and authorities that can lead to differing approaches to regulation as well as occasionally overlapping interests and regulatory authorities. Creating a regulatory regime that satisfies all stakeholders and streamlines the process among them for commercial actors is a complicated process.

Lastly, the United States is not the only country currently revising and updating its commercial space regulation. For example, New Zealand recently put in place the world's first regulatory framework for satellite servicing[5], and the European Commission is expected to soon reveal a space law for the European Union.[6] Many other countries have or are developing their own regulatory frameworks as part of enabling their own commercial space industries and influencing international norms and standards. If the United States wants its commercial industry to compete internationally, then it must also consider the impact of international regulatory regimes on U.S. companies. If U.S. regulations are markedly different than those of international partners, it will make international business more difficult as well as create potential interoperability challenges between allies and partners.

All three failure modes from not addressing these challenges—lack of certainty, overly cumbersome regulations, or total absence of regulation—pose risks to U.S. leadership in space. An unclear regulatory environment may, in turn, cause uncertainty in the long-term viability of commercial space activities that deters investors from investing in new space technologies or entrepreneurs from working in this space, prompt questions about whether the United States is fulfilling its international treaty obligations, and create liabilities U.S. taxpayers could be on the hook for. If U.S. companies are hindered by regulation, the United States may lose access to certain commercial capabilities due to companies' inability to stay financially viable and innovate. U.S. companies may also turn to "flags of convenience" and register their operations in countries with more permissible regulatory environments. While this poses a clear issue for U.S. competitiveness, it could also lead to a less safe space environment, which, in turn, could lead to additional risks and costs of operating in space that are borne by U.S. government and commercial space operators.

Current Issues and Debates

Several previous administrations have grappled with the challenge of modernizing the space regulatory framework, with varying degrees of success due to the persistent challenges outlined above. These efforts can be grouped into reform of the existing regulations for commercial remote sensing and launch and reentry, reform of the existing spectrum regulations to incorporate large broadband constellations, and development of new regulations to cover emerging commercial space activities, including human spaceflight.

Commercial Remote Sensing of Earth and Space Objects. Commercial remote sensing of Earth was one of the earliest areas in which the United States established regulations, driven by the competing desires to promote private sector enterprise and protect national security. In 1992, Congress passed the Land Remote Sensing Policy Act, which provided continuity for the previously government-controlled Landsat satellite program by shifting it to a commercial procurement model.[7] This shift was accompanied by the authorization of the Secretary of Commerce to license private sector parties to provide remote-sensing space systems, which was further delegated to NOAA. Although the attempted commercialization of Landsat failed, the licensing framework was developed, and multiple commercial companies began operating to provide satellite imagery of Earth.

The main challenge with the commercial remote-sensing regulations was that they imposed significant restrictions, known as "conditions" in regulatory parlance, on U.S. commercial companies to protect national security. These included restrictions on the quality and types of imagery that could be captured, along with certain locations on Earth that could not be imaged. The existing regulations also prohibited commercial spacecraft from imaging other space objects and commercial radar imaging entirely. The restrictions were opaque and difficult for new companies to navigate, and there was little to no option for recourse. Meanwhile, very few of the same restrictions were imposed on foreign companies operating outside the United States. Over the last two decades, these dynamics led to a thriving global remote-sensing market that U.S. companies could not fully compete in and several categories of remote-sensing products that were only available from foreign companies.

While discussions about how to resolve this situation occurred during the Obama administration and before, it was the Trump administration that began a formal review. Space Policy Directive 2 (SPD-2), "Streamlining Regulations on Commercial Use of Space," issued on May 24, 2018, directed the DOC to "review and rescind or revise" the existing regulations for commercial remote sensing on a relatively short deadline of 90 days.[8]

NOAA kicked off their formal revision of the existing regulations on June 29, 2018, with a request for public input to questions posed across an array of topics.[9] On May 14, 2019, NOAA published their draft proposed rule, which introduced a new two-category framework based on the risk posed by the remote-sensing system and a higher bar for imposing custom conditions on a licensee. NOAA received significant feedback from industry, both in support of the reforms but also indicating that they did not go far enough.

On May 20, 2020, NOAA published their final rule for public comment, which was significantly revised based on the previous inputs.[10] The final rule created three tiers of licenses and associated conditions but crucially based those tiers on the current state of the international market instead of a pre-defined set of criteria. The highest tier, and the most conditions, would be restricted to commercial remote-sensing capabilities that were unique to U.S. companies, and foreign companies offering those same capabilities on the open market would automatically trigger a reduction in tier (and restrictions). Furthermore, special conditions could only be imposed on entirely novel capabilities for a maximum of three years.

The revised commercial remote-sensing regulations were largely embraced by industry, and NOAA has stood by the new process they created. In August 2023, NOAA announced that the 3-year window had elapsed and they had removed 39 individual temporary conditions, while a few had been extended at the request of the DOD.[11] Notably, many of the new U.S. commercial remote-sensing capabilities now allowed under the revised regulation are being used to support Ukraine in its war against the Russian invasion.[12] Remote sensing is thus one of the regulatory issues that has seen impactful policy change in the last 20 years.

Commercial Space Launch and Reentry. Commercial space launch is another sector that saw early development of a regulatory framework driven by the political desire to foster a commercial sector. On May 16, 1983, the Reagan administration issued National Security Decision Directive (NSDD) 94, "Commercialization of Expendable Launch Vehicles," to encourage the development of private sector space launch capabilities for the benefit of the United States.[13] A little over a year later, in October 1984, Congress passed the Commercial Space Launch Act, which authorized the Secretary of Transportation to license private sector space launches from the United States or by its citizens.[14]

For the next two decades, actual commercial space launches were fairly limited until the period of radical change and growth that happened within the last decade. This change created a significant set of challenges for the existing regulatory framework, which were developed under the assumption that commercial space launches would be relatively infrequent, take place from a few specific locations owned by the U.S. government, and would happen independent of subsequent reentries.[15] The proliferation of potential spaceports across the United States, rapid increases in the overall number and cadence of commercial launches, shifting rockets between multiple pads and sites, and landing and reuse of rocket stages presented major challenges under the existing framework.

The most recent major revision of the launch regulatory framework was also directed by the Trump administration as part of SPD-2 in June 2018, which directed the Secretary of Transportation to "review and rescind or revise" the existing space launch regulations within 120 days.[16] While FAA/AST undertook a similar process to revise its launch and reentry regulations as NOAA did for remote sensing, the outcome was not seen in as positive a light by many in industry.

In April 2019, FAA/AST published its initial draft rulemaking of the revised launch and reentry regulations for public comment.[17] The public submitted more than 150 comments, along with many questions, and voiced significant concern for the scope and direction of the revision.[18] FAA/AST released the final version on October 15, 2020, which took effect on March 10, 2021.[19] It made significant changes that addressed many of the shortcomings of the old regulations, including a shift in philosophy from a prescriptive approach that specified how to meet a requirement to a performance-based approach that only specified what the goal was, instead of prescribing a specific solution to meet that goal, leaving more room for innovation.

However, the launch industry still expressed concerns over the new regulations. A large portion of this stemmed from its length (more than 600 pages as a PDF file) and the large number of unspecified details on how it would be implemented. In response, FAA/AST indicated that it would issue a series of advisory circulars to further clarify how it would be implemented over the coming months. During a congressional hearing in October 2023, industry witnesses called for Congress to request additional reforms to the launch licensing process.[20] In February 2024, FAA/AST announced it would establish a new committee to solicit industry input on how to improve a new launch licensing process.[21]

Commercial Human Spaceflight. Separately, there has also been continued debate over how the United States would, or should, regulate commercial human spaceflight, including suborbital and orbital tourism and future commercial space stations. In December 2004, Congress passed the "Commercial Space Launch Amendments Act of 2004" that directed the Secretary of Transportation to encourage, facilitate, and promote commercial launch vehicles designed to carry humans.[22] While Congress authorized FAA/AST to update its regulatory framework to include human spaceflight, it also imposed a moratorium, commonly referred to as the "learning period," of eight years before FAA/AST could impose regulations on the safety of individual spaceflight participants or crew beyond what is necessary to protect public safety[23]

During the intervening two decades, and particularly in the last few years, commercial human spaceflight has advanced and had some spectacular successes towards enabling suborbital space tourism. However, the sector has generally not progressed as fast as originally thought. While Scaled Composites won the original XPRIZE challenge in 2004, it wasn't until July 11, 2021, when Virgin Galactic was able to successfully make its first commercial tourist flight, with Blue Origin following shortly thereafter. As a result, Congress has periodically extended the learning period, most recently extending it to January 1, 2025.[24] In the meantime, there are few regulations on how commercial companies can protect passenger safety, outside of mandatory disclosure of the inherent risks of spaceflight.

The debate over how long it will take for industry to mature enough and for FAA/AST to learn enough to end the learning period continues. On the one side, much of industry is arguing strongly that it is still too early to impose what might be burdensome regulations that end up stifling innovation. On the other side, others are concerned that the lack of regulations for some activities might lead to a tragic loss of life that itself will smother the industry through public outcry, loss of investor confidence, and higher insurance premiums.

Large Satellite Constellations. The third major existing regulatory framework for commercial space involves the FCC and their oversight of the radio-frequency spectrum. Here, the biggest recent challenge has been the re-emergence of large constellations in low Earth orbit (LEO) to provide broadband communications. This concept was originally floated in the late 1990s by several companies and involves large numbers of satellites—hundreds to thousands or more—and complicated questions about mitigating interference between use of the same radio-frequency spectrum by other terrestrial and space applications.

Although the original attempts at developing these constellations were largely unsuccessful, technological advances in miniaturization and cloud computing, along with reductions in the cost of space launch, have led to a rediscovery of the concept in the mid-2010s. In 2016, a company called WorldVu filed a request with the FCC for authorization to use the spectrum allocated for the original LEO broadband constellations. In response, the FCC opened up new processing rounds to any other companies who wanted to use the same allocations, prompting a flurry of applications of varying maturity. The FCC then proposed adding additional domestic spectrum allocations to support this emerging service, which, in turn, resulted in a much bigger flurry of complex activity at the International Telecommunication Union (ITU), the United Nations–specialized agency that maintains the international radio regulations to enable radio operations without harmful interference from other countries. The ITU regulations are agreed to by Member States at each World Radiocommunication Conference (WRC) and include making global and regional spectrum allocations and conditions for their use.

The biggest challenge in this spectrum-coordination process was how these new satellite broadband services would co-exist with one another and with other space and terrestrial services that operate in the same or nearby frequencies without causing harmful interference to these operations. There is only one radio-frequency spectrum, and only certain parts of it are suitable for transmissions through the atmosphere. Still other parts of the radio-frequency spectrum are especially good for specific applications and are in high demand by both space and terrestrial users. Adding in the costs and engineering challenges of developing practical applications, the end result is increasing congestion and risk of interference by the growing number of radio-frequency spectrum users and uses.

While the spectrum-coordination process for large constellations continues to be sorted out by national administrations and ongoing (and intensive) ITU studies, there are still other oversight aspects of large LEO broadband constellations that are unresolved. The existing regulatory system was designed to handle spectrum allocation and coordination matters and had lots of experience and expertise in doing so. However, this regulatory system was not designed to handle the other emerging oversight questions resulting from putting tens of thousands of new satellites into orbit, such as those concerning orbital debris mitigation and physical congestion, environmental impacts of space activities, and light pollution that affects astronomy.

Orbital debris mitigation itself is not a new concept; the United States has had national policy for orbital debris mitigation for almost the last forty years.[25] Each successive presidential administration since Ronald Reagan has included orbital debris mitigation in their national space policies and gradually built upon the requirements laid down by their predecessors. In 2006, the George W. Bush administration's national space policy formally directed the Department of Transportation (DOT), DOC, and FCC to include orbital debris mitigation in their licensing of commercial space activities.[26] Subsequent administrations have continued this focus on orbital debris mitigation and added improving space situational awareness and removal or remediation of existing orbital debris as well.

Thus, in addition to spectrum management, the FCC has also spent several years working through a formal rulemaking process on what the orbital debris mitigation standards should be for all the satellite systems they license and has established some initial rules.[27] The FCC's focus on orbital debris mitigation as part of its large constellation licensing process has also generated controversy. The authority for the FCC to include orbital debris mitigation in its licensing stems from both executive policy and its own interpretation of its regulatory authorities to protect public interest, but not everyone agrees that it has a clear grounding in congressional legislation. But at the same time, there are no other U.S. agencies that have licensing authority over large constellations, so others have applauded the FCC for filling what otherwise might have been seen as a gap in the United States' ability to carry out its international obligations. The FCC has also used its unique position outside the executive branch as an independent agency to put in place requirements that go beyond the Orbital Debris Mitigation Standard Practices (ODMSP) that are the baseline for other departments and agencies.

With the recent Supreme Court decisions of *West Virginia vs. Environmental Protection Agency*[28] and *Loper Bright Enterprise vs. Raimondo*[29], the FCC's orbital debris mitigation regulations and further regulatory activity from agencies may face intensified scrutiny if they fall outside of the agency's authorizing statute. *West Virginia* increased the focus on having explicit legislative authority for regulatory powers, and *Loper Bright* changed the deference given to regulator expertise in interpreting authorities and determining regulatory standards. Together, these ruling could result in challenges to the FCC's orbital debris mitigation guidelines and the executive branch's authority to set orbital debris mitigation standards.

The questions around light pollution and environmental impacts of large constellations remain unresolved. Current FCC rulings conclude that outer space is not an environment that falls under the National Environmental Policy Act (NEPA) and, as such, environmental impact analyses are not required for activities in space. However, there is growing concern about the carrying capacity of heavily used orbital regions and also emerging scientific research that suggests the reentry of large quantities of metals into the upper atmosphere may have significant effects on the upper stratosphere.[30] Several large-constellation operators are working with the astronomy community on ways to lessen the visible brightness of their satellites, but these efforts remain voluntary, and it is unclear whether the FCC has authority over optical interference. These are all challenging problems that will need to be addressed by the next administration.

"Novel" Space Activities. In addition to updating the current processes for regulating the existing private sector space activities outlined above, several administrations have also looked at how to authorize and supervise so-called "novel" space activities that do not clearly fall into the existing framework. Examples of these activities include in-space refueling, active removal of space debris, commercial space stations, and commercial activities on the surface of the Moon. Formal action on this topic was officially kicked off as a result of the U.S. Commercial Space Launch Competitiveness Act (CSLCA), which became law on November 11, 2015.[31] Section 108 directed the Office of Science and Technology Policy (OSTP) to assess the current authorization and supervision framework and provide recommendations to Congress within 120 days. On April 16, 2016, John Holdren, then director of OSTP, submitted the Obama administration's official response, which was a proposal for creating "Mission Authorization" framework, modeled on the FAA's existing Payload Review Process and intended to be a "light touch" approach instead of a comprehensive regulatory framework.[32] The legislative proposal attached to Holdren's letter proposed that the DOT be given the authority for mission authorization. The DOT was also the agency leading the Obama administration's interagency work on space traffic management (STM).[33]

However, implementation of this approach was not completed before the end of the Obama administration and the 114th Congress, leaving the matter in the hands of the incoming Trump administration. While the Trump administration largely maintained much of the substance already developed by the Obama administration, they did switch the lead agency for STM from the DOT to the DOC in Space Policy Directive 3, issued on June 18, 2018.[34] The National Space Policy released by the Trump administration on December 9, 2020, also stated that the DOC should take the lead in implementing mission authorization of novel space activities.[35] Once again, the new authorities contained in these policies were not enacted by Congress before the end of the Trump administration's term and the 116th Congress in 2020.

The Biden administration picked up this issue in March 2022, when Vice President Kamala Harris tasked the National Space Council with developing a proposal for authorization and supervision of novel space activities.[36] The White House held a pair of "listening sessions" in November 2022 to solicit input from the private sector as part of the process.[37] Before the Biden administration could release their official proposal, Republicans in the House of Representatives introduced the Commercial Space Act of 2023 on November 1, 2023, which proposed that the DOC take on a very narrow set of authorities to issue "certifications for the operation of a space object."[38] The Biden administration released their legislative proposal two weeks later, which proposed to split mission authorization between the DOT and the DOC,[39] followed by a policy framework to support the legislative proposal on December 20, 2023.[40]

As of October 2024, this issue of how to authorize and supervise novel space activities remains unresolved. The proposals from the White House and House of Representatives are fundamentally at odds. Meanwhile, some senators have criticized the White House proposal's split between the DOC and the DOT, as has the National Space Council's Users' Advisory Group and prominent industry groups.[41] No alternative legislation has been officially proposed in the Senate at the time of publication of this article. In the meantime, novel missions, such as satellite life extension and lunar landers, are being authorized by the FCC or other agencies on an experimental or ad hoc basis.

Export Control Reform. An additional area of space regulation that has been particularly difficult to reform is export controls. Starting in 1976, commercial satellites were categorized under the U.S. Munitions List (USML), which is controlled by the Department of State's International Traffic in Arms Regulations (ITAR), due to the dual-use nature of the technology. In the 1980s, the Reagan administration and Congress moved some satellite technologies to the Commerce Control List (CCL), which falls under the DOC's less-restrictive Export Administration Regulations (EAR), to enable U.S. companies to use foreign launch capabilities.

In the 1990s, export controls on space technologies became a much bigger political issue. Following a series of launch failures of U.S. payloads on Chinese launch vehicles, a few U.S. companies provided China with technical data and analysis as part of the mishap investigations. An investigation by Congress into broader Chinese theft of U.S. technology concluded that the launch failure analyses were in breach of existing export controls, used by China to improve the reliability of its space launch vehicles, and could potentially be used to improve the performance of its ballistic missiles used for nuclear deterrence.[42] The report also found lapses in enforcement of existing protections on satellite technical data used by space insurers and other commercial entities.[43] Congress subsequently returned all space technologies to the USML, placing them once again under ITAR, and upped enforcement.

During the Obama administration, pressure from industry led to a major effort to reform space export controls. Analysis provided by the Satellite Industry Association showed that placing all space technologies under ITAR led to 40 percent drop in the U.S. share of the global space market since 1995 as other countries aggressively marketed so-called "ITAR-free" satellites that could be more easily obtained by foreign entities.[44] The Obama administration worked within Congress to pass legislation that gave the executive branch the authority to determine which technologies could be moved to the CCL, while continuing the strictest export controls for a list of specific countries, including China.

Both the Trump and Biden administrations have also focused on reforming space export controls. The Trump administration's SPD-2, in addition to kicking off the reforms of remote sensing and launch regulations discussed above, also directed the executive secretary of the National Space Council to "initiate a review of export licensing regulations affecting commercial space flight activity" and provide recommendations.[45] While Congress did pass the Export Control Reform Act of 2018, there were no significant effects on the space industry or further changes to export controls under the Trump administration.[46] In April 2024, under the Biden administration, the State and Commerce Departments announced that they would start a process in the summer of 2024 to update space systems on export control lists.[47] In October 2024, the Biden administration released a set of final and proposed changes to space export controls that created exemptions for specific allied partners and moved several categories of technologies from the USML to the CCL.

Priorities for the Next Administration

It should be clear from the short history lesson above and the graphical summary shown in Figure 1 that there has been a significant amount of focus on space regulatory reform over the last 20 years, but tangible results have been few and far between. These areas are persistent wicked problems that do not have clear "right" answers, and all of them involve

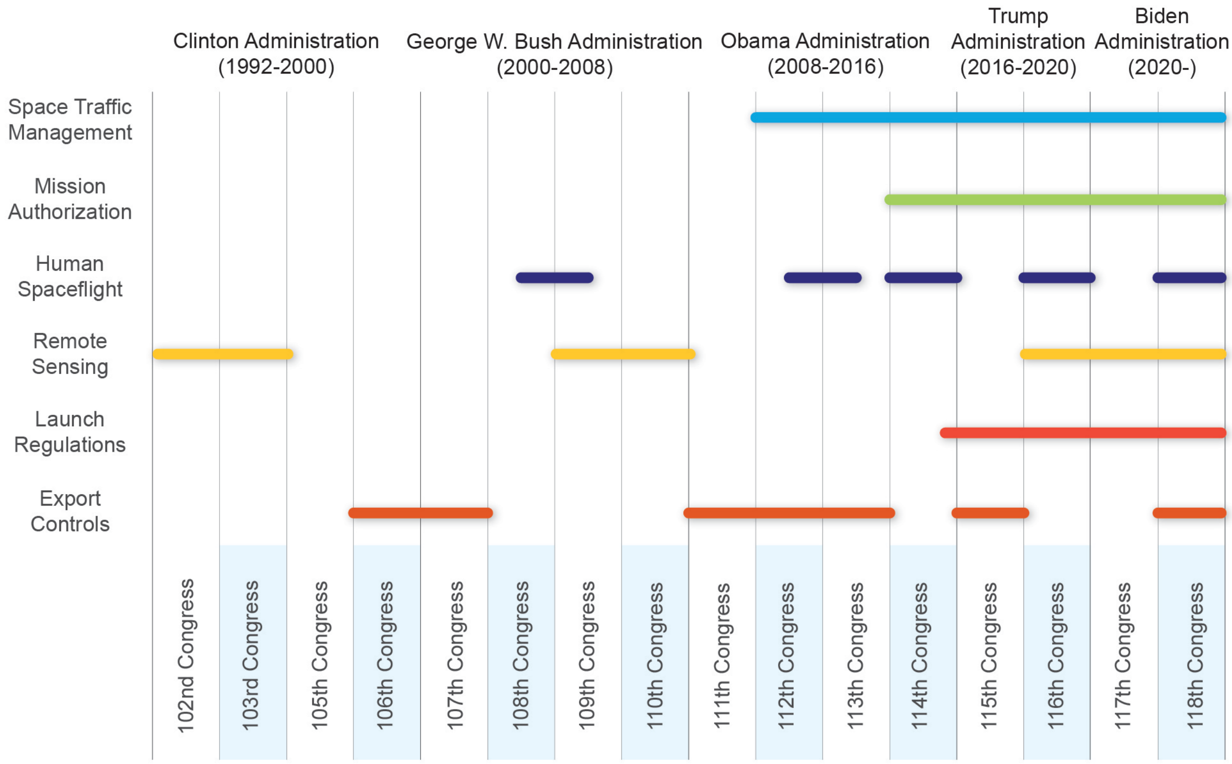

Figure 1: Executive branch or congressional activity on space regulatory issues over time.*

balancing uncertain costs and benefits while navigating an entangled set of bureaucratic relationships and governmental politics. There will not be any easy answers or quick resolutions to any of them, no matter the amount of political capital invested. That said, these are still issues the next U.S. administration needs to tackle. Incremental, positive change can lead to significant improvements over time.

Our first recommendation is that reforming the space regulatory and oversight regime must be dealt with urgently. Issues such as deciding who has the authority for mission authorization have been under debate for more than a decade, long past the time they should have been decided. The longer they remain unresolved, the greater the chances for negative impacts on the commercial sector and loss of U.S. global leadership on space.

Our second recommendation is that the next administration needs to decide which of these issues can be handled at the agency level and which ones require the White House to convene an interagency process to resolve. The latter is important for dealing with topics that involve multiple constituencies across the executive branch but is time consuming for both the White House and the participating agencies. The next administration must also decide which issues are the highest priority for expending their interagency attention and which other issues can be handled primarily at the agency level with the White House still holding those agencies responsible for completing the task.

Our third recommendation is to focus as much, or more, political capital on implementation of policy decisions as on their formulation. It is easy to announce that a policy review is underway, more difficult to actually develop a policy proposal that is acceptable to all the stakeholders, and extremely difficult to ultimately implement a policy to yield real change.

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[*] The bars shown in this figure are estimates based off formal executive branch activities, such as interagency policy working groups, rulemaking processes, and procedures, and legislative activities, such as introduction or consideration of legislation and hearings. It is meant to give a representative depiction of overall work on these issues and should not be considered authoritative.

Finally, we recommend that the next administration work constructively with Congress on these issues. While there are a few elements of regulatory reform that can be done entirely within the executive branch, the most pressing and complicated questions are ones that require legislative action. Some of the historical delays on resolving these questions were a result of administrations not working with—or in some cases actively working against—Congress. Recent Supreme Court rulings will also require increased clarity from Congress in specifying the authorities for each of the involved agencies. The next administration must find a way to actively engage with Congress to convey the importance of working on these issues and coming to a compromise solution that can be accepted by all stakeholders.

Conclusion

The continued growth and evolution of the commercial space sector represents great opportunities and complex challenges for the U.S. government. A vibrant and innovative commercial sector is a key advantage the United States has over every other space nation. Supporting and enabling the sector's continued growth is critical to maintaining U.S. leadership in space, achieving a wide range of policy goals, and meeting our international treaty obligations. At the same time, this growth and innovation create a variety of policy and regulatory challenges that the U.S. government has historically not easily dealt with for a variety of structural and bureaucratic reasons.

The next U.S. administration must focus significant energy on this topic. It needs to continue the good work that has been started or accomplished by previous administrations while also making difficult decisions to resolve the seemingly perpetual debates that have existed for decades.

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About Space Agenda 2025 Publications

This paper was published as a chapter of *Space Agenda 2025*, with Angie Bukley, Colleen Stover, and Victoria Woodburn serving as editors in chief. *Space Agenda 2025* is an effort by the Center for Space Policy and Strategy (CSPS) at The Aerospace Corporation to highlight and provide insights into some of the major space challenges facing policymakers. You can find the complete list of individual *Space Agenda 2025* papers at http://csps.aerospace.org/SA2025, as well as download the combined set of 16 chapters in the *Space Agenda 2025 Compendium* at https://csps.aerospace.org/papers/space-agenda-2025-compendium, all available to you with our compliments.

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RATIONAL EXUBERANCE: UNDERSTANDING VALUE AND PERFORMANCE IN THE SPACE ECONOMY

Karen L. Jones and Brian Weeden

Executive Summary

Policymakers, commercial and government space stakeholders, and the space investment community rely on fair assessments of the space economy's value and performance. However, accurate valuations are far from straightforward as various approaches have different strengths and weaknesses. Methodologies include:

- **Top-down** – Measures "use side" revenues and sales forecasts. These estimates may capture adjacent market value with connected industries as banks and investors try to value business synergism and growth opportunities. However, top-down valuations may include double counting, particularly if analysts sum values from both "make" and "use" sides of the space value chain.

- **Bottom-up** – Measures "make side" inputs from capital, labor, energy, materials, and purchased services. Valuations are designed to avoid double counting but exclude adjacent markets, which may miss emerging growth opportunities.

- **Derived Economic Value** – Uses a third-party valuation as the basis to project growth. Provides expedient forecasts but may be unrealistic in the absence of original research or due diligence.

In addition to valuations, published financial data examine relative movement of traditional and start-up space sector companies to provide performance, volatility, and growth insight. These include space funding indexes, publicly traded space stock performance indexes, and exchange traded space sector funds (ETFs).

Despite the rising profile of the global space economy to investors and stakeholders, valuation and forecasting methods remain an imprecise art. For instance, bias might sneak into space sector valuations such as "straight line" forecasts, a tendency to project the past into the future without full consideration of all factors affecting the longer-term space economy. Additionally, embedded conflicts of interest could exist with "sell-side" analyst reports and could introduce bias.

Taking a longer-term view, the value of the space economy will become amplified as satellite capabilities, such as remote sensing, positioning, and communications, continue to grow as fundamental enablers in other industries. Ultimately, the space economy's value will become a critical but also a less distinctive economic quantity within the larger global economy.

Introduction

The commercial space economy is an area of high interest for policymakers, the media, the financial community, and the public, especially in terms of measuring the return on government and private sector investments that underpin it. Over the last two decades, the commercial space sector has experienced significant technological breakthroughs and rapid growth in commercial investment. This has, in turn, fueled interest in determining exactly how consequential the space economy is in terms of its value, trajectory, and its impact on the future of human activities in space and socioeconomic benefits on Earth.

Measuring this growth, trajectory, and impact is not easy. The space sector has sobered up after several years of hyper-liquidity, fueled by low interest rates, a strong private capital market, and a SPAC frenzy.[*] Market exuberance is now giving way to healthy skepticism within many industries, including the space sector. While the "trillion-dollar space economy" looms large in many published space sector valuations, actual profitability remains elusive for many companies.

In the remote sensing sector, strong revenue growth and demand has not led to profits and some firms have implemented layoffs to reduce expenditures. In the space launch sector, spectacular recent successes from a few firms has likewise not led to widespread profitability and some analysts believe the sector could experience a shortfall of capacity in the short term followed by longer term market saturation and excess capacity.[1] The satellite communications (SATCOM) sector, long the largest source of industry revenues, is now responding to market challenges and competition through inorganic growth strategies, as they strive for synergy in part by merging GEO, MEO, and LEO networks.[†]

It is critical that policymakers have a solid grasp of the various methods that are used to measure the space economy because those estimates in turn influence many other important public policy decisions. To that end, this analysis evaluates multiple space sector valuation approaches. It also provides an overview of different estimation methods, tools for interpreting space sector valuations, and useful indexes to track publicly traded companies in the space sector. Economic data from space valuations and space indexes are designed to provide insight to commercial space companies, institutional and private investors, satellite service providers, and government stakeholders who depend upon space capabilities. However, before any investment decisions are made, it is important to understand the methodology and constraints behind these economic estimates.

Economic Valuation Methods

> ***"Knowing what to measure and how to measure it makes a complicated world much less so."***
> ***—Steven D. Leavitt, Freakonomics: A Rogue Economist Explores the Hidden Side of Everything***

There are several ways to calculate the size of the economy or a specific sector of the economy. This analysis classifies space sector valuations into three basic methods, based upon studying a range of widely circulated commercial, government and nonprofit space sector reports.

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[*] Special Purpose Acquisition Companies, or reverse mergers. In 2021, multiple space companies used the SPAC mechanism to go public with what turned out to be unrealistic revenue projections and eventual crashes in share prices. https://www.cnbc.com/2023/10/12/investing-in-space-a-reality-check-on-spac-frenzy-revenue-projections.html.

[†] Mergers and acquisitions include Eutelsat/OneWeb, Viasat/Inmarsat, and Intelsat/SES, creating future hybrid GEO, MEO, and LEO space networks for increased utility for commercial, civil, and defense purposes.

- **Top-down models.** Do not capture all business activity details. This methodology is often used by commercial banking and investors, and includes revenue estimates and sales forecasts.
  - *Advantages.* Captures adjacent market value and synergies with "reach" industries. This can be important as economists try to value business synergism or network effects. Can be less time-consuming to create.
  - *Disadvantages*. Often prone to optimistic forecast models.
- **Bottom-up models.** Use capital, labor, energy, materials, and purchased services for measuring industry inputs and gross domestic product. Methodology is designed to avoid double counting and does not include adjacent markets. This methodology is often used by governments as they have easier access to the underlying data.
  - *Advantages*. Provides a detailed view of specific products within an economic sector.
  - *Disadvantages*. Possibly provides a pessimistic view as this method does not give full consideration of the added value for adjacent market synergy. Also requires a significant amount of time to prepare detailed bottom-up estimates.

A third hybrid model has emerged, which we refer to as *derived economic value estimates*.

- **Derived Economic Value Models.** Involve a third-party valuation as the basis to project growth. Table 1 shows that several financial institutions derive their top-down forecast using the Satellite Industry Association's (SIA) annual State of the Satellite Industry Report (SSIR) as the basis.
  - *Advantages*. Provides an expedient way to forecast. If the derived model uses a trusted source as the basis, this method can provide some level of legitimacy.
  - *Disadvantages*. May not be grounded in actual business data; may allow a more favorable prediction of market value without original research or due diligence.

In general, top-down valuations are an easier way to develop an estimate as the analyst can avoid the intensive bottom-up calculations across capital, labor, energy, material, and purchased service inputs. However, this methodology can involve unintentional double counting of inputs because the calculation method lacks precision and the data lacks granularity to catch potential problems when quantifying reach or adjacent markets.

Adjacent Markets, Business Synergy, and Network Effects. A complicating factor to evaluating the value of the space industry is the emergence of network effects and linkages with adjacent markets. Some space sectors, such as SATCOM, are experiencing network convergence as multiple segments (GEO, MEO, LEO) combine with nonspace segments (terrestrial wireless and broadband) and will benefit from an economic principal known as "business synergy" or "network effects" wherein the joint activity of several networks (and their constituent markets) makes the sum value greater than the parts. To consider just one concrete example, consumers may be willing to pay more for a cellular telephone service that incorporates SATCOM to close coverage gaps, but the entire price those consumers pay is clearly not attributable to the satellite segment. On the other hand, the value provided by the satellite segment may be significantly greater than the direct price charged for it by the SATCOM provider. Metcalfe's Law, coined by Robert Metcalfe (the inventor of Ethernet), states that "the value of a network is proportional to the square of the number of connected users. As the physical cost of the network grows linearly, its value grows exponentially." Put simply, networks become more valuable as more users join.

Both satellite operators and terrestrial mobile network operators, for instance, could view satellite-enabled direct-to-device "D2D" or the combining of terrestrial and satellite communications as a means to amplify value through networks effects or synergies.[2] As another example, the availability of commercial cloud analytics could multiply the value of satellite remote sensing data, as the geospatial data merges with other types of data to contextualize and make it more valuable. Exemplifying this strategy, the U.S. Department of Defense is undergoing a cultural shift towards cloud synergies to harness commercial capabilities and take advantage of private sector innovation, such as advanced data analytics.[3]

Comparing Space Economy Valuations

There are a growing number of products that attempt to use the methodologies discussed above to create a valuation for the space economy with a wide range of results. A detailed assessment of these various valuations was published by the Institute of Defense Analyses Science and Technology Policy Institute (IDA-STPI) in 2020.[4] The STPI report included a discussion of what to include in the definition of "the space economy" and whether that should include activities that are enabled by space but are primarily generated terrestrially. Importantly, the report noted that including supplier industry revenues can lead to double counting if those revenues are primarily funded by government expenditures that are also directly counted in the market valuation.[5]

The following section discusses several prominent space industry market estimates in more detail, which are summarized in Table 1. In addition to the space sector valuations listed in Table 1, the Organization for Economic Cooperation and Development (OECD) published "OECD's Space Economy in Figures," which details overarching trends in space innovation and the economic significance of space infrastructure and its role in the broader economy. The report also summarizes each OECD country's[‡] institutional space budget as a share of gross domestic product and provides a comparative perspective of national space sectors.[6] A relative perspective is important as the United States and other countries strive to retain dominant or competitive space sector positions for various commercial, government, or defense advantages.

Satellite Industry Association's State of the Satellite Industry Report – Top-Down Valuation. For the past 27 years, the Satellite Industry Association (SIA) has published the "State of the Satellite Industry Report" (SSIR). Analytics and engineering firm BryceTech has independently produced the report for over a decade.[§] The report uses unique datasets, including proprietary surveys, in-depth public information, and independent analysis. The SSIR applies a revenue-focused model which summarizes global satellite industry data across the following segments: satellite services, satellite manufacturing, satellite launch, space sustainability activities, and ground equipment. The report estimates total global revenue for each of these segments. The report also includes metrics reflecting segment activity; for example, number of satellites launched or subscribership for different services.

The SSIR aggregates satellite industry segments to provide an estimate of the global satellite industry ($285 billion), and an estimate of the global space sector ($400 billion) that includes government budgets. It should be noted that one of the segments in this aggregated estimate, manufacturing, is a "make" segment of the satellite sector, and others are "use" segments.[**] As a result, depending on the intended purpose, it may be appropriate to adjust this estimate to exclude "make" values to accurately estimate the size of all the "use" segments of the satellite industry. (Manufacturing is about 6 percent of the total value of $285 billion) (see Figure 1).[††]

[‡]Thirty-eight member countries spanning North America and South America to Europe and Asia-Pacific.
[§]BryceTech CEO Carissa Christensen is a member of the CSPS Senior Advisory Council, a group of outside experts who support CSPS research.
[**]This is related to the concept of gross output which measures the value of products throughout the value chain. According to Bureau of Economic Analysis, gross output double counts "the value of intermediate products (which are used by others in their production processes) and final products (which count toward GDP)." Gross output is sometimes referred to as "gross duplicated output."[**]
[††]All monetary values are stated in United States dollars, $USD. B = billion.

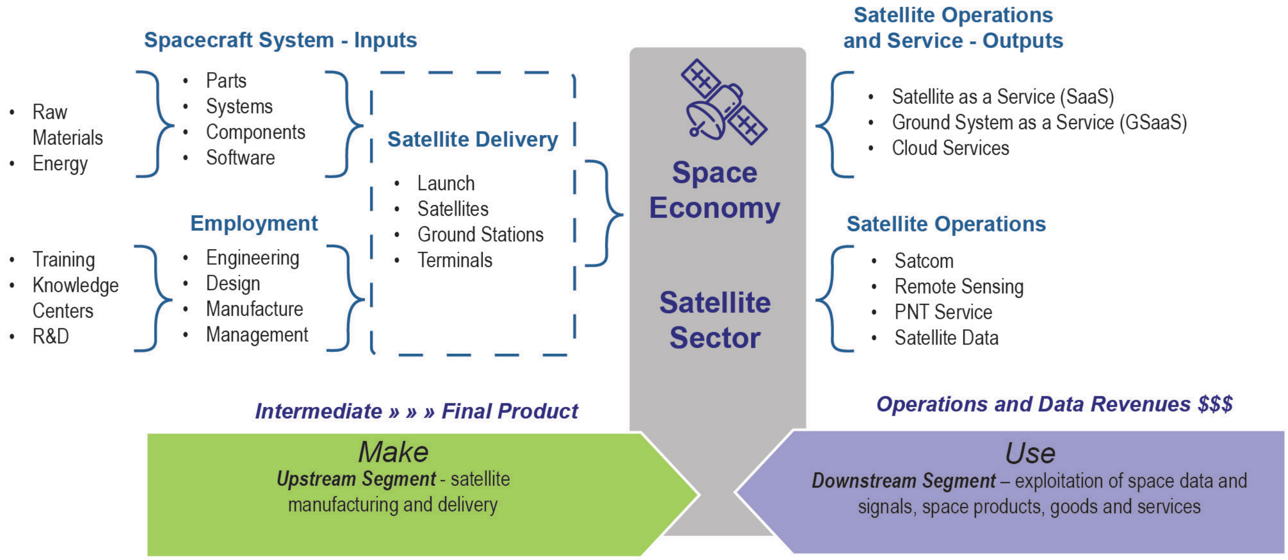

Figure 1: Notional diagram to illustrate the two sides of the satellite economy (a subset of the larger space economy). *The "Make" side includes inputs, starting with various raw materials, parts, and components. Inputs also include labor from personnel involved in delivering a satellite to market. The "Use" side of the sector involves the delivery of satellite-generated products and services such as SATCOM, remote sensing, geospatial data, and PNT services.* ***Note****: Double counting can occur when a valuation includes both the "make" side input values and "use" side outputs or revenues.*

Importantly, the SSIR emphasizes the *satellite* industry (including commercial, civil, and defense) rather than the entire space sector and does not provide details on the entire space sector- (non-satellite-) related activities such as research and human exploration.[7] Also, while the SSIR measures past growth, it does not provide future growth projections. While it is not all-encompassing, the SSIR's steady annual tempo and analytical rigor for collecting and managing unique datasets has earned it a respected position within financial analyst circles. It often serves as the current value baseline for several market projections by UBS, Morgan Stanley, and Bank of America and others. In brief, the SSIR report has become a stepping off point for financial analysts to create their own valuations which often include adjacent industries, such as telecommunications, supply chain, weather, location-based services, and other sectors benefiting from space data and applications.

World Economic Forum (WEF) – Top-Down Valuation. The World Economic Forum's 2024 report "Space: The $1.8 Trillion Opportunity for Global Economic Growth," coauthored with McKinsey & Company, takes a top-down approach to measure both the size of the space sector or "backbone" and the "reach" or adjacent industries that support or use space sector assets or services.[‡‡] The WEF report recognizes that reach is about "space increasingly playing a role in everything from the weather forecast you look at in the morning, to the dinner that gets delivered to your door, and the call you make from your smart watch." The report emphasizes that space will be more about "connecting people and goods" and that adjacent industries will generate more than 60 percent of the increase in the space economy by 2035.[8] This vision

[‡‡]The Executive Director of CSPS serves as a member of the World Economic Forum's Global Futures Council on Space Technology, but was not involved in the creation of the McKinsey report.

is in line with what Klaus Schwab, executive chairman of the World Economic Forum and author of *The Fourth Industrial Revolution*,[§§] refers to as a "staggering confluence" giving an exponential rise and mutually reinforcing progress "across the digital and biological worlds."[9]

WEF's 2035 forecast for the space economy shows that the backbone value is $775 billion, and the reach value is $1,035 billion. Although some might be concerned that the report has greatly exaggerated the size and growth prospects for the space sector, without including industry reach, the forecast would ignore the potential upside from network effects and adjacent industry growth. For instance, a 2024 McKinsey forecast notes that the total value for the Internet of Things (IoT) ecosystem might be $12.6 trillion by 2030. Given that satellite connectivity plays a critical role in the IoT market, it is reasonable to attribute some of this forecasted value for adjacent and rapidly expanding sectors.[10] But while many agree that "industry reach" should be counted as part of the space sector valuation, others recognize the potential for double counting and exaggerated estimates. One space business expert acknowledged the usefulness of the WEF valuation but also cautioned that the estimate "could use a haircut...perhaps 25 percent or so."[11]

U.S. Bureau of Economic Analysis (BEA) – Bottom-Up Valuation. The Bureau of Economic Analysis (BEA) within the U.S. Department of Commerce conducts assessments of several different economic sectors. In 2020, they released their first report on the U.S. space economy. The most recent BEA report, released in June 2024, estimates that the U.S. space economy amounts to $131 billion. At first glance, this seems low compared to other estimates, but this value addresses only the U.S. space economy, not the global space economy. If one assumes (based upon SIA's analysis) that the U.S. space economy is 37 percent of global industry, then the global space economy amounts to $354 billion, a level fairly close to several other current global estimates (see Table 1).

The Department of Commerce's BEA report applies "KLEMS" data, for inputs (K=capital, L=labor, E=energy, M=materials, and S=purchased services). These categories are considered "intermediate inputs that are consumed by industries in their production of goods and services" instead of finished or final product.[12] In an effort to avoid double counting, economists use intermediate goods to calculate gross domestic product (GDP). By using this bottom-up methodology, commonly referred to as value added approach, economists can avoid double counting intermediate goods once when purchased and again when the final goods are sold.

[§§]WEF defines the First Industrial Revolution as mechanized production using water and steam, followed by the Second using electric power to create mass production. The Third used electronics and information technology to automate production. The Fourth creates a fusion of technologies, "between the physical, digital, and biological spheres." (https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/.)

Table 1: Space Sector Valuations by Method and Organization[13]						
Financial Institutions (Top-down, listed banks started with SIA estimates)	**Method**	**Past Year**	**$ Billions**	**Forecast Year**	**$ Billions**	**Forward CAGR**
UBS (July 2023)*	TD/SIA	2016	$340	2040	$926	4.3%
Morgan Stanley Research*	TD/SIA	2016	$340	2040	$1,100	5.0%
Bank of America Equity Research*	TD/SIA	2016	$340	2045	$2,700	7.4%
Goldman Sachs* No 2016 est.; used SIA's 240 B to calculate percent growth for 2040 forecast	TD/SIA	2016	$340	2040	$2,000	7.7%
Citi Global Perspectives (May 2022)	TD/SIA	2020	$370	2040	$1,000	5.1%
Government and Nonprofit Institutions (Top-down except BEA; base estimates are original)	**Method**	**Past Year**	**$ Billions**	**Forecast Year**	**$ Billions**	**Forward CAGR**
IDA—Science and Technology Policy Institute (March 2020) – Excludes several space activities, goods, and services to avoid double counting	TD/with strict methodology	2016	$166	None	None	None
The Space Foundation—Annual Space Report (July 2024)	TD	2023	$570	2027	$772	7.9%
U.S. Chamber of Commerce**	TD	2017	$385	2040	$1,500	6.1%
Satellite Industry Association (SIA) and BryceTech (June 2024)****	TD, surveys, unique datasets	2023	$400	None	None	Past growth 2-5%
World Economic Forum/McKinsey (April 2024)	TD	2023	$630	2035	$1,800	9.1%
Bureau of Economic Analysis (June 2024) – projected***	BU	2024	$354	None	None	None

LEGEND: TD = top-down, BU = bottom-up, CAGR = Compound Annual Growth Rate

*Based upon SIA's estimate $340 billion for 2016.
**Based on the 2017 Space Foundation estimate.
***BEA provided U.S. values, to calculate global space sector value, applied SIA's metric that U.S. market share is 37 percent to yield a global space economy amount.
****SIA does not project growth. However, the past industry revenue growth was 2 percent and without the declining satellite TV market the industry grew 5 percent.

Indexing the Space Industry

Most financial analysts recognize market valuation as an imprecise art. They often turn to quarterly or annual financial reports to track changes and gain insight into industry health and trends. It follows therefore that another type of indicator is needed—one that focuses on *relative* movement rather than an absolute value. Indexes simplify and summarize financial report data and communicate insights across key disciplines such as economics, politics, market analysis, or various types of earth, environmental, or social sciences. Whether for tracking stock prices, ocean temperatures, consumer prices, social trends and attitudes, indexes are typically used to track *relative change* rather than absolute numeric value. Note a shortcoming of market indexes is that they only track publicly traded companies, which is significant for the space sector as some significant commercial players are privately owned companies. A few space sector indexes are described below, including funding indexes to track private capital space sector investments, publicly traded stock indexes to track performance of space-related stocks, and exchange traded funds to track space investments across a range of themes, such as traditional space, new space, and aerospace defense.

Space Funding Indexes

- **Seraphim Space Index** (since 2017). This venture capital (VC) firm, based in the United Kingdom, provides a yearly index on space sector funding and acquisition activity.[14]

- **Space IQ: Space Investment Quarterly** (since 2015). Equity investments range from seed to late-stage investments across the globe and across different space sectors (e.g., communications, positioning, imaging, satellite manufacturing and components, and launch).[15] Space Capital built this database to track 1,831 unique companies with a total investment value of $291 billion.[***]

- **IPOX® SPAC** (since 2020). This index is designed to track the aftermarket performance of Special Purpose Acquisition Companies (SPACs) in the U.S.[16] Looking forward, this index will likely have limited utility for the space sector as few new space companies are choosing SPACs to go public.

Publicly Traded Stock Performance Indexes for the Space Sector

- **S-Network Space Index (SPACE).** One of several S-Network Global Indexes and aims to be a benchmark for the space industry. SPACE is linked to the Procure Space exchange traded fund (UFO).

- **S&P Kensho Space Index.** A subsector of S&P Kensho New Economy Index. It covers 30 companies where space-related activities "serve as a principal component to their business strategy."[17]

- **SpaceWorks NewSpace Index™ (NSI).** Provides insight into how publicly traded start-up space companies[†††] are performing relative to two U.S. stock indexes: the Standard and Poor's (S&P) 500 and the Dow Jones Industrial Average (DJIA).[18] The index further classifies companies into launch, satcom, infrastructure, and satellite imaging subsectors to gain focused insight.

- **SpaceWorks Traditional Space Index (TSI).** Covers traditional space companies, such as Lockheed Martin and Northrop Grumman.

A relative performance comparison, developed by SpaceWorks (see Figure 2), measures four indexes' performance over time. Historical performance over the past year shows that the NewSpace Index (NSI) *outperformed* the Traditional Space Index (TSI) by almost 13 index points over a one-year time frame beginning in August 2023 (see Figure 2). However, this

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[***]Space Investment Quarterly surpasses index functionality. Database functions allow users to mine and filter.

[†††]*Satcom* - AST Spacemobile, Satixfy Communications, Spire Global, Inc. *Launch* – Astra Space, Rocket Lab, Virgin Galactic, Virgin Orbit Holdings delisted. *Imaging* – BlackSky Technology, Planet Labs, Satellogic. *Infrastructure* – Intuitive Machines, Momentus, Mynaric AG, Redwire, Sidus Space, Terran Orbital.

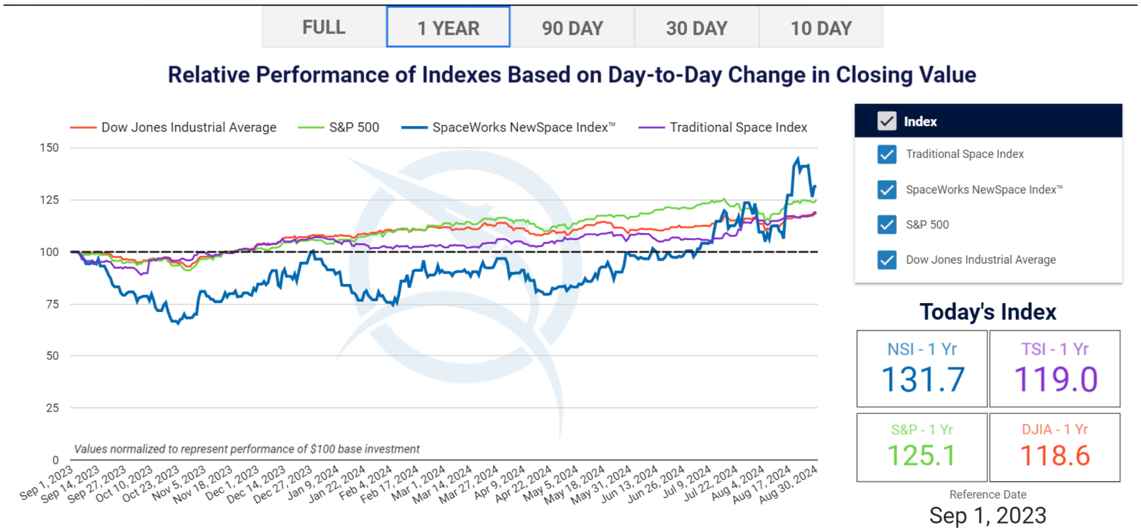

Figure 2: The relative performance of 15 new space companies listed in SpaceWorks' NewSpace Index‡‡‡ (NSI), compared to S&P, Dow, and Traditional Space Index (TSI) averages, provides insight into investor sentiment, trends, risks, and growth. *(Source: With permission from SpaceWorks; https://www.spaceworks.aero/new-space-index/.)*

does not reflect the historical *underperformance* of the NSI since January 2021, during a time when many Special Purpose Acquisition Companies (SPACs) emerged and then imploded. The longer-term story is quite different as a base investment of $100 during January 2021 in the NSI would amount to a September 2024 value of only $18 compared to a TSI value of 119.

The volatile performance of the New Space Index underscores the importance of financial and technical screening of new space vendors. This is particularly critical for potential customers of new commercial space as they strive to understand the risks that their suppliers could go out of business. It also highlights the degree to which major commercial and governmental buyers could drive the success of new commercial space companies if the buyers become better partners to improve return on investment (ROI) for new space providers.

Exchange Traded Funds (ETFs) for Space

"Don't look for the needle in the haystack. Just buy the haystack!"

— John C. Bogle, The Little Book of Common Sense Investing, 2017

Exchange Traded Funds (EFTs) are typically open-ended funds§§§ and provide a thematic style of tracking and performance for countries, regions, or specific industry sectors. For investors, ETFs provide diversification across a target industry or industry subsector that interests them. There are a wide range of market applications and motivating forces for a space sector index and new and surprising use cases can always emerge. Ideally, the index could inform users or markets on their past performance and potential future trends. A few examples of space-related ETFs are listed below:

‡‡‡Originally 16 companies, down to 15 companies as Virgin Orbit Holdings was delisted.

§§§As opposed to closed-end funds, any number of shares can be issued, there is no limit to the number of shares that can be issued. Most mutual funds are open-ended.

Table 2: Space Indexes (Performance Data Calculated on August 30, 2024)			
ETF Examples (Trading Symbol) (as of August 30, 2024)	1-year Performance	3-year Performance	Net Assets
Procure Space ETF (UFO) – since 2019. Seeks investment results in an equity index called the S-Network Space Index.	-8.3%	-13.7%	$33.1M
ARK Space Exploration and Innovation ETF (ARKX) – since 2021. Aims for long-term growth, 80% of assets in equity securities that fall into investment scheme. Sponsor: ARK Investment Management LLC.	-2.1%	-9.2%	$226M
SPDR S&P Aerospace and Defense ETF (XAR) – since 2011. Open-ended investment fund. Sponsor: SSGA Funds Mgt.	+29.1%	+14.3%	$2.25B
Invesco Aerospace and Defense ETF (PPA) – since 2005. Tracks investment results of the underlying SPADE Defense Index. Open-ended investment fund. Sponsor: Invesco Capital.	+22.4%	+11.8%	$3.6B
iShares U.S. Aerospace and Defense ETF (ITA) – since 2006. Tracks growth of the Dow Jones U.S. Select Aerospace and Defense Index composed of U.S. equities. Sponsor: Blackrock Fund Advisors.	+22.8%	+10.9%	$6.57B

While a general space sector index (either a publicly traded stock index or an ETF) is a *composite* variable made up of individual observed items, ideally, users could filter for specific space capabilities. A well-designed space sector index to inform space stakeholders would involve creating a composite performance measurement across satellite imaging; satellite communications; positioning, navigation and timing (PNT); data architecture and analytics; and perhaps more pioneering ventures, such as space tourism, lunar habitats, and space-based solar power.

Informing Government Investors

The United States depends upon commercial space innovation to deliver a range of defense and civil applications, including imaging, communications, and positioning and navigation. With demand highly concentrated within the government sector, civil and defense space customers can shape and influence the market for goods and services. However, with that market power comes responsibilities and statutory requirements to ensure the economic health and viability of the space industry.

Space sector market valuations and indexes serve as important tools for making both practical public and private investment decisions and meeting government acquisition requirements. For instance, both NASA and National Oceanic Atmospheric Administration (NOAA) must abide by requirements for Anchor Tenancy (51 USC 50506), which calls for the government buyer to ensure that a commercial space provider's long-term viability is not dependent upon a continued government market, and that private capital underlying the space venture is not at risk. Additionally, there are statutory termination liability requirements, so if government terminates such contracts for its convenience, it must provide funds to the space provider to cover termination liability.[19] To ensure that the government is making responsible funding decisions, these requirements seem fair. But it also means that the onus is on a government buyer to spend taxpayer dollars wisely. To this end, valuations and indexes can generally inform a government buyer or investor about space economy conditions, trends, and investment risks.

Recommendations for Understanding Space Economy Valuations

With a wide range of published space economy valuations, both government stakeholders and industry analysts might find themselves desperately grasping for profundity. Here are some guidelines for understanding market valuations and trends:

- For a conservative value–avoid or discount top-down valuations that include "reach" industries, as these most likely involve some double counting. Instead, bottom-up valuations provide a more direct measure of economic impact, such as job creation.

- For investors and analysts seeking growth opportunities and new spin-off space applications for adjacent industries, top-down valuations which include synergy value can be particularly useful. Perhaps discount this value to correct for double counting.

- Government, industry, and investors should exercise caution as commercial investment analyst reports are sometimes underwritten by marketing departments with a financial incentive to generate investor interest in specific companies. Moreover, their reports tend to be derived from baseline estimates already provided by trade associations. Instead, space stakeholders should rely on economic reports derived from nonprofit, nongovernmental organizations, trade associations, and government organizations such as BEA.

- Use space sector indexes to gain a historical perspective on risk and performance and to inform future investment decisions and timing.

Whether buying space services, seeding innovation through grants, or optimizing value for money for a public private partnership—industry reports, valuations, and indexes will become increasingly important for data-driven decisions. As the industry continues to grow and mature, more analysts will regularly publish research on the space economy. This bodes well for reducing risk and uncertainty across a range of space investment decisions, particularly anchor tenancy contracts, and the long-term ability to support future defense and civil space programs and initiatives.

The crucial issue for policymakers and investors alike is to find the right balance between optimism and pessimism. Nearly 10 years ago, several optimistic space market projections emerged from investment banks and nonprofit organizations that sparked a surge in enthusiasm for commercial space. While weakening market signals over the intervening years have undercut many of those projections, "zombie statistics" seem to have taken on a life of their own and are still routinely cited in the media and op-eds. In reference to the situation, space columnist John Holst stated, "[A] reanimation of some space industry numbers that should have been left for dead is a repeating cycle."[20] Investment bank sell-side equity research analysts have been criticized for contributing to these high addressable market estimates. Today, investment banking research is often seen as a marketing expense, without rigorous or objective economic methodology.[21]

"Wall Street indices predicted nine out of the last five recessions!"

—Paul A. Samuelson in **Newsweek*****, Science and Stocks, 1966***

Extrapolating past results may not adequately address future market potential for some industries that are entering a steep growth or contraction cycle. Despite the need for grounded current estimates, analysts should avoid "straight line bias," a tendency to project the past into the future. In fact, sometimes the straight-line trend will not continue and the projection could be an S- or U-shaped trend. Space sector analysts and decisionmakers should also be wary of too much gloom. It can be difficult to measure the socioeconomic impact of new technologies and applications, which can have immense unforeseen impacts. An example of this is space-based positioning, navigation, and timing (PNT), whose nonmilitary impact was radically underestimated when originally developed in the 1970s. The confluence of PNT with the information technology boom starting in the 1990s and later its role as a fundamental enabler of telematics and location-based services was transformative, yielding benefits that far surpassed the Department of Defense's investment.[****, 22]

There are also potential benefits from the space sector's mutually reinforcing adjacent industries. As an example, emerging direct-to-device capabilities[††††] will allow the world's 6.9 billion consumer grade smartphones to connect with satellites in areas underserved or unserved by terrestrial mobile network operators. In terms of revenue expansion, the $2.3 billion satcom market[‡‡‡‡] merging with the $2 trillion global wireless telecommunications market could significantly extend the value of space.[23] Other industrial sectors, ranging from supply chain logistics, agriculture, and pharmaceuticals will continue to look to space applications for operational advantages or new discoveries. Perhaps, in an ironic twist, a future economist may measure the economic value of purely space activities as zero because the space economy will be so intertwined with the ledgers of adjacent industries and a growing national and global economy.

[****]A comparison by National Institute of Standards and Technology of GPS's comprehensive costs to only its private sector benefits for 2010 through 2017 produced a benefit-to-cost ratio of about 100 to 1.
[††††]Direct-to-device refers to the ability of satellites to communicate directly with end user devices, such as smartphones, without needing specialized receivers or terminals.
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About Space Agenda 2025 Publications

This paper was published as a chapter of *Space Agenda 2025*, with Angie Bukley, Colleen Stover, and Victoria Woodburn serving as editors in chief. *Space Agenda 2025* is an effort by the Center for Space Policy and Strategy (CSPS) at The Aerospace Corporation to highlight and provide insights into some of the major space challenges facing policymakers. You can find the complete list of individual *Space Agenda 2025* papers at http://csps.aerospace.org/SA2025, as well as download the combined set of 16 chapters in the *Space Agenda 2025 Compendium* at https://csps.aerospace.org/papers/space-agenda-2025-compendium, all available to you with our compliments.

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Section 3
Charting Future Value

- The Invisible Link: Key Spectrum Issues for Space
- Space Sustainability in the Context of Contested Space
- Mind the Gap: Commercial Space Stations and the ISS
- Moonstruck! International Aspirations in Cislunar Space

THE INVISIBLE LINK: KEY SPECTRUM ISSUES FOR SPACE

Audrey L. Allison

Executive Summary

The radio-frequency spectrum is a finite resource whose value increases as the world's need for "always-on" connectivity grows. This has led to fierce competition, especially in the most attractive frequency ranges, between terrestrial and space services. Decisions on spectrum use can substantially impact incumbent users, particularly space-based services such as national security communications; positioning, navigation, and timing; space traffic management; weather forecasting; climate research; and emergency response. This chapter describes the complex world of domestic and international spectrum regulation and outstanding spectrum issues facing the U.S. space enterprise, including:

- Protection of critical spectrum allocations that power commercial and federal satellite systems
- Important spectrum issues in play for the next World Radiocommunication Conference (WRC) in 2027
- Decisions regarding key U.S. proposals and positions on WRC-27 agenda items needed early during the next administration

In preparation for WRC-27, work is underway on space issues needing early administration attention, such as:

- Protection of X-band space services
- Spectrum for lunar surface and lunar orbit communications
- Space-to-space links from geostationary orbit to other orbit regimes to enable multi-orbit services
- Spectrum for space weather receivers

Spectrum may be invisible, but assured access to it is mission critical for satellites and space services to enable a vast and growing array of essential capabilities. Planners and operators must educate and inform regulators and other government decisionmakers to fully recognize the value of spectrum and be vigilant about protecting the bands they need for essential missions.

Introduction

Although invisible and often overlooked, the radio-frequency spectrum is critical to all space missions for command and control, communications, and mission performance. Spectrum is also a crucial resource that enables wireless broadband content delivery to smartphones and supports many other uses around the world. Spectrum is a finite natural resource whose use must be carefully managed in order to avoid interference between radio signals that can prevent the reception of the desired transmission. Thus, spectrum use has historically been regulated to ensure that radio links of all desired services can be completed without harmful interference caused by other transmitters. Spectrum regulation has also included bilateral and global coordination to avoid interference from radio services of neighboring countries and to ensure that one's radio operations may successfully operate in blue waters, international air space, and outer space.

Radio-delivered services have proliferated as always-on connectivity has become a necessity for modern lifestyles and commerce. As a consequence, the most attractive ranges of spectrum have become increasingly congested.[*] With the value of spectrum on the rise, Congress has looked to the U.S. commercial spectrum regulatory agency, the Federal Communications Commission (FCC), to auction off frequency bands to wireless operators to enable new wireless broadband services, such as 5G.[†] These auctions have raised $233 billion for the U.S. Treasury, a significant revenue source to offset other congressional initiatives.[1] However, the most suitable frequency bands are all in use. Freeing up spectrum for new intensive uses, such as 5G, is difficult without substantially impacting incumbent users. Thus, there is fierce competition for spectrum resources in the United States and internationally. The 5G industry and its powerful trade associations are fully engaged in ongoing spectrum campaigns.[2]

In 2023, the White House issued a National Spectrum Strategy calling for the modernization of national spectrum policy to make the most efficient use of this vital national resource by creating a pipeline of spectrum resources to support private sector innovation while ensuring sufficient spectrum access to support federal agency missions. [3,4] The release of the Strategy coincided with the opening of the International Telecommunication Union's (ITU's) World Radiocommunication Conference (WRC) 2023 in Dubai, United Arab Emirates. During WRC-23, the United States and another 162 delegations negotiated a treaty on global spectrum use and the agenda for the next WRC, which will take place in 2027.[5]

In this highly competitive and economically driven spectrum arena, there is a slow-motion uphill battle facing some commercial, nonprofit, and governmental spectrum-dependent enterprises, including those that rely on space-based services. Some of the services under pressure include weather forecasting; climate change research; precision agriculture; wildfire monitoring; wildlife tracking and fish monitoring; search and rescue; emergency response and disaster relief; positioning, navigation, and timing; national security communications; and space traffic management.[6]

Thus, it is essential that lawmakers, regulators, and policymakers are informed on key spectrum issues and are cognizant of the significance of spectrum uses beyond the economic ambitions of commercial 5G interests—including vital services that enable the achievement of other societal goals, including U.S. national space policy goals.[7] This analysis introduces the complex world of national and international spectrum regulation and describes outstanding spectrum issues facing the U.S. space enterprise, including protection of critical spectrum allocations that empower commercial and federal satellite systems. This chapter further highlights important spectrum issues in play for the next WRC in 2027, including new spectrum allocations to support cislunar exploration. Although WRC-27 seems far in the future, preparations and disagreements between the wireless industry and space communities are already heating up.[8] Preparations of U.S.

[*] Some wavelengths offer better characteristics for transmitting information through the atmosphere and buildings, higher throughput or data speeds, or longer reach (distance). The wireless industry is demanding additional "mid-band" spectrum as "it offers a good mixture of coverage and capacity for 5G." GSMA, 5G Mid-Band Spectrum Needs – Vision 2030 (2021), CTIA, America's Spectrum Policy: A Roadmap for Action in 2024.
[†] Congressional authority for FCC spectrum auctions expired in 2023 but is the subject of numerous congressional efforts for reinstatement (e.g., the Spectrum and National Security Act [S-4207]).

contributions relating to WRC-27 are already at issue and decisions on key U.S. proposals and positions will need to be made early during the next administration.

Regulation of Spectrum for Space Services

National Regulation: In the United States, radiocommunications are regulated pursuant to the Communications Act of 1934, as amended, which establishes a dual-agency regime of spectrum regulation, shown in Figure 1, based on whether the radio operator is the federal government.[9] Commercial radio services and all other radio services not operated by the federal government are regulated by the FCC, an independent agency created by Congress.[‡] All U.S. federal government radio services are managed by the National Telecommunications and Information Administration (NTIA), an executive branch agency located in the Department of Commerce. The NTIA's administrator, the Assistant Secretary of Commerce for Communications and Information, serves as the president's principal advisor on telecommunications policies and is responsible for "developing telecommunications policies pertaining to the Nation's economic and technological advancement and the regulation of the telecommunications industry."[10] Thus, the NTIA was a key contributor to the recent National Spectrum Strategy and is responsible for its implementation.

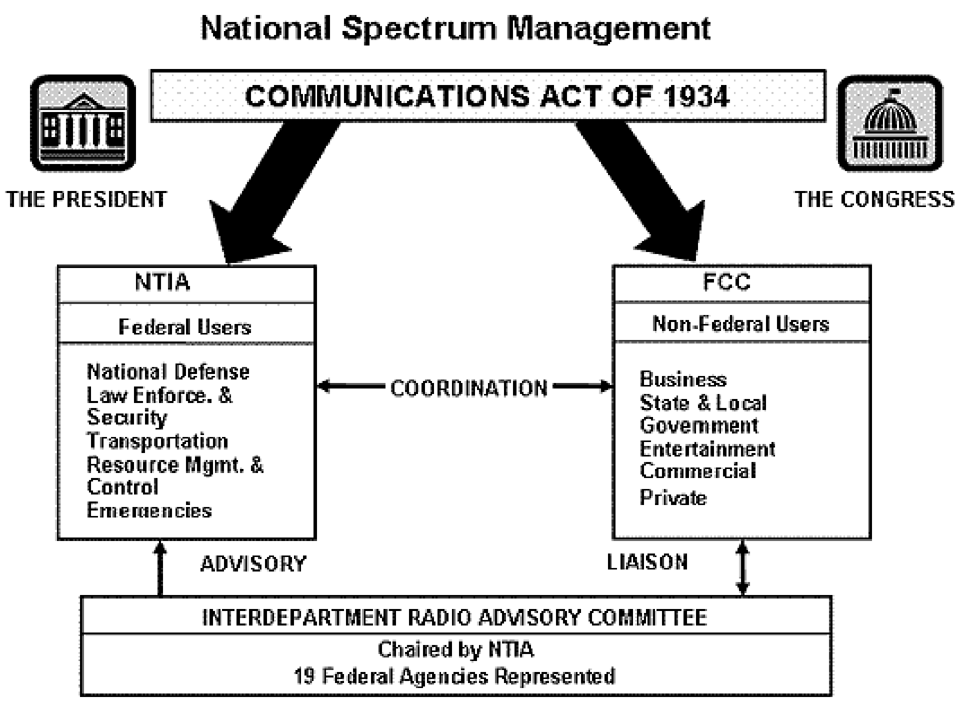

Figure 1: U.S. dual-agency spectrum regulation. *(Source: NTIA website (https://www.ntia.doc.gov/book-page/who-regulates-spectrum.)*

Structural Challenges: The dual-agency structure of U.S. spectrum regulation raises unique challenges. The NTIA is charged with serving both as the lead agency representing the interests of federal spectrum stakeholders and as the president's principal advisor on telecommunication policies. The NTIA must work carefully to ensure its actions do not compromise either of these important but possibly competing responsibilities, including when resolving spectrum issues with the independent FCC.[11]

‡The FCC also regulates radio use by state and local governments, including by their public safety agencies, amateur radio operators, educational institutions, and nonprofit organizations.

On the other hand, the FCC, which is charged to make decisions in the broader public interest, is viewed more as an advocate for the U.S. wireless industry that it regulates.[§] The FCC often finds that the public interest benefits afforded by awarding more spectrum for wireless services, such as 5G, outweigh the value of services provided by other spectrum uses, such as space services. These challenges notwithstanding, recent efforts to improve coordination between the NTIA and the FCC include a 2022 update to their longstanding memorandum of understanding[12] and the president's November 2023 Memorandum on Modernizing United States Spectrum Policy and Establishing a National Spectrum Strategy. This presidential memorandum establishes an interagency spectrum advisory council "to serve as the principal interagency forum for heads of agencies to advise NTIA on spectrum policy matters and to ensure that all decisions made by NTIA take into consideration the diverse missions of the federal government." [13]

National Table of Frequency Allocations: The FCC and the NTIA jointly develop the National Table of Frequency Allocations, the fundamental roadmap of spectrum use. The National Table, which tracks closely to the ITU's International Table of Frequency Allocations, indicates which radio services may assigned to operate in specific frequency bands (ranging from 9 kHz to 275 GHz).[14] The allocations are accompanied by special conditions on those operations designed to limit interference to other allocated services. The National Table also indicates whether the frequency bands are reserved exclusively for federal use, non-federal use, or shared use.[**] Based on the National Table, the FCC and the NTIA assign frequencies (and FCC issues licenses) to specific users, and thus authorize radio operations consistent with agency regulations.

In the National Table, radio services are allocated to frequency bands for either terrestrial or space services. Terrestrial services include broadcasting, fixed, and mobile services and services such as maritime, aeronautical, and radio determination (radar). Space services include satellite services, such as fixed-satellite, mobile-satellite, space research, Earth-exploration satellite, and space operations services, that may take place in Earth's orbit or in deep space. Forty-three radio services are defined by the ITU and incorporated into the U.S. regulations. The United States, as a Member State of the ITU and party to its constitution and other treaty instruments, must ensure that its radio operations do not cause harmful interference to the duly authorized operations of other Member States operating in accordance with the ITU's Radio Regulations.

Beyond National Boundaries—Signals from Space: Space services are inherently international radio systems as outer space is not subject to claims of national sovereignty.[15] In addition, radio signals from orbit are often capable of illuminating multiple national territories and may potentially cause harmful interference to radio operations in multiple nations or with other nations' satellites. From their position in orbit, satellites require assured access to spectrum resources that will be internationally recognized and protected from harmful interference throughout their mission lifetime. Associated ground network systems also require protection from harmful interference. Thus, space service allocations and the regulations for their use need to be harmonized. This harmonization of spectrum regulations around the world takes place through the ITU.

International Regulation: The ITU, a specialized agency of the United Nations (UN), is devoted to extending the benefits of new telecommunications technologies to all the world's inhabitants.[16] Based in Geneva, Switzerland, the ITU has a nearly universal membership with 194 Member States. Although each Member State has equal voice with one vote per

[§]The FCC has long been characterized as having a revolving door with industry. (Jacob Plaza, "Unmasking FCC's Revolving Door with Telecom Giants. Revolving Door Project," August 1, 2024; Jon Brodkin, "FCC's Revolving Door: Former Chairman Leads Charge against Title II," ars Technica, 2015.) CTIA president and CEO, Meredith Atwell Baker, is a former FCC commissioner (2009–2011). Former FCC chairman Tom Wheeler (2013–2017) was CTIA president and CEO (1992–2004). In 2023, the FCC chairwoman's chief of staff became CTIA senior vice president for Spectrum and then General Counsel. (CTIA Press Release, "Tom Power to Retire; Umair Javed Named New CTIA General Counsel," July 24, 2024.)

[**]5.5 percent of spectrum below 30 GHz is reserved exclusively for federal government use and 1.4 percent exclusively for commercial use. Thus, 93.1 percent of spectrum in this range is shared among all commercial users. (NTIA website; https://www.ntia.doc.gov/book-page/who-regulates-spectrum accessed August 6, 2024.)

country, most decisions are reached by consensus. The ITU is largely funded by Member State contributions with the United States being the top contributor at 35 units or $12.8 million annually. The ITU's secretary-general is Doreen Bogdan-Martin, a U.S. citizen, who is currently serving her first four-year term in office.[††] The United States derives great benefit from its participation and investment in the Union, which has been one of the few UN bodies to consistently produce new agreements as technology and economic factors change.[17]

The International Radio Regulations: The ITU's Radio Regulations are a treaty document that provides the global framework for international management of spectrum and associated orbital resources. Established in 1906, this 2,000-page document includes the International Table of Frequency Allocations and the accompanying technical and operational rules to enable the most efficient use of spectrum while avoiding harmful interference among radio services operating within these allocations. The ITU's Radio Regulations also provide a registration process for obtaining international recognition for specific radio operations operating from specified locations, including orbital positions. This regulatory status is of particular importance for satellite systems whose stations are designed for long-term missions operating at very distant locations from space.

The ITU's Radio Regulations are adopted and updated by the WRCs, which the ITU convenes approximately every four years. The regular cadence of WRCs affords a means of keeping up with the rapid pace of technological change, including the development of new space systems. Following each WRC, Member States implement the changes to the ITU's Radio Regulations into their domestic telecommunication regulations.

WRCs: The marquee topic of the past several WRCs has been the award of additional spectrum resources to support growth of advanced mobile wireless technologies, such as 5G. The most recent conference, WRC-23, proved to be markedly different. Notably, most attention and excitement focused on the growth and innovation of space services, including issues related to the implementation of very large low Earth orbit (LEO) constellations, spectrum to support upcoming missions to the Moon, and consideration of additional spectrum to support satellite services, including those in the mobile-satellite service, which are developing capabilities to provide services directly to devices, such as personal cellphones or Internet-of-Things (IoT) terminals.[18] Even the agenda that WRC-23 developed for the next conference in 2027 is largely dedicated to space-related topics.

After four years of preparation and four weeks of exhaustive negotiations, WRC-23 concluded with Final Acts comprising 629 pages, including changes to the ITU's Radio Regulations to:

- Enable use of LEO constellations to deliver services to ships and aircraft.
- Allow multi-orbit operations between geostationary orbit and LEO in certain frequency bands.
- Improve due diligence measures for large LEO constellations, including adopting orbital tolerances.
- Identify new spectrum resources for satellite and wireless services.

Although these actions may seem like routine ITU accomplishments, they are nevertheless notable as they embody new provisions of space law responding to the need to develop emerging space missions and technologies to deliver benefits to the world. The ITU's ability to respond to the rapid rise of new technologies and applications has, to some degree, addressed concerns about its ability to keep up with an increasingly dynamic telecommunications sector. Indeed, the ITU's historic success in its incremental, process-driven, consensus-based approach to treaty-making stands as a model of space-law creation for this century.[19]

[††]The ITU's constitution limits the secretary-general to two 4-year terms in office. The United States is expected to run Bogdan-Martin for reelection in late 2026 at the ITU's next Plenipotentiary Conference.

Preparations for WRC-27 are already well underway. The United States is preparing its proposals through parallel commercial and federal processes: the FCC's WRC Advisory Committee for WRC-27 (WAC)[20] and a federal process to advise the NTIA through the Interdepartment Radio Advisory Committee (IRAC) and its Radio Conference Subcommittee.[‡‡] The draft proposals generated by these processes are "reconciled" by the FCC and the NTIA. The State Department has final authority over the U.S. proposals submitted offshore. The United States typically shares its proposals with its regional spectrum organization, the Inter-American Telecommunication Commission (CITEL), part of the Organization of American States (OAS).[21] The United States negotiates with fellow CITEL Member States to develop Inter-American Proposals, thus achieving regional consensus on joint proposals, which are then shared with other regional groups and ultimately with the world as WRC proposals.

Key Topics in Space Spectrum

Allocations and Harmonization: Space services have long benefited from harmonized spectrum allocations in the ITU's Radio Regulations as these services were foreseen to be inherently international, requiring major investments and long mission cycles, and vital to fulfilling the Union's mandate of extending universal connectivity. Global and regional satellite allocations are found in several frequency ranges, including the L-, S-, X-, Ku-, Ka-, and Q-/V-bands. As shown in Figure 2, the ITU Table of Frequency Allocations divides the world into three Radio Regions. Some allocations, such as Kuband downlinks, are allocated on a regional, rather than global basis. These international satellite allocations are largely reflected in the National Table of Frequency Allocations. Even in cases where the FCC has chosen to deviate from an international satellite allocation to make a domestic terrestrial allocation, the United States remains nevertheless tied by its treaty obligations to protect foreign satellite services operating within the international allocation from harmful interference due to the nonconforming domestic spectrum use.[22]

Over the years, these international space allocations have proven extremely attractive to commercial mobile equipment manufacturers aiming for global markets and economies of scale and to mobile service operators seeking to increase capacity to enable growth and international roaming. Additional spectrum resources enable increased capacity and revenues. The idea of tapping into these space allocations is also enormously popular with regulators as a means of extending connectivity to local citizens and businesses, helping to build local economies, and providing government revenues through tax and auction proceeds.[§§] Thus, many WRC cycles since the late 1990s have been characterized by the relentless pursuit of satellite allocations by terrestrial mobile proponents, in particular for enabling emerging "international mobile telecommunications" (IMT) technologies, the ITU parlance for 5G and its future iterations.[***]

These same international spectrum campaigns also take place in the United States. These debates occur not only in the preparation for ITU meetings, but in the advocacy of industry and trade associations; in Congress (highlighted in various "spectrum pipeline" bills); in FCC rulemakings and applications before the spectrum regulators; and at the White House, including the National Spectrum Strategy.

Spectrum Competition—Terrestrial versus Satellite Services: One of the most difficult negotiations at WRC-23 involved new spectrum resources to support IMT/5G. WRC-23 identified a modicum of additional spectrum for IMT

[‡‡]IRAC was established in 1922 "to assist the Assistant Secretary of Commerce in assigning frequencies to U.S. Government radio stations and in developing and executing policies, programs, procedures, and technical criteria pertaining to the allocation, management, and use of the electromagnetic spectrum." NTIA, Manual of Regulations and Procedures for Federal Radio Frequency Management (2023). Its membership is available at: https://www.ntia.gov/page/interdepartment-radio-advisory-committee-irac.

[§§]A developing country may see less tangible benefit in licensing a foreign satellite operator with very little local presence or other connection with the nation or community versus a wireless company building local cell towers and offering coverage on the ground in that country.

[***]Due to its attractive physical characteristics, the C-band (3,400 to 7,025 GHz) has been the hardest fought-over allocation during this time period, and the terrestrial industry has made incremental progress on obtaining access to this frequency range over the course of multiple conferences. It will continue this campaign at WRC-27.

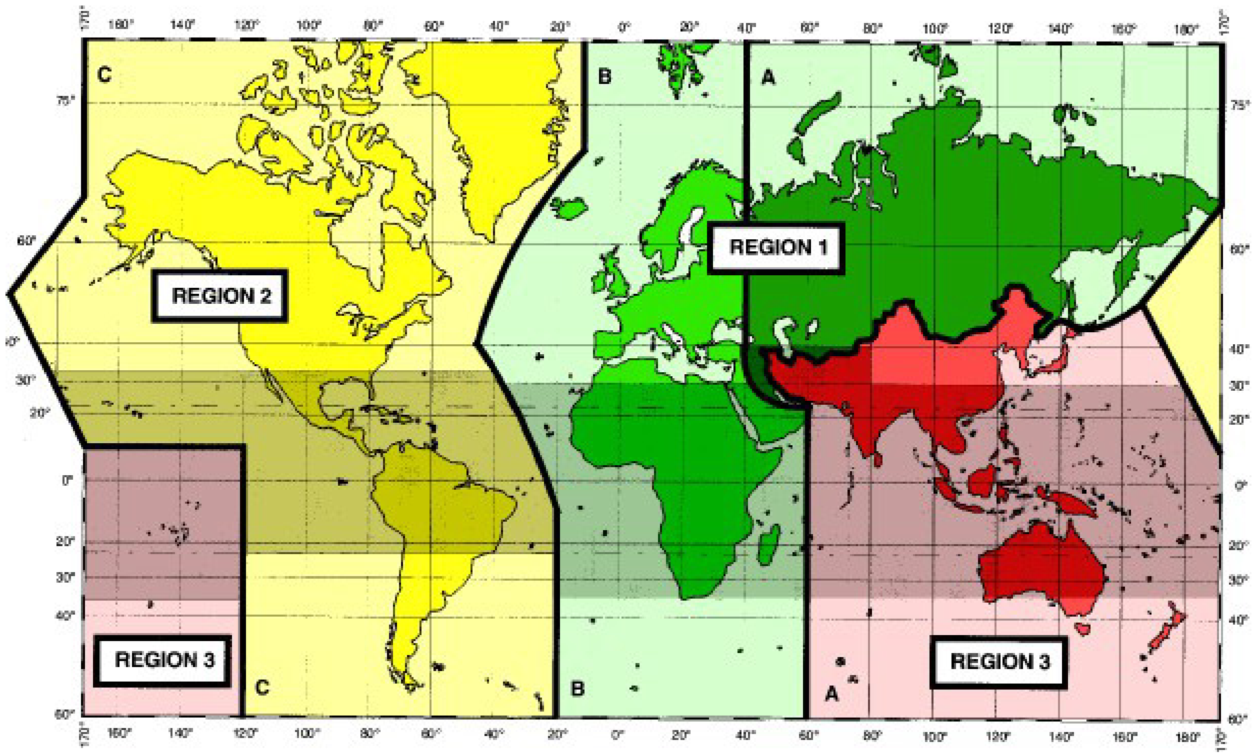

Figure 2: ITU Radio Regions: The ITU's Radio Regulations divide the world into three Radio Regions for its Table of Frequency Allocations (No. 5.2). *Some satellite allocations are global, while some differ by region (for example, Ku-band downlink allocations). This arrangement is also reflected in the National Table of Frequency Allocations. NTIA, Manual of Regulations for Federal Radio Frequency Management, 2023.*

limited to some countries and regions, but no broad swaths of frequency bands across the planet.[†††] The conference turned down a popular hard-fought proposal to identify the 10 to 10.5 GHz band for IMT. This band uniquely supports synthetic aperture radar (SAR) systems that provide high-resolution satellite images essential to early-warning networks and supporting a broad range of environmental monitoring, illegal fishing, sustainable agriculture, climate, and disaster management. These systems operate in the Earth Exploration Satellite Service (EESS) recently allocated by WRC-15.[23] This negotiation reflected the oft-repeated theme of whether to protect largely noncommercial spectrum uses that are of social or scientific value versus those that drive immense commercial value. At WRC-23, Aarti Holla-Maini, the new director of the UN Office of Outer Space Affairs (UNOOSA), addressed the Plenary, supported by the World Meteorological Organization (both observers to the conference), to plead for protection of space allocations that are essential to humanity, including 10 to 10.5 GHz.[24] The effort proved successful in terms of protecting SAR spectrum, at least for the time being.

The WRC-27 agenda includes yet another item to consider, which is additional spectrum for possible IMT/5G identification. Initial discussions considered studying the entire range of spectrum between 7 and 24 GHz.[25] The inclusion of such a broad range of frequency bands would have required a tremendous effort to be able to complete the necessary

[†††]WRC-23 identified portions of the C-band: 3,300 to 3,400 MHz, 3,600 to 3,800 MHz, 4,800 to 4,990 MHz, and 6,425 to 7,125 MHz for IMT limited to specific countries and regions. ITU, WRC revises the ITU Radio Regulations to support spectrum sharing and technological innovation, December 15, 2023), https://www.itu.int/en/mediacentre/Pages/PR-2023-12-15-WRC23-closing-ceremony.aspx.

sharing and compatibility studies for all the incumbent services in these allocations. Ultimately, WRC-23 decided to limit the scope of the study for WRC-27 to three bands: 4,400 to 4,800 MHz, 7,125 to 8,400 MHz (or parts thereof), and 14.8 to 15.35 GHz. The inclusion of the band known as the X-band (7,125 to 8,400 MHz) is a particular concern to the space industry and others who rely on the services provided in this band.[‡‡‡] Notably, in the United States, X-band spectrum was already targeted for study for possible repurposing for 5G.

Protection of a Quiet Neighborhood—X-Band Space Services: As illustrated in Figure 3, the X-band (7,125 to 8,400 MHz) is home to a diverse array of space services. It is a quiet spectrum neighborhood designed to allow sensitive systems to share with other space services and terrestrial fixed services on the ground under specified conditions. The X-band includes communications satellites in the Fixed-Satellite Service (FSS), Mobile-Satellite Service (MSS), and Maritime-Mobile-Satellite Service, and science services such Meteorological-Satellite Service (MetSat), Space Research Service (SRS) (including some designated for deep space), Earth Exploration Satellite Service (EESS), and Space

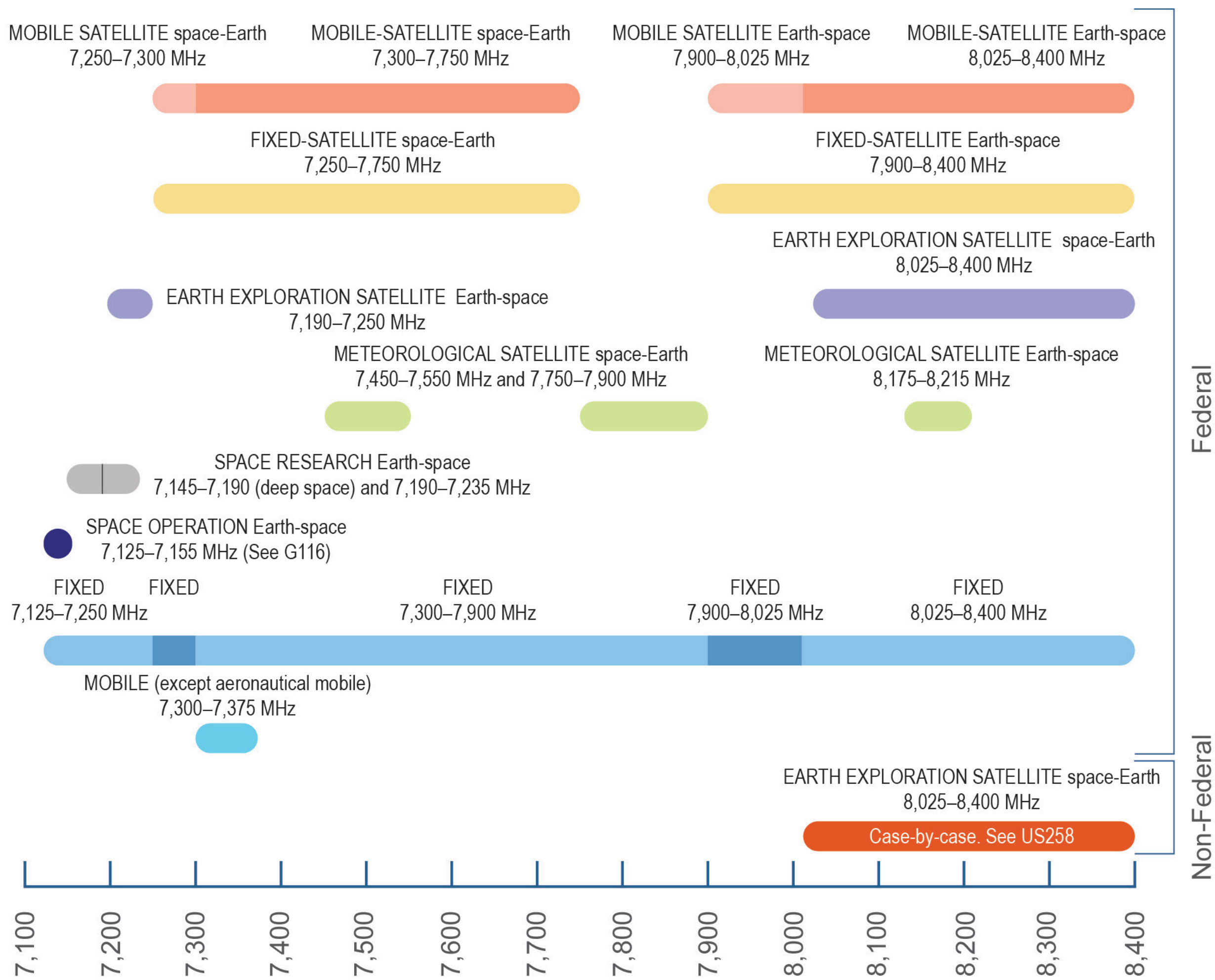

Figure 3: Frequency allocations from 7,125 to 8,400 MHz. *An illustration of radio services currently allocated to the X-band (7,125 to 8,400 MHz) in the United States. Radio services shown in uppercase are primary services and those in lowercase are secondary services that must protect operations in the primary services from harmful interference.*

[‡‡‡]There are also existing secondary allocations in the 14.8 to 15.35 GHz band to the SRS and, via footnote, to the EESS.

Operation Service (SOS) (in the National Table). The X-band has long supported U.S. military satellite systems, NASA's deep space program and current lunar operations plans, management of civil weather satellites, and a growing array of commercial and governmental remote-sensing satellite systems operating in the EESS. It is no surprise that the proposed addition of powerful terrestrial IMT/5G has raised serious concerns in these user communities.

Commercial Imaging Satellites Rely on X-Band: The commercial remote-sensing industry is taking off and growing. Approximately 1,200 remote-sensing satellites are now in orbit, which represents a sevenfold increase over the past five years.[26] These satellites offer an increasing diversity of sensor types delivering imagery solutions, including multispectral, hyperspectral, and radio frequency mapping. These satellites rely on X-band spectrum to support their imaging activities. The commercial remote-sensing industry provides vital support to U.S. military and intelligence operations with "imagery, analytics, and other data that enable enhanced global awareness and transparency, including most recently in Ukraine."[27] These capabilities also support scientific, civil, and commercial applications, such as gathering scientific data to support research, climate monitoring, environmental responsibility reporting, locating underwater oil and gas leaks, providing agricultural data, monitoring cargo and shipping lanes, and other supply chain activities.

National X-Band Repurposing Efforts. It is not only the ITU that is studying the X-band for possible repurposing for auction to 5G operators. Senate Bill (S-4207), the Spectrum and National Security Act, currently awaiting markup, would direct the NTIA and other agencies to perform a feasibility assessment of whether spectrum in X-band can be made available for other uses.[28] The National Spectrum Strategy also tees up the X-band, among four other frequency bands, for detailed study for possible repurposing to ensure that spectrum resources are made available to support private sector innovation. The Strategy, however, observes that the X-band's current "variety of mission-critical Federal operations will make it challenging to repurpose portions of the band while protecting incumbent users from harmful interference."[29] As part of the implementation of the Strategy, the NTIA launched a public multistakeholder process on the Strategy's spectrum studies in August 2024.[30]

The Strategy further calls for long-term strategic spectrum planning to include development of an evidence-based national spectrum decisionmaking methodology that will better reflect the public interest. This methodology will include assessing the societal value of spectrum based on the calculation of direct and indirect benefits of different uses to the nation. Although such a methodology may not be developed in time for these particular repurposing studies, national decisionmakers should act to ensure that the value of X-band services is broadly considered and fairly evaluated, including oversight of decisions on U.S. proposals to the ITU.

Other Spectrum Issues of Note. Eighty percent of the WRC-27 agenda items[§§§] addresses space services and technologies. Many of these agenda items are already being fought by the wireless community and their supporters in WRC preparatory activities. Included in these agenda items are:

- Expanded spectrum allocations (including possible expansion of the SRS [space to space]) to support future development of communications on the lunar surface and between lunar orbit and the lunar surface, as envisioned by NASA in Figure 4 (WRC-27 agenda item 1.15)
- Consideration of allowing space-to-space links between geostationary and non-geostationary satellites in additional frequency bands to enable multiorbit services (WRC-27 agenda item 1.11)
- Additional spectrum allocations to support satellite services: FSS (geostationary and nongeostationary), MSS (including direct to device), and EESS (multiple agenda items)

[§§§] The WRC-27 agenda is contained in Resolution 813 (WRC-23) and can be found at: https://www.itu.int/dms_pub/itu-r/oth/0c/0a/R0C0A0000100036PDFE.pdf.

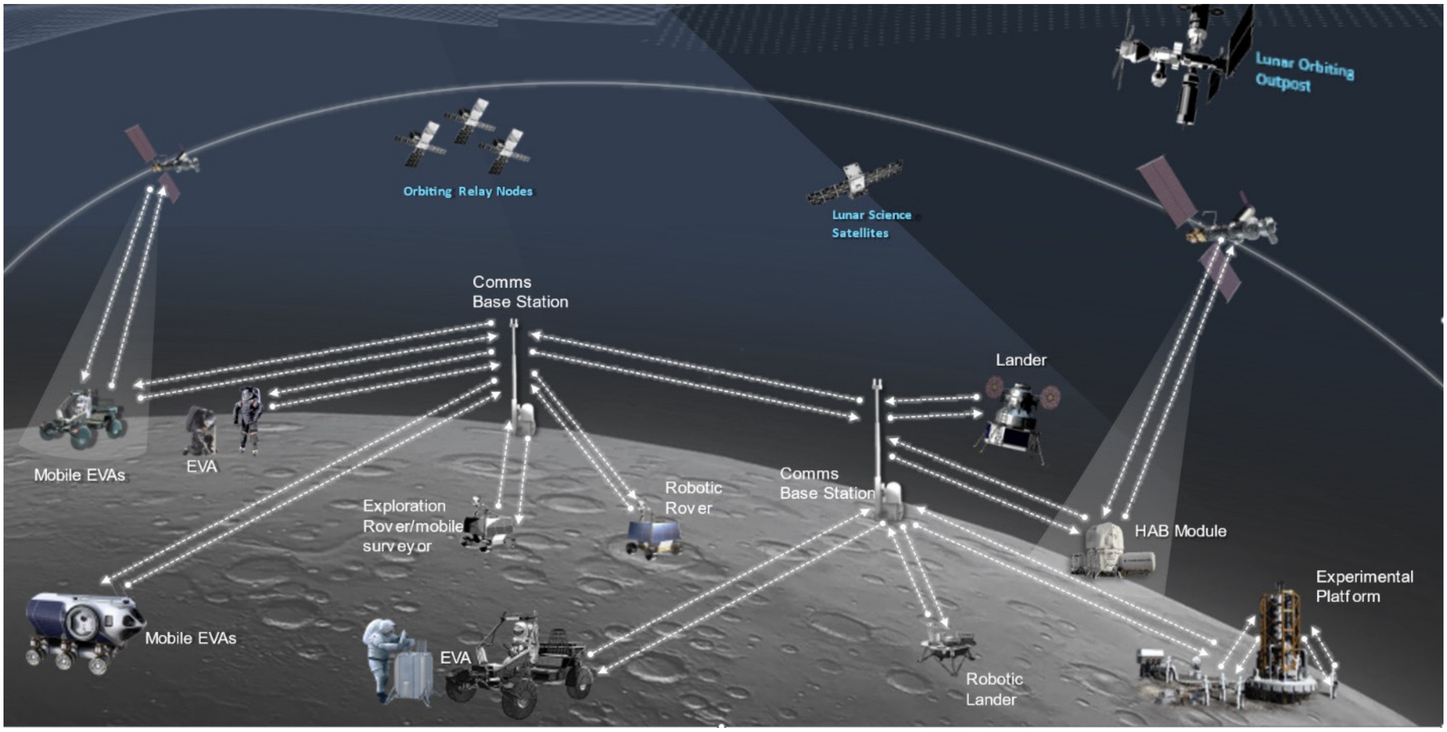

Figure 4: A NASA illustration of the concept of operations for communications in the vicinity of the Moon, including its surface and with lunar orbiting satellites. *These links may require new spectrum allocations. This information was submitted by the United States to the ITU-R Working Party 7B for the preparation of studies to support WRC-27 agenda item 1.15.*[31]

- Regulations to support extension of FSS to Earth Stations in Motion (maritime and aeronautical) in the Q-/V-band (WRC-27 agenda item 1.1)
- Regulatory provisions for space weather receive-only sensors and their regulatory protection (WRC-27 agenda item 1.17)
- Improvements to the satellite coordination, planning, and due diligence procedures for large constellations, and other regulatory/procedural matters (agenda item 7)

There were many more proposals for the WRC-27 agenda than could be accommodated due to limited resources available to conduct and complete the required studies. Although many of these items were included in the proposed preliminary agenda for WRC-31 (which will be revisited by WRC-27), this demonstrates not only the growing innovation and demands for spectrum and regulatory changes needed to bring in new telecommunications services (including space services), but the increasing numbers of engaged Member States and their regional organizations who are bringing their own proposals into the mix.

Conclusion

Spectrum may be invisible, but assured access to spectrum is mission critical to satellites and all other services delivered from space. In addition to commercial broadband connectivity, these services uniquely enable a vast and growing array of essential capabilities for national security, science, public safety, agriculture, resource management, and commerce, yet spectrum rights necessary to deliver these services are at risk. Thus it is essential that lawmakers, regulators, and policymakers become aware, informed, and engaged on spectrum issues, including oversight of the ongoing regulatory decisionmaking processes to ensure that societal goals are understood and fairly balanced and considered, both in national processes and international processes leading up to WRC-27 and beyond. Decisions on key U.S. proposals and positions for WRC-27 will need to be made early in the next administration.

At the same time, mission planners and operators of space systems should fully recognize the value of spectrum and be vigilant about protecting the bands that they need to perform their essential missions. They must educate and inform their government representatives and regulators of their spectrum needs and the benefits their services provide to help ward off potential reallocation of this vital, albeit invisible, natural resource.

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This paper was published as a chapter of *Space Agenda 2025*, with Angie Bukley, Colleen Stover, and Victoria Woodburn serving as editors in chief. *Space Agenda 2025* is an effort by the Center for Space Policy and Strategy (CSPS) at The Aerospace Corporation to highlight and provide insights into some of the major space challenges facing policymakers. You can find the complete list of individual *Space Agenda 2025* papers at http://csps.aerospace.org/SA2025, as well as download the combined set of 16 chapters in the *Space Agenda 2025 Compendium* at https://csps.aerospace.org/papers/space-agenda-2025-compendium, all available to you with our compliments.

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SPACE SUSTAINABILITY IN THE CONTEXT OF CONGESTED AND CONTESTED SPACE

Marlon E. Sorge and Gregory A. Henning

Executive Summary

The last decade has seen dramatic changes in the scope and scale of space operations. These changes are straining the effectiveness of traditional practices to maintain a safe and sustainable operating environment. The number of satellites has risen to an unprecedented level and the potential for conflicts in space has also grown as space becomes more contested. If unmanaged, the combination of congested and contested space has the potential to make operating in parts of Earth orbit very difficult.

There are several stressors on the orbital environment with both short- and long-term consequences which include:

- Increase in space activity, large constellations, mass-produced satellites
- Concentration of satellites for large constellations
- Larger number of satellite operators across more countries
- Increase in number of derelict objects and debris, such as rocket bodies

These stressors can amplify the effects of a conflict in space, making the consequences far more severe than the direct effects of the conflict alone.

The sudden addition of large amounts of small debris or many additional derelict objects from a conflict in space can rapidly compound any existing orbital debris problems, resulting in significant long-term challenges for space operations. To prevent this, several observations can be made and critical actions should be taken:

- Managing the orbital debris environment is an intrinsically international effort.
- It is critical for all spacefaring nations to strictly adhere to responsible debris mitigation practices.
- The execution of debris mitigation is more critical given the potential for space conflict.
- Considerations of debris management goals should include margin for managing the effects of conflicts.
- Development of anti-satellite systems should consider the effects on future space operations. Congested and contested space effects must be considered in combination to maintain acceptable operating conditions in space.

Introduction

The last decade has seen dramatic changes in the scope and scale of space operations. These changes are straining the effectiveness of traditional practices to maintain a safe and sustainable operating environment. With the advent of large commercial constellations of mass-produced satellites for Earth observation and internet service, the number of active satellites has risen at an unprecedented rate (see Figure 1).

Many of the new developments in space activity have the potential to significantly improve life on Earth and our ability to operate and conduct business in space. The development of small, useful satellites with standardized form factors—enabling them to easily ride as secondary payloads on many launch vehicles—has significantly increased access to space for a wide variety of nations and even academic institutions.[1] Many new types of missions have been or will soon be demonstrated, including satellite servicing, life extensions for satellites,[2,3] space manufacturing,[4] and the removal of dead satellites and rocket bodies from space.[5,6,7,8] But, if not properly managed, these developments can have a negative effect on the future ability to operate safely and sustainably in space. Although space sustainability can cover a variety of issues, from the debris environment to radio frequency spectrum usage to maintaining dark and quiet skies for astronomy,[9,10] this paper focuses on aspects of space sustainability related to congestion and orbital debris as well as their effects on space operations and ground safety.

Space is also becoming more contested, which has the potential to significantly complicate the problems of congestion. Potential adversaries are developing counterspace threats, including kinetic weapons, and are demonstrating a willingness to use them. In 2007, China tested a direct ascent (DA) anti-satellite (ASAT) weapon that blew up one of its own satellites,[11] creating thousands of pieces of debris, many of which remain in orbit today. As another example, Russia tested a DA-ASAT weapon in 2021 that also generated thousands of pieces of debris.[12] India's DA-ASAT test in 2019, although creating a relatively low amount of short-lived orbital debris, signaled that other countries may wish to test ASAT capabilities as a political demonstration.[13] The combination of these changes to space operations is resulting in

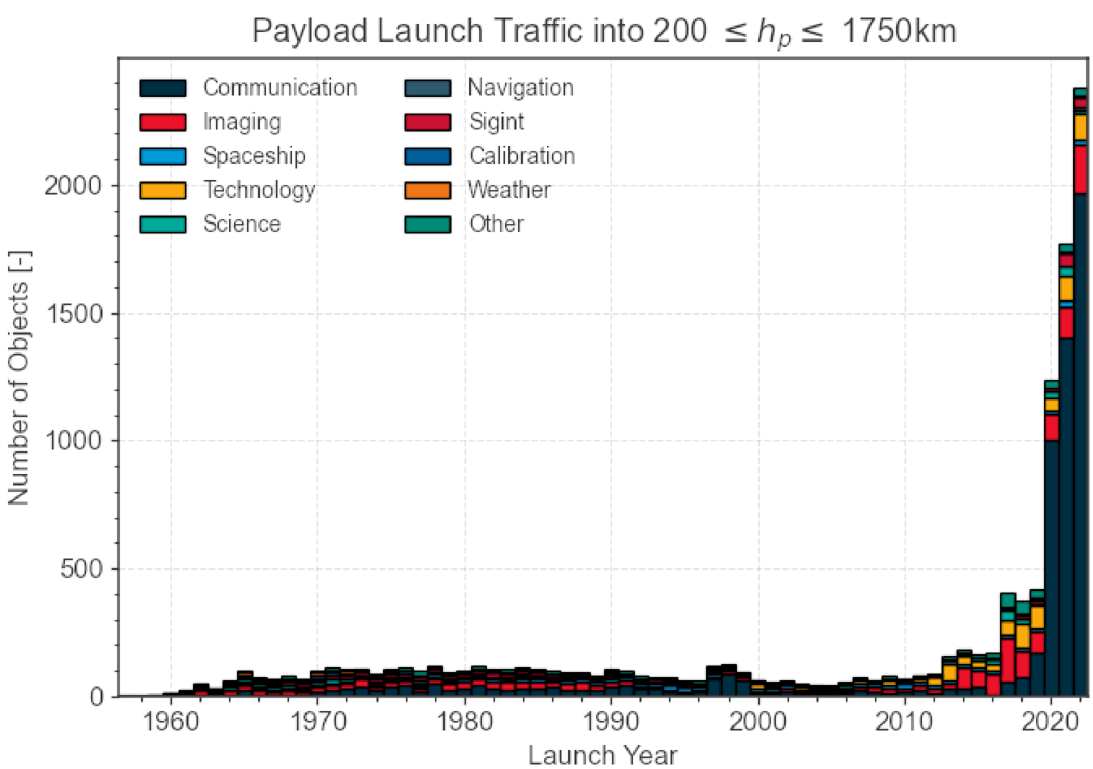


Figure 1: Evolution of launch traffic near LEO per mission type, from ESA 2023 Space Environment Report.

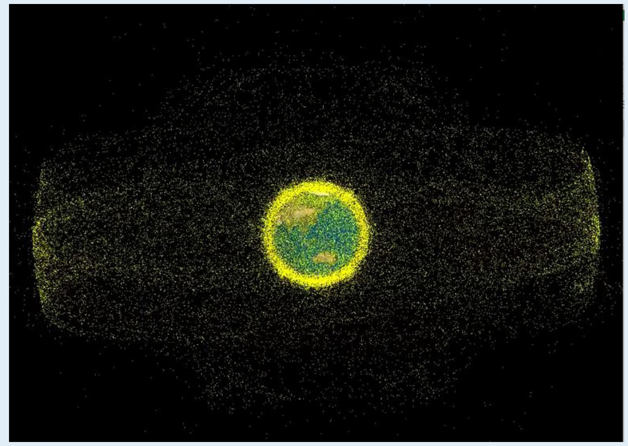
unprecedented stresses on maintaining a sustainable operating environment in space. U.S. government and commercial space leadership will need to carefully consider how to address these stressors to space sustainability, including how to manage them through policy and operations.

Space Traffic Consequences

The recent changes in space operations have the potential for negative effects on the space operational environment. The increase in space activity will mean more potential satellite failures and mass that could end up as debris. Large constellations of satellites in the same orbital regimes could lead to more collision risks. More operators managing satellites could result in coordination and communication challenges, and more launches could mean more derelict rocket bodies in orbit. In short, more traffic in space will increase the frequency of conjunctions and potential collisions between satellites and other objects; hence, operators will have to quickly respond and maneuver to avoid collisions and operate in an increasingly debris-filled environment.

Table 1 lists several of these environmental stressors and their short and their long-term negative effects.

Trackable Orbital Debris Environment



An important issue is the concept of "orbital capacity." Orbital capacity can have several different interpretations. It can encompass how many satellites can be operated within a certain region of space without producing numerous potential collisions, how many satellites can operate without interfering with each other's transmissions, and how much space traffic can operate before reaching unacceptable operating conditions.[14] A capacity then acts as an upper limit in some way, typically something one designs rules and best practices to avoid reaching. In none of these cases is the capacity truly a physical limit on how many satellites can "fit" in space, but rather ways that they can interfere with each other's operations.

Table 1: Environmental Stressors and Associated Negative Effects

Stressor	Short-term Effect	Long-term Effect
Increase in space activity, large constellations, mass-produced satellites	Errors, design flaws causing failures to have amplified effects	More mass that can end up as debris
Concentration of satellites for large constellations	More collision avoidance for other operators	Amplified debris-generation potential for satellite failures
Larger number of satellite operators across more countries	Coordination between systems more complex	Differing debris mitigation requirements can cause operating difficulties for U.S.
Increase in number of derelict objects and debris, such as rocket bodies	Strain on tracking systems, increased collision avoidance maneuvers, decreased launch opportunities	Increased satellite degradation and loss rates, faster self-perpetuating debris growth

Orbital debris that could result from poor management of these environmental stressors could affect operations in several ways (Figure 2). An obvious negative effect is a satellite being hit by debris too small to track and avoid. The U.S. Space Force's Space Surveillance Network can track objects roughly 10 cm (the size of a softball) and larger in low Earth orbit (LEO). Active satellites can avoid objects of this range, but accidental impacts with objects in this range would result in catastrophic collisions that generate large amounts of additional debris. Smaller debris, from about 1 to 10 cm, cannot be reliably tracked but would likely end a satellite's mission if it were to hit the satellite's body. Debris smaller than 0.5 to 1 cm might disable or degrade a satellite.

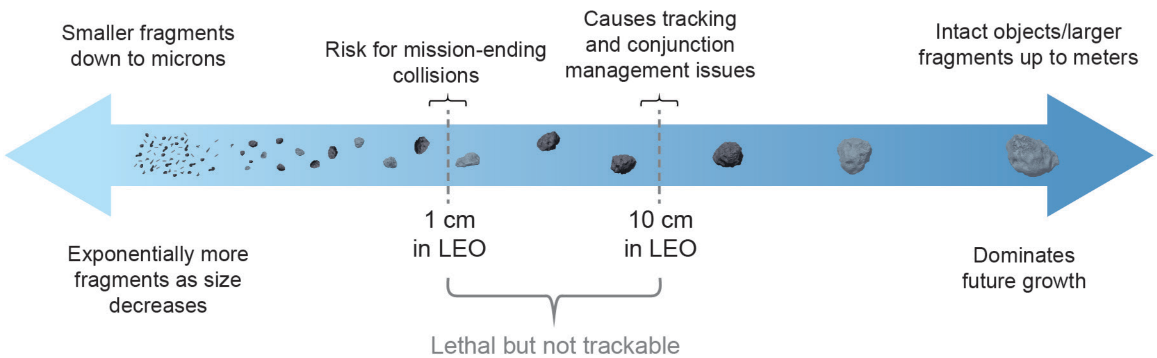


Figure 2: Debris effects by size.

In addition to some of the immediate effects on satellite operations, congested space could also produce longer-term effects on the environment itself. Space could be so populated that accidental collisions between objects occur, which could generate debris more quickly than can be removed by natural forces, such as atmospheric drag. In this situation, the debris population increases on its own. This is colloquially known as the "Kessler Syndrome," named after one of the NASA scientists who first proposed this potential scenario.[15] Several accidental collisions between tracked objects have already occurred, but it is unclear if debris production is currently outstripping natural removal. If the Kessler Syndrome were to begin, the effect would likely be initially very slow but also difficult to stop once it was clearly noticeable. In such circumstances, a large amount of derelict mass on orbit, which was enabling the collisions, would need to be removed to prevent continued accelerated debris growth. The removal of potentially tens of thousands of tons from orbit would be extremely difficult to execute considering technical, economic, and political challenges.

Location Matters. The congestion of the space environment will generally affect the risk of conjunctions and collisions, but there are parameters that can help mitigate these risks. The location of the traffic, and specifically altitude, weighs heavily on the risk of debris generation. When large constellation operators place many hundreds or thousands of satellites in orbits in a narrow altitude range, they can design and control their systems to avoid collisions between the constellation members. Given, as noted, that managing operations can become more challenging when multiple operators occupy orbits that are close to each other, coordination and communication between the operators is critical to avoid collisions. This is an important consideration for any owner when selecting an operational orbit and not limited to just avoiding other operators. There are also regions in space that contain higher concentrations of dead satellites and debris from breakup events, all of which are not maneuverable. Dead satellites and debris will never avoid conjunctions due to their lack of maneuverability. Any future breakup events from accidental explosions or collisions also have the potential to add significant amounts of debris to an orbit, amplifying these problems for any other satellites operating nearby.

All orbits are not created equal though. The problem of debris proliferation is worse at higher altitudes because there is no natural mechanism to remove the debris from orbit. At lower altitudes, the Earth's atmosphere is dense enough to cause objects to lose energy, lowering their orbits and causing them to reenter the Earth's atmosphere in a relatively short amount of time, some even in a matter of weeks. But the density of the atmosphere drops off exponentially as altitude increases, and debris orbiting at 700 km or higher can remain in orbit for decades. In higher orbits, debris can remain for hundreds or thousands of years. This is why altitude, or time on orbit, plays a critical role in determining an object's risk to the environment.

Mass and Size. In addition to how many objects there are and where they are, each individual object has characteristics that make it more or less likely to cause a risk to active satellites. Bigger objects are bigger targets, so the cross-sectional area or configuration of an object will affect how likely it is to be involved in a future collision. For example, a satellite with very large solar arrays or appendages that stretch out far from the main spacecraft body will pose more risk than a compact satellite with nothing sticking out. A large scientific observatory satellite will have a much higher collision probability over its life than a small CubeSat in a similar orbit.

In the unfortunate event of a breakup, whether it be a collision between two objects or a single object explosion, mass turns out to be a key parameter. The reason is that the mass of the object or objects directly correlates to the energy of a collision and how many debris fragments can be generated. More mass means more potential debris fragments, and more debris fragments means more objects that could potentially collide with other satellites in the future. From a debris perspective, a satellite is essentially a set of debris waiting to be released. For this reason, the mass of objects left on orbit is one of the most important parameters for understanding the effect of debris on sustainability.

Developing a Scalable Approach to Mitigation

Debris mitigation approaches generally have some cost associated with them whether it is higher reliability for certain systems, expenditure of propellant for disposal, or maintaining operations after mission completion. It is important to quantify the benefits of debris mitigation practices (or lack thereof) to identify those that are most effective and determine the appropriate levels at which they must be implemented.

As previously discussed, an approach to controlling orbital debris risk in LEO is to reduce or eliminate the accumulation of inactive mass on orbit. This can be done by reducing the amount of time objects spend on orbit (which is another way to say decrease the altitude because objects at lower altitudes will spend less time on orbit) and reducing the concentration of inactive objects so they are not as close to each other. So how does one put that principle into mitigation practice?

Disposal of Satellites

One good practice is for satellites to dispose of themselves at the end of their missions, removing themselves from heavily used regions of space. In LEO, to minimize the time nonfunctional satellites remain a collision risk, the Inter-Agency Space Debris Coordination Committee issued a limit of 25 years in which satellites could remain in a protected orbital region before being disposed or reentering the Earth's atmosphere.[16] Typically, a post-mission disposal (PMD) time requirement is accompanied by a minimum success rate because it is not currently possible to design satellites with perfect reliability. The rate in the current U.S. Government Orbital Debris Mitigation Standard Practices (ODMSP) is >90%.[17] This success rate requirement limits the number of satellites that could accidentally end up in long-lived orbits that are dangerous for the environment.

Rules to limit reentry time directly, like the 25-year rule, are already in place and should continue to be enforced and refined based on the state of the environment. Refinement may mean shortening that duration with increasing traffic as has been proposed by the FCC for large constellations in LEO. Some countries are moving towards even lower timelines than 25 years and a growing number of commercial companies have voluntarily pledged to abide by as low as 5 years.[18] A possible unintended consequence of a shorter disposal duration rule is that disposed satellites will be more concentrated in a narrow altitude range, increasing the collision probability in that range. Some operators have found success with maintaining control of their satellites during the post-mission disposal phase or even intentionally "driving" them down to the atmosphere. This method is referred as Control-To-Reentry (C2R) and enables a satellite to avoid large collisions as it deorbits. With the proliferation of large constellations in LEO, this approach may become a critical tool to complement the disposal duration rules.

Active debris removal, also known as orbital debris remediation, offers another means of removing large, already inactive objects that are currently in the environment. Similar to highly reliable post-mission disposal, this reduces the amount of inactive mass on orbit. Although the process of grabbing and removing inactive objects is much more expensive than properly disposing of a satellite at the end of its mission, it is the only means of removing already inactive mass from orbit. There is also an ongoing debate within the community over the relative priority of removing large (massive) debris objects, which will reduce population growth over the long term, and removing small, untracked debris objects, which will reduce the current collision risk to active satellites.

As previously discussed, the longer a satellite is left on orbit, the greater the chance it collides with another object and the longer other operators must avoid it. The sooner inactive mass can be moved out of orbit, the better. Ultimately, a high PMD success rate is the best way to reduce debris risk, ensuring a high likelihood the uncontrolled mass is moved away from operational orbits and its time on orbit is shortened. Ensuring a high PMD rate, as high as possible, is the best way to contribute to a sustainable future in space, but measuring the actual rate of PMD success is of course a lagging indicator.

Launching Efficiently. There are other actions that can be taken, particularly by large constellation operators, to continue tipping the balance in favor of sustainability. Extending satellite operational lifetime (but not in a way that sacrifices a high PMD success rate) means that constellation replenishment does not need to be done as often. That means fewer launches and fewer disposals, which also means fewer chances for failures that may generate debris. This and other actions that manage the proper disposal of upper stages are critical as poorly managed launch vehicle disposal can be as much or more of a risk than the constellation itself. In a large constellation of thousands of satellites, a few extra years of operation per satellite adds up to a significant reduction in potential debris mass. This, however, may run contrary to the way new constellation operators conduct technology refreshes of their systems. Smaller, cheaper satellites are the new norm, and a rapid replacement strategy to keep up with the latest technologies is the business model.

As satellite size and mass shrink, and as launch vehicle capability increases, more satellites can be deployed with fewer launches. Most launch vehicles have some components that will become on-orbit debris after deployment, so fewer launches to replenish and maintain a constellation means less potential debris. Launch providers can reduce the number of components left on orbit and use propulsion to reenter the upper stage in a controlled manner immediately after they separate from their payloads.

Increased Communication and Coordination Among Operators. Increased traffic in space, especially in narrow regions as with large constellations, necessitates better communications among operators. Typical satellite operators can coordinate passage through or near a large constellation if the large constellation operator is diligent about providing information on the current and near-future locations of its satellites. This is particularly important as most large constellations execute frequent maneuvers to maintain constellation geometry. Without foreknowledge of maneuvers, tracking a large constellation’s satellites accurately enough for conjunction management via an external tracking system becomes difficult.

This issue is significantly amplified if two large constellations are operating in close proximity to one another. In these cases, communication is critical because thousands of satellites will be interacting and may be trying to avoid each other through potentially incompatible automated systems. As of publication, existing large constellations have been good about communicating with each other and other satellite operators, even including sharing details of their automated conjunction management systems. China, however, has recently started deploying its own large constellations, some of which are planned in close proximity to existing and planned constellations from other countries. Historically, Beijing has been far less communicative about their satellite operations, which could be particularly problematic when it operates large constellations.

A Scalable Approach. These mitigation practices can be modeled by simulating space traffic and breakup events and projecting the resulting environment into the future. By varying input parameters (such as the PMD duration, PMD success rate, operational lifetime, satellites per launch, etc.), these modeling techniques can provide policymakers the analytical evidence needed to determine how to apply effective space debris mitigation rules.

The many mitigation measures available can be used to develop scalable debris mitigation rules, where larger systems that present a much higher risk to the environment than smaller single-satellite systems would be required to implement more rigorous mitigation techniques to comply with the rules. Such a scalable approach would need to strike a balance between the requirement for more stringent rules to ensure sustainability and the difficulty of implementing the techniques. Smaller resource-constrained missions will likely have more difficulty with reaching shorter duration disposal orbits or achieving higher PMD reliability rates, but the very large systems will likely have the resources and capabilities to do so. Space environment projection modeling will be very important for testing and comparing various approaches to scalable debris mitigation rules.

Sustainability in a Contested Environment

A conflict in space could exacerbate stressors to space sustainability. The worst long-term debris problems can occur where there are large numbers of both intact objects and smaller objects. The larger objects, such as constellation satellites, provide the mass to create new debris and enhance the self-perpetuation of debris. An exchange of DA-ASATs, for example, could generate more small debris that could trigger the breakup of the larger objects. Based on the Chinese and Russian ASAT tests, each future DA-ASAT event would be expected to produce at least thousands of pieces of debris, pieces which would be large enough to fragment a satellite. Another means of creating more disabled satellites is through impacts with the smaller debris created in high-energy ASAT intercepts. This debris from approximately 1 to 10 cm is too small to track and avoid, but it is likely big enough to disable an operational satellite even if it does not completely fragment it.[19] A typical ASAT engagement could be expected to generate hundreds of thousands of these fragments. This, again, adds to the number of potential debris-creating objects in orbit.

Cyberattacks on satellites could disable a large number of assets, increasing the number of intact objects that cannot maneuver. Disabled satellites would be unable to avoid collisions, increasing the chance of debris-generating events. The more disabled satellites, the greater risk of debris generation, although likely on a longer timeline than with destructive ASAT attacks.

Although a large-scale ASAT attack would have devastating environmental consequences over the long run, it would be an extremely unreliable tactic for intentionally disabling a constellation on a tactically relevant timeline. An example of this effect is the 2009 collision between an active Iridium satellite in a constellation and a dead Russian satellite. While other satellites have maneuvered to reduce risk of conjunction with debris from this collision, there was no short-term loss of other satellites in the constellation. The reason such a large-scale attack would not immediately wipe out a constellation of satellites is that space is big compared to the size of satellites and debris, so even a large amount of debris occupies only a small amount of the volume of space it passed through. Additionally, satellites in a constellation typically do not operate at exactly the same altitude, even if in similar operational shells. Orbital perturbations move the satellites up or down by kilometers on a single orbit, and station-keeping typically allows some variation in orbits so regions where fragmentation debris is concentrated after a breakup are not encountered by most of a constellation. Even though it is quite likely that other satellites would be hit by the debris over time, analysis shows that the increase in satellites lost due to secondary and tertiary collisions would be slow and likely smaller than the number of satellites directly attacked in a major conflict and to the amount of debris produced from those first-generation impacts. Although the short-term debris effects of kinetic strikes in space may be less than expected, the consequences would be severe on a longer time scale. It would also be nearly impossible to target these effects against one specific adversary's satellites, especially in highly used orbital altitudes where satellites from many countries and constellations all operate.

Conclusion

Successfully controlling the orbital debris environment is a truly global problem requiring not only U.S. adherence to rules and practices, but also that all space-faring organizations follow good mitigation practices. Important among these is avoiding the testing of destructive anti-satellite weapons.[20] Because orbital debris effects are cumulative, one other way to mitigate the effects of a potential conflict in space is to lessen debris risks pre-conflict. The fewer large objects that are in orbit and unable to maneuver, the fewer potential sources of new debris. Maintaining strict adherence to post-mission disposal requirements and encouraging all space-faring organizations to do likewise would be a valuable step. This is generally a good idea and made even more important by the potential for conflict. Other approaches, including improving communication and coordination among satellite operators, launching efficiently, and C2R and active debris removal would all be helpful.

Governments should also incorporate margin between the environment targeted by debris mitigation rules and that which is considered acceptable. Not only does this provide some safety with respect to the uncertainties in anticipating how the debris environment will grow, but it also provides some robustness to withstand the effects of contested situations and their consequences. Any efforts to define capacity for satellites should factor in the possibility of conflict.

There are also approaches specific to lessening the effects of a conflict in space. As noted, kinetic direct ascent ASATs could produce devastating long-term effects on the space environment, even if not an effective military tactic to destroy an adversary's constellation. Along these lines, measures like the U.S.-led moratorium on direct ascent ASAT testing,[21] which as of August 2024 had 37 adherents and could disincentive states from pursuing destructive, debris-producing ASATs.[22]

The combination of congested space operations and the potential for contested space scenarios has increased the importance and complexity of maintaining a sustainable space operating environment. Given the complexity of the challenge, policymakers should carry out steps now to help ensure a sustainable environment over the long term. These should include both improved debris mitigation measures to manage the effects of the ever-growing operational satellite population and efforts like the U.S. moratorium on direct ascent ASAT testing to limit the impacts of contested space.

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MIND THE GAP: COMMERCIAL SPACE STATIONS AND THE ISS

Colleen Stover and Angie Bukley

Executive Summary

Low Earth orbit (LEO) is an important testbed and proving ground for advancing space activities and human exploration, as well as a close-to-Earth location for new entrants and potential in-space manufacturing for return to Earth. LEO space science and research has been rooted in decades of international cooperation and diplomacy, specifically the International Space Station (ISS), which is an enduring source of national pride and prestige. With the planned retirement of the ISS around 2030 and the development of several private space stations to replace it, there is now a need to consider how the U.S. government can help minimize disruption of current space science initiatives and supply chains, while maintaining a cooperative leadership position in exploration and science.

If the national goals for deep space exploration, a future LEO in-space economy, and U.S. leadership in space diplomacy are to be maintained, then the U.S. government must create opportunities and an environment to thrive that buys down risk and encourages more partnerships and private investment. A stable commercial station customer base is highly speculative without continued government interest for such things as funding relevant government projects, maintaining oversight of safety and liability, transitioning LEO activities from the ISS to newly launched commercial stations, and helping private companies to diversify partnership models.

Other nations are now competing for space science leadership by demonstrating technological developments supporting cislunar and deep space exploration and by funding commercial LEO activities. The U.S. government should continue developing opportunities to fulfill its mandate to advance knowledge and space exploration that overlap with prospective partnerships and the development of a future in-space economy.

Introduction

The International Space Station (ISS) has been on orbit for 25 years as the longest-running and continuously human-occupied space station in history.* However, it is not the first orbital habitat and will not likely be the last (see Table A-1). Russia's early Salyut and *Mir* space stations, as well as the U.S.' Skylab, fueled our collective imagination of living in space, but humans have considered visiting and living in space for centuries.[1]

The ISS has enabled research across five lines of business, including: education and outreach, fundamental science, technology demonstration, applied research and development, and commercial facility utilization.[2] Within the microgravity environment where matter behaves differently, the ISS has hosted more than 3,700 onboard experiments[3], including hundreds of student experiments involving 2.6 million students across the United States.[4] Observing how humans survive and thrive in space long term has led to fundamental insights into how we live on Earth, such as how to improve bone health, build water purification systems, and increase crop yield in challenging environments.[5] Positioned in LEO, the ISS also serves as a supplemental Earth and deep space observation platform.

The ISS is currently planned for decommissioning and deorbit between 2030–2031.[6] Today, several private space stations are in various phases of planning and development under NASA's Commercial LEO Destination (CLD) Development Program through partnership agreements with commercial companies. The CLD Development Program aims to provide a LEO space station presence overlapping with the end of life for the ISS. Through a series of contracts and agreements, various private companies intend to provide a private space station's integrated infrastructure and services such as transport, refueling, and robotics. (For a list of planned LEO space stations, see Table A-2.) The U.S.-planned commercial space stations take a wide variety of technical approaches, but all are intended for shared use and funding between the public and private sectors, shifting from a model of incidental commercial use of a government capability to a commercial-first approach—albeit with the government serving as a heavy source of revenue.

Planned commissioning dates for these future space stations are scheduled to occur before retirement of the ISS to ensure continuity of U.S. activity in LEO. However, there is concern in the space community that the U.S. commercial stations currently planned will not be fully operational by the time the ISS is retired. Perhaps even more concerning, the CLDs could fail to build a non-governmental customer base in the long term and become economically unviable to maintain.[7] Losing U.S. access to a space station in LEO even temporarily could have longer-term negative impacts, particularly on U.S. companies supporting LEO activities, including:

- Loss of momentum for ongoing space science and research
- Disruption or loss of ground support for services, resupply, and launches
- Disruption of the space supply chain, especially for fragile lower-tier suppliers and developers[8]
- Termination of international agreements with like-minded states
- Allies and industry turning to non-U.S. LEO stations to pursue science and technology (S&T) goals[9]

With NASA placing priority on human exploration missions to the Moon and beyond, there will be less resourcing available for LEO science and technology work. The planned transition to commercial LEO destinations has risks, but it also offers an opportunity for NASA, as the national space agency for the United States, to maintain its mandate for deep space human exploration and for private industry to establish and grow a LEO economy. While commercial space destinations will likely be less central to space-based soft power diplomacy, they are nonetheless a tool worth pursuing.

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*For the purposes of this chapter, "space station" will refer to those stations which are pressurized and intended for more than short-term human habitation, and is limited to those in low Earth orbit, not potential future stations beyond LEO.

Rooted in cooperation. Russia initially led the development of LEO space stations (cosmonauts have lived and worked in space almost continuously since 1971[10]) but the ISS' rich history of human spaceflight and international cooperation is significant. As early as 1972, a cooperative agreement between the United States and the Union of Soviet Socialist Republics (USSR) was signed. Titled the "Agreement Concerning Cooperation in the Exploration and Use of Outer Space for Peaceful Purposes," this bilateral treaty called for a wide range of cooperative ventures, including an experimental Apollo-Soyuz rendezvous and docking mission.[11] Beyond the world's superpowers, space cooperation was also embraced by other nations. Beginning in 1988, the United States partnered with the Canadian Space Agency (CSA), European Space Agency (ESA), and National Space Development Agency of Japan (NASDA) to establish an international coalition supporting Space Station Freedom. In 1994, the United States and Russia established the Shuttle-*Mir* program that delivered 10 shared docking missions and ultimately funneled $400 million into Russian science programs and the workforce. And finally in 1998, the "Intergovernmental Agreement (IGA) on Space Station Cooperation" was renegotiated and Russia was brought into the existing international coalition; the International Space Station program was born.

To this day, the ISS continues to be a five-agency international coalition of space agency decisionmaking and ownership. ISS visitors have been astronauts and "spaceflight participants" from government, academia, the private sector, and citizen advocates. As of March 2024, the ISS has hosted 280 visitors from 23 countries (including 13 private visitors).[12] The ISS has been a hub for a globally distributed group of launchers, operators, designers, and builders. Private industry partners have tested microgravity manufacturing concepts for products intended for use on Earth, such as artificial retinas, pharmaceuticals, microchips, and optical microfiber. In some cases, these products are smoother, more uniform, and higher performing than those produced on Earth.[13] These partnerships have offered research dividends to partially offset cost and risks and have demonstrated the myriad benefits of international collaboration for science and technology research.

> ***Besides government and industry collaboration, the ISS "also brings together international flight crews and globally distributed launch, operations, training, engineering, communications networks, and scientific research communities. Although the primary Mission Control centers are in the U.S. and Russia, several ancillary control centers in Canada, Japan, and Europe also have a role in managing each nation's elements and crew members.***
>
> ***—May 2023 https://www.nasa.gov/reference/international-space-station/.***

Splintered competition. Cooperation in space today has evolved to include emerging spacefaring nations looking for opportunities, and the interests of private industry that are sometimes outside those of single governments. There is growing international competition in space, including the Russian Orbital Station (ROS) recently announced to launch in 2027,[14] though the current war in Ukraine may strain the $7 billion budget. Additionally, India's Bharatiya Antariksh Station recently completed the preliminary development phase and will initially focus on robotic activity with a longer-term eye toward human spaceflight.[15] China is proposing the most comprehensive alternatives to U.S. space programs and is seeking to fill any gaps in LEO and/or cislunar space science left open by the United States.[†]

Though much smaller than the ISS, China's Tiangong orbits Earth today as the country's first long-term LEO space station and the only on-orbit alternative to the ISS. China unveiled initial program plans for Tiangong in April 2011–the same month that the U.S. Congress passed the Wolf Amendment, which limited most direct, bilateral cooperation between NASA and the Chinese national space program.[16] Tiangong first launched in 2021, became fully operational in 2022 with three modules, and has three more modules promised for the future. As China was barred from taking advantage of U.S.

[†]Cislunar is defined as beyond Earth's geosynchronous orbit and mainly under the gravitational influence of the Earth and/or the Moon, including Earth-Moon Lagrange point regions and the lunar surface. National Cislunar Science & Technology Strategy 2022 https://csps.aerospace.org/sites/default/files/2024-07/11-2022-NSTC-National-Cislunar-ST-Strategy.pdf.

government collaboration in space science and technology, the country chose to compete through its own human habitat program, building upon previous successes of its human space program.

More recently, China has signed a number of S&T agreements with other national space agencies and institutions. As of August 2023, China had "signed [Tiangong] cooperation framework agreements with the United Nations Office of Outer Space Affairs (UNOOSA), ESA and space agencies of Russia, France, Germany, Italy and Pakistan," with 110 on-orbit experiments lined up."[17] The China-led International Lunar Research Station (ILRS) that was jointly announced with Russia has also gained attention for its space partnerships, including cooperative agreements with nations such as South Africa, Venezuela, Azerbaijan, Pakistan, Belarus, Brazil, and Egypt, and with non-governmental universities and associations.[18] See Table A-2 for more information on the various non-U.S. station plans.

Why do we need LEO anyhow? In 2017, Public Law 115-10 directed NASA to begin transitioning from human space flight activities in LEO such as that of the ISS regime "that relies heavily on NASA sponsorship, to a regime where NASA is one of many customers of a low-Earth orbit commercial human space flight enterprise," while maximizing utilization of the ISS and LEO in pursuit of deep space human exploration objectives.[19] Since then, fiscal pressures have grown, with final enacted appropriations for FY2024 that included the deepest cuts relative to the presidential administration's request in decades.[20] Meanwhile, today's ISS operations and maintenance require substantial (and ever-growing) funding and astronaut time,[21] and both U.S. and global attentions are turning toward the Moon and Mars. The U.S.-led Artemis campaign has now secured 45 countries as signatories to the Artemis Accords as of October, 13, 2024. However, there are compelling reasons to *not* leapfrog LEO and go straight to lunar and cislunar.

First, maintaining a U.S. government presence in LEO facilitates further exploration overall. The Moon is hard, and Mars even harder. If the United States intends to pursue these far-off destinations, LEO remains the optimal environment in which certain scientific and technological steppingstones exist. Many of the support systems for extended human activity in space still need to be developed. These systems need to withstand the harsh environments associated with missions to other celestial bodies, including high levels of radiation, lunar surface ejecta (dust), sustained extreme cold, limited communications, robotics, and in-situ recycling. From relatively easy-to-reach lower orbits, researchers can study human physiology and test advanced technology for living and working in space. However, while commercial space companies may have the savvy to solve these hard problems, they may not have the risk tolerance. This is because business plans are more likely to target markets such as those using robotics and tele-operation that do not have the high cost and risk of maintaining humans in space, or markets where using an orbiting platform designed for a single purpose (e.g., manufacturing) is more optimal than an all-in-one platform that includes humans. Therefore, LEO remains an important proving ground to buy down the risk of any future deep space human exploration missions.

Second, access to LEO requires less fuel and is cheaper to get to and return from. This is especially relevant to any actors wishing to do space science with limited funding, such as private start-up companies, academia, and new entrant nations. In terms of the potential for off-planet industrial manufacturing and biotechnology for return to Earth, LEO is logistically more affordable; the shipping lane from LEO is ~158,000 miles shorter than from a lunar orbit. Moreover, future commercial stations that are in a lower-inclination LEO than the current ISS could further reduce launch and return costs.[‡] Therefore, as a testbed for small business, like-minded emerging space nations, and academia, LEO still offers the most promise for continuing current research, revealing new research and business opportunities, and establishing flight heritage.

Third, the strategic imperative of maintaining a strong U.S. presence in LEO goes beyond getting to Mars or normalizing in-space manufacturing and transport, and beyond basic science and fundamental research. Studies show that investments in S&T, including that for space, improve overall economic growth, increase skilled technical jobs, and lead to new

[‡]Inclination is the angle of the orbital plane (e.g., of a satellite) relative to Earth's equator. The higher the inclination, the more energy required to reach the orbit when launching from lower latitudes. Launching from Florida, USA, for example, takes much more energy to reach the highly inclined ISS orbit than launching from Kazakhstan—the primary launch site for the Russian Soyuz rockets used to reach the ISS.

discoveries, technologies, products, and industries.[22] Supporting development of basic scientific research in LEO around commercial space stations, and the services and products they could provide, could stimulate adjacent sectors and follow-on technology.

Finally, while soft-power diplomacy of government-to-government space partnerships is often underappreciated, it has long been recognized[23]—and the so-called *diplomatic calculus of space collaboration* cannot be overlooked. Soft-power diplomacy gleaned from civil space exploration and science does not come exclusively from having technology and knowledge, it also comes from *the sharing of that knowledge* with others. The knowledge and prestige associated with space activities is often exported to new partner nations participating in U.S.-led private space missions, potentially strengthening alliances and global stability. And regardless of nationality, there is true power in the shared experience of the *overview effect* when viewing Earth from space.

The case for commercial. Along with billionaires and venture capitalists across the globe and a growing number of niche space start-ups, there are also many emerging spacefaring nations and regional space efforts looking to gain a foothold in the growing global space industry and reduce their dependency on international partners for space services. For instance, India recently loosened its foreign investment policy for building and launching satellites to stimulate its aerospace industry.[24] Additionally, regional efforts like the African Space Agency (2023) and Latin American and Caribbean Space Agency (2021) are looking to benefit members and advance indigenous space capabilities and collaboration among signatory nations. Even Space Florida[25] and the Texas Association of Business[26] have signed agreements with the Israeli Space Agency. Elements of these types of regional partnerships, driven by both geopolitical and commercial ambitions, will continue to shape the space sector. However, the 1967 Outer Space Treaty, and subsequent multilateral space treaties, define space activities and oversight of sub-national space entities to be the responsibility of nation states. Given that governments play this essential role in commercial LEO development, major governmental players should consider how they can best build national capacity and leadership.

Thus far, government has been the primary enabler for research performed by private space companies in LEO. For instance, NASA awards millions of dollars through the In Space Production Applications (InSPA) program for selected companies to demonstrate and implement key technologies on the ISS.[27] But government-provided seed capital in terms of research, prototyping, and early-stage operations can only take industry so far. Predictably, commercial space station companies expect two things: (1) government will continue to fund investments at some level in microgravity science and research, and (2) the ISS will be decommissioned in a timely fashion to make room for new LEO entrants. It will also be necessary to seek ways to reduce risk in investments in areas such as increased space safety, supply chain, and workforce (see Table 1).

Table 1: Model of Success for Private Industry

	Seed	Revenue and Growth
Prerequisite	Continued government interest in microgravity R&D ↓	Timely ISS decommissioning and few competing commercial on-orbit labs ↓
Needs	Help secure the customer base	Business model to generate and grow revenue
Throughout the project lifetime, monitor project value and de-risk across costs, markets, regulatory compliance, safety, and orbital requirements, etc.		

The primacy of NASA and other governmental entities as customers has the added benefit of government being able to continue targeting key technologies and high-priority agency needs for the Moon and deeper space exploration. In fact, absent NASA funds, research on necessary long-term spaceflight human factors is likely to atrophy. For example, while robotics material processing and pharmaceuticals manufacturing could yield the highest returns with the lowest risk for commercial space companies, they do not match the highest priority of NASA to advance human deep space exploration.

The March 2023 U.S. National Low Earth Orbit Research and Development Strategy (National LEO Strategy) presents a plan to maintain and expand the "microgravity research ecosystem" in collaboration with the commercial sector and international partners. Among the challenges:

- Maintain the necessary capabilities and human presence in LEO during the transition from the ISS to commercial successors
- Attract new, impactful research from the U.S. government, academia, and international partners
- Support the development of commercial R&D and in-space manufacturing before and after the retirement of the ISS

Seeding innovation, targeting deep space technologies and research, and maintaining priorities of the National LEO Strategy should be continued.

In terms of a prerequisite to revenue and growth for commercial space stations (see Table 1)—from research to manufacturing—minimal competition from government-owned stations will be necessary. If the ISS, for example, is still on-orbit accepting micro-gravity experiments and hosting visitors, the much-smaller commercial stations may have trouble finding customers and maintaining investors, especially if the ISS is providing services at what amounts to subsidized rates. To that end, if NASA desires a smooth transition to a commercial LEO model, it will need to maintain the scheduled retirement of the ISS to avoid cannibalizing the commercial space station market share. NASA should also continue refining its requirements for how it will use commercial space stations in the future.[28] The ability of planned commercial stations to capture NASA use-cases in their design planning will be integral to a growth-minded business model.

However, the business case on LEO commercial activities will most likely depend on a strong government commitment. The level of support needed for CLDs is up for debate—anchor tenancy on one hand or "just another customer" on the other.[§] While LEO space science has had many government and private customers, a stable commercial station customer base continues to be speculative without continued government interest.[29] U.S. Code Title 51 lays out specific requirements when considering anchor tenancy, such as meeting mission requirements, achieving cost effectiveness, and ensuring a competitive process for selection.[30] The business requirements are the most challenging, wherein commercial space stations must:

- Identify existing or potential customers for the good or service other than the U.S. government
- Prove that long-term viability of the venture is not dependent upon a continued government market or other non-reimbursable support
- Ensure private capital is at risk in the venture (e.g., CLD Program providers should have "skin in the game")

The future of commercial LEO endeavors and the stature of the United States as a global space leader could be diminished by business failures. Therefore, government should assess commercial station business plans to ensure compliance to

[§]While the term "anchor tenancy" is defined for NASA's purposes in U.S. Code Title 51 as procurement sufficient to make a commercial venture viable, the concept has its origins in the retail sector. An anchor store—which attracts customers, and in turn attracts other smaller stores hoping to piggyback on the increased activity, *usually enjoys discounted rent in exchange for signing a long-term lease*.

Title 51 including: clear milestones to avoid business failures, and a means to support the establishment of a viable commercial LEO *economy* that is not reliant on government subsidies.

Particularly noteworthy is the plan to attach the Axiom Orbital Segment to the ISS and then detach the segment before retirement. However, Axiom Space announced several schedule slips in early 2024. NASA subsequently announced renegotiations for its direct contract, and in September 2024, media stories broke of Axiom Space's financial struggles and adoption of a smaller, less-powerful module, thus affecting the business case for non-governmental customers.[31]

To be sure, government funding for continued space science in LEO and for ISS retirement is necessary to support almost any development of the nascent commercial LEO ecosystem. But a successful program will require a balanced and well-crafted partnership model to ensure a reasonable sharing of risks, costs, and benefits. In this regard, public-private-partnership arrangements will play a critical role in sustaining human presence in LEO, applying a range of potential contractual arrangements to finance, design, build, maintain, and/or operate projects whereby both parties share risk and investment.[32]

A look at NASA partnership models. NASA uses several types of funding modalities to support commercial space station and LEO technology development. To advance the CLD Program, NASA-to-private development models range from traditional direct contracts awarded via competitive Broad Agency Announcements (BAAs) to Space Act Agreements (SAAs) which are written into the Space Act of 1958 charter as "other transactions."[**]

- Through the competitive BAA, Axiom Space was awarded a $140 million firm fixed price contract to provide at least one habitable commercial module to augment the ISS. Upon ISS decommissioning, the Axiom Space station would detach and remain in orbit.

- The Orbital Reef and Starlab teams are each working under *funded* SAAs. Initial awards totaling $415 million were made in late 2021 at the beginning of the CLD Program Phase 1 Design Maturation activity.

- Through *non-reimbursable* SAAs, NASA has partnered with seven companies through the competitive Collaborations for Commercial Space Capabilities (CCSC)-2 to develop LEO infrastructures, architectures, or transportation in support of the CLD Program. [††]

NASA plans to implement a five-year CLD Program Phase 2 Certification and Purchase of Services in 2026.[33]

These innovative agreements may not be traditional public-private-partnerships, but while government is building up the U.S. commercial industrial and innovation base, private companies are simultaneously able to leverage these funding models to gain NASA's knowledge and experience.

Other types of funding strategies. Having a range of partnership strategies allows for many ways to increase innovation, build U.S. economic power, and reduce risk to government. Table 2 shows a general partnership framework across various considerations.[‡‡] It is notable that both leadership and diplomatic opportunities for the United States may depend on the sharing of data, information, and technology with other countries. While these exemplars are narrowly described here, a

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[**]SAAs are a type of contracting vehicle to enable external partnerships and include *reimbursable* agreements wherein NASA costs are reimbursed by the SAA partner and *non-reimbursable* wherein NASA and one or more partners each cover the cost of their own participation with no exchange of funds. These SAAs aim to specifically leverage private, commercial companies to design, build, launch, and operate LEO space stations.
[††]They are Blue Origin, Northrop Grumman, Sierra Space, SpaceX, Special Aerospace Services, ThinkOrbit, and Vast. https://www.nasa.gov/news-release/seven-us-companies-collaborate-with-nasa-to-advance-space-capabilities/.
[‡‡]Detailed analysis of possible international partnerships—bilateral or multilateral—are outside the scope of this chapter.

Table 2: Partnership Strategies—Optimizing Investment and Lowering Risk			
	Leadership	**Diplomacy**	**Doing Business**
U.S. Government Only	Sole U.S. government ownership may diminish global leadership opportunities	Limited opportunities	• Domestic market • Subject to budget variability
U.S. Government + International Governments/Agencies	Opportunity for United States to lead partners, allies, and emerging spacefaring countries	Builds upon existing space diplomacy	• Global market • Balances risk and investment across shared operational capabilities
U.S. Government + U.S. Commercial Companies	U.S. government maintains leadership among near peers and private space competitors	Limited opportunities	• Competitive global market will demand strong business case • Boosts U.S. space industrial base • U.S. government seed money imperative
U.S. Government + International Commercial Companies	U.S. government maintains leadership position among spacefaring governments	Builds global space business that could be more sustainable than "going it alone"	• Global market necessitates open sharing of technology (export controls) with competing entities

combination of U.S. government, other governmental space entities, and commercial space offers the greatest reach across markets and possibilities for international relations.

Still, there are other types of partnerships that may appear frivolous yet serve to raise public awareness—e.g., unique marketing stunts such as launching a sports car into space (SpaceX, 2018), or name-brand experiments like baking chocolate chip cookies on the ISS (DoubleTree by Hilton, 2020), but there are other examples of more lasting partnerships. In 2022, Hilton partnered with Starlab to design the interior facilities for visitors of their futuristic hospitality-first habitat. In January 2024 the food group Barilla sent ready-made pasta to the ISS on Axiom Space's private astronaut mission. This type of brand recognition promotes interest in space and appeals to new audiences, which may in turn attract diverse investors.

Finding synergy between U.S. government and private industry. While there is still no singular application or key technology considered indispensable to the future of LEO activities, there are developments that could lead to synergetic business models that provide value to both the U.S. government (e.g., a public good) and private industry (e.g., expanded markets, revenues, or profits). While not an exhaustive list, Table 3 explores some of these.

As stated earlier, delivering a public good and benefiting private sector partners are typically the central design goals of any public—private partnership; however, intellectual property and other information that bring competitive advantage are often the drivers for private involvement. There is a tug of war between space "for the benefit of all humanity" and private-sector goals that may decrease open data and free sharing of S&T discoveries. Understanding how to balance private ownership and public benefits will be important.

There are myriad other ways to sometimes find synergy between government mission and strategic commercial goals that may or may not be specific to pressurized space stations—e.g., the Department of Defense's in-space access, mobility, and logistics (SAML) programs that are rooted in resilience through maneuvering and resupply in space and rely on some of the technologies that feed into commercial space stations such as launch on demand, robotic maneuvers, universal docking systems, and vehicles for transport of power, data, and goods. Private companies should look for ways to tap into those

Table 3: LEO's Next Big Things—Maximizing for Government and Industry		
	What are the benefits of LEO to U.S. government goals?	What has timely and significant return on investment (ROI) for private industry?
Growth—Scaling Up	◆ **Testbed** for small-scale manufacturing, robotics ▸ Informs human habitation on Moon and Mars	◆ **Industrial manufacturing**—retinas and other body parts, microfibers, microchips, etc. ▸ If scalable in space or on Earth, return trip is cheaper from LEO
Technology Transfer	◆ **Human spaceflight science**—effects on the human body biomedical, testing new technology (robotics, materials), biology, agriculture ▸ Informs human habitation on Moon and Mars (eventually must test longer-term/higher radiation environs)	◆ **Biotech, pharmaceuticals, and materials science**—stem cell research, life sciences research, patented medicine, luxury cosmetics, etc. ▸ Highest profit margins will mean launch/return and in-space experiments pay off
U.S. Competitiveness	**Allies' alternative to China's** Tiangong or other nations controlling and owning S&T from LEO	**Intellectual property (IP)** ownership is held among like-minded players
Space Leadership	National **pride and prestige** of sending people to/from space	Novel approaches to **space marketing** and business-to-business partnerships

needs and find new market applications. Another example is NASA's focus on in-space servicing, assembly, and manufacturing (ISAM) that aims to build and diversify the U.S. industrial base[34] and present opportunities for new technology to feed into the launch and continued operations of commercial space stations—especially in terms of resupply or space rescue. Private companies that develop a technology that contributes to just one aspect of the complexities of SAML and/or ISAM could be positioned for other business opportunities related to future human-tended LEO stations.

Conclusion

A future viable commercial LEO ecosystem offers enormous potential, but strong foundations must be in place. To that end, this analysis emphasizes the role of cooperation and competition in LEO space science past and present; the continued relevance of LEO as a proving ground and manufacturing hub; and the need for continued government interest and support for development of a viable LEO ecosystem. Fortunately, there are now opportunities for success through partnerships, which allow private sector and government stakeholders to combine their expertise and strengths to advance LEO-based science, technology, research, and manufacturing.

Some observers, particularly the Chinese, will attempt to present an ISS end-of-life narrative as a diminishment of NASA capabilities and a symbol of the decline of the West. That narrative must be countered with the message that the transition to long-term, viable commercial operations—however long it takes—will define the future course of cislunar development. A post-ISS gap in services could take many forms—short (not more than a year or two) or long (several years), depending on the line of research. If the latter becomes reality, it could also create a gap in U.S. prestige and a missed opportunity for domestic and allied private industry alike.

Acknowledgments

Thank you to Jerry Miller, James Vedda, Martha Hess, and Jeff Hanley for their reviews. Thank you to Karen Jones for serving as editor.

Appendix

Table A-1: Space Stations Then—The Shift from Pilots to Scientists[35]			
On-orbit	**Name**	**Ownership**	**Of Special Note**
1971–1991	Salyut Stations	USSR	Seven iterative missions from single- to multi-module, longest stay 237 days
1973–1974	Skylab	United States, NASA	Experimental using "spare parts" from Apollo's launch vehicle and other spare parts; designed for crew of 3; total of 3 scientific missions; longest stay ~90 days
1986–2001	*Mir*	Russia	Multi-module,1-year visits
1998–Present	ISS	Multi-national: United States, European Space Agency, Canada, Japan (then-USSR 1998)	Multi-module
2006–2007	Genesis I, II	Bigelow Aerospace	Prototypes
2011–2018	Tiangong-1	China	Single module

Table A-2: Space Stations Planned for Longer-term Human Habitation (Selected List)					
Space Station	**Origin**	**Funding**	**Proposed Purpose**	**Design Features**	**Of Special Note**
Axiom Station	• Axiom Space • MOUs with ESA, NZ, other international organizations	• NASA-funded • Firm-fixed-price contract, indefinite-delivery/quantity • Initially $140 million	• Private citizen launches to ISS currently using SpaceX Dragon	• Late 2026 • Comparable to ISS • Capacity: 4 modules of 4 crew each	• Contract content being renegotiated January 2024 • Initial ISS rendezvous, then free-flying
Orbital Reef	• Blue Origin and Sierra Space • Boeing Transport, Redwire Labs, Amazon	• NASA-funded • 2021 Space Act Agreement (PPP)	• "Mixed-use business park" for science and tourism with sports facilities	• Baseline by 2027 • Free-flying • Capacity: baseline 6 people	• $172 million as of January 2024
Starlab Space	• Nanoracks/ Voyager Space, Airbus Defence and Space, Mitsubishi Corporation, and MDA Space Ltd.[36] • (U.S. majority-owned)	• NASA-funded • 2021 Space Act Agreement (PPP)	• Privately operated, First free-flying, habitable, includes a "science park" • Partners include Hilton, Northrop Grumman	• Could launch late 2028/2029 • Free-flying, rotating artificial gravity • Single launch inside Starship • Capacity: 4 people	• $217 million as of January 2024 • Global joint venture network • Northrop Grumman pulled out

Table A-2: Space Stations Planned for Longer-term Human Habitation (Selected List)					
Space Station	**Origin**	**Funding**	**Proposed Purpose**	**Design Features**	**Of Special Note**
Haven-1	• Vast Space[37] (Long Beach, CA)	• NASA (unfunded SAA) • Part of NASA CCSC-2 program	• Tourism; all-commercial crew	• End of 2024 • Spinning artificial gravity[38] • Capacity: 4 people	
ThinkPlatform-3	• Think Orbital	• Privately funded • Part of NASA CCSC-2 program	• Depot, ISAM, then research and tourism	• Spherical, scalable • Capacity: 40 people	• Includes additive manufacturing for large-scale, in-space fabrication
Pathfinder	• Sierra Space	• Privately funded • Part of NASA CCSC-2 program	• Standalone version end of 2026	• Large Integrated Flexible Environment (LIFE) technology is inflatable, scalable	• First missions set for biotechnology
Starship	• SpaceX	• Privately funded • Part of NASA CCSC-2 program			• Already planned for crew and cargo transport
Tiangong Space Station[39]	• China Manned Space Agency	• Government of China	• Crewed on-orbit scientific research facility	• Operational • Currently 3 modules with plans to add 3 more	• Occupied nearly 3 years • Crew of 3
Indian Orbital Space Station, Bharatiya Antariksha Station (BAS)[40]	• Indian Space Research Organisation (ISRO)	• Foreign civil government agency with potential private and public partnerships		• Design phase as of June 2024; part of India's Space Vision 2047 • First module launch 2028; completion by 2035	• Modular, in-space assembled, permanent escape module included • Capacity: robotic initially
Russian Orbital Station (ROS)[41]	• Roscosmos Agency	• Foreign government space agency with potential private and public partnerships		• Roadmap for development announced July 2024 • Phased deployment 2027 to 2033 • Crewed and uncrewed options	• Modular, in-space assembly, gyroscopic power generation, autonomous enabled

Table A-2 Notations

In the design of LEO space stations and for the purposes of this chapter, there are several considerations:

1. **Modularity.** Single-module design requires a large launch vehicle versus a multi-module design that can be launched in pieces but that requires the added complexity of assembly on orbit.
2. **Occupancy.** The number of intended occupants dictates how usage fees are planned and delivered, whether government-funded or by private customers.
3. **Intended purpose.** Tourism, science, and manufacturing yield varying infrastructure and life support needs that could raise complexity as well as liability issues.
4. **Partnerships.** Including cross-national, private investors could either grow or stymie design factors.
5. **On-orbit lifespan.** The added costs of maintenance (internal and external) and resupply could become expensive factors as is the case with ISS more recently.

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About Space Agenda 2025 Publications

This paper was published as a chapter of *Space Agenda 2025*, with Angie Bukley, Colleen Stover, and Victoria Woodburn serving as editors in chief. *Space Agenda 2025* is an effort by the Center for Space Policy and Strategy (CSPS) at The Aerospace Corporation to highlight and provide insights into some of the major space challenges facing policymakers. You can find the complete list of individual *Space Agenda 2025* papers at http://csps.aerospace.org/SA2025, as well as download the combined set of 16 chapters in the *Space Agenda 2025 Compendium* at https://csps.aerospace.org/papers/space-agenda-2025-compendium, all available to you with our compliments.

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MOONSTRUCK! INTERNATIONAL ASPIRATIONS IN CISLUNAR SPACE

Angie Bukley and Colleen Stover

Executive Summary

Interest in cislunar space is increasing, both nationally and internationally. For the purposes of this chapter, cislunar space is defined as that volume of space above geosynchronous orbits, including the Earth-Moon Lagrange point regions and the lunar surface. In the United States, NASA has the lead in exploration and science while the U.S. Space Force and U.S. Space Command are out front protecting national security interests. Commercial space companies are interested in cislunar space because of possibly valuable resources that might be profitably harvested from the Moon. Internationally, the People's Republic of China (China), India, Japan, South Korea, the United Arab Emirates (UAE), Israel, and Russia have plans for lunar robotic missions. The United States, China, and India are planning human landing missions with the United States and China aiming to establish crewed lunar science and research stations. It is imperative that the United States develops capabilities to monitor, track, and assess these activities to protect our national interests and assets. The overarching issue is governance and establishing operational norms of behavior. Three recommendations are proffered based on the research findings detailed in this chapter:

1. The United States should continue to invest in lunar exploration and exploitation aimed at establishing foundational interoperable cislunar infrastructure in concert with public relations and education campaigns.
2. The United States must establish and then enhance its cislunar situational awareness capabilities, which will be crucial to the success of lunar orbital and surface missions.
3. The United States must take a leadership role in establishing and contributing to governance agreements and international norms of behavior to promote sustainable science, exploration, and resource utilization and to protect personnel working in cislunar space.

If the United States maintains its enthusiasm and motivation to push cislunar development forward on the civil, commercial, and security fronts, it has the possibility of maintaining its leadership in space. If there is a path to cooperation, or at least a healthier "coopetition," the nation should take the initiative to lead humanity in that direction.

Introduction

There is a burgeoning interest in cislunar space across a broad range of players, both nationally and internationally, with wide-ranging goals and aspirations.[1] NASA is leading the charge on the civil front for the U.S. government (USG) through its most visible activity, the Artemis campaign, aiming to land U.S. astronauts on the Moon in the late 2026 time frame with an eye toward preparing for future crewed Mars missions. In support of Artemis, NASA is also sending robotic missions to explore the Moon both on the surface and from lunar orbit. As part of Artemis mission architecture, NASA is leading the international Gateway program to build a space station orbiting the Moon. The science community also has shown substantial interest as the Moon presents a unique environment in which to conduct research to help us better understand the origins of our planet and the universe.

NASA is not the only entity interested in the Moon. From the standpoint of protecting national interests on and around the Moon, it is in the interest of the United States to monitor, track, and understand the current and future activities of competitor nations, a task that is now in the remit of the U.S. Space Force and the U.S. Space Command. Concerns in the national security community are elevated because several other countries have already executed missions both in lunar orbit and on the surface, with plans for more. Commercial interest is also high because evidence points to water ice in the lunar southern polar regions, which could potentially be used to make oxygen and rocket fuel on the Moon. Finally, commercial space sees the potential for lunar infrastructure construction and the harvest of other valuable resources, such as rare earth metals, if a cost-effective process is developed.

On the international front, countries including India, Japan, South Korea, the United Arab Emirates (UAE), and Israel have executed or plan to execute lunar robotic missions, with India planning a crewed landing on the Moon by 2040.[2] The People's Republic of China (China) is leading the way with recent successful missions to the surface of the Moon. In June 2024, following on the heels of the Chang'e-5 lunar sample return mission, the Chang'e-6 mission became the first ever to return lunar material from the far side of the Moon.[3] China has big plans for cislunar space, including landing humans on the Moon by 2030.[4] China and Russia have partnered on developing the International Lunar Research Station (ILRS)[5], which now includes 13 countries and a number of other institutions, that will be a research outpost on the lunar surface near the south pole. China's rapid advancement in space technology and exploration is a concern to many in the national security sector.

It is important to understand where in space the United States and other countries and coalitions will be operating in the near future and why cislunar space is so attractive. This chapter provides a description of what comprises cislunar space, identifies reasons for the heightened interest in cislunar space, summarizes the main players and their aspirations, and highlights both uncrewed and crewed missions through the 2040 timeframe. The chapter concludes with observations on the state of play in cislunar space as well as recommendations for actions the United States should undertake to ensure space leadership and influence in the development and use of the emerging cislunar ecosystem.

What and Where Is Cislunar Space?

There are competing definitions of cislunar space.[6] US Code, Title 42, Section 18302 defines cislunar space as "the region of space from the Earth out to and including the region around the surface of the Moon."[7] One of several NASA definitions states that cislunar space is that area of deep space under the gravitational influence of the Earth-Moon system including all Earth-centered orbits, low lunar orbits, and the Earth-Moon Lagrange points (Ls), which are the locations in space where the gravitational forces of Earth and the Moon are essentially balanced.[8] In other words, cislunar space is the volume of space extending from the surface of Earth to beyond Earth-Moon Lagrange point 2 (L2).

Figure 1 is a simplified diagram showing Earth in the center, the geosynchronous Earth orbit (GEO), the Moon's orbit, and locations of the five Earth-Moon Ls. If a spacecraft is positioned in orbit about an L, then it can operate there with very little propulsion required for station keeping. Of particular interest for lunar operations are L1 and L2 regions given their proximity to the Moon. For example, the L2 region is ideal for placing communications satellites for missions operating on the far side of the Moon. Cislunar space is not a flat planar geometry—it's a huge volume in space, more than 1,000 times larger than the volume of space below GEO.

Policymakers define cislunar space in the 2022 *National Cislunar Science & Technology Strategy (NCSTS)*.[9] "Cislunar space is the three-dimensional volume of space beyond Earth's geosynchronous orbit that is mainly under the gravitational influence of Earth and/or the Moon. Cislunar space includes the Earth-Moon Lagrange point regions, trajectories utilizing those regions, and the lunar surface." Unlike NASA's definition, cislunar space as defined by the NCSTS is the region excluding below GEO but adding the lunar surface. The reason for excluding orbits closer to Earth below GEO is that Earth's gravity overwhelms that of the Moon in this region; the gravity level on the surface of the Moon is one-sixth that at Earth's surface. As a spacecraft moves beyond GEO, lunar gravity has a greater effect on its trajectory as it moves further from Earth and closer to the Moon.

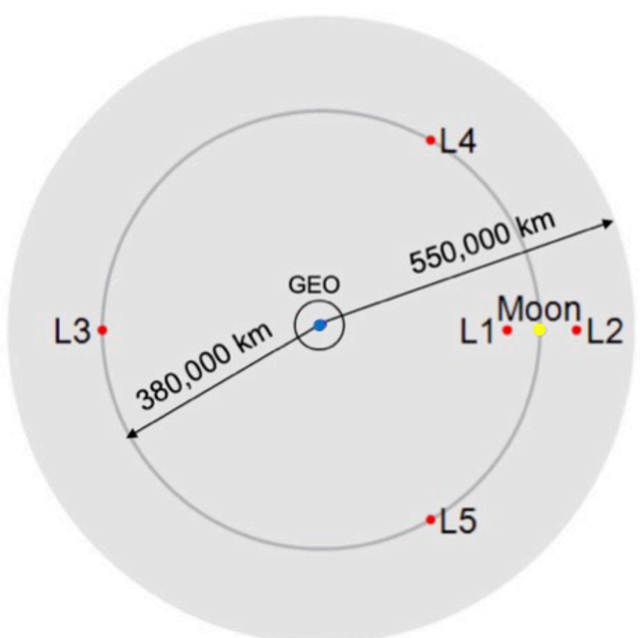


Figure 1. Cislunar space.

Figure 2 is a more complex diagram of cislunar space. It shows the low Earth orbit (LEO) of the International Space Station (approximately 400 km altitude), a GEO orbit, and halo orbits around L1 and L2 where future spacecraft will operate. The diagram also provides a figurative depiction of the gravitational strengths of Earth and the Moon, or their gravity wells. The "deeper" in the gravity well, the more energy is needed for an object to depart for another location. The gravity well for Earth's surface is deepest, the ISS next, and so on. Note that orbits about the Lagrange points are quite shallow and can serve as efficient departure points to visit either Earth or the Moon.

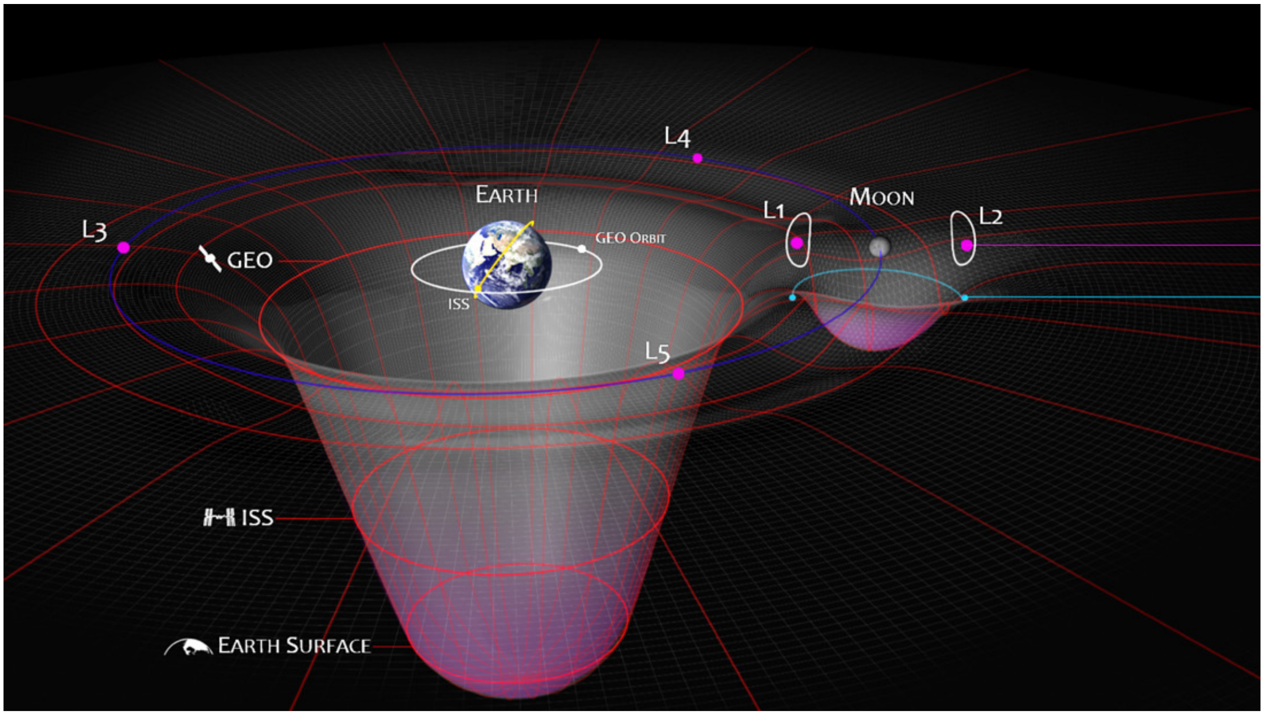


Figure 2. Depiction of cislunar space (not to scale). *(Source: NASA)*

Why Is There So Much Interest in Cislunar Space?

When NASA confirmed the existence of lunar ice in the permanently shaded regions of the Moon in 2018, the idea that humans might be able to survive and even thrive on the Moon significantly enhanced the prospects for lunar exploration and exploitation.[10] Lunar ice could be used to produce water to drink or irrigate crops or be separated into oxygen to breath and hydrogen to use as rocket fuel. Being able to produce propellant on the Moon would open many possibilities for exploration beyond lunar orbit as the launch energy required to reach other places in the solar system is reduced. Based on the *rocket equation,*[11] the amount of energy required to leave Earth's gravity well is about six times more than to leave the lunar gravity well.

All these possibilities have stimulated a confluence of global international interest in leveraging cislunar space in the areas of exploration, science, commercial enterprise, and security. There are interdependencies among these four areas offering the opportunity for synergistic projects and programs.[12,13] In other words, a program aimed at exploration may also yield results or technology beneficial to the commercial space sector or vice versa. The four strategic objectives in the 2022 NCSTS support these enterprise areas and call for international cooperation and extended space situational awareness capabilities. The NCSTS seeks to foster a viable cislunar ecosystem through supporting and stimulating U.S. government, academic, and commercial cislunar activities, consistent with the U.S. Space Priorities Framework.[14]

National Cislunar Science & Technology Strategy

The NCSTS is the first interagency strategy aimed at guiding U.S. governmental actions in cislunar space. It supports the U.S. Space Priorities Framework in which it is stated that the United States will "advance a robust cislunar ecosystem."

The four strategic objectives of the NCSTS are:

1. Support research and development to enable long-term growth in Cislunar space.
2. Expand international S&T cooperation in Cislunar space.
3. Extend U.S. space situational awareness capabilities into Cislunar space.
4. Implement Cislunar communications and position, navigation, and timing (PNT) capabilities with scalable and interoperable approaches.

Exploration. Since the United States last landed humans on the Moon in the early 1970s, there have been numerous NASA programs initiated to return humans to the Moon.[15] These have fluctuated with presidential administrations; however, the NASA Artemis missions to return humans to the Moon[16] have endured two administrations. While the long-term goal is to establish sustainable permanent lunar settlements and drive cislunar economic development, the Moon is also seen as a proving ground to pave the way for sending humans to Mars. Both China and India have set their sights on landing humans on the Moon by 2030 and by 2040, respectively.

Science. The Moon offers a unique opportunity to perform both fundamental and applied scientific research in the areas of planetary science, astrophysics, biophysics, solar physics, solar system evolution, and even Earth sciences. Cislunar space affords an environment in which to execute research in trajectory planning, navigation, and control to improve object tracking and position determination and prediction capabilities. Lunar surface processes can be studied in situ to better understand volatiles distribution and the cooling and crystallization of the Moon's upper mantle. The environment of cislunar space provides an ideal testing ground to study the effects of space radiation on humans and hardware. Moreover, it may be possible to perform radio astronomy observations that are not possible anywhere else in the vicinity of Earth from a lunar zone that is shielded from radio frequency interference known as the shielded zone of the Moon (SZM).[17]

Commercial Enterprise. To establish outposts on the lunar surface, a substantial amount of infrastructure will be required. This presents opportunities for the commercial space sector to provide hardware and software services for needed functions such as communications; positioning, navigation, and timing (PNT); power; propellant; surface transportation and mobility systems; and space situational awareness capabilities. [18] See Figure 3 for more examples. Other commercial opportunities include in-situ resource utilization (ISRU) and the potential to harvest water, helium-3, rare earth metals, and regolith that potentially have value on both the lunar surface and back on Earth.[19] In fact, the formation of a company to harvest helium-3 (a useful element that is rare on Earth) from the lunar regolith and bring it back to Earth was recently announced.[20,21] A startup company has also recently demonstrated the application of robotic technology to construct a five-meter tower that could be used for lunar communications systems.[22] NASA has established the Commercial Lunar Payloads Services (CLPS) Program, leveraging commercial landers to deliver both governmental and commercial science and technology payloads on or in orbit around the Moon.[23] Not until a solid business case can close around such ventures will commercial enterprise be motivated to participate. Companies follow the money.

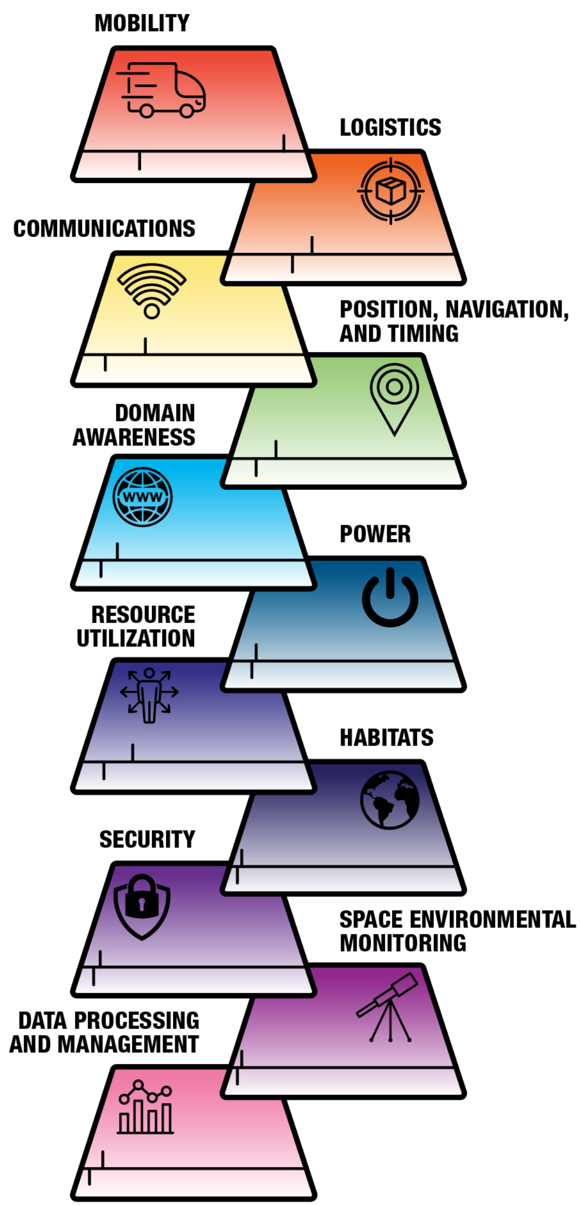


Figure 3. Cislunar infrastructure opportunities.
(Source: Guidi et al., 2022)

Security. With growing interest in the cislunar region and the lunar surface for scientific and commercial developments, there will be a growing desire to protect those investments. Concerns include dual-use technologies, orbital surveillance, trusted communications, and limited interference. One area of great need is increasing space situational awareness (SSA) to help ensure safety and security in the region for all players. Obtaining and maintaining cislunar SSA is challenging because of the sheer volume, which dwarfs (by over a thousandfold) that enclosed by GEO. Not only distances but also finding objects in cislunar space is further complicated by unpredictable orbits,[24] solar reflection off the Moon, keeping sensors in the correct orientation relative to the Sun, and a lack of continuous coverage from Earth.[25] Areas where SSA infrastructure can be placed include lunar bases (especially on the lunar far side), stable lunar orbits (elliptical, high altitude, and inclined), halo orbits around Lagrange points (Ls 1, 2, 4, and 5), and transit orbits between Earth and the Moon. In the United States, consistent with Objective 3 of the NCSTS, the Air Force Research Laboratory (AFRL) is developing the Oracle family of systems comprising two programs, Oracle-Mobility (Oracle-M) and Oracle-Prime (Oracle-P), which are designed for cislunar SSA to provide the foundations for safe operations in cislunar space in support of responsible and sustainable lunar exploration.[26] In the future, it is likely that security concerns similar to those on and around Earth will propagate into cislunar space.

Governance. The capstone to all the above interests—exploration, science, commercial enterprise, and security—is governance. While no single nation has governance over cislunar space and the Moon, there are efforts to provide frameworks for protecting the interests in cislunar, for example, the Artemis Accords.[27] Moreover, the foundation of any governance or pursuit of normative behavior in the cislunar region is situational awareness—or the basic element of security interests in the region.

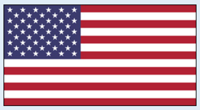
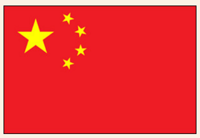
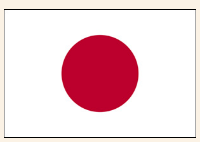
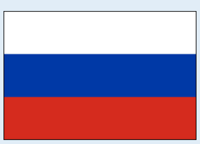
Science, exploration, and commercialization efforts involve time and money, be they from the public or private sector; therefore, any normative behavior that protects safe operations also protects those investments. When considering successful commercial enterprise, it is recognized that would-be investors are more attracted to stable environments, making this essential for a future cislunar market economy where government is one of many customers.

While creating a universal, stabilizing operational framework will need leadership and diplomacy, it also heightens safety and security interests in the region. Foremost is protecting the free movement of entities without endangering other users in transit, in orbit, or on the lunar surface. The protection of commercial surface operations, such as mining or ground stations, against endangerment from close-proximity operations, intentional cyber damage, or spectrum interference is of primary concern. One might even include protection of heritage sites from unintentional damage, like that of the Apollo 11 lander.

Which Nations Are the Main Players?

Even with the elevated level of interest in cislunar space demonstrated over the last 20-plus years, there are only a handful of main players involved in its development through history. The United States is the only country to have landed humans on the Moon with the last Apollo mission completed 52 years ago, followed by a spattering of robotic and orbital flyby missions by the United States, the Union of Soviet Socialist Republics (USSR), and Japan. Since late 2010, there have been 24 lunar missions comprising flyby, orbital, impactor, and landing scenarios executed by the United States, China, Japan, India, South Korea, Israel, Russia, and the European Space Agency (ESA). Other spacefaring nations that have sent payloads or independent orbiters as ride shares include Luxembourg (with China), Italy (with the United States), the UAE (with Japan), Mexico (with the United States), and Pakistan (with China). Not all of these recent missions have been fully successful, but the broadened international interest in space is apparent.[28, 29]

Table 1 summarizes aspirations of the main players in cislunar space exploration as gleaned from the references cited thus far that address plans for cislunar development.[30]

Table 1: Aspirations of the Main Players in Cislunar Exploration	
Main Players	**Cislunar Aspirations**
United States 	• Continue lunar robotic missions through the NASA CLPS Program • Stimulate commercial participation in the development of cislunar space • Land humans on the Moon in 2026 on Artemis III • Build the Gateway space station in lunar orbit • Establish Artemis base camp for longer lunar surface expeditions
China 	• Continue exploration progress with the Chang'e-7 and Chang'e-8 missions • Continue to expand communications infrastructure building on the Queqiao-2 relay satellite (successfully used in Chang'e-6 mission, planned for use in 7 and 8) • Land humans on the Moon in 2030 • Lead the development of the International Lunar Research Station, a permanent research base, with support from its signatory countries
India 	• Continue lunar robotic exploration with Chandrayaan missions 4–7 • Crewed Gaganyaan orbital missions • Implement lunar cruiser missions to NASA-led Gateway space station • Use Launch Vehicle Mark 3 Launcher for human Moon landing by 2040
Japan 	• Collaborate with NASA on Gateway space station and provide lunar terrain vehicles and rovers • Launch LUPEX lunar lander/unpressurized rover to south pole (with India) • Send Japanese astronaut to the lunar surface on Artemis V
Russia 	• Continue Luna series of landers and rovers • Participate with China in the International Lunar Research Station

Human landings are part of plans for the United States (2026), China (2030), India (2040), and Japan as part of Artemis. China is planning and partnering for the ILRS on the lunar surface, while the United States and partners are focusing on the robotic Gateway lunar space station that will be integral to the Artemis human missions. India will build on its success as the first country to land an uncrewed rover at the lunar south pole, and partner with Japan on a lunar lander.

Announced and Projected Uncrewed Cislunar Missions Through the Early 2030s

A plethora of cislunar missions is planned from now until the early 2030s. According to BryceTech,[31] there have been 131 uncrewed cislunar missions announced or projected for 2024 through 2033. Of the total, 83 are planned by the United States with the 48 international cislunar missions planned by 16 countries plus ESA.

Table 2 summarizes the U.S. mission breakdown by mission name, number of planned missions, and mission type. Table 3 does the same for international missions by country. A database of cislunar missions (see reference) has also been developed and is kept current.[32]

Table 2: Uncrewed U.S. Cislunar Missions 2024–2033

U.S. Missions	Number	Lunar Mission Types
NASA Lunar Gateway Habitat and Logistics Outpost/Power and Propulsion Element	1	Orbiting space station core (Gateway)
NASA Lunar Gateway Airlock	1	Orbit
Commercial Gateway Logistics Services (GLS) Missions	8	Orbit supply
NASA Artemis Base Camp Foundation Habitat	1	Surface habitat
NASA Artemis Base Camp Mobility Habitat	1	Surface habitat
NASA Artemis Base Camp Logistics Mission	2	Surface logistics
NASA Lunar Terrain Vehicle	1	Surface rover
NASA Lunar Trailblazer (SIMPLEx 5)	1	Orbit–mapping
NASA Lunar Vertex Rover 1 (on a CLPS platform)	1	Surface lander/rover
NASA CLPS Missions (multiple spacecraft from different organizations)	26	Science and Technology
Air Force Research Laboratory (AFRL) Defense Deep Space Sentinel	1	Surveillance demonstrator
AFRL Oracle	1	Mobility, detection, and tracking
Defense Innovation Unit Nuclear Propulsion Demonstrations	2	Nuclear propulsion/power
DARPA Demonstration Rocket for Agile Cislunar Operations (DRACO)	1	Nuclear thermal rocket
LunaNet/NASA	2	Lunar network capability
Argo Space Corp	1	Space transfer vehicles
AstroForge	1	Asteroid mining
Astrolab	1	Planetary surface rovers
Blue Origin	4	Surface landers
Crescent Space	1	Communications satellites
Firefly Aerospace	8	Landers
Interlune	1	Lunar resource harvesting
Lonestar Data Holdings	1	Off-planet data storage concepts
Lunar Outpost	4	Rovers
Quantum Space	10	Orbital data platform infrastructure
SpaceX Cislunar Tourist Mission	1	Orbit around the Moon

USG MISSIONS COMMERCIAL MISSIONS

Table 3: Uncrewed International Cislunar Missions 2024–2033		
Country	**Number**	**Mission Types**
Australia	1	Rover
Canada	2	Canadarm3 (Gateway), rovers
China	6	Orbiters, relay satellites, rovers, hoppers
Europe (ESA)	4	Flyby, orbiter, relay satellite, lander
Europe/Japan	1	CubeSat
India	1	Lander/rover
Italy	1	Instrumentation for precision landing
Japan	3	Flyby, rovers
Pakistan	1	Flyby/lander
Russia	4	Orbiters, landers, rovers
South Korea	2	Lander and rover
Thailand	1	Orbiter
Türkiye	2	Landers
United Arab Emirates	2	Rovers
Canada	2	Orbiting CubeSats
Germany	2	Landers
Germany/Israel	3	Landers
Israel	1	Orbiter, landers
Japan	3	Lander
Mexico	1	Multiple microrobot explorers

GOVERNMENT MISSIONS (rows Australia through United Arab Emirates) NON-GOVERNMENTAL MISSIONS (rows Canada through Mexico, following)

Lagrange Missions Are Also Being Planned

In addition to the cislunar missions listed in Table 2 and Table 3, a total of 20 uncrewed missions to Lagrange points are planned during this time frame. Ten are to be executed by the USG (NASA and the National Oceanographic and Atmospheric Administration), one by a U.S. nongovernmental organization, and nine to be carried out by ESA, China, Japan, and Russia.

The interest in cislunar space is highlighted through both the growing number of announced or planned missions and the number of countries and companies engaged. How this phase of our exploration of the solar system unfolds will be determined by the enthusiasm of the governments providing the funding and the business cases that can be made to spur commercial involvement.

To the Moon! Crewed Lunar Missions

The U.S.-crewed return to the Moon was energized in December 2017 with the national Space Policy Directive-1, “Reinvigorating America’s Human Space Exploration Program.”[33] The stakes were raised in March 2019 with the announcement from the White House National Space Council that NASA would send “the first woman and the next man” to the Moon by 2024 through the execution of the Artemis campaign.[34]

Meanwhile, China has been systematically pursuing their lunar exploration aspirations first with a series of uncrewed lunar landings and placement of communications elements in cislunar space in support of their planned lunar landing and research station development.[35] India is also developing its own human spaceflight program with goals of putting an Indian space station in Earth orbit by the mid-2030s and landing humans on the Moon by 2040.

NASA-led Artemis Campaign. The NASA Artemis campaign comprises six major programs to develop the systems required to put U.S. astronauts back on the Moon with the ultimate goal of establishing a long-term human presence on the lunar surface for science and technology development. Systems include the Space Launch System, the Orion crew vehicle, ground systems to support both USG and commercial launches, the Gateway lunar space station, Human (lunar) Landing System (HLS), and the surface exploration vehicle system. Figure 4 shows several the Artemis campaign systems.

Having successfully completed the Artemis I mission in late 2022, NASA continues preparations for the 2025 Artemis II mission, which will fly humans around the Moon. Artemis III, planned for late 2026, will be the first time the United States has landed astronauts on the Moon since 1972. Artemis IV–VI missions are planned through 2031 and will include the on-orbit assembly of the Gateway space station.

Figure 4. Clockwise from left, the space launch system (SLS) launching Artemis I mission, HLS design concepts from SpaceX and Blue Origin, the Orion Spacecraft, and the Axiom Extravehicular Mobility Unit (AxEMU). *(Source: NASA)*

The Artemis campaign has not been without challenges. The mission architecture is complex, eventually requiring multiple launches on multiple launch vehicles (SLS, Starship, and Falcon Heavy), including three separate crewed spacecraft (Orion, Gateway, and HLS). Exacerbating the situation is the fact that each of the system elements is managed as a separate program with no overarching systems engineering function defined (hence the use of the term "campaign" rather than "program"). The Artemis I mission revealed critical issues with the Orion heat shield, separation bolts, and power distribution system. These anomalies pose a danger to the crew and must be addressed before the next flight.[36] NASA continues to struggle with schedule slips and cost overruns, as has been widely covered by the media. The NASA Inspector General stated that Artemis costs could reach $93 billion between 2012 and 2025, not including $42 billion for formulation and development costs. It is estimated that the first four Artemis missions will incur $4.2 billion each in production and operating costs for the SLS and Orion.[37]

A major strength of the campaign is the international interest and participation that has resulted from the Artemis Accords, first announced by the U.S. Department of State and NASA in May 2020. The eight founding members of the Accords are Australia, Canada, Italy, Japan, Luxembourg, the United Arab Emirates, the United Kingdom, and the United States. Now signed by 45 countries as of October 13, 2024 (see Figure 5),[38] the Accords are a set of principles and norms of behavior for operating safely and cooperatively on the Moon in the name of scientific and commercial activities. They are separate from the Artemis campaign, which involves bilateral science and technology cooperative agreements with the United

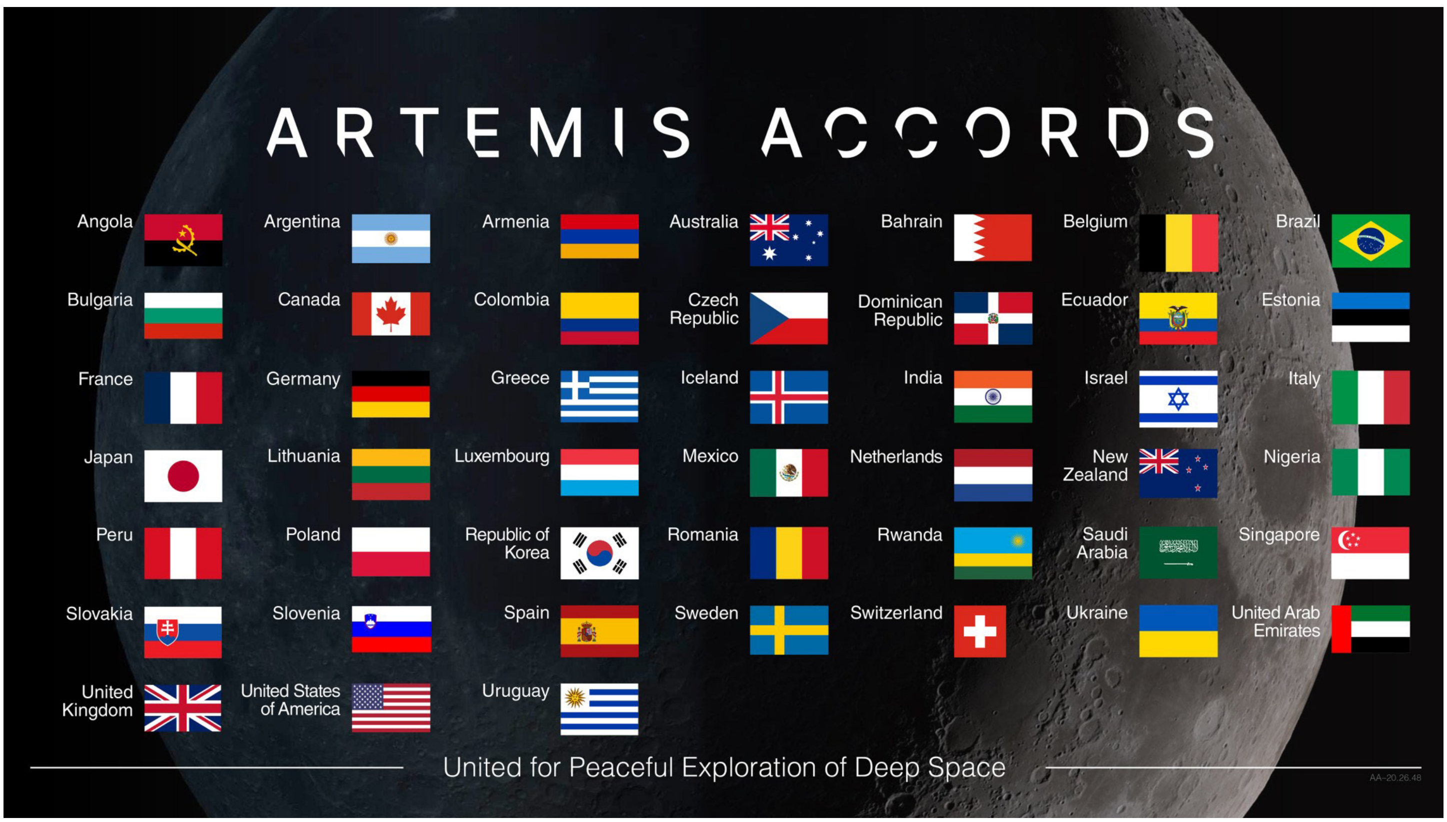


***Figure 5. Signatories to the Artemis Accords as of October 13, 2024**. (Source: NASA)*

States. With so many international and private sector players planning to conduct missions and operations in the cislunar region, the Accords aim to establish a nonbinding common set of principles grounded in the Outer Space Treaty to govern those activities.

International Lunar Research Station (China). China is also progressing on plans to establish a place in cislunar space. The ILRS will be developed over the next decade and consists of five development phases. This long-term research station at the lunar south pole was proposed by China initially, with Russia as a partner, in 2021. China hopes to partner with as many as 50 other countries to develop the ILRS.[39] Current partners include 13 countries and nearly 30 international research institutions (see Table 4). Similar to NASA's plans, their goal is to develop a comprehensive scalable science research facility for multidisciplinary large-scale technical and scientific research activities including exploration, resource development, and technology verification. The intention is for the ILRS to operate autonomously on the lunar surface using assets in lunar orbit with short-term crew participation.

Table 4: International Lunar Research Station Signatories (as of October 2024)

China	Russia
Azerbaijan	Senegal
Belarus	Serbia
Egypt	South Africa
Kazakhstan	Thailand
Nicaragua	Venezuela
Pakistan	

The Chang'e series of missions has already laid the foundation for developing the technologies needed to land humans on the Moon. For example, the recent Chang'e-6 far-side sample return mission included a complex lunar orbit and rendezvous maneuver, which was not necessary for the sample return mission, but an important steppingstone to transporting humans safely to and from the lunar surface.[40]

China's Queqiao-1 communications relay orbiter was deployed in 2018 to a halo orbit around L2 and the Queqiao-2 relay satellite was deployed in 2024 in a highly elliptical orbit around the Moon.[41] The Queqiao-2 mission included deployment of two experimental Tiandu CubeSats to verify important communications technologies supporting a full range of Chinese cislunar missions.

Chang'e-7, planned for 2026, will include a lander and an orbiter and use the Queqiao-2 relay for communications to execute a detailed investigation of the environment and resources at the lunar south pole, similar to what the nearly completed, but now canceled, NASA Volatiles Investigating Polar Exploration Rover (VIPER) mission would have done.[42] Chang'e-8 (2028) will include a lander, a hopper (leaping robot), a rover, and a lunar operations robot to test technologies for in-situ resource utilization.

Gaganyaan Missions (India). Building on the successes of the three Chandrayaan lunar robotic exploration missions and the Aditya L1 mission, the Indian Space Research Organization (ISRO) initiated a crewed spaceflight program in November 2022.[43] Known as Gaganyaan (celestial vehicle), the ISRO program aims to develop a human-rated launch vehicle and a crewed orbital vehicle, including service module, and has initiated crew training at the Astronaut Training Facility in Bengaluru. In addition to the Bharatiya Antariksha Station planned for LEO by 2035,[44] India also plans a human lunar landing by 2040. Quoting from the prime minister's press release, "To realize this vision, the Department of Space will develop a roadmap for Moon exploration. This will encompass a series of Chandrayaan missions, the development of a Next Generation Launch

Chandrayaan-3

The Indian Chandrayaan-3 mission achieved humanity's first successful soft landing of a spacecraft in the region of the lunar south pole, making India the fourth country to soft land on the Moon after the USSR, the United States, and China.

Vehicle (NGLV), construction of a new launch pad, setting up human-centric laboratories and associated technologies." The program is still evolving.

Observations and Recommendations

Observation 1 – Exploration and Lunar Outposts. The strategic importance of cislunar space to exploration, science, and research goes beyond the coveted lunar south pole region. The first nation or coalition of nations to successfully establish long-term lunar surface operations could potentially have an advantage and, by virtue of their presence, discourage other nations from using a particular area. While the United Nations' Outer Space Treaty[45] precludes claiming sovereignty over a particular area, it does not address how to resolve issues that might arise between two entities using the same or nearly the same location. For example, how might one actor's launch and landing activities affect mining equipment or human safety of another actor?

Media reports indicate that China is on track to reach its goal of landing humans on the Moon by 2030. While nominal Artemis milestones are scheduled to happen well before 2030, early delays, heat shield issues, and governmental analysis have already delayed Artemis II to late 2025, possibly 2027.[46, 47]

Recommendation 1. The United States should continue to invest in lunar exploration and exploitation through the NASA Artemis campaigns, CLPS Program, and national security space missions (e.g., AFRL Oracle) aimed at establishing foundational interoperable cislunar infrastructure commensurate with Objective 4 in the NCSTS for a strong U.S. presence in cislunar space; this includes supporting civil and commercial lunar surface operations. Investments should be at a level to ensure mission success while seeking cost-effective solutions, to include partnering with other nations and private space companies.

Recommendation 1 – Supplemental. It is essential that a public relations and public education campaign be mounted to help ensure continued funding for Artemis and other vital USG activities in cislunar space.

Observation 2 – Situational Awareness. Some experts argue that China is moving ahead of the United States in light of recent successes of the four Chang'e lunar landing missions versus only one partial success of the four recent U.S. commercial and international partners' landing mission attempts.[48, 49] China is also operating a communications relay satellite at L2 and has twice landed spacecraft on the far side of the Moon. The United States and its partners cannot observe these operations—be they scientific or military—because the only capable U.S. asset, the Lunar Reconnaissance Orbiter, has very limited viewing opportunities due to orbital mechanics.

Recommendation 2. The United States must establish and then enhance its situational awareness capabilities in cislunar space. Observation and tracking capabilities are key infrastructure components to maintaining safe operations and security in this strategically important region. These capabilities are also crucial for successful lunar orbital and surface missions. The AFRL initiatives (e.g., Oracle) are a good start.

Observation 3 – Governance. It is clear that the United States will be one of a number of international players in the cislunar mission space. How those players from different nations, regional agencies, and governmental or commercial entities govern themselves is still evolving. The partnerships forming around the Artemis campaign and the ILRS represent different camps. In comparison to the Accords, there is also the ILRS Guide for Partnership developed by China.[50] The guide aims to define the research station, describe the scientific areas of interest, and establish a framework for cooperation and opportunities for collaboration in ILRS activities. While it does not appear that these two sets of guidelines are in conflict, there may still be misperceptions or tensions that arise from current geopolitics. How the Artemis and ILRS partners interact with each other to deconflict cislunar activities and prevent interference remains an open question.

In addition to agreements already in process, there is also concern for operational norms of behavior and increased cislunar space debris, which could include ejecta from lunar launches and landings, and other hazards as discussed in the Bulletin of the Atomic Scientists (January 2022).[25] A recent study posits that many aspects of operating in the cislunar regime are not compatible with the current space debris mitigation guidelines and requirements.[51] Collisions or explosions in low lunar orbit would endanger humans on the lunar surface with no atmosphere to slow down debris. And because orbital trajectories are not always predictable in the cislunar region, tracking objects becomes a challenge, meaning collision avoidance warnings are not reliable, particularly for debris or retired spacecraft, at least for the foreseeable future.

Recommendation 3. The United States must take a leadership role in establishing and contributing to governance agreements and international norms of behavior to promote sustainable science, exploration, and resource utilization and to protect personnel working in cislunar space. More important is that we work to ensure that key regions of cislunar space do not become unusable as a result of space debris or haphazard resource exploitation that might either restrict or prevent the use of certain areas of the Moon, like the lunar south pole.

Conclusion

Through providing a physical description of cislunar space, describing reasons behind increased interest in this region, and summarizing planned lunar missions, both crewed and uncrewed, this chapter has presented the current cislunar state of play. The analysis presented in the observations informs the three recommendations that have been provided. As long as the United States maintains its enthusiasm and motivation to push cislunar development forward on the civil, commercial, and security fronts, it has the possibility of maintaining a place of leadership in space. If there is a path to cooperation, or at least a healthier "coopetition," the United States should take the initiative to lead humanity in that direction.

Acknowledgments

Thank you to Jeff Hanley, Martha Hess, George Pollock, David Eccles, and Brian Weeden for their reviews. Thank you to Marlon Sorge for serving as editor.

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This paper was published as a chapter of *Space Agenda 2025*, with Angie Bukley, Colleen Stover, and Victoria Woodburn serving as editors in chief. *Space Agenda 2025* is an effort by the Center for Space Policy and Strategy (CSPS) at The Aerospace Corporation to highlight and provide insights into some of the major space challenges facing policymakers. You can find the complete list of individual *Space Agenda 2025* papers at http://csps.aerospace.org/SA2025, as well as download the combined set of 16 chapters in the *Space Agenda 2025 Compendium* at https://csps.aerospace.org/papers/space-agenda-2025-compendium, all available to you with our compliments.

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