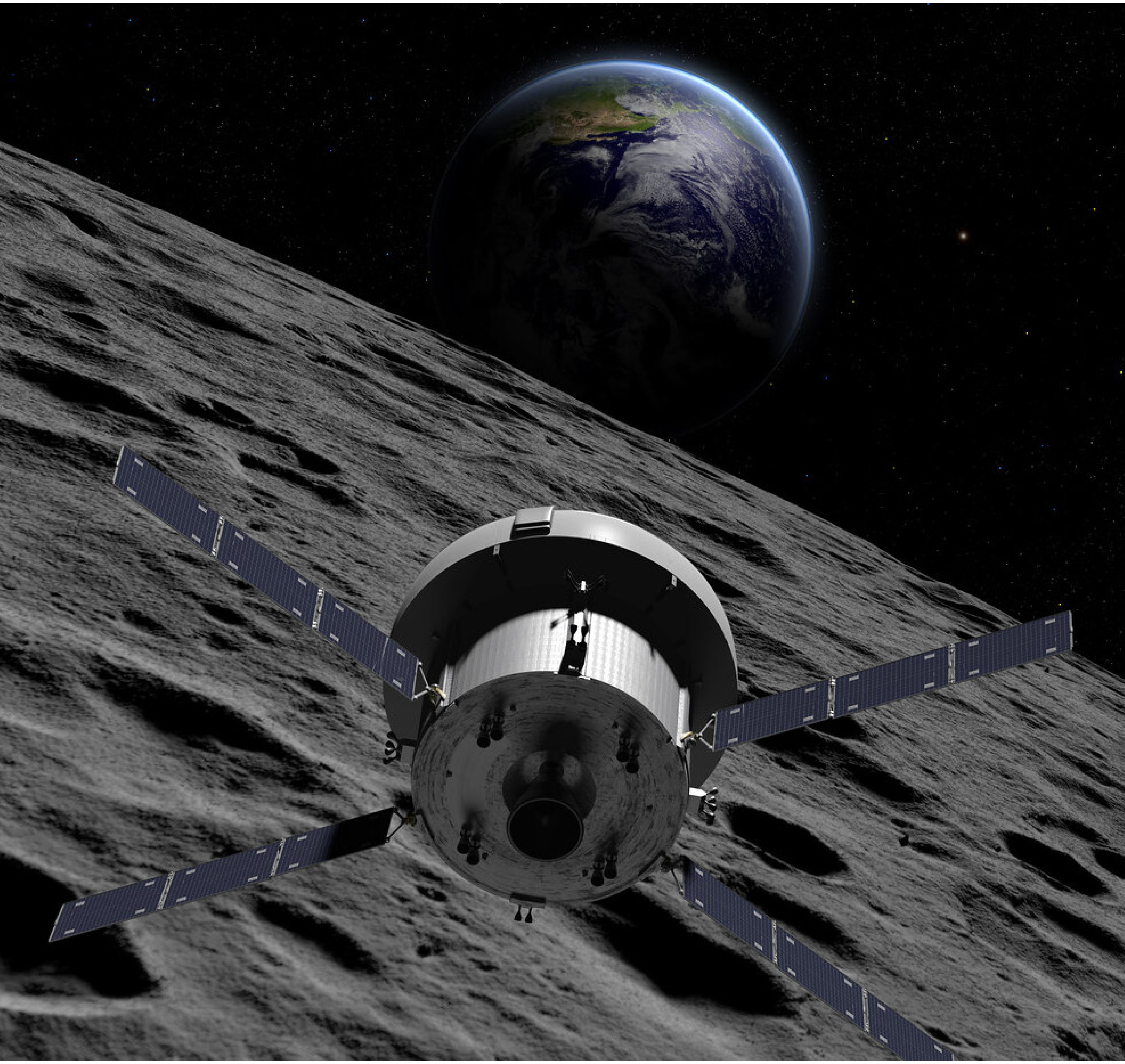
THE SPACE REPORT

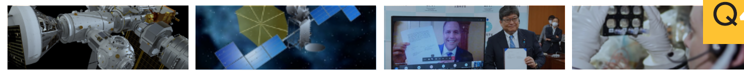
SPACE FOUNDATION

THE AUTHORITATIVE GUIDE TO GLOBAL SPACE ACTIVITY

2020 Q4



LEO BROADBAND | CISLUNAR SPACE | INTELLECTUAL PROPERTY RIGHTS IN SPACE



Small Satellite Mass Categories

Femtosatellite: 0.001 – 0.01 kilograms
Picosatellite: 0.01 – 1 kilograms
Nanosatellite: 1 – 10 kilograms
Microsatellite: 10 – 100 kilograms
Minisatellite: 100 – 180 kilograms

Note: 1 kilogram equals 2.21 pounds

Source: "What are Smallsats and Cubesats." NASA. February 26, 2015. https://www.nasa.gov/content/what-are-smallsats-and-cubesats (Accessed March 10, 2019).

Common Cubesat Useful Volume Dimensions and Masses

1U: 10x10x10 centimeters/1.33 kilograms
1.5U: 10x10x15 centimeters/2 kilograms
2U: 10x10x20 centimeters/2.66 kilograms
3U: 10x10x30 centimeters/4 kilograms
6U: 10x20x30 centimeters/8 kilograms
12U: 20x20x30 centimeters/16 kilograms

Note: 1 centimeter equals .39 inches. 1 kilogram equals 2.21 pounds.

Source: "Cubesat Design Specification," Revision 13. California Polytechnic State University, San Luis Obispo. April 6, 2015. https://www.cubesat.org/s/cds_rev13_final2.pdf (Accessed March 10, 2019).

Primary Mission Segment Descriptions

Civil Government: Government-sponsored space products and services provided to the public, usually for little or no profit.

Commercial: Products and/or services sold to the public, using little or no public investment for running the business and mission.

Military: Government-sponsored missions and products serving a nation's defense and/or power projection.

Common Orbit Descriptions

- **Low Earth Orbit (LEO)** is commonly accepted as being between 200 and 2,000 kilometers above the Earth's surface. Spacecraft in LEO make one complete revolution of the Earth in about a 90-minute window.
- **Medium Earth Orbit (MEO)** is the region of space around the Earth above LEO (2,000 kilometers) and below geosynchronous orbit (35,790 km). The orbital period (time for one orbit) of MEO satellites ranges from about two to 12 hours. The most common use for satellites in this region is for navigation, such as the United States' Global Positioning System (GPS).
- **Geosynchronous Equatorial Orbit (GEO)** is a region in which a satellite orbits at approximately 35,790 kilometers above the Earth's surface. At this altitude, the orbital period is equal to the period of one rotation of the Earth. By orbiting at the same rate in the same direction as Earth, the satellite appears stationary relative to the surface of the Earth. This is effective for communications satellites. In addition, geostationary satellites provide a "big picture" view, enabling coverage of weather events. This is especially useful for monitoring large, severe storms and tropical cyclones.
- **Polar Orbit** refers to spacecraft at near polar inclination (80 to 90 degrees) and an altitude of 700 to 800 kilometers. Many polar-orbiting spacecraft are in a **Sun-Synchronous Orbit (SSO)**, in which a satellite passes over the equator and each latitude on the Earth's surface at the same local time every day, meaning that the satellite is overhead at essentially the same time throughout all seasons of the year. This feature enables collection of data at regular intervals and consistent times, conditions that are particularly useful for making long-term comparisons.
- **Highly Elliptical Orbits (HEO)** are characterized by a relatively low-altitude perigee (the orbital point closest to Earth) and an extremely high-altitude apogee (the orbital point farthest from Earth). These extremely elongated orbits have the advantage of long periods of visibility on the planet's surface, which can exceed 12 hours near apogee. These elliptical orbits are useful for communications satellites.
- **GEO Transfer Orbit (GTO)** is an elliptical orbit of the Earth, with the perigee in the LEO region and apogee in the GEO region. This orbit is generally a transfer path after launch to LEO by launch vehicles carrying a payload for GEO.

This methodology and algorithm is used to classify orbits based on their most recent orbital elements. It is not meant to classify other special orbits (heliocentric, planetocentric, selenocentric, barycentric, solar system escape, etc.).

Q4

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THE SPACE REPORT

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2020 Q4

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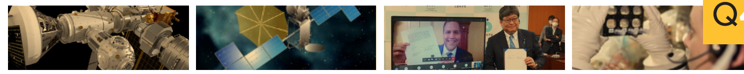
ABOUT THE COVER IMAGE:
The Orion crew capsule orbits above the moon as earth rises in the background in this artist's rendering.
Credit: NASA



Introduction to *The Space Report* | Quarter 4

In a year when simply surviving seemed accomplishment enough, the global space industry thrived. A number of nations advanced their space programs across of variety of sectors, and in doing so, have set a level of expectation for greater achievement in 2021.

China, the UAE, and the United States launched missions to Mars last year. Months after China launched its Tiawen-1 Mars rover, its Chang'e 5 collected and returned robotically retrieved Moon rocks. Though a first for China, Russia accomplished a similar sample return with the Luna 20 in 1972.

The United States and Japan used robot technology to land on asteroids and collect samples, and both nations have missions planned to collect rocks and soil from Mars. NASA's Perseverance is on its way; Japan's Martian Moons eXploration (MMX) mission is scheduled for launch in 2021.

The European Space Agency (ESA) set its sights on studying the Sun's heliosphere, launching its Solar Orbiter in February. The Solar Orbiter will get closer than any other solar spacecraft and for the first time, will examine the sun's polar regions.

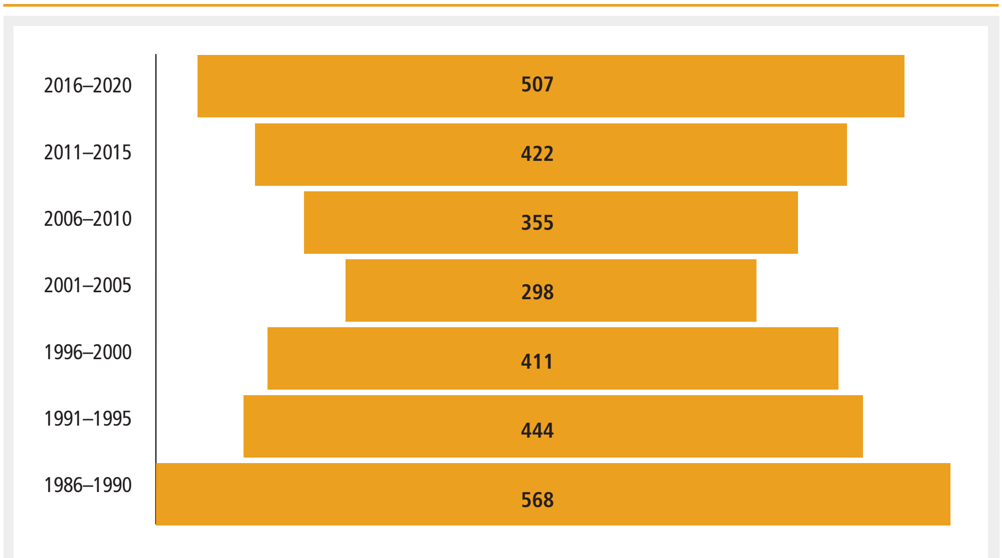
In the United States, the maturity of private space corporations reached beyond coordination with NASA. In December, SpaceX tested its Starship SN8, a reusable space launch system intended for missions to the Moon and Mars. In February, Northrop Grumman's Mission Extension Vehicle (MEV-1) connected with an out-of-service Intelsat 901 satellite in geosynchronous orbit and restored it to an expected five more years of operation.

The Space Report 2020 Q4 provides insight about what is happening across the space industry and provides end-of-year analysis on the space economy and global policies. Here's a more detailed look at this issue:

1 | Space Infrastructure

Despite COVID-19, global launches in 2020 surpassed 2019 launches, reaching a level close to the pace of activity from the Space Shuttle era. More new launch vehicles were introduced than any year of the past decade.

Global Orbital Launch Attempts by Five-Year Increment



Source: Space Foundation Database

More countries are planning lander and rover missions to the moon in 2021 than at any time in space history. The Moon and cislunar space hold the promise of more space-based satellite servicing and operations, lunar and asteroid mining and, perhaps within 25 years, even the potential of space-based solar energy on Earth or for satellites.

Closer to home, in low Earth orbit, the growth of broadband satellite constellations continues exponential growth. More than 1,000 of the constellation satellites are in orbit, with thousands more planned. Overall communications satellite deployments for 2020 grew 477% from 2019's record-high deployment of 175 communications satellites. That growth primarily comes from two broadband companies: OneWeb and SpaceX.

2 | Space Economy

The year was not without its failures. Late in the year, OneWeb emerged from bankruptcy, but other companies were not as fortunate. In the S-Network Space Index, three of the space companies that were on the index a year prior were no longer tracking due to bankruptcy. By the second half of the year, however, the addition of new companies expanded the index to 31 companies. Performance of S-Network Space constituent companies in Q4 was positive, with 25 companies advancing while 6 declined.

Quilty Analytics' fourth-quarter analysis tracked strong financial activity, including 20 announced mergers and acquisitions totaling $11.7 billion in disclosed activity.

Our newest feature, Nation in Review, examines Germany's space economy and infrastructure activities. Germany's overall space spending has increased 56% since 2009, and its domestic space spending in 2019 increased more than 30% from 2018, reaching €1.3 billion (US$1.53 billion).

3 | Space Policy

Two articles in this section examine the gains made in space policies around the globe and the challenges that lie ahead in intellectual property rights and space law. Jack Stuart is a partner at Martensen IP Law in Colorado Springs, Colorado, and has prior service at the National Security Space Institute. He lays out the foundation of current space law and advises on the pitfalls that startups must skirt to avoid becoming "tech philanthropists".

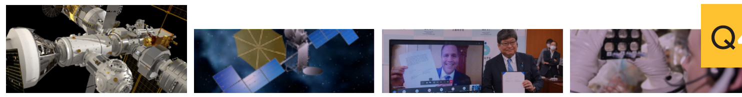
4 | Space Products & Innovation

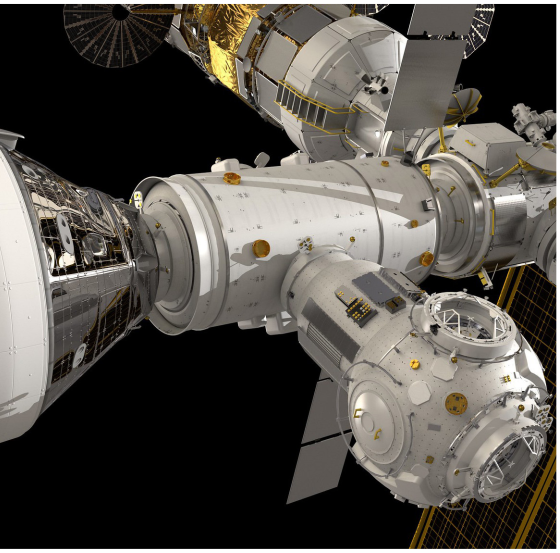
While attention and exploration may be shifting to the Moon and Mars, important research advancements are still happening on the International Space Station, which marked its 20th anniversary in service in 2020. Human heart cells are now being printed on the ISS using 3D Biofabrication, and there is tremendous potential in microgravity stem cell research. Between 1982 and 2013, there were 34 publications regarding ISS stem cell research. Since 2014, that number has nearly doubled, the data show.

As you read this report

The data presented is a quarterly snapshot of global space activity.
To learn more, updates from *The Space Report* are available on a subscription basis, as are data sets that are not included in this document. To find the data you need, sign up today at:

TheSpaceReport.org





Introduction | *Apollo 17 astronauts Eugene Cernan and Harrison Schmitt in 1972 were the last of a dozen men to walk on the Moon.[1] For the past 48 years, lunar exploration has been largely replaced by deep space exploration, space station construction, and reusable launch vehicle development. With advancements in space technology, lower launch costs, and growing investor confidence, the Moon is about to undergo more exploration and development than at any time in history.*

A closeup view of the ESA's ESPRIT communications module and connecting module that will be part of Gateway.
Credit: ESA

The Race to the Moon and the Promise of Cislunar Space

The Moon is fast becoming the new economic frontier of the global space economy. By 2024, at least 11 nations and four private businesses, many affiliated with Artemis, plan to have landers, rovers and scientific equipment operating on lunar surface, exploring for ice and water, measuring solar radiation, collecting regolith — or Moon dust — evaluating possible sites for human settlement, and taking the first steps toward developing space-based industries from its resources. China and the European Union (EU) plan similar lunar lander missions before the end of the decade.[2, 3] (See Appendix 1)

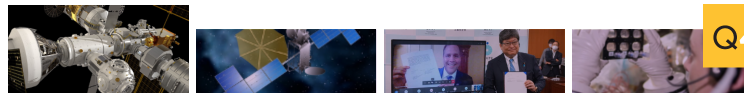
On the current but increasingly tentative timeline, NASA in 2024 will land the first woman and next man on the Moon.[4] China has made its intentions known for human crewed missions and a lunar research station by 2036,[5] part of an Earth-Moon economic zone China values at $10 trillion for its nation by 2050.[6, 7] At the 2020 China Space Conference, Bao Weimin, director of the Science and Technology Commission of the China Aerospace Science and Technology Commission, said he expects that by 2045, China will be operating more than 1,000 spaceflights a year to transport 10,000 tons of freight and 10,000 passengers.[8]

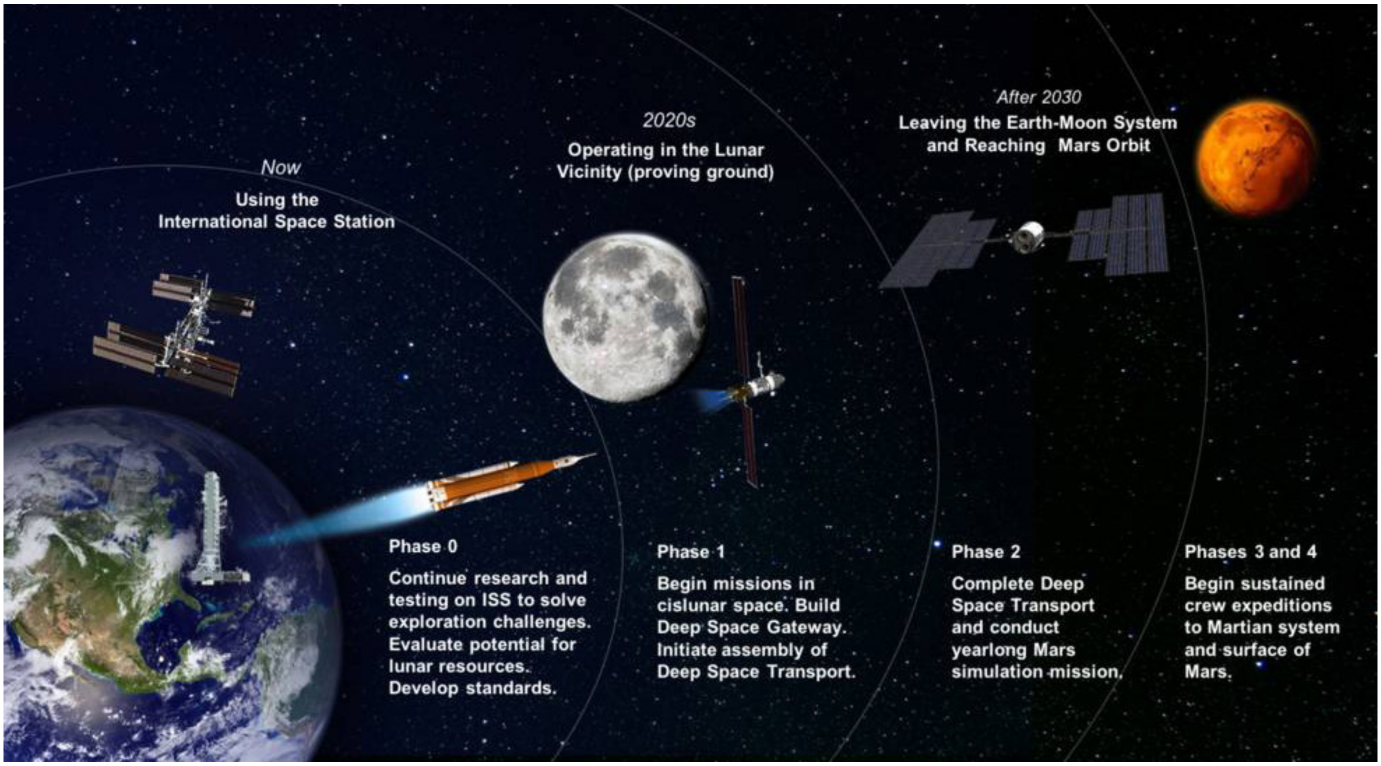
These lunar endeavors promise to serve as foundational efforts in expanding space exploration — first as a stepping-stone to better preparing for Mars missions — but also as a near-term economic and technological igniter of the larger cislunar space, the vast area of approximately 239,000 miles/384,400 kilometers between Earth and the Moon. Cislunar space invites potential for developing technology such as on-orbit satellite servicing, space-based solar energy, resource mining, and communications and observation systems capable of monitoring Earth-Moon traffic and activity in low Earth and geosynchronous orbits.

For all the advancements that have been made in space, the preponderance of technology and services is still very close to home. The International Space Station (ISS) is only about 200 miles/322 kilometers from Earth, and geosynchronous orbit, at 22,238 miles/35,790 kilometers above Earth, is only one-tenth the distance to the Moon. Mars, at closest orbit, is 33.9 million miles/54.6 million kilometers away, 1,524 times further.

"We go to the Moon to learn how to live and work on another world for long periods of time so that we can ultimately go to Mars. That's the goal," NASA Administrator Jim Bridenstine said during an October presentation for Space Foundation's Space Symposium 365.[9] "We think about the Moon as the proving ground. We're going to go with commercial partners. We're going to go with international partners, and we're going to go to learn how to live and work using the resources of the Moon. Ultimately, we're going to take all this knowledge, and we're going to Mars."

Chris Thayer, president and CEO of Motiv Space Systems, calls lunar exploration the next gold rush. He considers Motiv's multipurpose xLink robotic arm the modern-day equivalent of a prospector's pickax.[10] Christopher Stott, executive





An artist's rendering captures the stages of exploration planned for the Moon and Mars.
Credit: NASA

chairman of the Isle of Man company ManSat, compares the importance of the Moon to Earth to the role the Rock of Gibraltar plays to the Mediterranean Sea.

"Whoever controls Gibraltar controls the Mediterranean," Stott said in an interview with The Space Report. "Whoever controls the Moon controls the Earth. It's the ultimate high ground strategically, economically, and politically. It's a game-changer. The Moon is Earth's natural space station, and it's resource rich. It is literally purpose-built for all sorts of applications on and around the Moon."

Thayer and Stott are entrepreneurs of the new space age, but their enthusiasm is shared beyond those in the startup and investor frontier. James Vedda, a senior policy analyst for the Center for Space Policy and Strategy at The Aerospace Corporation, envisions cislunar infrastructure developing from increasingly advanced market-driven needs such as communications, remote sensing and near-Earth navigation. Private commercial interests, more than government, will drive development, Vedda believes.

"Once you overcome the giggle factor, serious things are going to be happening within about 10 years in cislunar space," he said in an interview with *The Space Report*. "That doesn't mean they'll make a profit in 10 years, but serious things are going to be happening. Space tourism mid-2000 got past the giggle factor. While it's not up and running, it will be soon, and a lot of serious people are investing money."

Vedda and his colleague, Dr. George E. Pollock, consider the cislunar future so near that in June, they published a policy paper, *Cislunar Stewardship: Planning for Sustainability and International Cooperation,* to urge global collaboration to resolve issues such as managing space debris and improving space situational awareness.

ULA President and CEO Tory Bruno is also among the cislunar proponents. U.S. government investment of about $20 billion in infrastructure could spur economic development of nearly $3 trillion by 2050, according to ULA economic models, Bruno said during an October webinar. He, too, predicts that 1,000 people will be living and working on the Moon by 2050.[11]

Robert Brumley II, chairman of CommStar Space Communications, and his investors see a much different lunar landscape than that of even a decade before. CommStar in June announced its intention to launch the first hybrid cislunar communications satellite in 2023.

"The private sector has bought in," he said. "Whether NASA goes back or not, we're going there, and the capital is there to get there. Private investors are viewing the Moon as an opportunity with or without government."

Understanding the Potential

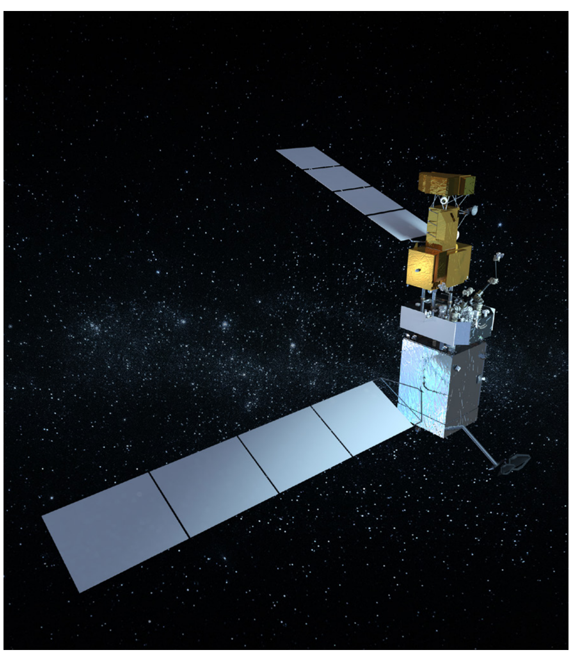
The growing interest in the cislunar economy is based on several developing fronts that — theoretically —promise to provide new technology and sources of energy for Earth, and the foundation to establish human settlements beyond the planet, all while creating new industry and new jobs.

That potential is tempered by many challenges. Aside from the financial underwriting, there are the sheer distances involved, the scarcity of stable orbits, shard-like Moon dust that clings and cuts, radiation 200 times that of Earth, extreme temperature fluctuations, increased risk of meteor strikes, and up to 350 consecutive hours of nightfall.[12, 13]

All recognized hazards that a burgeoning space industry is willing to encounter. Initiatives are underway in several areas:

Cislunar communications: In May 2018, China launched the Queqiao satellite, which relays communications between Earth and the far side of the moon, a first for any nation.[14] As NASA prepares for the Artemis mission, it is looking to commercial partners to provide direct-to-Earth communications services and lunar communications and navigation relay services.[15]

Brumley and CommStar plan to be ready for NASA and any other international customers. Its CommStar-1 satellite will offer radio frequency and laser optic communications with cloud-based data distribution between Earth, cislunar and the Moon.[16] Any current lunar communication must be managed by a government entity and coordinated through their personnel, but the CommStar-1 satellite will rely coordinate with an established network of commercial providers on Earth, Brumley explained.

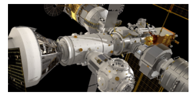


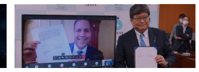
An artist's rendering of the OSAM-1 servicer as it extends its robotic arm to grasp and refuel a client satellite on orbit.
Credit: NASA

"A university scientist with a 1-kilogram payload on a NASA lander will be able to access that data just as they would their own activity data on a FitBit," Brumley explained. "Whether they are in Cambridge, Massachusetts, at MIT or in Lagos, Nigeria, they will be able to survey their data in lunar time from the surface of the Moon, bypassing all the people who once had to access that data for them."

CommStar in January is expected to announce its design contract with Thales Alenia, and though its business plan calls for pursuing business with NASA or other space agencies, the company has long-term public and private revenue sources that will allow it to support up to 80% of the CommStar business plan. The company initially had more than 30 Expressions of Interest, and by December, had approximately 10 Letters of Intent, primarily from lunar lander and mobility (rover) companies. CommStar-1 would provide a communications link 85% nearer than Earth.

"What we're figuring is whoever goes to the Moon must communicate with Earth and vice versa," Brumley said. "It's a bit like being the last point of contact for 200,000 miles."






On-orbit servicing, assembly, and manufacturing (OSAM): Within the decade, NASA estimates, robots will be working in space to extend the lifespan of satellites, assembling telescopes and structures in space, and refueling and repairing spacecraft. In May, NASA approved implementation of the Maxar-built OSAM-1 and its attached infrastructure robot, which will be tasked with refueling a satellite in space, assembling a communications antenna, and manufacturing a beam.[17] Motiv's xLink is scheduled to be part of OSAM-2, and once in orbit, the robotic arm will position parts to build a 3D-printed 60-foot solar array.[18] More than 100 organizations in 17 countries are engaged in OSAM-related technology, with the United States, Russia, and the United Kingdom leading.[19]

Space-based solar energy: Russia was one of the earliest to experiment with beamed sunlight in 1993[20] and photoelectric lasers between spacecraft in 2015, but Japan, India, China, and the United States are all making initial forays into capturing a near-uninterrupted supply of sunlight in space and redirecting it to Earth.[21] Proponents cite solar as a clean energy source that, because of lower launch costs, improved solar cell efficiency, and the growing number of commercial space products, is now a more viable option for microwave transmission to Earth or for use in satellite servicing.[22] Smaller experiments continue; in May, the U.S. Naval Research Laboratory flew a photovoltaic radio-frequency module aboard the Air Force's X-37B spaceplane to test whether solar power could be transmitted to Earth with a military application of powering ships or remote bases.[23]

Vedda, who in October co-authored a paper on the subject for the Center for Space Policy and Strategy, predicts that space-based solar will come of age within 20-25 years.

"That has so much potential for growing space infrastructure and needs on the ground such as environmental preservation and battling climate change," he said. "If you learn the technology of collecting very large amounts of solar energy and wireless transmission of that energy, there's a wealth of applications you can use that for. It's catching interest all over the world, and it's going to be competitive."

Lunar and asteroid mining: This sector offers mind-boggling possibility and a cautionary tale of cislunar space. ULA's data[24] shows the Moon alone holds 20 billion metric tons of H2O, which potentially could be processed into liquid hydrogen and liquid oxygen, creating propellants for deep-space exploration. ULA research also shows 17,000 near-Earth objects contain 150 metric tons of precious metals — more than the world's entire gold, silver, and platinum reserves — and 1,000 years of Earth's production of industrial metal.[25] ULA brought the data to the National Space Council, Bruno said in the webinar, along with the recommendation of creating a strategic propellant reserve. The first extraction efforts have begun. Japan in 2020 became the first nation in the world to return an asteroid sample when its Hyabusa2 returned in December after a six-year mission.[26] A U.S. mission, the OSIRIS-Rex, obtained asteroid samples in October.[27] Luxembourg, Russia and China are also pursuing cislunar mining, with Luxembourg — a leader in the sector — in November announcing creation of a European Space Resources Innovation Centre.[28] But development costs are high. The exploratory nature of cislunar mining, the uncertainty of how much could be obtained, and where materials would be processed were factors leading to the recent transitions of two resource-mining companies, Planetary Resources and Deep Space Industries, both acquired by new owners,[29] underscoring the long-term, high-dollar investment nascent space ventures often require.

Nations at the Forefront

Reaching the Moon, whether by lunar probe or astronaut, initially happened because of the massive spending that nations — first Russia, then the United States and now China — were able to dedicate to the newly possible reality of lunar exploration.

By September 1962, with Russia and the United States in a dead heat over manned human spaceflights, President Jack Kennedy committed America to being first to landing on the Moon within the decade.

"…the vows of this Nation can only be fulfilled if we in this Nation are first, and, therefore, we intend to be first," Kennedy said. "In short, our leadership in science and in industry, our hopes for peace and security, our obligations to ourselves as well as others, all require us to make this effort, to solve these mysteries, to solve them for the good of all men, and to become the world's leading spacefaring nation."[30]

ESA tracked and depicted the path of China's Chang'e-5 lunar mission, which returned Moon rocks to Earth for the first time since 1976.
Credit: ESA

Having accomplished the first astronaut landing, the United States by 2009 under President Obama redirected NASA's efforts toward Mars, a decision President Trump reversed in 2017 with Space Policy Directive-1 and a renewed focus on the Moon. Both administrations promoted the need for partnering with private commercial launch services.[31, 32]

Funding is already flowing to commercial companies that will support Artemis and other cislunar missions. In 2020 alone, NASA and its international partner, the European Space Agency, approved contracts with maximum values worth more than $11.5 billion for landers, crew transport, space modules and scientific equipment. (See Appendix 2.)

With the prospect of a new administration and economic consequences from the COVID-19 pandemic, however, there is increasing expectation the Artemis program will be delayed. Congress last month approved 2021 spending that was less than a quarter of NASA's $3.3 billion Artemis request.[33]

For the last two years, it's been clear that China, not the United States, has been at the forefront of lunar achievement. Eight months after the 2018 success of the Queqiao, China in January 2019 landed the Chang'e-4 rover on the dark side of the moon, another historic first.[34] By December 2020, the Chang'e-5 mission had collected and returned about 60 ounces of lunar material to Earth. Its lunar orbiter then redirected to establish orbit between the sun and Earth at the Lagrange point known as L1.[35] At least two more Chang'e missions are planned, including the Chang'e-8, expected to conduct in-situ resource utilization and 3D printing tests meant to support a robotic base.[36]

The differences between the U.S. and Chinese political systems are creating distinct advantages for China, believes ManSat's Stott, who is now also an American citizen.

"The Chinese have spent more than 700 days on the Moon claiming territory, they have nuclear-powered ability, and they have access to metallic deposits on the South Pole on the far side of the moon," he said. "While we're debating all this and our policy is seesawing between the Moon and Mars, the Chinese don't. They plan to have a human base in place before 2030 and are building a provider's network. There's really a high-stakes game going on right now."

A 2019 report to Congress by the U.S.-China Economic and Security Review Commission detailed the strategic advantages China seeks by establishing a leading position, particularly in industrializing cislunar space. China wants to realize the "great rejuvenation of the Chinese nation" and geopolitical advantages for its Belt and Road Initiative (BRI) by providing launch services, research space on its planned Chinese space station, and access to its Beidou global navigation system[37]— all similar to initiatives the United States has shared with its global partners. Commission documents also noted China has fielded an array of weapons capable of targeting early every class of U.S. space asset, whether by disrupting, destroying or intercepting.[38]

"Beijing is clearly of the view that the country that leads in space may also be economically and militarily dominant on Earth," the commission report states.

U.S. defense efforts in space are being evaluated on multiple fronts. In September, the Air Force Research Laboratory selected a Cislunar Highway Patrol System (CHPS), which would develop new ways to evaluate and track object in cislunar space, for a vanguard program that could provide additional funding and research from the Air Force. The Air Force also has contracted with Rhea Space Activity and its partner, Sabre Astronautics, to develop a cockpit-based dashboard that will show objects in cislunar space.[40]

The United States and China are seeking international partners in their lunar planning, with Russia and the ESA considering participating in both efforts.[41] Russia,[42] Japan,[43] India,[44] and the United Arab Emirates[45] are planning research missions to the Moon, though not yet on the scale of the United States and China.

Commercial Growth, Investor Interest

The breadth of nations heading to the Moon isn't the only shift occurring in this second wave of Moon exploration. Private companies, some supported by NASA and ESA contracts, are exploring opportunities beyond government needs.

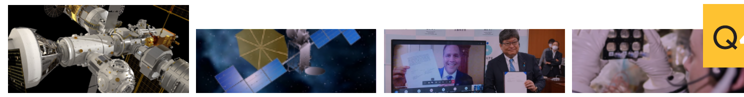
Masten Space Systems plans to land its XL-1 on the lunar South Pole in 2022 for NASA and is inviting other commercial customers to use some of its available payload. Lunar Outpost has a $1 contract with NASA to collect Moon rocks , but in December, the company also announced a partnership with Moon Mark, a Reno, Nevada-based company, to develop high-resolution videos of rovers racing on the lunar surface, an effort that will be developed partly through the help of competing high school engineering students.[48]

The Japanese firm ispace offers one of the boldest assurances of cislunar development, explaining on its website that the company believes by 2040 the Moon will support a population of 1,000, with 10,000 people visiting every year.[49] The company plans to achieve the world's first commercial lunar exploration program, HAKUTO-R, with its first lunar landing anticipated for 2022.[50] In December, ispace Japan won a $5,000 NASA contract to deliver the lander, but the company also plans to deliver payload for commercial customers; ispace Europe won another $5,000 contract for a 2023 Moon lander mission.[51] The company announced in December that after raising another US$4.8 million in funding, its cumulative funding equals about US$130 million.[52]

Another Japanese firm, Astroscale, which is developing space debris and space situational awareness systems, announced in December its total capital raised climbed to US$191 million following another round of funding that generated US$51 million.

Given all the lunar activity planned in the next few years, Vedda and Pollock, his co-author on cislunar stewardship, believe global discussion and policy decisions about debris mitigation, situational awareness, shared orbits and other issues must be made.

"We're getting beyond the typical space services we're all used to — communications, remote sensing, and navigation," Vedda said. "They're all relayed electromagnetic signals. We're getting into an era where we'll be more and more moving physical stuff around. We have to get more rules in pace to make it feasible to move physical stuff around legally as easily as we do on Earth. The laws shouldn't be that hard, but these things on an international cooperative basis take a lot of time, so we need to get started."



Planned Lunar and Cislunar Missions

Country	Name	Expected Launch	Type	Agency/company
Canada	STEM payload	July 2021	TBA	Canadensys via Astrobotic's Peregrine
China	Chang'e 6	By 2030	Robotic probe	CNSA
	Chang'e 7	By 2030	Robotic probe	CNSA
	Change' 8	By 2030	Robotic probe	CNSA
EU		By 2030	Lander	ESA
Germany	DHL	July 2021	TBA	DHL via Astrobotic's Peregrine
Hungary	Team Puli	July 2021	Rover	Puli Space Technologies via Peregrine
India	Chandrayaan-3	2021	Lander and rover	ISRO
Israel	Beresheet 2	First half of 2024	2 landers, 1 orbiter	Space/IL
Japan	SLIM	Jan. 2022	Lander and rover	JAXA
	Yaoki	July 2021	Rover	Dymon via Astrobotic's Peregrine
Mexico	COLMENA	July 2021	Microrovers	ICN via Astrobotic's Peregrine
Russia	Luna-25	Oct. 2021	Lander	Roscosmos
	Luna-26	2024	Lander	Roscosmos
UAE	Rashid	2024	Rover	UAE MBRSC
UK	Mission 1	July 2021	"Spider" lander	Spacebit UK via Astrobotic's Peregrine
	Mission 2	End of 2021	Lander	Spacebit UK
USA	CAPSTONE	Early 2021	Navigation cubesat	Advanced Space
	Peregrine	July 2021	Lander/ NASA equipment	Astrobotic
	Nova-C	Oct. 2021	Lander	Intuitive Machines
	PRIME-1	By Dec. 2022	Ice mining equipment	Honeybee Robotics/INFICON/NASA
	VIPER	Late 2023	Water explorer	Astrobotic
	Artemis 1	Nov. 2021	SLS, Orion capsule test	NASA/Boeing/Lockheed Martin
	Artemis 2	2023	First human-crewed test	NASA/Boeing/Lockheed Martin
	HALO/PPE	2023	Gateway modules	Northrop Grumman/Maxar
	Artemis 3	2024	Human Moon landing	NASA/Boeing/Lockheed Martin
	CommStar-1	2023	Communications satellite	CommStar/Thales Alenia

Source: Space Foundation Database

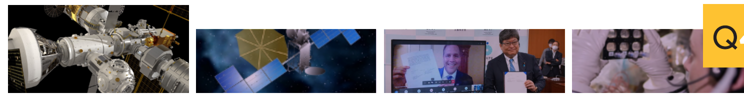
Lunar and Cislunar Contracts Awarded 2020

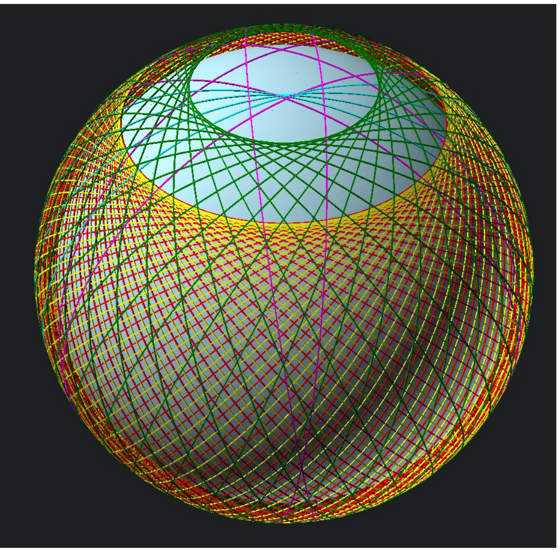
2020 NASA/ESA Lunar Contracts

Name	Date Awarded	Contract Amount	Contractor
CAPSTONE	Feb. 2020	$9,950,000	Rocket Lab
Psyche asteroid mission	Feb. 2020	$117,000,000	Space X
Artemis/Gateway	March 2020	$7,000,000,000	SpaceX
ARDES II	March 2020	$2,000,000,000	John Hopkins APL
Science/tech payloads	April 2020	$75,900,000	Masten Space Systems
Propellants/Life Support	April 2020	$165,000,000	AECOM Management Services
Human landers	April 2020	$967,000,000	SpaceX, Blue Origin, Dynetics
VIPER delivery	June 2020	$199,500,000	Astrobotic
Gateway habitat	June 2020	$187,000,000	Northrop Grumman
PRIME-1 delivery	Oct. 2020	$47,000,000	Intuitive Machines
Tipping Point tech development	Oct. 2020	$372,000,000	Alpha Space Test and Research Alliance, Astrobotic, Eta Space, Intuitive Machines, Lockheed Martin, Masten Space Systems, Nokia of America, pH Matter, Precision Combustion, Sierra Nevada, SpaceX, SSL Robotics, Teledyne Energy Systems, United Launch Alliance
I-Hab module by ESA	June 2020	$383,000,000	ESA as NASA partner/Thales Alenia Space
Contract Totals:		**$11,523,350,000**	

Source: Space Foundation Database

Lesley Conn is senior manager of Research & Analysis for Space Foundation.





Introduction | *At the end of 2020, more communications satellites orbited the Earth than all communications satellites deployed during the previous 10 years. Operators deployed more than 1,000 communications satellites last year, mainly into low Earth orbit (LEO). Two new satellite communications operators deployed most of those LEO communications satellites for broadband purposes. Thousands more satellites will join them as these companies and their competitors carry out their plans. One LEO broadband operator is already conducting continent-spanning tests using technology previously unavailable to consumers.*

Visualization of the orbital planes for the full 4408 satellite Ku-/Ka-band constellation.
Credit: Thomas McLaughlin for NASASpaceflight

Broadband Constellations: Market Challenges Remain as Launched Satellites Climb to More Than 1,000

OneWeb/WorldVu (OneWeb) is the earliest company of the latest group of LEO broadband satellite contenders to enter the space telecommunications sector. It and three other companies — Amazon (Project Kuiper), SpaceX (Starlink), and Telesat (Telesat LEO) — have been the most persistent in pursuing their LEO broadband plans. As 2020 began, two of these companies had already accomplished a feat their predecessors had not: They deployed satellites. OneWeb and Starlink have significant headstarts on the other two competitors.

Through these competitors' disparate efforts, LEO broadband service — fast internet communications to Earth's citizens through networked satellites in LEO — appears to be available and working in specific parts of the world. But is LEO broadband a viable business? The new LEO broadband operators are in different stages of finding out the answer to this question. OneWeb already entered and emerged from bankruptcy. The challenges facing these companies, while difficult, may not be as insurmountable as previously thought.

The biggest challenges — funding and technical maturity — are separate but entwined. The scale of these constellations is large, requiring billions in capital for manufacturing, launching, and communicating with thousands of satellites. Some of the technologies required for making these constellations more useful, flexible, and less capital-intensive still require large investment as well. LEO broadband competitors in the 1990s failed in overcoming those challenges. But the latest competitors appear to have overcome the first big hurdle: funding.

Project Kuiper is the only LEO broadband constellation of the four contenders with nearly unlimited fund access. Amazon, Project Kuiper's parent company, is willing to invest over $10 billion into it.[1] OneWeb, after filing for Chapter 11 bankruptcy in early 2020, has resurfaced with government investment from the United Kingdom, which also owns nearly 50% of the company. Considering that nation's pushes toward an independent space industry, OneWeb will likely receive whatever funding it needs (estimated at $2.5 billion) from the U.K. to be successful.[2]

Starlink, too, appears to have enough capital for its initial phase — at least according to SpaceX.[3] Telesat, while appearing to garner leaner funding than its competitors, may enjoy status as a Canadian space company supported by its government, which allocated $600 million (Canadian) to Telesat LEO for connecting isolated citizens and indigenous communities.[4]

Like their predecessors, the newest LEO broadband operators hope to open markets and regions geosynchronous operators have ignored or cannot support. Another similarity between them and the 1990s LEO broadband companies: their mission statements for providing space-based internet to people in areas with limited or no internet access.

LEO Broadband History: 1990-2004

The idea of LEO broadband service initially took hold in the late 1980s. Most attempts to promote and build the required constellations occurred in the 1990s.[5] During that decade, U.S. companies Teledesic and Motorola (M-Star and Celestri), and French company Skybridge announced plans for large constellations dedicated to LEO broadband. Teledesic, Skybridge, and Celestri offered internet connectivity to those who had slow or no internet service. Businesses would use M-Star constellation as a high-speed private data network.

Teledesic conducted the first serious forays into the LEO broadband business, initially as Calling Communications, in 1990.[6] The company planned the deployment of 973 satellites in LEO, estimating the overall satellite deployment costs to be $9 billion.[7] By 2001, Teledesic decreased the satellites required to less than one-third its initial number in updated plans.[8] Even though the plan called for fewer satellites, the manufacturing costs for those 300 satellites increased more than threefold, from $6 million per satellite to $20 million.[9] Overall estimates for the constellation grew 67% from $9 billion to $15 billion.

In 1995, a competitor from Europe announced plans for a LEO broadband constellation. Alcatel Alsthom SA's SatIVOD (Skybridge later), would be a 48-satellite LEO broadband constellation.[10] During the following years, the European company updated its plan almost annually, each time increasing the baseline number of satellites for its constellation. It eventually stayed with plans to deploy 80 satellites, intending its constellation to be ready by 2001.[11]

A year after Skybridge's announcement, Motorola introduced plans for a business-focused private network of 72 LEO broadband satellites, M-Star.[12] A few years after M-Star, the company announced Celestri, a constellation consisting of 63 LEO broadband satellites to serve consumers.[13] Motorola projected Celestri's cost to be as high as $13 billion and planned for it to be operational by 2000.[14] Motorola's plans did not last long.

Motorola was the first LEO broadband company to give up on its plans in 1998, throwing its name and funding behind Teledesic instead.[15] Four years after Motorola's capitulation in the LEO broadband business, Alcatel stopped work on its Skybridge plans.[16] Teledesic suspended all satellite work in late 2002 and surrendered its Ka-band radio spectrum rights license to the Federal Communications Commission (FCC) the next year.[17]

Depending on the year within the '90s, the total satellites required for these LEO broadband plans oscillated from ~500 to over 1,000. However, aside from a demonstration satellite that Teledesic launched in 1998, none of these companies succeeded in launching satellites.

The failure of all the LEO broadband companies' earlier efforts drives much skepticism surrounding up-and-coming LEO broadband providers' latest plans. With one exception, the current companies promote mission statements similar to those of the failed 1990s companies.

LEO Broadband History: 2012-2020

Communications entrepreneur Greg Wyler founded OneWeb in 2012 but publicly hinted at his intention to field a LEO broadband constellation of over 300 satellites in late 2014.[18] Wyler's acquisition of Skybridge's Ka-band radio spectrum from the International Telecommunication Union (ITU) earlier that year supported this intention. In November 2014, SpaceX's Elon Musk also stated his company was "…developing advanced micro-satellites operating in large formations."[19] By January 2015, both companies confirmed their intent to deploy LEO broadband satellites and provided a few other details.

The constellations both companies planned were larger than OneWeb's original estimate of "over 300." In its 2015 announcement, OneWeb more than doubled the number of satellites required for its constellation: 648.[20] The company estimated the constellation cost to be between $1.5 - $2 billion. After OneWeb's announcement, SpaceX announced it would deploy at least 4,000 satellites for its constellation.[21] Musk estimated the SpaceX constellation would cost $10 billion.[22]

In April 2016, OneWeb applied to the FCC to operate 720 satellites in the U.S. market. Canadian satellite communications company Telesat announced plans to enter into the LEO broadband satellite business that same month. SpaceX submitted its FCC application late in 2016, requesting approval to operate 4,425 satellites. Telesat also submitted its application to the FCC in November, requesting approval in the U.S. market to operate 117 satellites in its Telesat LEO broadband constellation.[23]

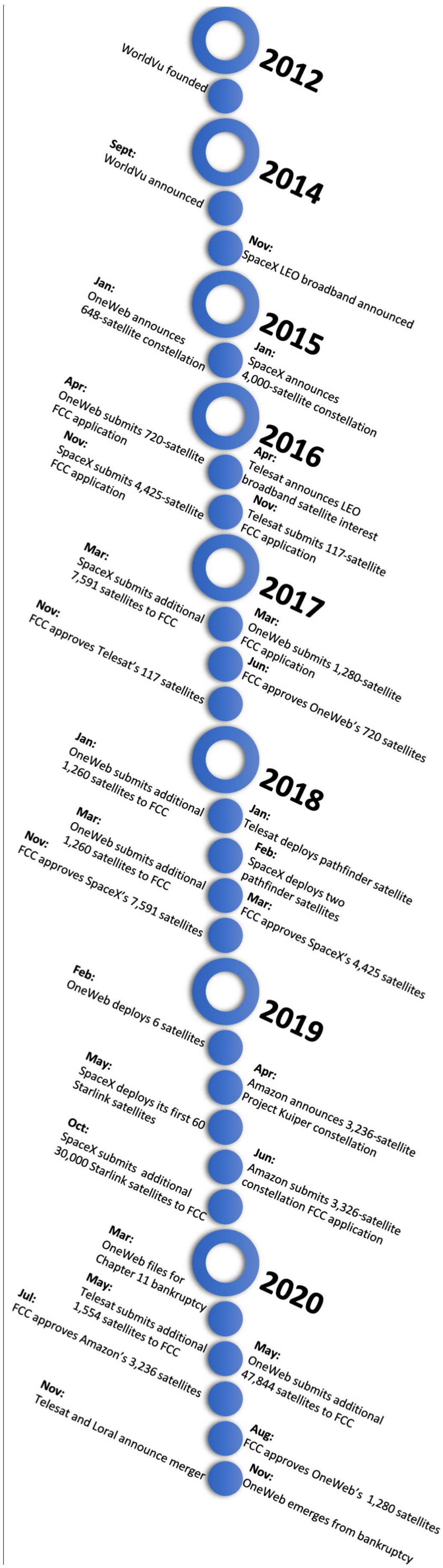
From 2016 through early 2019, OneWeb, SpaceX, and Telesat updated their required number of constellation satellites. OneWeb's planned constellation grew to 1,908 even as SpaceX increased its Starlink constellation to 11,924. Telesat also added more satellites to its plans from 117 to 512. All would deploy these additions in phases. SpaceX and Telesat deployed demonstration satellites during that period, too.

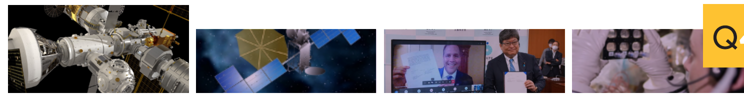
During February 2019, OneWeb deployed six satellites. In April 2019, Amazon announced plans for Project Kuiper, its version of a LEO broadband constellation. Amazon's constellation would have 3,326 satellites.[24] The company announced later it would invest $10 billion into its project.[25] In May, SpaceX deployed 60 Starlink satellites. A month later, Amazon applied for FCC approval of its Project Kuiper plans. By October, SpaceX submitted another planned Starlink expansion to the FCC: 30,000.[26] SpaceX deployed another 60 Starlink satellites in November.

By January 1, 2020, SpaceX had deployed 120 of its Starlink satellites, and OneWeb had deployed six. Both are the only companies of the current batch of LEO broadband competitors with operational satellites. Both have added more satellites to their constellations since January 2020.

OneWeb filed for Chapter 11 bankruptcy protection in the United States in late March 2020. The company sought bankruptcy because partners and investors were not providing any more funding and because of the challenges of operating during the COVID-19 pandemic.[27] While still in bankruptcy in May 2020, OneWeb applied to the FCC to add 47,844 satellites to its constellation.[28] That same month, Telesat updated the number of satellites it required to 1,671.[29] In July 2020, Amazon received FCC approval to deploy and operate its 3,326 satellites.[30] At the end of August 2020, the FCC approved OneWeb's request to add 1,280 satellites to its constellation.[31]

OneWeb emerged from bankruptcy with new owners — Bharti Global Ltd. (from India) and the U.K. government — on November 20, 2020.[32] Together, Bharti and the U.K. government own 84.4% of OneWeb, with the remaining share split among creditors.[33] On November 24, Telesat announced an agreement with Loral Space & Communications (Loral) and the Public Sector Investment Board (PSP). In that agreement, Telesat Canada and Loral merge to become subsidiaries under the Telesat Corporation (renamed "New Telesat"). The company will be publicly listed on the NASDAQ. The finalized agreement should be completed during the second or third financial quarter of 2021.[34]





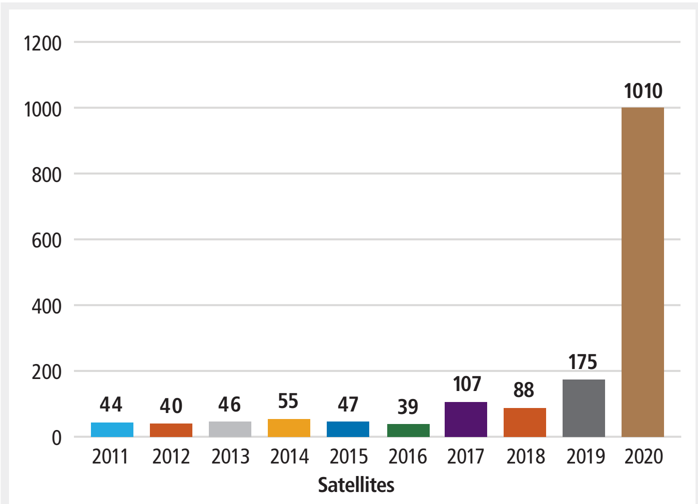
Adding Up LEO Broadband Satellite Deployments

Constellation Progress

	Deployed	Deployment Target	Progress to Target
One Web	110	720	15%
Project Kuiper	0	3236	0%
Starlink	953	4409	22%
Telesat	1	117	1%

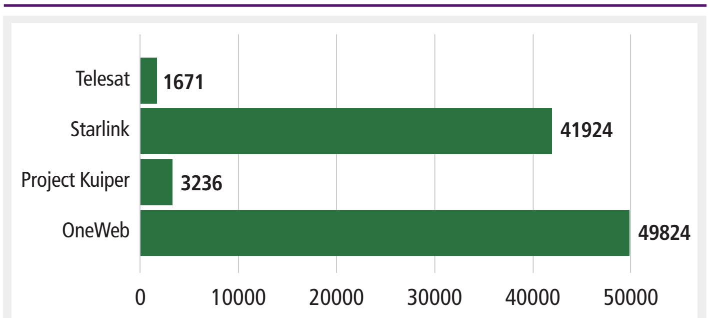
Source: Space Foundation Database

Total Annual Communications Satellite Deployments 2011-2020



Source: Space Foundation Database

Planned LEO Broadband Constellation Size By Operator



Source: Space Foundation Database

During the nine years before 2020, communications satellite deployments were increasing, but nothing like they have in the last year. Overall communications satellite deployments for 2020 grew 477% from 2019's record-high deployment of 175 communications satellites. That growth primarily comes from two broadband companies: OneWeb and SpaceX.

SpaceX deployed 953 Starlink satellites since May 2019, 22% of the 4,409 satellites (the FCC granted the reduction from 4,425 in April 2019) planned for the constellation's first deployment phase. OneWeb has deployed ~15% (110) of its initial phase's 720 satellites.

Focusing on 2020, communications satellite operators around the world deployed 1,010 satellites. Two companies, SpaceX and OneWeb, accounted for 93% of that total. SpaceX's Starlink satellites comprised 83% (833) of 2020's global 1,010 communications satellite deployments. OneWeb's satellites took 10% (104) of those worldwide deployments.

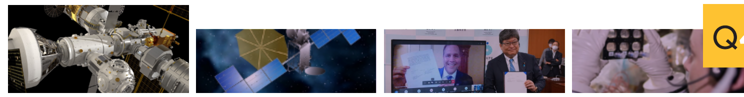
If Amazon, OneWeb, SpaceX, and Telesat launch all their planned satellites, they will have deployed 96,655 satellites in various LEOs. Whereas OneWeb and SpaceX are manufacturing and deploying their satellites, Amazon and Telesat have merely publicized plans with limited satellite platform information. Neither Amazon nor Telesat has selected a satellite manufacturer nor signed contracts with operational launch providers.

Launching LEO Broadband Satellites

For these companies to deploy thousands of satellites before their deadlines expire, they require launch service providers with specific capabilities. These launch providers should:

1) operate reliable launch vehicles
2) operate inexpensive launch vehicles
3) operate launch vehicles that can deploy
   a. large masses
   b. large numbers of satellites
4) maintain a frequent annual launch cadence

OneWeb and SpaceX are using launch service providers with reputable launch vehicles and capabilities. Telesat has contracted with launch service providers with no operational launch vehicles — Blue Origin and Relativity Space.[35] Amazon has yet to contract with launch service providers. Since neither Amazon nor Telesat is working with operational launch service providers, the remainder of this launch discussion will focus on OneWeb and SpaceX.



OneWeb contracted with France's Arianespace for the use of its Soyuz launch vehicles. The company would conduct 21 Soyuz launches with 34-36 OneWeb satellites deployed each launch. Arianespace will launch from Vostochny Cosmodrome in Russia and Guiana Space Center in Kourou, French Guiana. After OneWeb's bankruptcy filing and re-emergence, Arianespace amended the agreement to provide 16 launches for the remaining OneWeb satellites in the constellation's first phase.[36]

Vehicle	Soyuz-ST-A	Soyuz-ST-B
Launch Reliability, 2020	(1/1) (100.0%)	(2/2) (100.0%)
Launch Reliability, 2011–2020	(16/17) (94.1%)	(9/9) (100.0%)
Year of First Launch	2011	2011
Launch Sites, 2020	BK	CSG
Payload to LEO in kilograms (pounds)	4900 (10801)	4340 (9566)
Payload to GTO in kilograms (pounds)	3150 (6943)	2760 (6084)
Cost Per Launch	$73M	$73M

Source: Space Foundation Database

The Soyuz LV generally meets the criteria for deploying a large broadband constellation to LEO. A single Soyuz can deploy large numbers of small satellites, up to 8,250 kg (18,188 lbs) worth, to LEO from Vostochny. It launches between 7-8 times annually (adding launches in Kazakhstan, Russia, and French Guiana). The estimated per launch price for OneWeb is low, at $48 million.

However, its overall launch reliability is 93%, low when compared with contemporary launch vehicles. That rate (and operational history) indicates at least one, perhaps two, of OneWeb's Soyuz launches will fail. The potential loss of as many as 72 of its satellites could cost OneWeb $72 million, not including the inevitable launch delays resulting from failure boards. Arianespace has conducted at least two of the 21 launches OneWeb requires.

SpaceX uses its Falcon 9 launch vehicle for deploying its Starlink satellites. The Falcon 9 LV carries up to 60 satellites per launch, which means the company requires 74 launches to deploy its initial constellation. SpaceX has been using both launch complexes on Florida's east coast to launch its operational satellites.

Vehicle	Falcon 9 Block 5
Launch Reliability, 2020	22/22 (100%)
Launch Reliability, 2011–2020	43/43 (100%)
Year of First Launch	2018
Launch Sites, 2020	CCAFS, KSC VAFB
Payload to LEO in kilograms (pounds)	22,800 (50,265)
Payload to GTO in kilograms (pounds)	8,300 (18,300)
Cost Per Launch	$28 M

Source: Space Foundation Database

The current iteration of the Falcon 9 meets all criteria for deploying large broadband constellations. A single Falcon 9 can deploy large numbers of small satellites. It can lift as much as 22,800 kg (50,265 lbs) to LEO. From 2018-2020, the Falcon 9 has averaged between 14-15 launches annually. It costs SpaceX $28 million at most to launch a Falcon 9.[37] It may cost as little as an estimated $24 million per launch after reuse. Because Starlink is a part of SpaceX, the assumption that Starlink launches at cost seems safe. The latest Falcon 9 iteration has a 100% launch reliability rate.

Comparing the two launch vehicles each company uses highlights the differences in costs, risk, and capability OneWeb and SpaceX inherit from their selections.

OneWeb's 21-launch contract with Arianespace (at or slightly above $1 billion) gave it a low per-launch price using a launch vehicle with heritage. The company weighed the Soyuz' lower reliability with other significant factors, such as an established launch frequency, mass capability, and cost to launch. However, the total mass of a single deployment of 36 OneWeb satellites is 5,292 kg (11,667 lbs). At an estimated $48 million per Soyuz launch, OneWeb is paying $9,070/kg for each satellite launched.

SpaceX's advantages as a satellite manufacturer/operator and launch service provider come to the fore in this comparison. The company customized how it deployed satellites so that there was little mass dedicated for a Starlink deployment mechanism. The

	OneWeb/Soyuz	Starlink/Falcon 9
Launch Reliability	93%	100%
Estimated Launch Cost (million)	$48	$24
Satellite Mass per launch	5,292	15,600
Satellite Launch Cost per kg	$9,070	$1,538
Satellites Required	720	4,409
Launches Required	21	74
Estimated Constellation Launch Cost (million)	$1,008	$1,776
% Deployed (EO 2020)	15%	22%

Source: Space Foundation Database

customization allowed the company to maximize the number of Starlink satellites deployed in each launch (60). The mass of those 60 satellites comes to 15,600 kg (34,392 lbs) per launch. The first phase of the constellation is larger than OneWeb's, however, and so SpaceX must launch at least 74 Falcon 9's with Starlink satellites on top.

SpaceX has launched all Starlink satellites with "flight-proven" Falcon 9 first stage boosters. Significantly, first-stage booster reuse means the company's Starlink activities benefits from a lower cost per launch, $24 million. That lower launch cost results in an ultra-low $1,538/kg for most Starlink launches. In launch costs alone, even though SpaceX requires 50 launches more than OneWeb, it will only cost SpaceX $1.78 billion to deploy all 4,409 Starlink satellites.

Mixed Maturity: LEO Broadband Satellite Communications

Satellite/Constellation Characteristics (First Phase)	OneWeb	Starlink
Mass (kg)	147	260
Propulsion	Electric	Electric
Inter-Satellite Links	No	No (planned)
Antenna	Fixed	Phased-Array
Mission Life (years)	5-7	3-4
Spectrum	Ka/Ku	Ka/Ku
Latency (milliseconds)	32	19
Per Satellite Data Throughput	10 Gbps	~20 Gbps
Min/Max Orbital Altitudes (km)	1,200	540/1,350

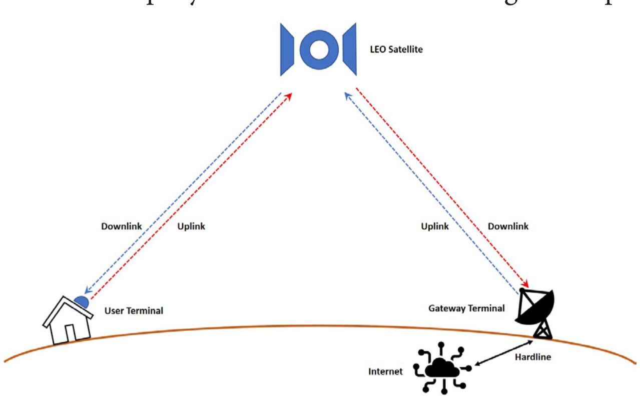
The satellites the LEO broadband operators are manufacturing have a straightforward task — quickly route radio signals containing data from earthbound users to terrestrial internet gateways and back. The LEO broadband operators are capitalizing on areas of the space-based communications business that are challenging to geostationary operators. Some of these challenges are because of selected orbits (GEO) and technology:

- High communications latency (.5-1 sec)
- Slow upload/download speeds (12-100 Mbps)
- Field-of-view/latitude limits (no polar coverage)

Other challenges derive from GEO operators' business practices:

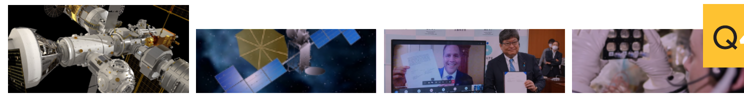
- Data caps (12-150 GB)
- High subscription prices
- Slow technology refreshes/rollouts (satellite manufacturing delays)

OneWeb's and SpaceX's satellites overcome the first set of challenges in similar ways. Their satellites are in low orbits to meaningfully lower latency (to tens of milliseconds) while providing global coverage with fast space-based broadband routers. They are deploying thousands of satellites at several altitudes in several inclinations to provide global service coverage. Their LEO broadband satellites have limited operational life, unlike their geostationary counterparts. However, each company modifies its satellites during launch pauses.



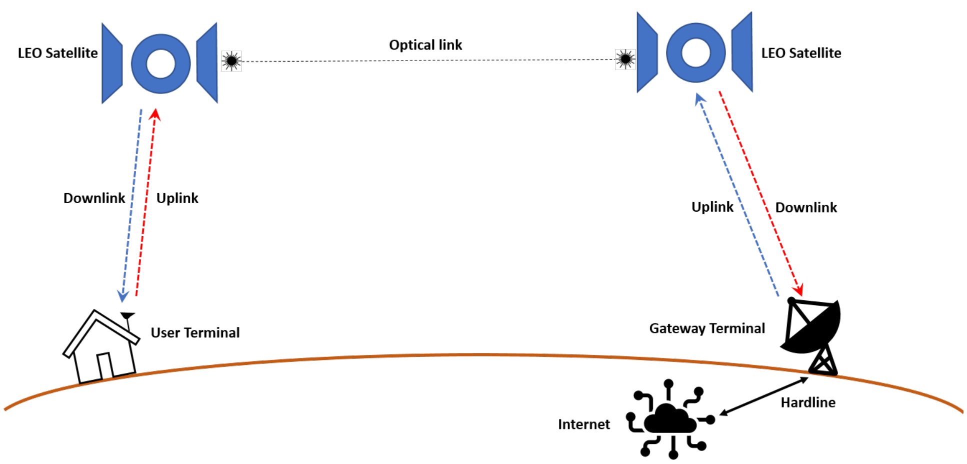
By current design, OneWeb and Starlink satellites must communicate with gateway stations and user terminals within a single satellite's field of view. As both terminals pass out of view of that one satellite, another satellite takes the broadband connection with the gateway and terminal in view. Ideally, this constant process provides seamless broadband connectivity to the users.

The operation is capital intensive, requiring many gateway terminals in different locations around the world that each company must build. The communications links between the users



and satellite, and then satellite and gateways are also potentially impacted twice by weather, such as rainclouds. The higher a satellite's orbit, the more land area is in its view. However, radio communications with higher altitudes have more latency. Two companies are pursuing a technology that eliminates latency and the need for many gateway terminals: OISLs.

Currently, neither company has operational optical inter-satellite links (OISL) mounted on their satellites because the technology is not mature enough to make fiscal sense. OISLs mounted on a satellite would allow it to connect to a user without needing a gateway station in view. The OISLs provide quick, large, and accurate data connectivity between satellites, keeping communications latency low throughout the communications link between a user and a gateway. OISLs would negate a satellite's requirement to have the user and a gateway in its view simultaneously. The technology would minimize the number of gateways a LEO broadband company requires for its constellation, which would minimize ground system costs.



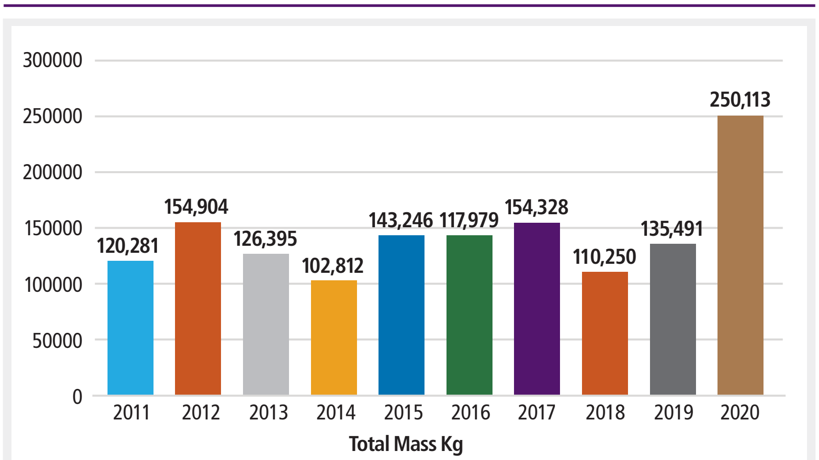
SpaceX has at least two Starlink satellites with OISLs but is using those for testing purposes. The drawback concerning OISLs is that they add significantly to a satellites' mass and power draw. They are also expensive, in some cases costing more than an operator's LEO broadband satellite. Despite the expense, SpaceX intends to deploy more Starlink satellites with OISLs eventually. It is attempting to bring down their cost while mass-producing them.[38] Telesat also plans to install OISLs on its satellites, even though it has not selected a satellite manufacturing company.

LEO Broadband Satellite Masses and Deployments

OneWeb and SpaceX have contributed substantially to the overall mass of communications satellites deployed annually. A geostationary communications satellite typically has a large mass when compared to satellites in lower orbits. For example, a Telstar satellite launched in 2018 had a mass of over 7,000 kg (15,432 lbs.). The mass from large GEO satellites historically made up the bulk of communications satellites deployed annually. In contrast, OneWeb and SpaceX:

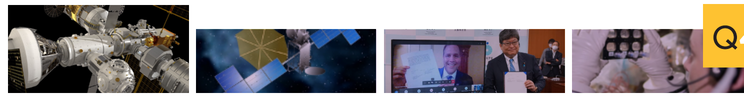
- Use small satellite structures
- Use modular satellite structures
- Deploy many satellites per launch
- Manufacture satellites in-house

Total Annual Communications Satellite Deployments by Estimated Mass, 2011-2019

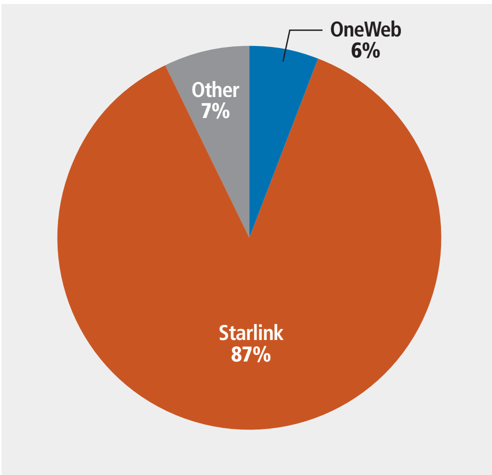


Source: Space Foundation Database

The satellites deployed by SpaceX and OneWeb fall into the small satellite (SmallSat) category. OneWeb's satellites have a mass of 147 kg (324 lbs), while Starlink satellites have a little more mass at 260 kg (573 lbs). Both companies have deployed large numbers of their satellites, significantly contributing to the overall mass of communications satellites deployed in 2020. Neither Amazon nor Telesat has selected a satellite manufacturer. Based on reports, a Telesat LEO satellite will be 800 kg (1,764 lbs.) in mass.[39] The estimated annual mass average of communications satellites deployed from



2020 Estimated Communications Mass: 250,113 kg

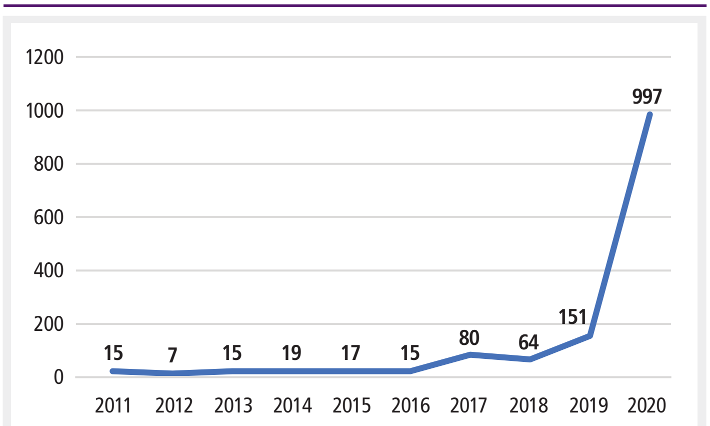


Source: Space Foundation Database

2011-2019 was 129,521 kg (285,545 lbs). The total mass resulting from communications satellites deployed during that period was an estimated 1,165,686 kg (2,569,898 lbs). During 2020, the mass total of communications satellites deployed nearly doubled the annual average, reaching 250,633 kg (552,551 lbs). OneWeb's satellites made up 6% (15,288 kg) of that total. The mass of SpaceX's Starlink satellites deployed in 2020 totaled 216,580 kg (477,477 lbs) — 87% of the yearly mass total.

The large masses of multiple satellites OneWeb and SpaceX have launched add up to record numbers of communications satellites (and satellites overall) deployed in LEO in 2020. On average, about 15 communications satellites were deployed to LEO annually from 2011-2016. During that same period, GEO communications satellites deployed averaged 26-27 satellites each year. That started changing in 2017. By 2019 LEO communications satellites had increased to 151 deployments, a 907% increase from the annual average. By 2020, 997 LEO communications satellites were deployed, a 560% increase from 2019's total.

Annual LEO Communications Satellite Deployments, 2011-2020



Source: Space Foundation Database

SpaceX's Starlink deployments took 84% (833) of LEO communications satellites deployed in 2020. OneWeb's share of the 997 LEO communications satellite deployments was 10% (104). Both companies expect their annual deployment rates to grow in 2021 based on their comments and goals. The other two competitors, Amazon and Telesat, have not selected satellite manufacturers, indicating little likelihood of either conducting any LEO broadband launches during 2021.

LEO Broadband Satellite Manufacturing and Deployment

These high annual deployments require factories that manufacture satellites in days, not the years scheduled for manufacturing a typical GEO satellite. OneWeb and SpaceX have addressed this challenge by building factories and manufacturing their satellites in-house.

Estimated Satellite Manufacturing and Deployment costs	OneWeb	Starlink
Satellite Cost (million)	$1	$0.30
Daily Production Rate	1.1	4
Monthly Production Rate	33	120
Annual Production Rate	540	1440
Deployed Satellites	110	953
Constellation Target (first phase)	720	4409
Deployed Satellite Costs (million)	$110.0	$285.9
Constellation Costs (million)	$720.0	$1,322.7

OneWeb, working in partnership with Europe's Airbus, constructed a satellite manufacturing facility in Florida that could, pre-pandemic, build about two satellites per day. That daily rate suggests OneWeb initially manufactured ~60 satellites per month. The company noted it manufactures each satellite for $1 million.[3] However, during the pandemic and OneWeb's bankruptcy, the company slowed manufacturing to one per week or about four satellites per month. OneWeb stated a goal to increase production to eight satellites per week — slightly more than one satellite per day.[41]

OneWeb's launch service provider, Arianespace, launches 34-36 OneWeb satellites per launch. These circumstances indicate Arianespace must wait slightly over a month as OneWeb builds enough satellites for each launch. As of December 2020, the total estimated value OneWeb satellites deployed so far is $110 million (out of an estimated initial phase constellation cost of $720 million).

SpaceX is manufacturing its satellites in Washington at an estimated rate of four satellites per day at an estimated cost of $300,000 each. The daily rate results in 120 Starlink satellites per month or enough satellites to fill two Falcon 9 Starlink launches a month.[42] The company's Starlink manufacturing rate supplies enough satellites in a year to keep up with SpaceX's annual goal of 24 dedicated Starlink launches (although the company has yet to achieve that goal).[43] As of December 2020, the estimated total of Starlink satellites deployed is $285.9 million. The entire first phase Starlink constellation deployment is estimated at $1.3 billion.

Both companies have filed post-mission disposal plans for their satellites. When a satellite's mission ends, each company would lower that satellite's perigee to a 200-300 km (124-186 miles) altitude.[44] Both companies expect that satellites would then naturally deorbit within about a year after being lowered.[45] SpaceX has already deorbited 47 Starlink satellites.[46]

SpaceX also designed the newest versions of its satellites to disintegrate completely during reentry.[47] For scenarios involving a Starlink satellite no longer responding to communications, it is supposed to automatically orient itself so that the Earth's atmosphere drags it in.[48]

Immature and Expensive: Connecting to LEO Broadband Satellites

The potential customers for these companies are why they are deploying these LEO broadband constellations. Customers require terminals (an antenna and electronics) to communicate with LEO broadband satellites and the internet beyond. SpaceX applied to the FCC for a license to deploy 1 million user terminals in early 2019. In late 2019, OneWeb applied to the FCC for a similar license for 1.5 million terminals.[49] The FCC gave SpaceX its approval in early 2020.[50] In mid-2020, SpaceX made another FCC license request for 5 million user terminals.[51]

The companies have admitted user terminals are a formidable but short-term problem because of the technology costs involved. The terminal antennas must "hop" (slew the antenna quickly) from one overhead satellite to another, then track that satellite before hopping to the next one, etc. This hop and track capability is critical for maintaining a steady broadband connection from the user's terminal to the operator's constellation. The motors moving the antennas are expensive.

These are a few of the reasons why using flat antennas (in this case, phased array) instead of traditional (and less expensive) parabolic antennas are appealing. OneWeb and SpaceX are engaged in efforts to manufacture these antennas for customer use. However, the spectrum the terminals use to communicate with satellites requires expensive electronics. A phased array antenna theoretically helps eliminate the motors, but the phased array technology has never been mass-produced for commercial users. It is also expensive. Both companies predict cost decreases for their terminals over the next few years.

LEO VSAT (User Terminal)	OneWeb	Starlink
Antenna	dual parabolic	phased-array
Spectrum	Ku	Ku
Average Latency (ms)	32	30
Average Speed Down (Mbps)	400	100

OneWeb has stated little about its user terminals, choosing instead to focus on larger community terminals. SpaceX is the only company selling user terminals in what it acknowledges is a beta program. Both companies have touted low latency and high downlink speeds.

OneWeb's numbers may not represent real-world performance, as the company tested connectivity with only six satellites in orbit and a single user terminal.[52] Starlink's performance numbers, however, are borne out with results from its limited for-pay beta-testing program. In late 2020 SpaceX rolled out a limited Starlink beta test to users residing in Northern tier states in the United States and southern portions of the Canadian provinces.[53]

In late October 2020, the company sent out emails to those interested in its Starlink beta-testing program. Beta-testers pay $499 (plus shipping) for the user terminal and $99 per month for Starlink access. The user terminal kit contains a hybrid motorized/phased-array antenna on a freestanding tripod, power/network cables, a power adapter, and a network gateway/

Customer/provider costs	OneWeb	Starlink
Equipment cost, user	$1,500	$499
Estimated equipment cost, service provider	$1,500	$2,400
Monthly subscription cost	TBD	$99
Availability	2Q22	Northern U.S., Canada, (Southern U.S. projected 1H21)

router. Users have noted terminal setup is extremely simple, taking perhaps five minutes to put together, plug in, and surf the internet at high speeds. SpaceX plans to expand the beta program in early 2021.

SpaceX outsourced its user terminal design and manufacturing to Swiss company STMicroelectronics. One unnamed source indicated SpaceX paid STM $2.4 billion for one million user terminals.[54] If the source is credible, SpaceX is subsidizing nearly $2,000 of each user terminal it sells or ~$2 billion for 1 million terminals. Before its bankruptcy, OneWeb had indicated it expected its user terminals (likely the dual parabolic terminal) to cost up to $1,500.[55] Telesat has stated it was not planning to pursue in-home user terminals.[56]

Of the four LEO broadband competitors, Amazon and Telesat show potential but little progress. Amazon is interested enough to apply for an FCC license and hire expertise for Project Kuiper. Telesat, too, is messaging its intent to deploy its Telesat LEO constellation and has applied to the FCC as well.

Amazon's commitment seems apparent in its steps to provide space industry support with its services. The company stood up an Aerospace and Satellite Solutions segment that is part of its Amazon Web Services (AWS) network cloud business.[57] Amazon's ground infrastructure and cloud hosting/processing services for its satellite operations customers provide the company experience with satellite ground architecture equipment, operations, and processes.[58] Aside from FCC filings, little else of the company's actions reflects progression with Project Kuiper.

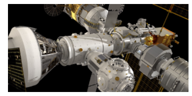
Telesat stated it would select a satellite manufacturer and deploy at least 30 satellites by January 2023.[59] The company must select a satellite manufacturer soon to meet that deadline. The selected manufacturer must then design, test, and produce more than 15 satellites a year — within two years. The task is not impossible, but Telesat's Loral merger's actions and requirements will make it challenging to accomplish, much less accomplish quickly. As relevant, Telesat has set LEO project deadlines in the past and then not achieved them.

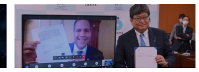
LEO Broadband Moves Ahead — for Some

While Amazon and Telesat maintain narratives of interest in building and operating LEO broadband constellations, OneWeb and SpaceX are moving ahead despite their challenges. Both are busily deploying and testing their constellations, increasing their leads over Amazon and Telesat. SpaceX, satisfied with its funding, is moving quickly to gain commercial users with its beta-testing program. OneWeb now has government-funding to draw upon for its constellation completion and operations. It too, is moving ahead with satellite deployments.

OneWeb's and SpaceX's experiences throughout their manufacturing and deployment efforts point to challenges Amazon and Telesat have yet to face and answer. OneWeb and SpaceX will be well ahead of Amazon and Telesat by the time the latter two companies eventually deploy their constellations. SpaceX is already selling services, even though those services are in "beta." OneWeb plans to start limited service in similar latitudes as SpaceX's beta-test by late 2021.[60] Both companies will establish soon the viability of the LEO broadband business.

John Holst runs Ill-Defined Space, providing analysis of activities, policies, and businesses in the space sector. His analysis of the space industry has been published in The Space Report: The Authoritative Guide to Global Space Activity from 2014-2019 and in Quilty Analytic's series of LEO Broadband Reports. He worked in the United States Air Force, Missile Defense Agency, Cobham, Space Dynamics Laboratory, the Space Foundation, and Quilty Analytics.

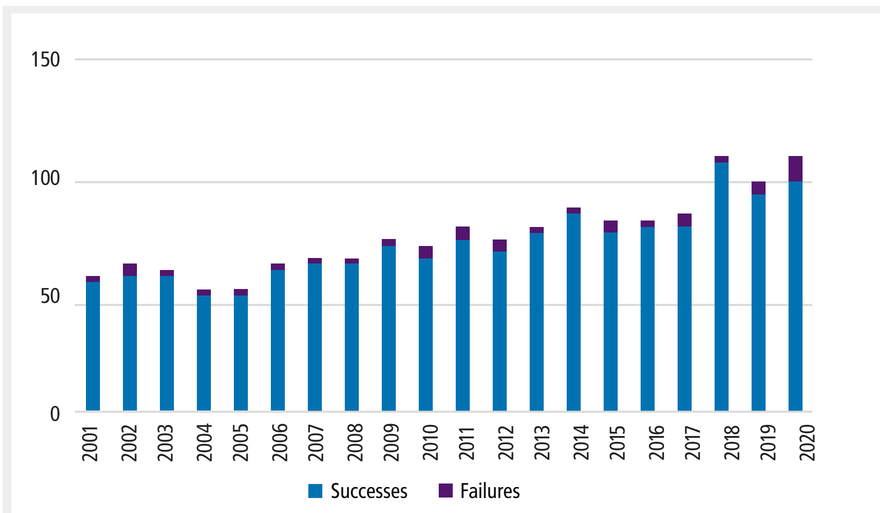





2020 in Launches: Successes, Failures, and Everything in Between

This was the year of the partial success. From the LauncherOne demo to the maiden flight of the KZ-11, 2020 saw explosions and anomalies around the world. Companies such as Virgin Orbit and SpaceX released launch summaries of these failures, emphasizing what went right and what was learned. This is notably different than, say, the dialogue surrounding the Boeing Starliner launch in December 2019. The launch was a partial success given that orbit was achieved, but the craft failed in its mission to reach the ISS. As a result, Boeing has yet to make another attempt due to a thorough review of every element of the vehicle and its software, although the company is aiming for a March 2021 launch. In comparison, Rocket Lab launched again two months after its failure in July 2020. The distinction lies in where the capital comes from — government contracts and public trading sustain Boeing, whereas companies such as SpaceX are still privately owned by enigmatic billionaires not held to the same governmental review process as government contractors. The flexibility to fail gave SpaceX the space to experiment and arguably explains how quickly they develop new launch vehicles (compare the timeline for the development of the Falcon Heavy to that of the SLS, for example) and how their vehicles came to dominate the launch market in a little over a decade.

Orbital Launch Attempts, 20 Years, 2001-2020



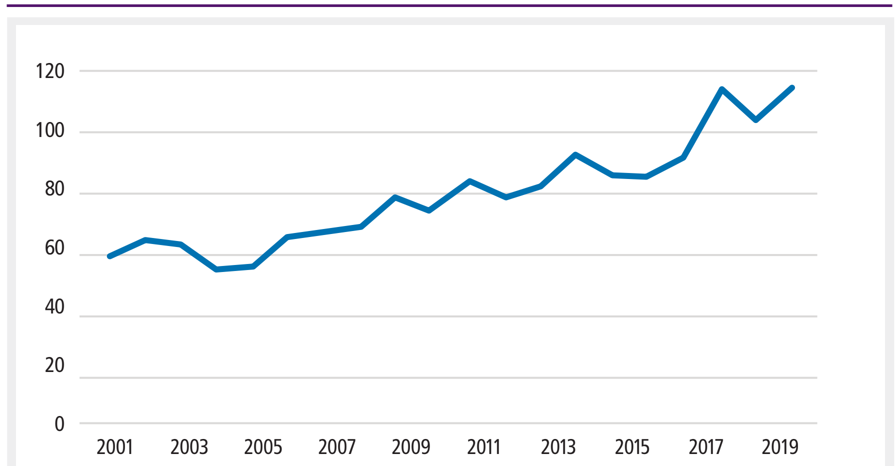
Source: Space Foundation Database

SpaceX may have competition on the horizon, however. Booster recovery is SpaceX's other operational leg up above competitors and has propelled it to be the most active U.S-based launch provider by a factor of more than four. Rocket Lab and the China National Space Agency (CNSA), however, took major steps in 2020 toward launch vehicle reusability. The Long March 8, which debuted in December, is the first of the Long March series with reusability in mind. Rocket Lab recovered a first stage booster for the first time in November 2020. SpaceX may be boxed in — CNSA is the only launch operator that was more prolific in 2020, and Rocket Lab shares with SpaceX the flexibility that comes with being privately owned. Luckily for SpaceX, the Electron and CZ-8 are in far smaller mass classes than the Falcon 9 Block 5 — but greater ridesharing competition is likely to emerge from the introduction of more reusable vehicles.

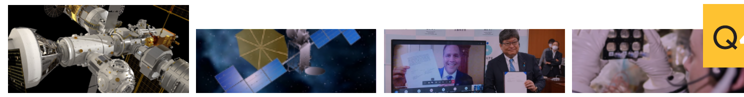
Major Launch Trends for 2020:

- More launches failed in 2020 than any year since 1971. It's easy to conclude that launches are becoming less reliable, but the global launch vehicle reliability has not dropped below 90% in over 50 years.
- The number of launches conducted annually has increased over the past two decades — 2020 tied with 2018 with 114 launch attempts, itself the highest launch tempo since the mid-Shuttle era. More launch vehicles debuted in 2020 than any year of the past decade.

Orbital Launch Trend, 20 Years, 2001–2020

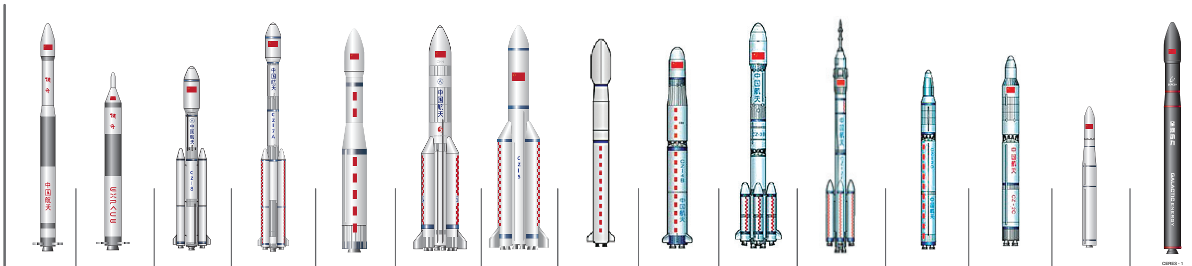


Source: Space Foundation Database



- Preliminary totals from NORAD place 2020 spacecraft deployment at over 1,200 — triple the amount deployed in 2019. Furthermore, only 15 payloads (not counting dummies) were lost over the year, meaning nearly 99% of payloads loaded in a fairing this year made it to orbit. It is worth noting, however, that not all lost payloads are equal — the Vega failure in November incinerated two spacecraft with a combined value of $400 million.

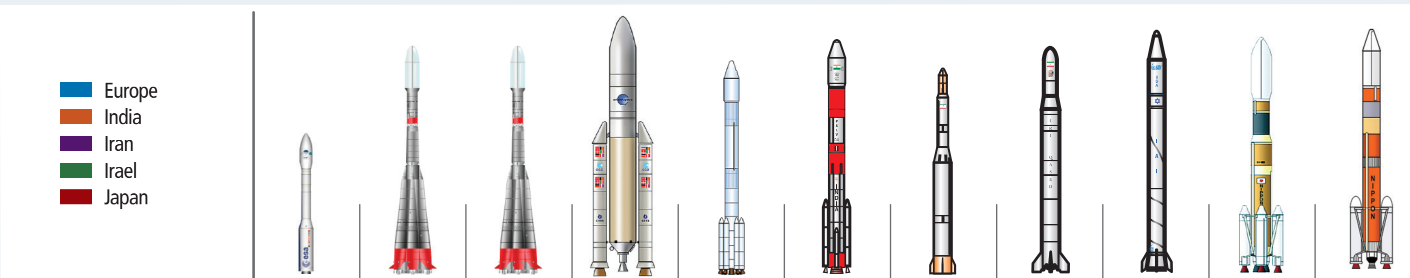
Chinese Orbital Launches, 2020



Vehicle	KZ-1A	Kuaizhou-11	Chang Zheng 8	Chang Zheng 7A	Chang Zheng 6	Chang Zheng 5B	Chang Zheng 5	Chang Zheng 4C	Chang Zheng 4B	Chang Zheng 3B	Chang Zheng 2FT1	Chang Zheng 2D	Chang Zheng 2C	Chang Zheng 11	Ceres-1
Launch Reliability, 2020	(2/3) (66.7%)	(0/1) (0.0%)	(1/1) (100.0%)	(0/1) (0.0%)	(1/1) (100.0%)	(1/1) (100.0%)	(2/2) (100.0%)	(1/1) (100.0%)	(5/5) (100.0%)	(7/8) (87.5%)	(1/1) (100.0%)	(7/7) (100.0%)	(3/3) (100.0%)	(3/3) (100.0%)	(1/1) (100.0%)
Launch Reliability, 2011– 2020	(9/10) (90.0%)	(0/1) (0.0%)	(1/1) (100.0%)	(0/1) (0.0%)	(4/4) (100.0%)	(1/1) (100.0%)	(4/5) (80.0%)	(20/22) (90.9%)	(26/27) (96.3%)	(37/38) (97.4%)	(2/2) (100.0%)	(35/36) (97.2%)	(25/26) (96.2%)	(11/11) (100.0%)	(1/1) (100.0%)
Year of First Launch	2017	2020	2020	2020	2015	2020	2016	2006	1999	1996	2011	1992	1975	2015	2020
Launch Sites, 2020	JQ	JQ	WEN	WEN	TY	WEN	WEN	JQ	TY, JQ	XC	JQ	TY, XC, JQ	XC, TY	XC, DB3	JQ
Payload to LEO in kilograms (pounds)	300 (661)	1500 (3307)	4083 (9001)	—	1000 (2205)	19958 (43991)	25000 (55105)	2950 (6502)	2230 (4915)	13600 (29977)	8600 (18956)	4000 (8817)	3850 (8486)	700 (1543)	350 (771)
Payload to GTO in kilograms (pounds)	—	1000 (2205)	—	7000 (15432)	—	12701 (27996)	14000 (30859)	1500 (3306)	—	5100 (11241)	—	—	1250 (2755)	—	230 (507)
Cost Per Launch	—	—	—	—	—	—	—	—	—	—	—	—	—	—	$4M

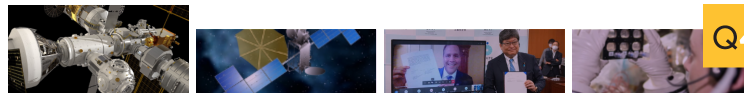
Source: Space Foundation Database

Europe, India, Iran, Israel and Japan Orbital Launches, 2020

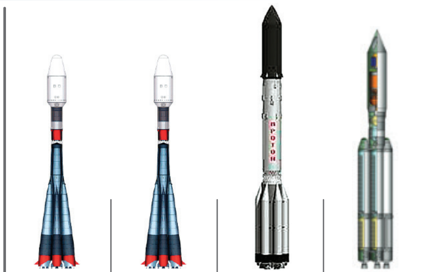


Vehicle	Vega	Soyuz-ST-B	Soyuz-ST-A	Ariane 5ECA	PSLV-XL	PSLV-DL	Simorgh	Qased	Shavit-2	H-IIB	H-IIA 202
Launch Reliability, 2020	(1/2) (50.0%)	(1/1) (100.0%)	(2/2) (100.0%)	(3/3) (100.0%)	(1/1) (100.0%)	(1/1) (100.0%)	(0/1) (0.0%)	(1/1) (100.0%)	(1/1) (100.0%)	(1/1) (100.0%)	(3/3) (100.0%)
Launch Reliability, 2011–2020	(14/16) (87.5%)	(16/17) (94.1%)	(9/9) (100.0%)	(47/47) (100.0%)	(19/20) (95.0%)	(2/2) (100.0%)	(0/2) (0.0%)	(1/1) (100.0%)	(3/3) (100.0%)	(8/8) (100.0%)	(22/22) (100.0%)
Year of First Launch	2012	2011	2011	2002	2008	2019	2017	2020	2014	2009	2001
Launch Sites, 2020	CSG	BK	CSG	CSG	SHAR	SHAR	SEM	SEM	PALM	TNSC	TNSC
Payload to LEO in kilograms (pounds)	1500 (3306)	4900 (10801)	4340 (9566)	21000 (46288)	1700 (3747)	1523 (3357)	—	—	—	16500 (36369)	10000 (22042)
Payload to GTO in kilograms (pounds)	—	3150 (6943)	2760 (6084)	10000 (22042)	1425 (3141)	—	—	—	—	8000 (17634)	4000 (8817)
Cost Per Launch	$46M	$73M	$73M	—	$22M	—	—	—	—	$155M	$82M

LEO - Low Earth Orbit, GTO - Geosynchronous Transfer Orbit. Note: Launch reliability is determined by analyzing the number of successful and failed launches of a particular vehicle; mission outcome (success or failure) is not used in the calculation of launch vehicle reliability. Images of rockets not to scale.
Source: Space Foundation Database



Russian Orbital Launches, 2020

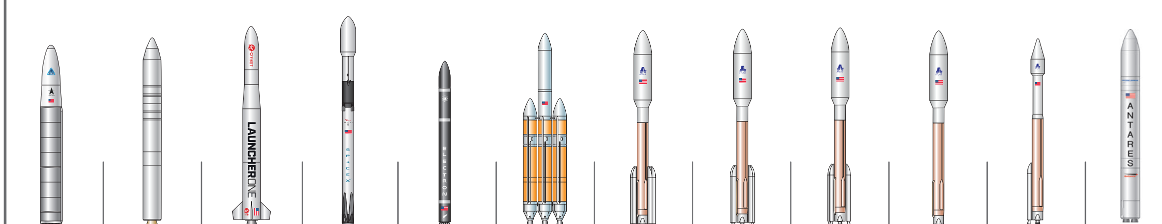


Vehicle	Soyuz-2-1B	Soyuz-2-1A	Proton-M/ Briz-M	Angara A5
Launch Reliability, 2020	(7/7) (100.0%)	(5/5) (100.0%)	(1/1) (100.0%)	(1/1) (100.0%)
Launch Reliability, 2011–2020	(35/37) (94.6%)	(34/35) (97.1%)	(51/56) (91.1%)	(2/2) (100.0%)
Year of First Launch	2006	2004	2001	2014
Launch Sites, 2020	BK, PLES, VC	PLES, BK	BK	PLES
Payload to LEO in kilograms (pounds)	8250 (18185)	7400 (16311)	23000 (50697)	23800 (52460)
Payload to GTO in kilograms (pounds)	1800 (3968)	1500 (3306)	6920 (15253)	6110 (13468)
Cost Per Launch	$48.5M	$48.5M	$105M	—

Source: Space Foundation Database

A Delta IV Heavy rocket carrying the NROL-44 mission lifts off from SLC-37 at Cape Canaveral Air Force Station on December 10, 2020.
Credit: ULA

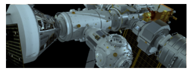
United States Orbital Launches, 2020

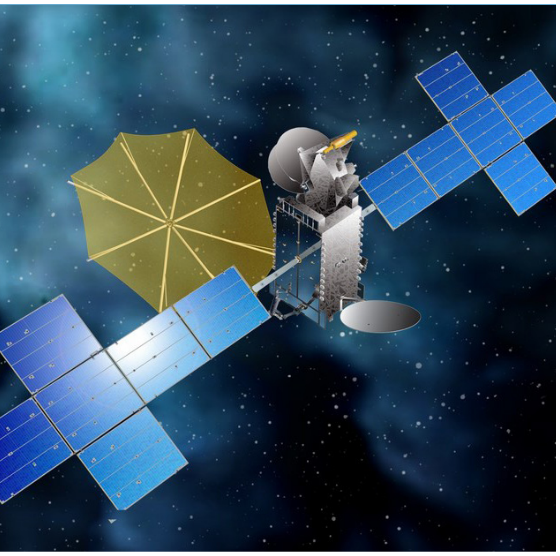


Vehicle	Rocket 3	Minotaur IV	LauncherOne	Falcon 9 Block 5	Electron	Delta IV Heavy	Atlas V 551	Atlas V 541	Atlas V 531	Atlas V 501	Atlas V 411	Antares 230+
Launch Reliability, 2020	(0/2) (0.0%)	(1/1) (100.0%)	(0/1) (0.0%)	(25/25) (100.0%)	(6/7) (85.7%)	(1/1) (100.0%)	(1/1) (100.0%)	(1/1) (100.0%)	(1/1) (100.0%)	(1/1) (100.0%)	(1/1) (100.0%)	(2/2) (100.0%)
Launch Reliability, 2011–2020	(0/2) (0.0%)	(2/2) (100.0%)	(0/1) (0.0%)	(46/46) (100.0%)	(15/17) (88.2%)	(8/8) (100.0%)	(10/10) (100.0%)	(7/7) (100.0%)	(3/3) (100.0%)	(5/5) (100.0%)	(4/4) (100.0%)	(3/3) (100.0%)
Year of First Launch	2020	2010	2020	2018	2017	2004	2006	2011	2010	2010	2006	2019
Launch Sites, 2020	KLC	MARS	MOJ	CC, KSC, VAFB	MPLC	CC	CC	CC	CC	CC	CC	MARS
Payload to LEO in kilograms (pounds)	100 (220)	1591 “(3507)	500 (1102)	22800 (50256)	300 (661)	28370 (62533)	18850 (41549)	17410 (38375)	15530 (34231)	8210 (18096)	12030 (26517)	8800 (19397)
Payload to GTO in kilograms (pounds)	25 (55)	—	—	8300 (18295)	—	13810 (30440)	8900 (19617)	8290 (18273)	7450 (16421)	3780 (8332)	5950 (13115)	—
Cost Per Launch	$2.5M	—	$12M	$50M	$7.5M	$350M	$73M	—	$73M	$73M	$73M	—

LEO - Low Earth Orbit, GTO - Geosynchronous Transfer Orbit. Note: Launch reliability is determined by analyzing the number of successful and failed launches of a particular vehicle; mission outcome (success or failure) is not used in the calculation of launch vehicle reliability. Images of rockets not to scale.
Source: Space Foundation Database

Becki Yukman is a senior data analyst for Space Foundation.



Introduction | *The S-Network Space Index tracks a global portfolio of publicly traded companies that are active in space-related businesses such as satellite-based telecommunications; transmission of television and radio content via satellite; launch vehicle and satellite manufacturing, deployment, operation, and maintenance; manufacturing of ground equipment that relies on satellite systems; development of space technology and hardware; and space-based imagery and intelligence services.*

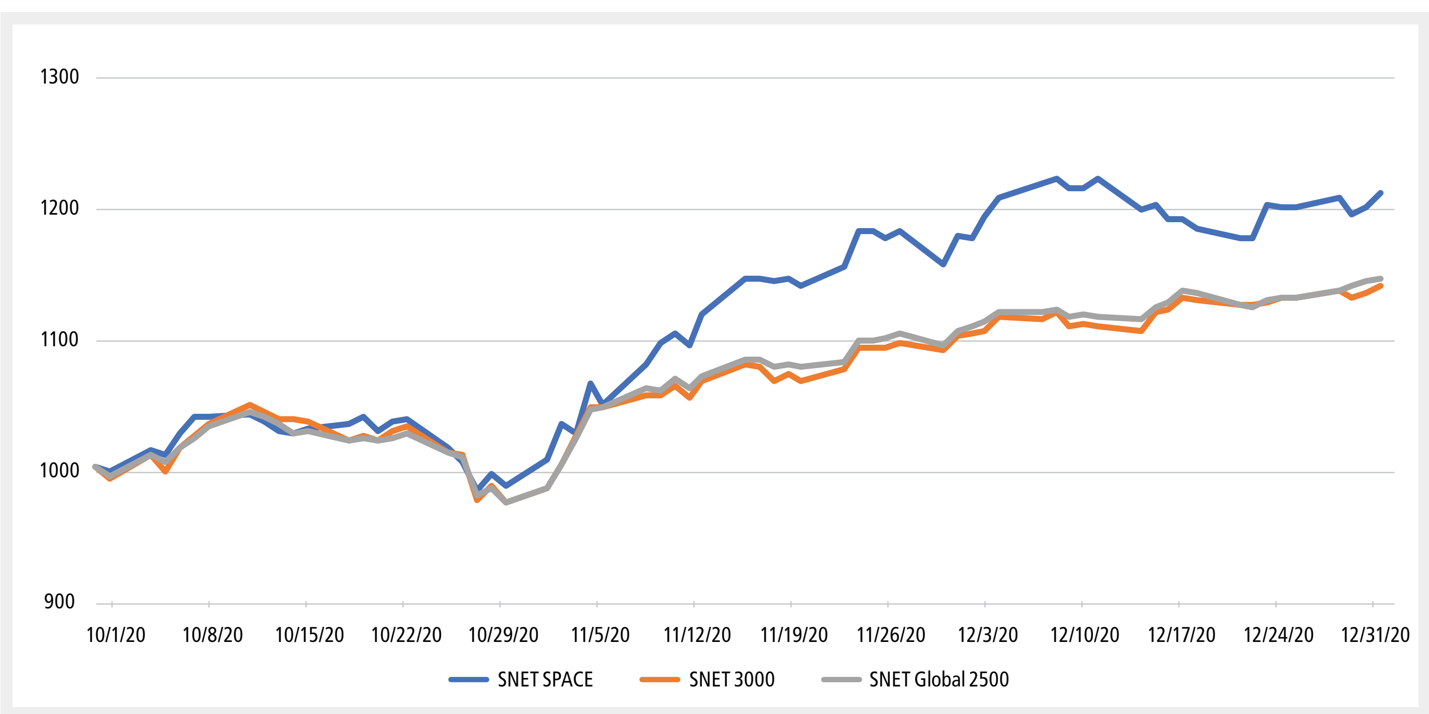
The SXM-7 satellite, shown in a rendering here, launched in October 2020 for SiriusXM. Popular satellite platforms, acquisitions, and a divestiture provided Maxar Technology the highest growth of any space-based company in 2020.
Credit: Maxar Technology

The S-Network Space Index℠ 2020 Performance

Index Performance

As happened in the second quarter of 2020, the S-Network Space Index (SNET SPACE) generally moved in line with other benchmark indexes during the third quarter, gaining 4.7% and slightly underperforming its peers. However, during the fourth quarter of 2020, SNET SPACE began to grow much more rapidly, gaining 21.4% by the end of the quarter. This compares to a 14.1% increase for the S-Network US Equity 3000 Index (SNET 3000), which tracks the 3,000 largest (by market capitalization) U.S. stocks. Similarly, there was a 14.7% increase for the S-Network Global 2500 Index (SNET Global 2500), which tracks a combination of the 1,000 largest U.S. stocks, 500 largest European stocks, 500 largest Pacific basin stocks (developed), and the 500 largest liquid Emerging Market stocks.

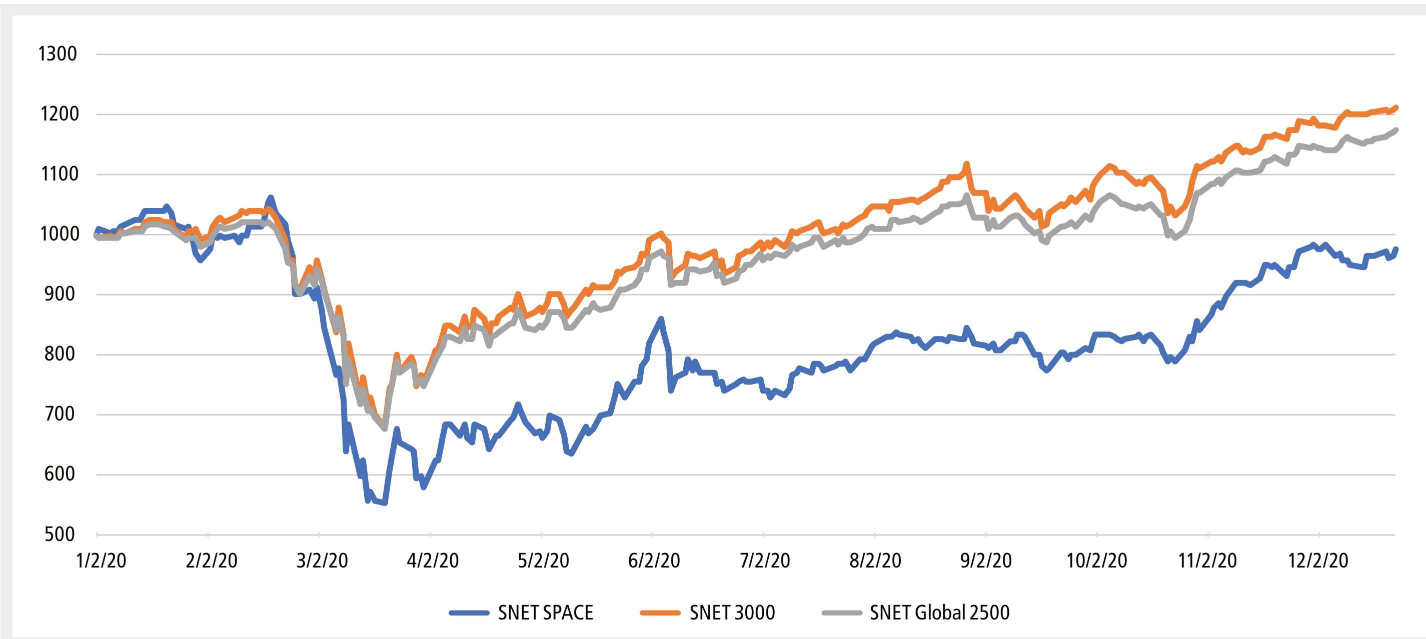
S-Network Space Index vs. Benchmark Indexes, Q4 2020



Note: Performance shown for each index is for the gross total return, assuming all dividends are reinvested.

Despite its outperformance in the fourth quarter, SNET SPACE closed out 2020 with an overall decline of 2.5%, while the SNET 3000 gained 21.2% and the SNET Global 2500 gained 17.2%. At its lowest point for the year, during the first quarter, SNET SPACE was 44.4% below its value at the beginning of January, as compared to a 32.3% drop in value for its closest peer. Even though Q4 2020 showed gains 50% higher than other indexes, SNET SPACE had substantially more ground to make up after a more precipitous decline.

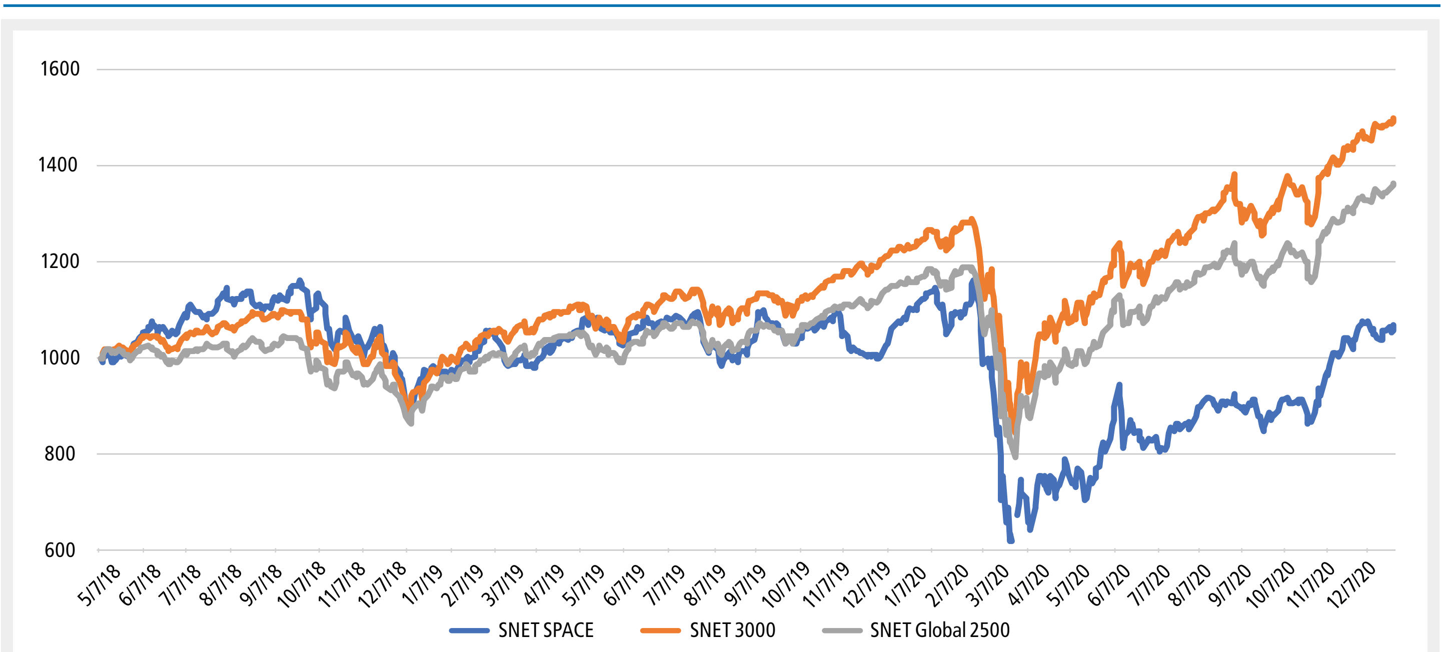
S-Network Space Index vs. Benchmark Indexes, Full Year 2020



Note: Performance shown for each index is for the gross total return, assuming all dividends are reinvested.

Assessing the multi-year performance of the S-Network Space Index since live calculation began in May 2018, the index climbed out of negative territory in mid-November 2020. Over the lifetime of the index, SNET SPACE is up 7.0% as compared to growth of 50.4% for the SNET 3000 and 36.7% for the SNET Global 2500. This disparity is mostly due to space-specific factors in the latter part of 2019 and the greater impact of the Covid-19 crash at the beginning of 2020.

S-Network Space Index vs. Benchmark Indexes, May 7, 2018 – December 31, 2020



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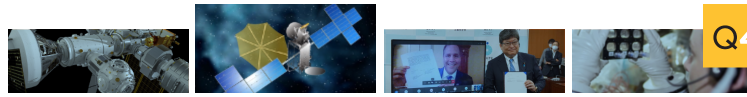
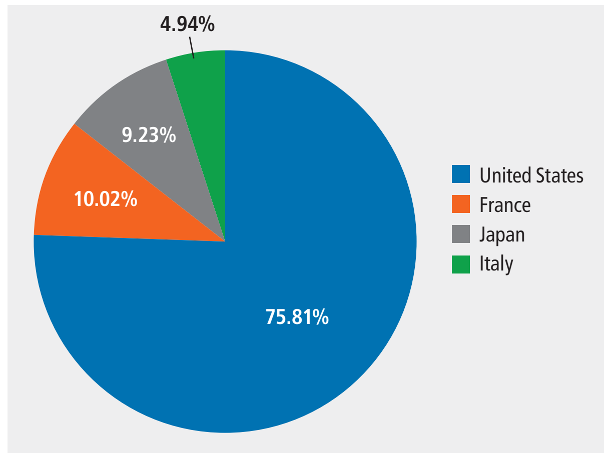


Index Constituents

The space industry is a global one, and the composition of the S-Network Space Index reflects this diversity. Companies listed on U.S. exchanges tend to dominate due to the larger number of companies that meet the financial requirements for inclusion in the index. In December 2020, the index underwent its semi-annual reconstitution—adding new companies and dropping current companies according to the index rules. In contrast with the first half of the year that saw multiple additions and deletions, there were no changes to the constituents this time and the same 31 companies remained in the index.

At the time of reconstitution, U.S. companies comprised 73.8% of the weight of the overall index, with France in second place at 11.2%, Japan at 10.2%, and Italy at 4.7%. Israel is not formally included because Gilat (3.5% of the index weight) is listed on both Israeli and U.S. exchanges, and the U.S. listing is used for the index due to higher trading activity.

S-Network Space Index Weight by Country as of June 21, 2020



Source: Space Investment Services

Q4 2020 Highlights

Performance of constituent companies in Q4 was positive, with 25 companies advancing while six declined. The results ranged from a decrease of 15% to an increase of 118%.

S-Network Space Index Constituents as of December 20, 2020

Company	Ticker	Country	Q4 2020 Performance
Aerojet Rocketdyne Holdings	AJRD	United States	32%
Airbus	AIR	France	45%
AT&T	T	United States	3%
Avio	AVIO	Italy	-15%
Ball	BLL	United States	12%
Boeing	BA	United States	30%
Comcast	CMCSA	United States	14%
Dish Network	DISH	United States	11%
Echostar Holding	SATS	United States	-15%
Eutelsat Communications	ETL	France	22%
Garmin	GRMN	United States	27%
Gilat Satellite Networks	GILT	United States	27%
Honeywell International	HON	United States	30%
IHI	7013	Japan	47%
Iridium Communications	IRDM	United States	54%
L3Harris Technologies	LHX	United States	12%
Leonardo	LDO	Italy	18%
Lockheed Martin	LMT	United States	-7%
Loral Space & Communications	LORL	United States	23%
Maxar Technologies	MAXR	United States	55%
Northrop Grumman	NOC	United States	-3%
Orbcomm	ORBC	United States	118%
Raytheon Technologies	RTN	United States	25%
SES	SESG	France	27%
Sirius XM Holdings	SIRI	United States	19%
SKY Perfect JSAT Holdings	9412	Japan	11%
Thales	HO	France	17%
Trimble Navigation	TRMB	United States	37%
Viasat	VSAT	United States	-5%
Virgin Galactic	SPCE	United States	23%
Weathernews	4835	Japan	-6%

On the low end, Avio (-15%) suffered a sharp decline in response to a mid-November failure of the Vega launch vehicle, for which Avio is the prime contractor. Since 2015, the Vega has launched two to three times per year, and a prior launch failure in 2019 meant the Vega had a 50% success rate two years in a row. Investors responded to the 2020 incident with concern and the stock only recovered slightly during the last six weeks of the year.

Echostar's performance (-15%) was the continuation of a downward trend that began in December 2019, resulting in a 51% decline during 2020. Although the company increased its consumer broadband subscriber base throughout the year, the pandemic also introduced uncertainty about customers' plans for the future. In addition, Echostar announced that the launch of its Jupiter 3 broadband satellite would slip from 2021 to 2022 due to pandemic-related manufacturing slowdowns and uncertainty in the launch market. As a result, the company will not be able to sell capacity from that satellite as soon as originally planned.

At the other end of the scale, Orbcomm's fourth quarter performance (+118%) resulted in an overall 76% gain for the year. The increase was at least partly driven by the announcement of a next-generation global Internet of Things (IoT) service to be delivered in partnership with mobile satellite communications provider Inmarsat.

From an annual perspective, Maxar (+55% in Q4) was the undisputed leader with growth of 147% in 2020. During the year, Maxar completed divestiture of its Canadian subsidiary MDA, as well as completing its acquisition of data and analytics firm Vricon. These transactions, combined with a series of favorable contract awards in the latter half of the year, helped drive investor enthusiasm.

Considering the truly unprecedented nature of the year 2020, it is not surprising that three of the 30 companies in the index as of December 2019 were no longer present at the end of 2020. Intelsat and Speedcast International were removed due to bankruptcy, and the average daily trading value of Globalstar's stock fell below the minimum threshold for inclusion in the index. These events happened in the first half of the year as the pandemic placed additional pressure on companies that were already facing challenges. However, the second half of the year was more stable, and other companies were added to the index as they met the criteria for inclusion, resulting in 31 constituents at the end of 2020.

Looking forward, the industry will continue to reshape itself and evolve in new ways, some of which will affect companies tracked by the index. For example, in December 2020, Lockheed Martin announced an agreement to acquire Aerojet Rocketdyne in a transaction valued at $4.4 billion, resulting in an immediate 26% surge in Aerojet Rocketdyne's stock to reflect the per-share purchase price being offered. Assuming the deal closes in 2021, this will result in the removal of Aerojet Rocketdyne from the index. In a different transaction, Loral Space & Communications announced its intent to merge with satellite operator Telesat, resulting in the creation of a public company that will be traded initially on the Nasdaq Stock Market (where Loral is currently listed) and may be cross-listed in Canada at a later date.

At the same time, additional companies are in the process of entering the public market, as two startups have announced mergers with special purpose acquisition companies (SPACs). Momentus, a provider of in-space transportation systems, announced a deal with an enterprise value of $1.2 billion in October 2020. AST & Science, which plans to build a space-based cellular broadband network accessible by standard smartphones on Earth, announced a $1.4 billion valuation in December 2020. A SPAC is a publicly traded entity that is established for the purpose of acquiring some other company in the future. The terms of a SPAC typically require its management team to use the money raised from shareholders within two years to acquire a company. For the companies that are acquired by SPACs, the process is often less intensive than meeting all the disclosure requirements and drumming up investor interest as part of an initial public offering (IPO). This is the same process that was used in 2019 by Virgin Galactic to go public, which likely spurred public-market investor interest in space startups.

As the nations of the world seek to expedite the end of the Covid-19 pandemic, it will be interesting to see the role that space companies play in the economy that emerges in the aftermath. While it is to be hoped that 2021 will not be as challenging for the space industry or the rest of the global economy, it is clear that space remains a dynamic field of endeavor and this will continue to be reflected in investors' perceptions of space companies.

The S-Network Space Index Methodology

The S-Network Space Index is considered a "pure-play" space index, unlike other indexes that combine space with other sectors such as aviation or defense. The index operates according to a clearly defined rules-based methodology overseen by an impartial Index Committee, as opposed to an actively managed index that operates at the discretion of its managers. In technical terms, it is a modified capitalization-weighted, free float-adjusted and space revenue percentage-adjusted equity index. In essence, it takes into account how much of a company's revenue comes from space-related business and combines that information with a variety of standard financial metrics to determine how influential that company's stock should be in terms of the overall index performance.

To be considered for inclusion in the S-Network Space Index, a company must generate either (1) at least 20% of its revenue or (2) at least USD $500 million in revenue from space-related business. In accordance with the pure-play nature of the index, 80% of the total index weight is assigned to companies whose space-related business generates at least 50% of annual revenue (in practice, most such companies generate 100% of their revenue from space). The remaining 20% of the index weight is assigned to diversified companies that earn the majority of their revenue from non-space businesses.

To further ensure that the companies are substantially engaged in space-related activities, each company must also meet at least one of the following criteria:

- The company was the prime manufacturer (i.e., the contractor responsible for managing subcontractors and delivering the product to the customer) for a satellite in the past five years.
- The company was the prime manufacturer or operator of a launch vehicle in the past five years.
- The company currently operates or utilizes satellites.
- The company manufactures space vehicle components (for satellites, launch vehicles, or other spacecraft).
- The company manufactures ground equipment dependent upon satellite systems.

In addition to its role as an educational and informational tool for tracking the performance of the global space industry, the S-Network Space Index is also designed to serve as a benchmark upon which investment firms can base products such as exchange-traded funds (ETFs), mutual funds, or other investment instruments. As such, the index rules take into consideration financial criteria such as the average daily trading value of candidate stocks, as well as SEC regulations regarding the minimum number of constituent companies and the maximum weights permitted for constituent companies. The rule book for the index, which describes the complete methodology, is available at http://space.snetglobalindexes.com.

Contact Information and Disclaimer

The S-Network Space Index is maintained by S-Network Global Indexes Inc., supported by space industry expertise from Space Investment Services LLC. For more information, please contact index@spaceinvestmentservices.com

Micah Walter-Range is the creator and manager of the underlying stock index for the world's first exchange-traded fund (ETF) focused on the space industry. As a leading expert on the global space economy, he has authored papers on space-specific topics such as the impact of export controls on the U.S. space industrial base, and cross-sector subjects such as the role of space technology in aviation.

Pandemic Surges, But So Does Space Finance

Quilty Analytics Quarterly Transactions Update:

Our core Satellite & Space index, which includes 27 publicly traded space-related companies, outperformed major indices, growing 27% in the fourth quarter with 2020 (4Q20) versus the 12% gain of the S&P 500 during the quarter. Our Frontier Space index, comprised of earlier-stage publicly traded space companies, trounced other indices, up 44% over that same timeframe.

Over the full year, there were 69 space-related acquisitions and buy-outs totaling $11.7 billion in disclosed transaction enterprise value ("TEV"), 141 equity financings totaling $5.7 billion in disclosed funding, and 13 public equity-related transactions totaling $1.8 billion in equity financing raised.

4Q20 Merger and Acquisition Activity Review:

Acquisitions and buy-outs announced in 4Q20 depict a surge in merger and acquisition activity. Lockheed's $4.4 billion pending acquisition of Aerojet Rocketdyne, motivated by Aerojet's position in hypersonics and space, was the largest by deal value of one of eight total transactions across the currently "hot" Enablement arena — the conglomerate of businesses that support space infrastructure, space segment systems, manufacturing, and launch. In November, Raytheon announced the acquisition of Blue Canyon Technologies (BCT), a leading U.S. provider of SmallSat platforms, an indication of the growing importance of small satellites within the government sector.

There were five Satcom-related acquisitions and buy-outs in 4Q20, most notably the Telesat/Loral and Viasat/RigNet transactions. In a long-rumored transaction, Loral Space and Communications announced an agreement in November to merge with Telesat Canada — in which it has a 62.7% economic interest — in a deal that will simplify the integrated company's ownership and governance while bringing Telesat public directly. We see the transaction as key for ongoing financing of a Telesat LEO program.

Shortly before yearend, Viasat announced its intent to acquire RigNet in an all-stock transaction valued at $222 million (representing 7.0x CY 2020E Adj. EBITDA). Viasat's acquisition of RigNet furthers the company's vertical market approach – initially oil and gas, but with the opportunity to target other new verticals for Viasat, including maritime — as completion of the first ViaSat-3 satellite grows nearer. Given the particulars of the situation, the all-stock deal structure provides certain mutual advantages.

4Q20 Equity Financing Activity Review:

Equity financing activity in 4Q20 was likewise vibrant, with nearly $1.3 billion raised across 43 Satellite and Space venture capital and private equity financings having disclosed values. As with mergers and acquisitions, Enablement was by far the leading sector, comprising 24 of the 43 announced financings, with Earth-observation and Geospatial sector the runner-up with nine financings.

Launch remained a major theme. Not only did Relativity Space close an impressive $500 million Series D round, but there were also smaller launch-related financings announced for Orbex ($24 million), Isar Aerospace ($91 million), and Galaxy Energy ($30 million). SpaceX reportedly commenced a massive funding round late in 4Q20 as well.

In the Earth Observation and Geospatial sectors, China-based, vertically integrated Changguang Satellite Co Ltd. (CGST) raised $375 million to expand with the development of a large constellation of optical Earth-observation satellites. Spire raised $24 million from the European Investment Bank alongside several smaller financing rounds for downstream geospatial solutions and analytics-related companies.

4Q20 Public Equity Transaction Review:

There were four public equity-related transactions during 4Q20. In addition to smaller financings completed by RF mapping startup Kleos Space and smallsat manufacturer AAC Clyde Space, two SPAC transaction announcements were part of a broader trend explored later.

AST SpaceMobile, the developer of a space-based direct-to-device network that interoperates with standard wireless handsets, announced that it will go public through a merger with New Providence Acquisition Corp. ("NPA"), a SPAC, raising a total of $462 million in gross proceeds. Momentus also announced its intent to go public via merging with a SPAC, Stable Road Acquisition Corp., raising $347 million for the in-space transportation business.

Recap of Key Transactional Trends:

The Satellite & Space index posted a blockbuster year in 2020, with investor interest and transaction activity continuing despite the unusual and often-challenging macro backdrop. Reflecting on Satellite & Space merger and acquisition transaction activity for 2020, we note four key trends that we expect to carry over into the first half of this year:

- Space segment (Enablement) sector activity goes from hot to hotter. As defense activity in the space sector picked up pace, so did the level of strategic acquirer interest in key systems, platforms, and technologies that enable defense-grade space capabilities. Large defense contractors and private equity firms alike began to reallocate resources and investment dollars from other areas into space, which is perceived as an engine for secular growth.
- Private equity (PE) consolidation: The Satellite & Space sector remains fragmented with numerous subscale companies, founder-run "lifestyle" businesses, and maturing venture capital-backed companies that fill important roles across the space engineering and industrial base. An increasing number of private equities are seeing accelerating interest in the space sector by larger strategic acquirers and jumping into the fray, prospectively playing a crucial role in consolidating and professionalizing these smaller players.
- Satcom ecosystem shake-up. The satellite communications industry is experiencing an unprecedented pace of change. Technology advancements (including HTS/VHTS and software-defined satellites), substantial LEO and MEO constell-tion development progress, and company bankruptcies all occurred concurrently in 2020, seeding opportunity, risk, and chaos, at times. The most visible transactional effect of these changes in 2020 was a pick-up in vertical integration, best exemplified by the Intelsat/Gogo and Viasat/RigNet transactions.
- Special Purpose Acquisition Companies. As described below, SPACs were an exceedingly popular financial vehicle in 2020, and they are beginning to make their mark within the Satellite & Space ecosystem.

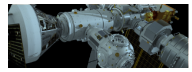
Special Purpose Acquisition Companies (SPACs)

Special Purpose Acquisition Companies, or SPACs, have enjoyed a resurgence over the last few years after falling out of favor during the 2008 financial crisis. Founded by sponsors (often experienced investors, deal-makers, and/or executives), the SPAC goes public (IPOs) as a "blank check company," raising a pool of capital to pursue mergers and acquisitions. Following that SPAC IPO, the SPAC's sponsors have a finite period (typically two years) to identify and consummate a merger and acquisition transaction or return capital to its shareholders.

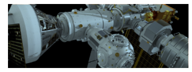
For various reasons, SPAC IPO activity exploded over the past year: roughly $80 billion in SPAC IPO proceeds were raised in 2020, up from $14 billion in the prior year. Many SPACs from the preceding year and most of the more than 200 SPACs that went public in 2020 are searching for a suitable merger and acquisition target, helping to bolster merger and acquisition activity, exit, and financing options for private companies.

The Satellite & Space sector is beginning to see the effect of this new financing structure. In addition to the Virgin Galactic transaction in 2019, there were two space-related SPAC transactions in 2020 (AST SpaceMobile and Momentus) and there are likely more to come in 2021.

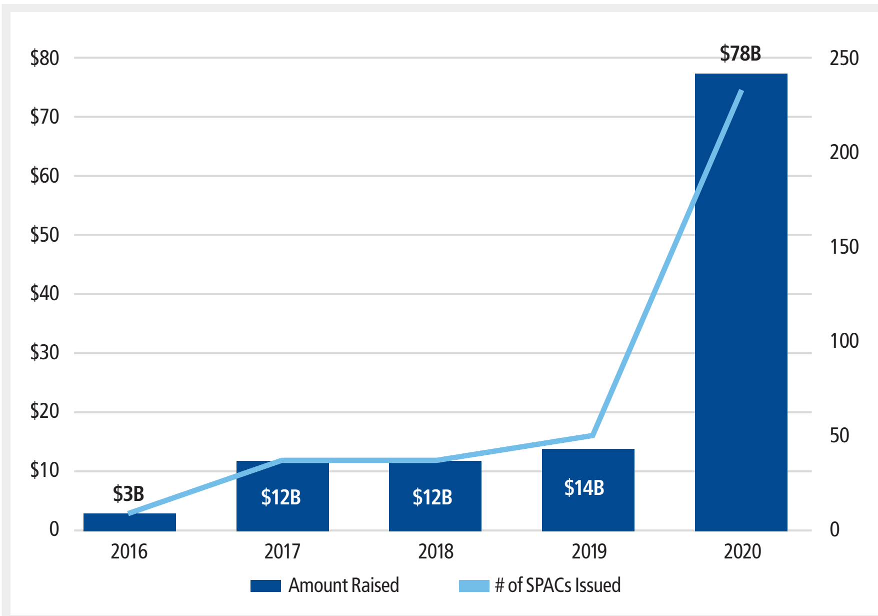
The structural and other considerations relating to SPACs are beyond the scope of this brief market update. Still, we would be happy to share additional background and insight with those who have an interest.




Announced	Target / Issuer	Acquirer / Investor	US$ Mil	Valuation	Category
Acquisitions / Buy-Outs			**Transaction Value**	**TEV/TTM Adj. EBITDA**	
12/23/20	Nanoracks (majority stake)	Voyager Space Holdings	n.d.	n.d.	Enablement
12/21/20	RigNet, Inc.	Viasat Inc.	222	7.0x[1]	Satcom
12/21/20	Base2 Engineering	BlueHalo	n.d.	n.d.	Other
12/21/20	Fortego	BlueHalo	n.d.	n.d.	Other
12/20/20	Aerojet Rocketdyne Holdings, Inc.	Lockheed Martin Corporation	4,400	16.8x	Enablement
12/15/20	LoadPath	Redwire (AE Industrial Partners)	n.d.	n.d.	Enablement
11/24/20	Telesat Canada	Loral Space & Communications	n.m.	n.m.	Satcom
11/19/20	The Launch Company	Voyager Space Holdings, Inc.	n.d.	n.d.	Enablement
11/16/20	Speedcast's IRB contracts	Inmarsat	14	n.d.	Satcom
11/11/20	Blue Canyon Technologies	Raytheon Intelligence & Space	n.d.	n.d.	Enablement
10/30/20	Speedcast's managed services business	NBN Co.	13	n.d.	Satcom
10/29/20	Roccor	Redwire (AE Industrial Partners)	n.d.	n.d.	Enablement
10/29/20	Braxton Science & Technology, LLC (BSTG)	Parsons Corporation	258	n.d.	Other
10/28/20	Guidestar Optical Systems, Inc.	General Atomics	n.d.	n.d.	Enablement
10/26/20	Analytical Graphics, Inc.	Ansys	700	n.d.	Other
10/26/20	CENTRA Technology, Inc	PAE	208	8.8	Other
10/20/20	TSG Solutions, Inc.	Continental Mapping Consultants, LLC	n.d.	n.d.	Other
10/15/20	SpaceQuest, Ltd.	AAC Clyde Space	8	n.d.	Enablement
10/07/20	Hyperion Technologies	AAC Clyde Space	3	n.d.	Enablement
10/01/20	Skyris, LLC	ASGN Incorporated	n.d.	n.d.	EO/Geospatial
VC / Private Equity & Related Investments			**Investment Size**	**Post-Money**	
12/28/20	Kymeta Corporation	Hanwha Systems	$30.0	n.d.	Satcom
12/17/20	Orbit Fab	Munich Re Ventures	$3.0	n.d.	Enablement
12/17/20	Magdrive	Led by Founders Fund	$1.9	n.d.	Enablement
12/17/20	PLD Space	CDTI	$0.6	n.d.	Enablement
12/11/20	Changguang Satellite Co. Ltd. (CGST)	Consortium of investors	$375.0	n.d.	EO/Geospatial
12/10/20	Orbex	Led by BGF & Octopus Ventures	$24.0	n.d.	Enablement
12/09/20	Isar Aerospace	Led by Lakestar	$91.0	n.d.	Enablement
12/09/20	Sunday	Led by Sequoia Capital	$19.0	n.d.	EO/Geospatial
12/08/20	Varda Space Industries	Led by Founders Fund & Lux Capital	$9.0	n.d.	Enablement
12/07/20	Aiko	Led by Primo Space Fund	$1.8	n.d.	Enablement
12/07/20	Nanoracks	Abu Dhabi Investment Office	n.a.	n.d.	Enablement
12/05/20	Solstar Space Company	Meyer Equity	n.a.	n.d.	Other
12/03/20	Spire (Venture Debt)	European Investment Bank	$24.0	n.d.	EO/Geospatial
12/02/20	Space Perspective	Led by Prime Movers Lab	$7.0	n.d.	Other
12/01/20	Fossa Systems	Undisclosed	n.d.	n.d.	Enablement
12/01/20	ClearSpace	Consortium of investors	$29.1	n.d.	Enablement
11/30/20	Totum Labs	Co-led by Heroic Ventures & Space Capital	$13.0	n.d.	Satcom
11/30/20	CesiumAstro (Debt)	Airbus Ventures & Kleiner Perkins	$15.0	n.d.	Enablement
11/30/20	NewRocket	UK's Consensus Business Group (CBG)	$1.0	n.d.	Enablement
11/28/20	Shetland Space Center (SSC)	Wildland Ltd.	$2.0	n.d.	Enablement
11/25/20	Satelligence	Led by 4impact	$2.3	n.d.	EO/Geospatial
11/24/20	Astrogate Labs	Consortium of investors	$0.8	n.d.	Enablement
11/24/20	Firehawk Aerospace	Led by Victorum Capital Club	$2.0	n.d.	Enablement
11/23/20	Carbice	Led by Downing Ventures	$15.0	n.d.	Enablement
11/17/20	Galaxy Space	Consortium of investors	n.d.	n.d.	Enablement
11/17/20	Relativity Space	Led by Tiger Global Management	$500.0	n.d.	Enablement
11/17/20	Gliff.ai	Northstar Ventures	n.d.	n.d.	EO/Geospatial
11/17/20	Picogrid	Undisclosed	n.d.	n.d.	Satcom
11/05/20	Emxys	Led by Mundi Ventures	$2.4	n.d.	Enablement
11/02/20	Galactic Energy	Consortium of investors	$30.0	n.d.	Enablement
11/01/20	IBISA	Draper University Ventures	$0.2	n.d.	Other
10/29/20	Slingshot Aerospace, Inc.	Led by ATX Ventures	$8.0	n.d.	EO/Geospatial
10/28/20	Sky & Space Global Ltd	Virgin Orbit LLC	$1.5	n.d.	Satcom
10/26/20	D-Orbit	Led by European Investment Bank (EIB)	$17.8	n.d.	Enablement
10/22/20	AiDash	Led by National Grid Parners & Benhamou Global Ventures	$6.0	n.d.	EO/Geospatial
10/22/20	Zero-Error Systems (ZES)	Airbus Ventures	$1.9	n.d.	Enablement
10/20/20	Kettle	Led by True Ventures	$4.7	n.d.	Other
10/20/20	Targomo	Earlybird Venture Capital	n.d.	n.d.	EO/Geospatial
10/13/20	Astroscale Holdings Inc.	Led by aSTART Co., Ltd.	$51.0	n.d.	Enablement
10/12/20	Venture Orbital Systems (VOS)	Consortium of investors	$0.9	n.d.	Enablement
10/12/20	Satyukt	Nabventures & Social Alpha	$0.5	n.d.	EO/Geospatial
10/06/20	Kayhan Space	Led by Overline	$0.6	n.d.	Other
10/05/20	Nu Quantum	Led by Amadeus Capital Partners	$2.7	n.d.	Other
Public Equity & Related Investments			**Investment Size**	**Enterprise Value**	
12/16/20	AST & Science	New Providence Acquisition Corp. (SPAC)	$462.0	$1,392.0	Satcom
11/09/20	Kleos Space S.A.	Follow-on	13.8	85.3	EO/Geospatial
10/15/20	AAC Clyde Space	PIPE	5.8	26.4	Enablement
10/07/20	Momentus	Stable Road Acquisition Corp. (SPAC)	347.0	1,200.0	Enablement




Growth of SPACs, 2016–2020



Source: Quilty Analytics
TEV/LTM Adj. EBITDA = Total Enterprise Value/Last Twelve Months Adjusted Earnings Before Interest, Taxes, Depreciation and Amortization
n.d. = not disclosed
n.m. = not meaningful
1) RigNet takeout valuation is based on TEV/2020 Adjusted EBITDA using the consensus Adjusted EBITDA estimate for the company

Justin Cadman is a partner with Quilty Analytics. He has more than 15 years of investment banking and capital markets experience.

Chris Quilty is the founder and partner of Quilty Analytics. Prior to establishing Quilty in 2016, he served as a sell side research analyst with Raymond James for 20 years.

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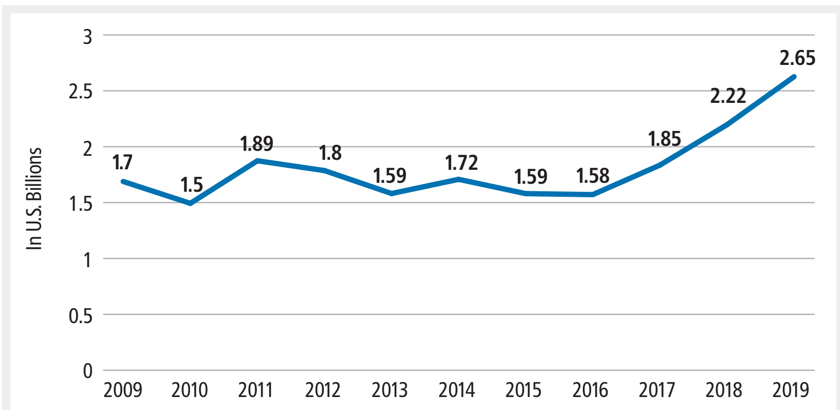
Nation In Review: Germany

Budget Overview

Germany's overall space spending has increased 56% since 2009, and its domestic space spending in 2019 increased more than 30% from 2018, reaching €1.3 billion (US$1.53 billion).[1] Finalized budget information for 2020 German space spending will not be available until early 2021.

And while the nation's 2019 contributions to ESA increased 3.6% to €944 million ($1.09 billion) from the prior year, Germany contributed 4.3 times as much to optional programs as to mandatory programs. Germany contributed more than any other member state to ESA's optional Earth observation, technology support, human spaceflight, and microgravity and exploration programs.[2]

10-Year Annual German Space Spending, Including ESA and EUMETSAT Contributions



Source: Space Foundation Database

German government officials and aerospace leaders have admitted feeling as though the nation is lagging behind other space-faring nations.[3]

"We are sounding the alarm that Germany and Europe are falling behind in space vis-a-vis China and the United States," said Dirk Hoke, defense and space chief at aerospace group Airbus in a 2019 Reuters interview. "We're at a critical juncture to ensure we stay in the top league."[4]

Head office of the German Aerospace Center in Lind, Cologne, adjacent to Cologne/Bonn Airport
Credit: DLR

Comparing 2019 domestic space budgets in U.S. dollars, Germany — Europe's largest economy — spent $1.52 billion. This surpasses Italy ($0.38 billion), Spain ($0.13 billion), and the U.K. ($0.20 billion), combined, but falls far behind the U.S. ($47.17 billion), China ($9.6 billion), Russia ($3.98 billion), and Japan ($3.01 billion). Germany ranked between India ($1.9 billion) and France ($1 billion) in space spending. The 2019 funding increase was a strategic move intended to elevate Germany's space status to one of the greatest benefactors of space data among ESA member nations and other major spacefaring nations such as the U.S and China.[6]

Space Spending as a Percentage of GDP

Germany falls in the middle of the field in terms of major nation's space spending as a percentage of its GDP. Its space spending, domestic and cooperative, combined to 0.040% of its national GDP. The global average is 0.07%, which is 0.03% greater than Germany's spending but is heavily weighted towards Russia and the U.S., with 0.23% and 0.22% respectively.[7]

Contributions to ESA and EUMETSAT

After three years of planning, in 2019, the ESA member states agreed to commit to nearly €14.4 billion ($16.5B) for joint space programs over the next few years.[8] Germany agreed to commit 22.9 percent or €3.3 billion ($3.6 billion), making the nation the greatest contributor to the ESA programs overall, followed by France with 18.5 percent or €2.6 billion ($2.9 billion).

Civil Government Space Budget Growth, 2017–2019

Country/Agency	Currency	2017 Funding	2018 Funding	2019 Funding	2017-2019 Change
United States	U.S. Dollar	$43.34B	$49.12B	$47.17B	8.1%
Brazil	Real	*R$0.084B*	R$0.109B	R$0.101B	16.2%
Canada*	Canadian Dollar	C$0.395B	*C$0.347B*	C$0.329B	-20.0%
European Space Agency (ESA)	Euro	*€4.620B*	€4.228B	€4.162B	-11.0%
France*	Euro	€1.09B	€0.99B	€1.04B	-4.4%
Germany*	Euro	*€0.891B*	*€1.016B*	€1.344B	33.7%
India	Rupee	₹91.555B	*₹111.884B*	₹131.3923B	30.3%
Italy*	Euro	*€0.285B*	*€0.322B*	€0.336B	15.3%
Japan	Yen	*¥342.100B*	*¥301.000B*	¥324.300B	-5.5%
Russia	Ruble	*₽181.800B*	₽182.000B	₽251.700B	27.8%
South Korea	Won	*₩660.536B*	₩692.026B	₩550.327B	-20.0%
Spain*	Euro	€0.137B	*€0.115B*	€0.115B	-19.0%
United Kingdom*	Pound	*£0.132B*	£0.179B	£0.158B	16.1%

**Excludes ESA spending*
*** Italicized numbers have been revised from previous data*
Source: Space Foundation Database

The European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) regularly receives its greatest contributions from Germany. Since 2017, Germany has contributed €343 million ($391.2 million) to EUMETSAT programs, increasing 26 percent from 2017's €102.8 million ($119.6 million) to 2019's €126 million ($146.6 million).

Near-Term Space Investment

The German ESA contribution will focus on these specific areas of study:[9]

Launch Systems – The largest investment in the area of launch systems, €230 million ($268 million), will go to the optional Launchers Exploitation and Accompaniment Program (LEAP). Germany's access to space, the European Spaceport in French Guiana, will receive €95 million ($111 million) for modern operational through the end of 2024. Along with the investment in launch vehicle infrastructure, Germany will continue contributing to developing the Ariane programs and the new Ariane 6 launch vehicle, agreeing to €90 million ($105 million), including preparation of the future upper stage.

Science – Committing to €578 million ($673.2 million) over five years, Germany will contribute more than any other nation to Europe's science programs. Some critical missions are JUICE (Jupiter exploration, 2022), EUCLID (dark energy/dark matter, 2022), PLATO (exoplanet exploration, 2026), ATHENA (X-ray telescope, 2031), and LISA (gravitational wave observatory, 2034).

Earth Observation – Germany maintains a leading role in the EU's Copernicus Earth Observation System, investing €520 million ($606 million).

Credit: ESA

The Copernicus system will expand with the addition of new satellites over the next few years. Copernicus guarantees long-term availability as well as continuity of data and products. The FutureEO program will receive €170 million ($198.03 million), and another €50 million ($58.24 million) for other Earth observation programs.

Telecommunications – Increased focus on the Core Competitiveness (CC) program has led to a €330 million ($384 million) investment in telecommunications. Optical communications (ScyLight), Business Applications and Space Solutions (BASS), and Secure Satcom for Safety and Security (4S) will receive the bulk of the investment. An additional €13 million ($15 million) will be used to expand the 5G mobile communications network.

Space Situational Awareness and Security – Germany plans to invest €84 million ($98 million) for space situational awareness and security. A significant portion of that investment, €60 million ($70 million), will go to the Hera mission. Planned for September 2022, Hera, working alongside NASA's Double Asteroid Redirection Test (DART), will investigate the risk of collision with Earth and the double asteroid Didymos /Didymoon. Some of the remaining funds will be used to address space debris removal through Project (ADRIOS). The program will receive €12 million ($14 million).

Technology Development – The General Support Technology Program (GSTP) intends to provide small- and medium-sized startups with competitiveness in the growing space industry. Germany's contribution will increase to €160 million ($186 million).

European Exploration Envelope Program – All European space exploration activities conducted by humans and robotic technologies will fall under the same umbrella called the European Exploration Envelope Program (E3P), including International Space Station (ISS), Mars, and moon missions. Germany has agreed to invest €550 million ($640 million) to support these programs' further development.

German Space Workforce

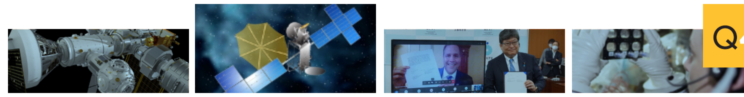
Top 4 Countries in Space Employment in Europe, 2019

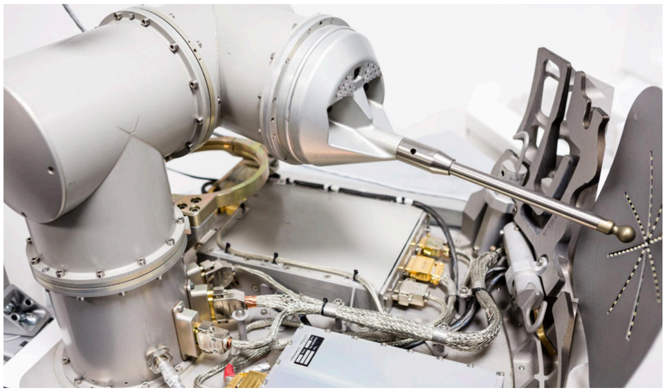
Country	Total Workers	5-Year Growth
France	18,186	16.90%
Germany	9,071	24.80%
Italy	5,215	13.20%
United Kingdom	4,263	12.60%
Total European space employment	**47,895**	**18.70%**

Source: Data provided by Eurospace in cooperation with Space Foundation.

German Space History

- Germany's first scientific satellite was the Azur. The spacecraft deployed Nov. 8, 1969, launching from the U.S. aboard a Scout B launch vehicle.
- Two years after establishing the European Space Agency (ESA), in 1977, Germany joined the organization, contributing more than any other nation behind only France. Nine years later, in 1986, Germany joined EUMETSAT.
- On Aug. 26, 1978, Sigmund Jähn became the first German in space when he lifted off with Soviet cosmonaut Valery Bykovsky aboard the Russian mission Soyuz 31.
- The German aeronautics research organization DFVLR was renamed DLR (German Aerospace Center) in 1988. DARA, the first German Space agency, was founded shortly after, in 1989. Less than 10 years later, in 1997, DARA and DLR merged under the DLR name.





The flight model of the ROKVISS robot has been used on the outside of the International Space Station (ISS) for five years.
Credit: DLR

German ESA astronaut Alexander Gerst on the main stage during German Aerospace Day 2015.
Credit: DLR

- For five years, beginning operations on March 22, 2005, and working steadily until Nov. 2, 2010, Germany's first space robot conducted nearly 500 successful tests. The DLR developed the Rokviss robotic arm. The arm extended 50 centimeters (almost 20 inches) in length, weighed 7 kilograms (15.4 pounds), and was controlled remotely by a team based in Oberpfaffenhofen, Germany.
- European Space Agency (ESA) astronaut Alexander Gerst of Germany fulfilled the role of commander during ISS Expedition 57 in 2018.

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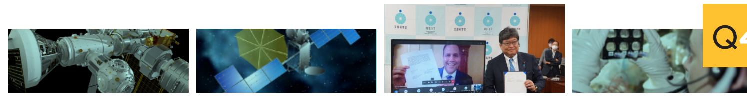


2.0 Introduction | *In 2020, many significant events influenced policy across the global space community. In the United States, new policy directives, along with the results of the 2020 election, will impact the national space industry and, by extension, international partnerships and global space planning. At the international level, nine countries signed the Artemis Accords , with Ukraine becoming the latest member in November. The United Nations also led several policy initiatives. This report highlights major policy activities, initiatives and changes in 2020 and their resulting or expected impacts on the global space community. This report does not capture all 2020 updates; it instead focuses on a number of key policy events at the national, multinational, and international levels.*

NASA Administrator Jim Bridenstine (on screen) and Government of Japan Minister of Education, Culture, Sports, Science and Technology (MEXT) Koichi Hagiuda hold copies of a Joint Exploration Declaration of Intent (JEDI) signed during a virtual meeting on July 9, 2020.
Credit: U.S. Department of State/Stephen Wheeler

Space Policy 2020 – Global Highlights

Collaboration, Situational Awareness, Debris Tracking, and Private Growth Dominate

United States

Executive Branch Highlights

In 2020, the Trump administration released two new Space Policy Directives (SPDs) which had been in development for years. The release of a new National Space Policy, not updated in a decade, is viewed as an opportunity to establish continuity regardless of leadership change.

Space Policy Directive 5 (SPD-5): Cybersecurity Principles for Space Systems

President Donald Trump signed SPD-5 in September. The directive[3] is intended to leverage public-private sector mechanisms to coordinate across 16 infrastructure sectors designated as critical. It responds to cybersecurity concerns from U.S. government officials and emphasizes the cybersecurity threats against commercial operators. The directive seeks to strengthen cybersecurity across all components of a space system[4] and directs U.S. government agencies to work with commercial companies to further define best practices, establish cybersecurity-informed norms and promote cybersecurity behaviors.[5] Among its new guidelines: better practices and hardware to ensure against unauthorized network access; encrypted telemetry communications; improved resistance to communications jamming; and, closer oversight of supply chain management. This policy is timely as commercial enterprises are working closely with U.S. government entities on various space missions, and the Department of Defense is rushing to integrate 5G capabilities, which rely heavily on space systems, across its bases.[6]

SPD-5 does not specify enforcement of these principles or assign responsibility for interagency coordination, nor does it outline requirements to report on implementation.[7] Nonetheless, SPD-5 is an important standard for other countries to use as they look at ways to address cyber threats, and it reflects top-level support in the United States for public-private partnerships regarding better cybersecurity practices in the space arena.

This latest directive builds on the ongoing efforts of federal agencies to review and publish new regulatory frameworks. Among them: The Federal Aviation Administration in September 2020 updated its space launch and re-entry regulations[8] in response to 2018's SPD-2, "Streamlining Regulations on Commercial Use of Space,"[9] which is designed to simplify the licensing process for the commercial use of space by consolidating four parts of the Code of Federal Regulations. The Commerce Department released a streamlined commercial remote-sensing regulation[10] to increase transparency in the licensing process and introduced a three-tier approach to assist data sellers and buyers. The remote-sensing rules received positive feedback from the industry and are seen as a big step in facilitating U.S. industry innovation in this arena.[11]

Space Policy Directive 6 (SPD-6): National Strategy for Space Nuclear Power and Propulsion

SPD-6[12] was unveiled at the end of the year and prescribes a road map to demonstrate national commitment to using Space Nuclear Power and Propulsion (SNPP) systems. The directive regulates the use of space nuclear power and propulsion systems to achieve the scientific, exploration, and commerce objectives of the U.S. The principles emphasize safety, security, and sustainability in collaborating with the private sector and pursuing a coordinated roadmap at the federal level to assist SNPP activities. Other principles include cost-effectiveness, commonality, and coordination and collaboration.

Some goals outlined in the directive include a fission power system on the Moon, advanced radioisotope power systems, uranium fuel processing capabilities that enable off-Earth production of fuel for lunar and planetary surface exploration, and in-space nuclear electric propulsion (NEP) and nuclear thermal propulsion (NTP).

This directive is seen as the White House's effort to revitalize the nuclear power industry by calling for the use of small modular reactors for terrestrial and space applications. The policy is in line with the recently released National Space Policy and past SPDs emphasizing interagency collaboration to build the industrial base of the U.S. space economy and incorporating innovations of the private sector into that industrial base.

National Strategy for Planetary Protection

The White House released a National Strategy for Planetary Protection at the end of December 2020. The National Space Council and Office of Science and Technology Policy led the initiative. The strategy outlines three objectives: creating a risk assessment and science-based guidelines for forward contamination; avoiding backward contamination by any extraterrestrial life by developing frameworks for assessing sample return mission risks; and incorporating private sector's role in meeting planetary protection guidelines. It is seen as a "work plan" and highlights interagency cooperation by leveraging knowledge across government bodies such as DHS, FEMA, EPA, and the CDC.

National Space Policy (NSP)

In December, at the eighth National Space Council meeting, the Trump administration unveiled its new National Space Policy,[15] updating the version released by the Obama administration in 2010. The policy emphasizes four areas: commercial development, international cooperation, exploration and science, and national security. The policy also directs, for integration at the highest federal government levels, a policy of sustainable exploration, and emphasizes the need to incentivize the private sector of the space industry. At this meeting, the director of National Intelligence announced that the U. S. Space Force would become the newest member of the intelligence community, and the Department of Energy announced a new space strategy with emphasis on space technology.

Other factors that contributed to regulatory changes by the executive branch last year included the commercial industry's fast pace of innovation; the growing collaboration between the private and public sectors; and military, economic and technical challenges by China and Russia.

The results of the 2020 U.S. election are expected to result in substantial changes in executive branch personnel with responsibilities for space policy, such as new secretaries of Defense, Energy and Commerce, and a new NASA administrator.

Legislative Branch Highlights

Space Force Caucuses

In September 2020, a group of U.S. Senators formed the Senate Space Force Caucus. The founding members are senators Cory Gardner (R-CO), Kevin Cramer (R-ND), Kyrsten Sinema (D-AZ) and Martin Heinrich (D-NM).

In October 2020, members of the U.S. House of Representatives formed their own Space Force Caucus, led by Representatives Doug Lamborn (R-CO) and Kendra Horn (D-OK).

The House caucus was originally the Space Power Caucus, founded by Lamborn and Rep. Adam Schiff (D-CA) in 2015. The former Space Power Caucus raised awareness on various space security issues; the Space Force Caucus will continue to connect congressional members and staff with space stakeholders to learn about the newly established Space Force's role in advancing space power.

The 2020 election results are expected to lead to substantial changes in space policy-related legislative activity and participants due to new assignments to and within various Congressional committees and caucuses. Sen. Gardner and Rep. Horn lost their bids for re-elections. Gardner also sat on the Senate Commerce, Science, and Transportation Committee, and Horn was also the chair of the House Space and Aeronautics Subcommittee of the Science, Space and Technology committee.

Other legislative highlights:

- Sen. Gardner and Sen. Gary Peter (D-MI) introduced a space weather bill titled "Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow" (PROSWIFT). The bill was signed into law by the president in October. It delegates specific space weather responsibilities to multiple agencies and creates an interagency working group to conduct a survey of space weather products users' needs and coordinates agencies' activities.[16] The bill also enables the National Oceanic and Atmospheric Administration (NOAA) to launch a pilot space weather program.
- Sen. Roger Wicker (R-MS) introduced the Space Preservation and Conjunction Emergency (SPACE) Act, in support of 2018's SPD-3, National Space Traffic Management Policy. SPD-3 transferred the responsibilities for providing publicly releasable (i.e., non-military) space situational awareness data as it pertains to collision avoidance and the mitigation of on-orbit debris concerns, and civil satellite collision avoidance policies from the Department of Defense to the Department of Commerce.[17] At the National Space Council meeting in December, the departments of Commerce and Defense finalized a memorandum of understanding for this aspect of space situational awareness and data sharing to encourage involvement of all interested parties in minimizing on-orbit collision risks.

Europe

This year, Latvia became the newest associate member of the European Space Agency (ESA). In October, the Agency and NASA signed an agreement outlining ESA's role in the Artemis Gateway program. ESA will contribute the habitation and refueling modules.[19]

The European Space Agency also had a key administrative change. On Dec. 17, the ESA Council appointed Josef Aschbacher as the ESA director general for the next four years to succeed Jan Woerner. Aschbacher was formerly head of the Copernicus Space Office and Head of Programme Planning and Coordination at ESA's European Space Research Institute (ESRIN).

Cultivating and adopting space traffic management standards are increasingly important to ESA, especially after last year's Aeolus satellite maneuver to prevent collision with a SpaceX Starlink satellite. Europe's efforts in space traffic management are expected to continue to progress in 2021. The main initiative will be driven by the European Union Agency for the Space Programme (EUSPA), a proposed agency of the EU to replace the Global Navigation Satellite Systems Agency (GSA). The EUSPA will hire an additional 600 people to manage the Galileo positioning, navigation, and timing system; develop the Governmental Satellite Communications (Govsatcom) program; and conduct space situational awareness activities.[20] The goal of the program is to maintain EU leadership, EU international relations and to encourage competitiveness among Europe's space sector-related industries.[21]

United Kingdom

Brexit, which concluded on December 31, 2020, has brought the U.K. government to a pivotal moment in its space policy evolution. As the country navigated its separation from the European Union, there was renewed government enthusiasm to shape space policy that focuses on growing a space economy that specifically meets U.K. industry needs.

Toward that goal, in 2020, the nation launched its first space census to survey the diversity of the U.K. space sector.[22] The U.K. government in June also announced the creation of a National Space Council led by Chancellor Rishi Sunak. This appointment is reassuring to the private sector as it formalizes the government's promise to bolster the use of space for national security and international cooperation purposes. Others joining the National Space Council are expected to include the foreign secretary, the cabinet office minister, and business, defense and digital secretaries.[23] On November 19, Prime Minister Johnson announced increased military spending for the U.K. Defense Ministry. A portion of this budget increase will go towards cyberspace and creating an RAF Space Command to "launch [the] first rocket in 2022"[24] from Scotland.

The U.K. in 2020 also strengthened its relationships with key allies through international agreements. It signed the Artemis Accords and formed a partnership with the U.S. through Operation Olympic Defender to secure their mutual space defenses.[25] The U.K. also launched the National Space Innovation Program to collaborate in trade, science, and security with major space players such as Australia, France, Japan and the U.S.[26]

India

Recognizing that space is necessary for economic growth, India drafted a new SpaceCom Policy-2020 to meet the growing demands of space-based communication requirements and support the country's private sector.[27] The policy also intends to encourage private investment, ensure protection of space assets, facilitate a responsive regulatory environment,[28] and adopt measures to authorize using space assets for communication within the country.[29] The draft was released mid-October 2020 for comments and is expected to be implemented in the near future.[30] Indian Space Research Organisation (ISRO) Chairman Dr. K. Sivan has said that ISRO alone will not be able to manage "such high demands" of space applications from start-ups and private companies, emphasizing the need to involve the private sector perspectives in policy making.[31] Based on the draft, the private sector can also expect reforms in the areas of satellite communications capacity, Earth observation, technology transfers, and rules for launch from ISRO facilities.

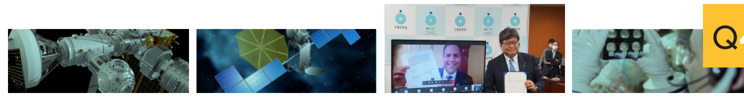
The most significant aspect of this draft policy is the potential opportunities for the private sector to collaborate with the government[32] by opening up a space exploration sector.[33] The private sector previously engaged with ISRO as a subcontractor. However, companies want this role to evolve so they have more autonomy to work in defense projects.[34] The commercial sector is also pushing for a new policy framework dealing with ground communication equipment and terminals.[35] In addition to strengthening Indian defense and procurement processes, these reforms were also created to assist India's COVID-19 recovery by providing a "level playing field"[36] for private space companies.

Over the last few years, India has emerged as a prominent space power in the global arena and a significant player in international security and diplomacy. India in June announced preparations for a National Security Council "space doctrine" and conducted an anti-satellite (ASAT) test (Mission Shakti) to demonstrate its policy resolve and technical prowess.

The nation took a major step forward in space situational awareness in October at the third U.S.-India 2+2 Ministerial Dialogue. The two countries agreed to increased sharing of space situational awareness information, expressed the intent to continue dialogue on space defense cooperation, and welcomed the signing of a memorandum of understanding on Earth observation data to better analyze marine weather conditions and systems in the Indian Ocean.[37]

ISRO on December 16 inaugurated its Space Situational Awareness Control Centre in Bengaluru.[38] The center is part of projects such as the Network for Space Object Tracking and Analysis (NETRA).

In his 2021 New Year message, Chairman K Sivan outlined that every center of ISRO has been directed to create a decadal plan.[39] Highlights include plans to develop heavy-lift launchers and semi-cryogenic engines and achieve partial and full reusability. In the next decade, ISRO will also focus on a variety of missions such as the Small Satellite Launch Vehicle (SSLV), the Aditya-L1 solar mission, the Gaganyaan human spaceflight program, and satellite constellation for broadband communication.[40]



Japan

Japan is one of the nine countries that signed the Artemis Accords in 2020. As part of its growing space relationship with the United States, the Japan Aerospace Exploration Agency (JAXA) also signed the Joint Exploration Declaration of Intent (JEDI) with NASA in 2020 to collaborate on the International Space Station (ISS) and lunar programs.

To further develop space relations, in August, U.S. Space Force Chief of Space Operations Gen. John Raymond visited Japan for the first time in his new position to discuss strengthening cooperation; during his visit, he described Japan as America's "most important partner in outer space." Japan also participated this year, along with seven other countries, in a two-day Schriever Wargame exercise at Schriever Air Force Base, Colorado, which was focused on strategic messaging in the space domain.[43]

Japan also revised its space policy for the first time in five years.[44] The policy aims to bolster space cooperation with allies such as the United States and prioritizes detecting and tracking missiles. The revised policy[45] was adopted by the government's strategic space development panel and, in November, by the Japanese cabinet.

Japan also held a joint demonstration of its JAXA Space Innovation through Partnership and Co-creation (J-SPARC) initiative between JAXA and ALE Company for commercial development of space debris prevention devices. J-SPARC is a joint commercialization dialogue between private businesses and JAXA to co-create new businesses by developing and demonstrating technologies.

Japan is also solidifying its role as a leader in space defense in the Indo-Pacific. Previously, Japan announced the development of a deep space radar. In 2019, Former Prime Minister Shinzo Abe announced Japan's Air Self-Defense Force would become the Air and Space Self-Defense Force.[46] In April 2020, Japan established the Space Domain Mission Unit, which is scheduled to be fully operational in 2023. Formalizing and integrating a self-defense force for space signifies Japan's growing interest in operationalizing space situational awareness, collaborating in space security with allies, and strengthening its space defense capability.

African Nations and the African Union (AU)

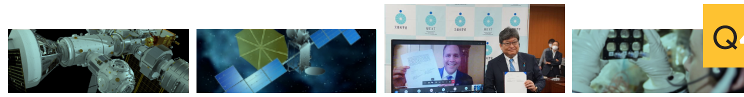
This past year brought a shift toward regional collaboration in developing coherent space policy, adopting conventions for space initiatives, and leveraging space to meet Agenda 2063, a blueprint for sustainable development of the AU.[47] After adopting the Statute of the African Space Agency in 2018, members' next steps include studying structural and financial implications of the Agency.[48]

By July, 2020, 19 African countries had established or begun to create a space program.[49] Fifteen of those countries have signed the Outer Space Treaty and 14 have signed the Rescue Agreement. Twelve countries have signed the Liability Convention, four have signed the Registration Convention, and one country has signed the Moon Agreement.[50] All of these treaties, agreements and conventions are international in content and membership.

Representatives from several AU countries, including Ethiopia, Nigeria, Morocco, and Egypt, participated in the United Nations Conference on Space Law and Policy held in December to discuss various topics such as long-term sustainability, registration of space objects, and space traffic management.[51]

There is some variation in space policy maturation across AU members:

- Nigeria is in the process of revising its space strategy to compete with other spacefaring nations. Currently, the government focuses on regulatory and supervisory roles.[52] For example, the Nigerian Communications Commission is preparing for 5G rollout by auctioning and issuing licenses for the new spectrum.[53] Nigeria's National Space Council (NSC) also regulates and issues licenses to the private sector. Despite some space industry growth over the past decade, Nigeria hasn't achieved some of the goals it set to achieve by 2025. These include establishing a full-capacity launch facility and manu-



facturing its own satellites. The National Space Research and Development Agency's (NASRDA) Acting Director-General, Dr. Francis Chizea, acknowledges these shortcomings and has stated that Nigeria is reviewing its 25-year road map and will adopt new changes to support its private sector.[54]

- Kenya this year set aside funds for a grant for space weather studies and created the Kenya Space Agency Strategic Plan (2020-2025).[55] The four strategic themes outlined in the plan are: delivering space services; developing national capability; sector coordination and leadership; and corporate positioning and sustainability.[56] The country also signed a space station agreement with China this year. This agreement alarmed U.S. government officials concerned that China is cultivating new allies through its space program to advance geopolitical goals and isolate the United States.[57]

International Space Policy – 2020 Highlights

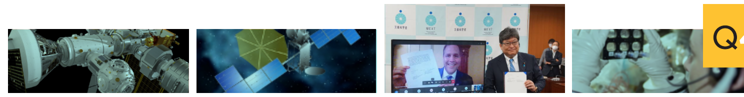
United Nations

Based on the treaties, agreements and conventions signed this year, the UN continues to guide the international space community when it comes to setting norms regarding space sustainability and accessibility. In 2020, the UN released a joint statement with Japan to address space debris concerns.[58] It also signed an agreement with the United Arab Emirates' (UAE's) Space Agency to advance space sustainability.[59] The United Nations Office of Outer Space Affairs (UNOOSA) signed a memorandum of understanding with Brazil's Ministry of Science, Technology and Innovation to advance cooperation on the exploration and peaceful uses of outer space.[60]

The UN also signed an agreement with Israel's Ben Gurion University of the Negev to create a regional support office for UNSPIDER, the UN's Space-based Information for Disaster Management and Emergency Response.[61] It also signed a funding agreement with Luxembourg to partner in the Space Law for New Space Actors project.[62]

The extensive amount of space policy activity in 2020 can be expected to continue, and perhaps grow, in 2021. This is also true with respect to the number of countries/organizations either maturing their space policies or joining the global space community and starting to establish those policies.

Hanh Le is the government affairs associate for the Space Foundation's Washington Operations team.



By Jack Stuart

The Role Of Intellectual Property In Space Innovation

Introduction

As the exponential growth of commercial space looms, this is a good time to survey several critical aspects of intellectual property (IP) as an enabler of innovation in commercial space. This article begins with a review of the vital role of IP in promoting innovation and an overview of the field of intellectual property law. The discussion then turns to the inherent tension between traditional IP law and space law and the impact commercial space innovation has had on that tension.

This analysis examines a few practical strategies for how to avoid becoming a "tech philanthropist" in commercial space, and finally, it speculates on how the legal regime for IP rights in space must change to better incentivize investment in commercial space innovation.

Early and Often

Everyone knows the name Mark Zuckerberg. But apart from those who viewed the 2010 movie The Social Network, very few know the names Cameron and Tyler Winklevoss. Why? Because the Winklevoss twins failed to proactively protect their intellectual property (IP). When they engaged Zuckerberg's services, they likely thought they would simply be using a "coder" to code the Harvard Connection, their proposed social app. But that coder retained and protected his IP rights in what would ultimately become Facebook.

The lesson: Protect IP early and often. By the time an IP asset is widely recognized as being valuable, the window to act has likely long since passed. The common phrase describing this error is, "Hindsight is 20/20." But entrepreneurs simply can't afford for this consolation catchphrase to be their motto: Protecting IP from the start is critical. This reality is especially true in the arena of outer space, whose billions-a-pop ventures are bet-the-company big for many companies. As monumental as these ventures are, budgets are not these companies' biggest problem.

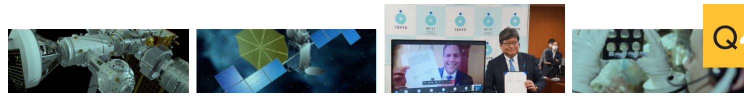
Indeed, whatever visions of tomorrow entrepreneurs may have for so-called commercial space — that is, commercial endeavors in or through outer space — none of these visions will see the light of day without solid intellectual property rights. Such rights are the lifeblood of research, development and innovation; they incentivize risks of time and capital in the hope of strong returns on investments. And while "tech philanthropy" may sound laudable at first blush, in the dog-eat-dog reality of the exceedingly expensive world of commercial space, the phrase more accurately — and sarcastically — refers to a company that has failed to secure its intellectual property rights and has thus "donated" its competitive advantage to the market.

The Fuel Of Interest: Intellectual Property

The Importance of Intellectual Property Rights

Space is poised to be an entrepreneurial frontier, analogously positioned for an explosion in IP creation in the same manner as aviation. Innovations in aviation took off — literally and figuratively — at the dawn of the 20th century. But an explosion of IP in space will not happen spontaneously; such exponential growth requires opportunity and incentive for invention.

Commenting on the preconditions for technical innovation, President Abraham Lincoln cited the introduction of patent laws as one of the three greatest innovations in world history — along with reading and writing, and the discovery of America. These three innovations facilitated "all other inventions and discoveries".[1] As the only U.S. president to be issued a patent, Lincoln had more than a passing interest in intellectual property; his invention, "Buoying Vessels Over Shoals", received a patent in 1849,[2] so his views on the subject were clearly credible and informed. Referring specifically to patent laws, Lincoln remarked:



> Next came the Patent laws. These began in England in 1624 and in this country with the adoption of our constitution. Before then any man might instantly use what another had invented; so that the inventor had no special advantage from his own invention. The patent system changed this; secured to the inventor, for a limited time, the exclusive use of his invention; and thereby added the *fuel of interest* to the *fire of genius*, in the discovery and production of new and useful things.[3] (emphasis added).

This fuel requirement is even more pronounced in the realm of space, where innovation costs are measured not incrementally, but in orders of magnitude. As Lincoln noted, the most effective way man has yet devised to provide that fuel is through the advent of patent laws — or, more generally, intellectual property law, which has continued to develop since Lincoln's day. Robust IP law has enabled this "fuel of interest" to span well beyond patents to support other IP fields, discussed below, in which the "fire of genius" further thrives. This raises the question, then: What *is* intellectual property?

> As used in this discussion, intellectual property means any legally protectable property created from and resident in the human brain. That is, intellectual property is an abstraction of the human mind, an artificial legal construct created within only the past few hundred years. It's called "intellectual" because it's intangible: it can't be touched or sensed, but it exists nonetheless. The "property" predicate alludes to the fact that while IP is intangible, it *can* be identified, secured and maintained — just as can be done for any other form of property. IP is broadly comprised of the subcategories of trademarks, trade secrets, licensing agreements, patents, and copyrights. (For background on key legal concepts, see sidebars next three pages.)

Subcategories of IP Rights

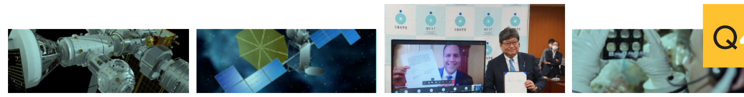
Trademarks

A trademark or service mark identifies a company with its product or service, respectively, and serves to protect a company's brand. The trademark can be a logo (e.g. the Starbucks mermaid, Nike's swoosh) or a word or phrase (e.g. Google, Hard Rock Cafe). A trademark can be a company's most valuable asset, associating its brand with its reputation in the marketplace. Unlike other forms of IP, trademarks can be either an asset or a liability, depending on the company's reputation — because in the mind of the public, the brand is a proxy for the company. Think of the perception associated with a popular brand known for its high quality. This perception acts as a market multiplier for the company owning that brand: namely, the expectation of continued high quality. The converse is also true. Enron and Edsel are two examples of brands whose negative public perceptions contributed to lowered company market values. In short, the value of a trademark is directly proportional to its fame or infamy, and as such, trademarks are a very public form of IP. In contrast, trade secrets are a very private form of IP.

While the basic tenets of IP law are widely understood by all nations with operative IP statutes and rules, their applications vary by country. Notably, several international agreements have been ratified to harmonize certain aspects of IP law globally — such as the *Patent Cooperation Treaty* (for patents)[4] and the *Madrid Protocol* (for trademarks).[5] At its core, though, IP law is nation-specific: it is not, fundamentally, international. Rather, it is a mottled patchwork woven from the legal conventions of various countries. Some of these conventions have impacted the way other countries treat IP law. A good example of this is the "first-inventor-to-file" patent date priority system, which the rest of the world had adopted well before 2011 — the year the U.S. finally aligned its laws with the global standard through the passage of the *American Invents Act*.[6] Even so, IP law is essentially territorial — not international. In contrast, space law developed from day one as a creature of international law — and has fundamentally different philosophical foundations.

The Fuel Of Interest: Intellectual Property

The precursors of modern IP law existed at least as far back as the Venetian Act of 1474.[7] In contrast, space law developed only starting in the mid-20th century, during the Cold War, when the primary concern of space-related treaties and conventions was avoiding global nuclear war. Given that threat, establishing space-related IP rules was not even a distant-second priority. While the topology of space-related activities has changed dramatically since these space treaties were ratified, space law has not evolved to match it.



Space Law Precepts

To understand the inherent conflict that has continued to develop between IP law and space law, it's important to understand the fundamentals of both bodies of jurisprudence. Understanding the foundational, philosophical differences between IP law and space law — as well as the history behind those differences — is necessary to gain an appreciation for the resulting disconnects and their potential solutions. For the purposes of this article, space law means the Outer Space Treaty and its progeny treaties, which were all drafted during the 1960s and 1970s, and the corpus of international law that has developed in the wake of these agreements.[8] These form the heart of the international body of law referred to as space law, both colloquially and within this article.

Amid the Cold War, the U.S. and the former U.S.S.R. — the prime movers behind the Outer Space Treaty (OST)[9] — were concerned about the very real potential of a nuclear-weaponized space. OST addressed this very pressing issue and the use of space, generally. The foundational tenet underlying this cornerstone treaty — and thus all of space law — is that the exploration and use of outer space is for the benefit of all mankind.[10] This means that no one (either a state or an organization) can claim space — either celestial bodies in space or space itself — as their property. Among the other major principles of these space treaties is the prohibition of nuclear weapons (or other weapons of mass destruction) in orbit or otherwise stationed in space, as well as the precept that the Moon and other celestial bodies shall be used for peaceful purposes only. Finally, nations are responsible for their space activities — whether carried out by governmental or non-governmental entities — and are also thus responsible for any damage caused by their space objects. The "responsible" nation is the one from which the object was launched or from which the launch was procured.

Trade Secrets

A trade secret is a confidential, proprietary IP asset. As the name implies, a trade secret must be maintained as a secret by — and provide an economic benefit to — its owner. Think of a trade secret as the "secret sauce" a company would not want to share with its competitors. Examples of trade-secret-eligible information include proprietary manufacturing methods, corporate profit margins, client lists, training methods, business development methods, and a host of other proprietary information. Like trademarks, trade secrets can be very valuable: Coca-Cola's secret formula, Kentucky Fried Chicken's spice recipe and WD-40's formula are examples of closely guarded trade secrets. Intellectual property that can be reverse-engineered or otherwise easily discovered should not be protected as a trade secret: once disclosed, it's no longer secret — anyone can use it. Thus, trade secrets exist at one end of the "disclosure spectrum"; at the opposite end are patents, which require full disclosure of an invention.

The preceding list of space law principles is by no means all-inclusive, nor is this brief treatment of the field meant to address the totality of space law. Rather, it is meant to survey the philosophical topology of space law sufficient for the discussion that follows. This model — that the national laws of the registering state apply to the celestial object — works great when only one object and one nation are involved. Problems arise, however, with multiple nations and multiple objects.

The Discord Between IP Law and Space Law

In contrast to space law, IP laws were developed over the course of centuries, through the lens of the *individual's* property rights — to the exclusion of all others — and under the laws of individual nations, not as agreements among many nations. Hence, an inherent tension exists between these two legal regimes. Further, under space law, the law applicable to a space object is the national law of the country under which the object is registered. This of course includes IP laws — particularly laws governing inventions (i.e. patent laws).

But how are such IP laws applied in multinational ventures? Who owns what? Which nation's law applies, if any? And how — if at all — are these laws enforced? These questions first surfaced in the early days of the International Space Station (ISS). The ISS is a multinational, multi-registered space object comprising multiple patent law regimes. Negotiations regarding inventions used, made or sold on the station yielded little more than nation-based IP balkanization of the ISS.[11] Specifically, the patent rules governing a particular invention depend on the section of the ISS in which the invention is made. For instance, the patent laws of Russia apply while in the Russian module, while the patent laws of the U.S., the European Union, or Japan apply in their respective modules. But this is just the beginning of complications. What happens, for instance, when a multinational consortium launches from a sea-based platform into space? Whose laws govern, then? How is patent protection obtained in such a case — let alone enforced?

> **Licenses**
> A "license" is a contractual agreement that enables the commercial sharing or transfer of specific rights. Thus, an IP license is a legal grant of particular IP rights by the owner to another entity. Licenses can be exclusive or nonexclusive; they can vary according to geographic region or sector of commerce; they can impose restrictions or be unrestricted; and they can be adapted to address a host of other factors. That is, the grant of IP rights conveyed through a license agreement is restricted only by the imaginations of the contracting parties..

And what about so-called process patents? For instance, what happens when one or two steps in a process must occur in the microgravity manufacturing environment of space? Is the patent still valid under a patenting nation's laws if the facilitating space object isn't registered by that nation? Prevailing international patent scholar wisdom is no help, spanning a gamut of what-if opinions. But these and other gray areas will become a lot more black-and-white as first-movers establish new topographies at the intersection of space law and IP rights. Ultimately, the question isn't simply, "Who owns the IP?", but rather: who has an IP *right*, where is that right valid and how can it be enforced?

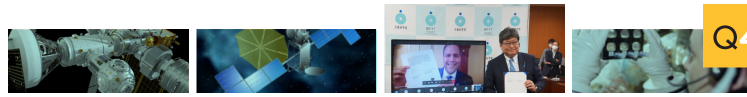
The issue is further compounded, of course, by the fact that space law itself is still far from being settled. For example, while space law addresses celestial bodies, it is silent about mining activities and other property-related rights. Is extracting a resource from a celestial body and then exploiting it for commercial gain the same as a claim of ownership to that celestial body? The unsatisfying answer is that we don't yet know. The signatories to the OST hold a wide spectrum of opinions on this topic, so the resulting international law is very unclear. The U.S., which lies at one end of this spectrum, passed the SPACE *(Spurring Private Aerospace Competitiveness and Entrepreneurship) Act of 2015*,[12] clearing the way for space-mining and other exploitation of celestial bodies short of ownership claims over those bodies. In contrast, Russia considers *all* space-mining activities to violate the principles of OST — explicit claims of ownership or not. The point: Space law isn't settled even within its own right, let alone settled well enough to address all other fields of law, especially very complex fields — like IP law.

Nevertheless, certain attempts have been made to address problems with space-related IP law — albeit with limited effectiveness. For example, the U.S. enacted *The Patents in Space Act of 1990* to address issues related to inventions made in or through space on U.S.-registered space objects. This statute effectively establishes that a space object under the jurisdiction of the U.S. has the same status as that of any other U.S. sovereign territory, as far as patents are concerned. Namely, U.S. patent law applies to inventions made, used or sold on such space objects. But this law does not apply to space objects under an international agreement to which the U.S. is a party. In such a case, U.S. IP law defers to space law under the international legal principle that no nation's laws should preempt those of another sovereign nation — a gap primed to be exploited under the present rules of space.

The Impact of Commercial Space Ventures

Before the proliferation of commercial space activities, nations had to worry solely about government-sponsored space endeavors. A major space vendor — Boeing, for instance — might be involved in a certain nation's space activities, but it was the nation, not the vendor, that was the primary actor in the enterprise. In the U.S., for instance, with the government backing virtually all space innovations, IP was not a major concern: The U.S. government owned it, or at least owned sufficient IP rights to grant the rights needed to whomever it chose. No "fight" over IP existed because, practically speaking, there was no IP to fight over. Claims of exclusive IP ownership were thus immediately frustrated by federal government awards to the "next" vendor — along with the IP rights necessary to perform the task.

That all changed with the rise of space entrepreneurship. The world's first commercial launch, by Arianespace in 1980, ignited the explosion of commercial space. That explosion has since greatly exacerbated the tension between IP law and space law. While governments are still responsible under space law for these commercial launches and activities, they no longer hold sway over all aspects of nongovernmental ventures. And "forum-shopping" among governments is now possible, which enables commercial agreements to be drafted to intentionally avoid clear jurisdictional lines. Why would such agreements be desirable? To *avoid* liability for patent infringement, as one possibility.



This is the specter of so-called "flags of convenience". The term refers to the practice of evading the nettlesome regulations of one nation by registering through — and thus falling under — those of another nation, one with more favorable rules. This problem has plagued the maritime industry — albeit in a completely different manner — for the better part of a century. But flags-of-convenience problems in space would be substantially more complex. There, would-be IP infringers could effectively evade the jurisdictions of nations whose IP owners would be harmed by such evasions. For example, it would be legal to register a spacecraft in Country A and to make, use or sell an invention on that spacecraft that is protected by the patent laws of Country B. Those activities would not infringe the patent, assuming the two nations had no agreement covering IP on the spacecraft.[14] Adopting a flag of convenience in a commercial space context is especially tempting for those wishing to escape infringement liability in countries that have granted millions of patents, such as the U.S.[15] And with ocean-based space launch capabilities having been amply demonstrated,[16] options to register in shill "spacefaring" countries will no doubt multiply.

The commercial space industry is relatively nascent and barriers to entry are very high, so "IP loopholes in space law" (such as flags-of-convenience, jurisdictional evasions) may not appear to be an imminent problem. But the volume of commercial space activities is increasing exponentially, so the dilemma is likely closer than many think.[17] Additionally, if the costs to access space continue to drop inversely-proportionally, then the barriers to commercial space are poised to fall dramatically. These events will, in turn, enable myriad smaller entities to participate — and to register in virtually any nation they wish. In such an environment, flags-of-convenience and similar IP loopholes will pose substantial obstacles to protecting IP in space — particularly for inventions made or used in space.

Patents

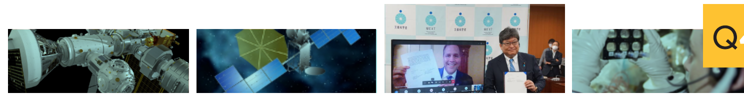
A patent can be thought of as the legal right to exclude others from making, using, selling, offering to sell, or importing a particular invention. Like most other patent systems in the world, the U.S. patent system developed under so-called "social contract" theory. The basic idea of patents is that "We the People" give "you" (the inventor) this "right to exclude" for a defined period – usually twenty years from the date of application. In exchange, the inventor must disclose everything they know about how to make and use the invention. This right to exclude is held by the patent owner, with the exact parameters of the exclusion prescribed by the patent's claims. Analogous to a physical fence around a house and its yard, claims are the legal "fence" around an invention, putting others on notice as to what the inventor regards as their property. A trespass beyond that fence would be an infringement of one or more of the patent's claims, for which the owner can seek redress in a federal court. A patent protects only the function of a thing – i.e. how it works. Another way to think of a patent is that it protects an idea that can be turned into either a method of doing something or a practical, working example: a "widget" (i.e. a machine or something manufactured). However, patents do not protect expressive works; for that kind of protection, a copyright is needed.

Practical Guidance for Today and a View Toward the Future of IP in Space

Undermining intellectual property rights also undermines incentives for the commercial development of space. The rationale is simple: the innovations needed for such development require large capital investments, and prospective investors must be certain that their investments will be rewarded. This certainty is at least in part realized through IP protection. But with loopholes that take advantage of the current dissonance between IP law and space law, what can be done? For the short term, commercial venturers must understand where the disconnects lie and gain a working knowledge of the legal tools currently available for bridging those disconnects. For the longer term, space law must be adapted to address the realities of and incentives for IP ownership. The following sections provide practical advice to inventors who wish to engage in commercial space markets, as well as several thoughts on how space law might be adapted to accommodate IP law.

Current Best Practices for Securing IP Rights in Space

Clearly, IP law in space is very much unsettled; nevertheless, certain fundamentals — let's call these the "old rules" — still apply. Among these old rules are these basic requirements: developing and maintaining an effective IP strategy; understanding IP protection in the context of existing, non-space-related transnational frameworks; wielding international cooperative instruments effectively; controlling disclosures; understanding first-to-file implications on transnational filings; and marking IP with notice-markings. These requirements are all examined in the following sections.



Start with a Plan

Mistakes in IP protection can be bet-the-company costly — especially in space — so protecting IP from day one is critical. The general saying "forewarned is forearmed" is very true. Another apt saying is more IP-specific — and certainly more foreboding: "Innovation without protection is charity"... and space charity is very likely to put its donor out of business. Early IP protection means having a plan before disclosing anything, to anyone. As a minimum, a company should take the following three steps: 1) Engage the company's general counsel early on to harmonize IP-related goals within the company's technical and business development branches; 2) Consult IP counsel, whether in-house or external, as early as possible for technical legal expertise in the applicable IP field; 3) Prioritize regular monitoring and updating of the company's IP goals.

Protect IP from the Beginning

Worldwide, small companies originate and sustain most innovation. These small companies typically have very tight budgets and very limited resources — and small companies in space commerce are no exception. Although the "big players" bankroll the prohibitively expensive elements of commercial space activities, they rely on smaller innovators for critically needed technologies. The dilemma each of these smaller innovators faces is the problem of "keeping the lights on" while also protecting the company's IP. Unfortunately, many companies do not recognize that these two drivers are tightly interwoven — especially in fields like space, where the IP is so cutting-edge that its relinquishment means almost certain death to its startup innovator. The problem thus boils down to how to "keep the lights on" without "giving away the store".

So what's the solution? Well, a good start is realizing that IP protection begins with knowing what to protect. That means being able to define "IP" in a sense that is practically useful. One effective way to identify valuable IP is to ask this question: "As a company, what do we — and only we — have that our customers and/or competitors want?" Whatever the answer, the company's IP is likely central to it. For example, the company's good name and brand; its secret method for fixing a problem or providing a service; its innovative process, machine or application; its cost margins and client lists; its training manuals; its general body of know-how; etc. — all of these are forms of IP that the company can and should protect. The only requirements for this audit are a pen, paper, and time — but that will be time well-spent: its results will establish the company's IP inventory. Once brainstormed, the company's general IP portfolio can be sorted according to IP categories — trademarks, patents, copyrights, trade secrets, and licenses (either owned or granted). This will provide a better picture of the specific type of IP protection needed for each item or group in the IP portfolio.

Copyrights

A copyright protects "original works of authorship fixed in any tangible medium of expression".[23] That last phrase simply means the work can be written on paper, electronically stored, or otherwise stored in a manner readily and reliably reproducible. Copyrights protect "expressive works", such as paintings, writings, songs, movies, architectural designs and other authored works. Another example of copyrightable IP is the expressive part of computer software – that is, the way the coder writes, or codes, the software. In contrast, the functionality of the software, or the what-it-does piece, can only be protected by a patent (or possibly a trade secret, assuming the functionality can't be reverse-engineered). A useful way to understand a copyright is to distinguish it from a patent, using a brief illustration. Imagine that two people both express the same idea for a new rocket engine in two separate drawings. Each would then have a copyright to their respective drawing. However, only one could get a patent on the way to make and use the actual, functioning rocket engine. Under the global, "first-inventor-to-file" standard, the first inventor to reach the patent office of a given country is the first – and thus, only – inventor to be entitled to a patent on that invention, in that country. Further, a patent is issued only for an invention not already known (or not viewed as a common-sense variant) within its field of art. This field of "prior art" (from which derives the widely-used phrase, "state of the art") is comprised of related inventions existing worldwide at the time a patent application is filed with a given country's patent office. The rights conferred by a patent — or any of the other types of IP — are held by the owner. But what if the owner wishes to convey certain of those rights? They can do so with a license.

Recall that "IP protection", generally, is analogous to a fence around a house and its surrounding real estate. Some houses are inexpensive or remotely located and don't even need a fence. Others are very expensive and in densely-populated areas, requiring not only very good fences but also security and other protective measures. In a similar vein, levels of IP protection vary. For example, when an innovation is immature and its eventual worth is not yet known, filing a provisional patent application is an inexpensive means to temporarily protect the invention. A nonprovisional, or "normal", patent application will cost considerably more, but will also provide much longer and more robust protection. For even broader protection, an application can be filed under the *Patent Cooperation Treaty* (PCT), which is essentially a multinational application — more on this, later.

In all cases, however, the protection must begin at the beginning, using basic IP precautions. Let's use, as an example, an invention having no IP protection. Depending upon the circumstances, disclosing the details of this invention could result in effectively giving away or losing the ability to obtain a patent on the technology. Likewise is the case with copyrights, where failure to provide copyright notice markings could result in the partial or total loss of copyright protection. Knowing the bare-bones of IP protection will not fully guard a company's IP, but some protection is better than none.

Among these basic protection measures are notices, nondisclosure agreements and preliminary filings. Notices — in the form of copyright and trademark notice markings — put others on notice of the owner's intent to claim these IP rights. Nondisclosure agreements provide some protection against public disclosures that would otherwise reduce or eliminate patent or trade secret rights. And preliminary filings — that is, provisional or PCT patent applications — provide foundational protection for inventions. All of these measures are inexpensive, but none of them is perfect. For example, while a copyright notice may be very helpful in the U.S. — especially if made in conjunction with federal registration of the copyright — it may be completely useless in a country whose copyright laws are weak or nonexistent. This reasoning also applies to all other forms of IP, which is why innovators should adopt an international perspective toward IP protection, rather than country-specific outlooks.

Protect IP Using an International Mindset

While the idea of protecting IP in space is relatively new, the concept of protecting IP internationally is not. This protection hinges on three factors: the target market, the markets of competitors, and the context of IP rights enforcement. An evaluation of the first two factors will render a list of nations; the last factor frames the laws to be applied and the process by which to apply them. The IP laws of each country on the list must be evaluated to determine where, if at all, IP enforcement is likely to be successful. The resultant, narrowed list must be further tailored to yield the best venue for the IP protection desired. For example, China has strong trademark laws, but relatively weak patent laws — though they have gained much strength in recent years. Companies must also assess which activities are likely to constitute IP infringement. These tell-tale activities will depend on the IP type. For example, for inventions (IP type: patents), the easily identified activities are making, selling and importing; for expressive works (IP type: copyrights), the primary triggers are production, distribution and use. Knowing the most likely IP infringement paths will facilitate the best enforcement responses. Optimizing IP protection for each asset requires holistically evaluating each of the above factors to determine the best strategy for successful enforcement, should the need arise.

Beyond multinational IP strategies, as discussed earlier, IP is only partially protectable under various international legal schemas; in short, there is no international patent, global copyright, universal trademark, etc. Even so, certain limited protections are available through multinational applications, such as PCT filings (patents), filings under the *Madrid Protocol* (trademarks), or filings under the *Berne Convention* (copyrights).[18] Each of these international IP protection frameworks has significant limitations, the scope of which is beyond this brief treatment, but to the extent that protection is provided by one or more of these frameworks, that framework should be engaged.

An interesting dynamic also exists in patents, particularly, because of a concept known as absolute novelty. Under this standard, a patent will be issued only for inventions for which no disclosure has been made prior to the filing of an application. Most nations have adopted this standard. The U.S. is unique in its extension of a so-called grace period to its patents: A one-year period is permitted between a public disclosure of an invention and the filing of its patent (or provisional patent) application. Thus, for international filings, a crucial precaution imposed by the absolute novelty doctrine is to keep a tight lid on any disclosures prior to filing — whether at a symposium, on a social media site, or on the company's website. This precaution further implies that companies must implement policies to educate personnel on the "why" behind such measures. Another result of absolute novelty, however, is that — if patent protection is not desired — innovators can engage in defensively publishing (i.e. publicly disclosing enough details of the invention so that others can make and use it). This practice can provide low-cost protection against patent infringement suits that, in the absence of patent protection or defensive publication, might otherwise be brought by competitors who have staked out related, patent-based market exclusion zones. This is especially useful when a company desires the freedom to operate in areas other than those of its core technologies and market.

The Future of IP Law in Space

As previously shown, the law governing IP rights in space has yet to be brought into harmony with space law itself — let alone to be codified into practically useful, international instruments through treaties or other multinational agreements. Nevertheless, the conflict between space law and IP law must be settled eventually, if commercial space is to become a reality — that is, a reality beyond the few multi-multi-billion-dollar players currently on the stage. A number of solutions have been proposed, and the following is not an exhaustive list of those proposals — nor is any proposed solution exhaustively evaluated, here. Rather, these are presented to spur further thought on potential harmonization paths between IP law and space law.

One seemingly obvious path is simply to expand the scope of the existing international treaties mentioned above — the *Patent Cooperation Treaty*, the *Madrid Protocol*, and the *Berne Convention*. The problem with this solution is that it isn't simple and it isn't one solution. Rather, it is a set of complex solutions, each requiring either the major overhaul or the complete scrapping of the international legal regime already in place. Each of these regimes recognizes the sovereignty of individual nations and each has its own limitations. For example, the *Berne Convention* permits a great deal of diversity among the laws of its member nations. Notwithstanding its seemingly strong, pro-author copyright rules, and despite additional pressure exerted by World Trade Organization[19] agreements,[20] countries vary dramatically in their ability and desire to enforce copyright laws — and such variation is perfectly permissible under this convention. Meanwhile, both the *Patent Cooperation Treaty* and the *Madrid Protocol* are treaties that address priority dates and filing — only — not substantive harmonization of patent or trademark laws. Clearly, then, upgrading these systems to standardize international space IP law would first require addressing these types of shortfalls. This is a challenge unlikely to be taken up in the foreseeable future by the members of these current systems. Thus, as seemingly straightforward as this path might appear at first blush, a closer examination reveals this solution to be unworkable.

Another proposed solution is to establish space as a territory of sorts, with IP governed solely by the international rules established within this outer space jurisdiction.[21] This would indeed eliminate the IP legal patchwork that exists among spacefaring nations. But it would come at the cost of national sovereignty in space activities, at least as far as IP is concerned. This is highly unlikely to happen without some strong forcing function to apply sufficient pressure for would-be member nations to accede to such a construct. Such pressure may ultimately come to bear, as commercial space ventures proliferate and the need for a standardized, reliable system for space-related IP rights becomes more pronounced over time. Currently, however, no major international movements along these lines are observable, beyond white papers and academic discussions. A more tenable and more feasible subset of the above solution is for commercial spacefaring nations to enter into limited pacts that establish rules governing intellectual property — particularly inventions. The ISS Agreement is one such pact that was successfully established, in 1998.[22] If commercial space activities continue to grow exponentially, such pacts are likely to proliferate, and may one day lead to an international regime of the type described in the previous paragraph. As things stand, though, few treaties of this sort loom on the horizon. In any case, however far in the future such pacts lie, they are still the most likely inroads into a global space IP rights framework of the type described above.

We can only speculate on the future framework of IP rights in space; however, we can state with confidence that the issue must eventually be addressed, if commercial space is to flourish. Even so, to the extent commercial space continues on its present trajectory, so will the pressures shaping the existing space IP frameworks. For now, however, IP rights largely remain territorially determined — whether on Earth or in space.

Conclusion

Intellectual property rights play a fundamental role in the growth of every market, and this reality is no less true in commercial space. These rights incentivize innovation by commercial enterprises, which are often backed by savvy investors looking for sizable rewards from their investments. Investment diminishes when the paths to those rewards become clouded by uncertainty — such as the uncertainty posed by the ongoing collision of the legal regimes of IP law and space law. This uncharted legal topology will likely endure until the collective, worldwide commercial space enterprise compels clarifications to and confidence in space IP rights. And while it is likely that the current first-movers in commercial space will eventually set the long-term rules of engagement to establish that framework, anyone else wishing to enter this exploding market will need to know the current IP landscape and be able to traverse it.

IP rights in the global commons of space will see dramatic changes in the coming years. However, these rights must undergo further refinement, strengthening and clarification if we are to see continued innovation to reach, explore and develop space. And for commercial space activities to become routine, these changes must arrive sooner rather than later. The pressure driving such acceleration will likely build as a function of the exponential growth of commercial space activities — much like the rise of the automobile industry, in the wake of Henry Ford's mass-production auto plants. Before that time, the automobile was a relative anomaly among the horses and horse-drawn carriages of the day. Ford's introduction of the mass-produced automobile revolutionized earthbound travel and the exploration and development of the Earth. Given the acceleration of innovation seen just since Ford's day, it seems likely that we'll see a similar revolution in space development, exploration and travel — as a result of commercial space activities. And intellectual property will undoubtedly be at the core of the fuel of interest and fire of genius that will propel those activities.

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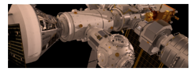



Introduction | *The microgravity conditions of the International Space Station (ISS) offer a profound opportunity to make discoveries in regenerative medicine that would not be possible on Earth. Scientists floating more than 200 miles above the ground are experimenting with ways cells grow and change, studying progressions of diseases, and developing 3D models to observe how muscle and bone cells organize into tissue.[1] These studies could help significantly with addressing chronic diseases in people here on Earth.*

Microbiologist and astronaut Kate Rubins examines stem cell–derived heart muscle cells aboard the International Space Station.
Credit: NASA

ISS Microgravity Offers Unique Opportunity for Regenerative Medical Research

Chronic conditions such as heart disease, stroke, dementia, cancer, and arthritis result in significant health effects for the human population. As of 2014, 60% of the adult population in the United States suffers from at least one chronic illness, and 42% of those have more than one condition.[2] Among the illnesses that are the deadliest to Americans are heart disease and stroke, which are responsible for more than 868,000 American deaths each year — approximately one-third of all deaths nationally.[3] Heart disease and stroke also take a hefty economic toll, according to the Centers for Disease Control and Prevention. The two alone cost the American health care system about $214 billion annually and cause $138 billion in lost productivity on the job.[4] Cancer, diagnosed in more than 1.7 million people nationally each year, was predicted to reach nearly $174 billion in health care costs in 2020.[5] One study from 2014 found that on average, Americans with five or more chronic conditions spend 14 times more on health services than people with no chronic conditions.[6]

Considering both the humanitarian and economic toll, scientists have turned to a new lab: aboard the ISS. Because cells behave differently when gravitational force is removed,[7] space offers an incredibly unique environment that does not naturally occur on Earth.

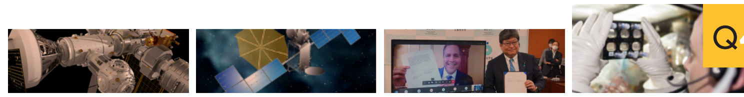
Using space for regenerative medical research is still relatively new. While the research has not yet yielded specific products or processes for use on Earth, there have been extremely promising advancements using the microgravity environment of the ISS labs to learn how certain conditions, drugs, and treatments affect the human body.

NASA astronaut Peggy Whitson checks out stem cell growth samples for the Microgravity Expanded Stem Cells investigation. The investigation studies whether stem cells will grow faster in microgravity, and the results may allow scientists to replicate faster growth on Earth to produce needed stem cells for treating of a variety of medical conditions.
Credit: NASA

Interest in studying stem cells in space has significantly grown the past six years, according to data provided by Emily Tomlin, associate director of communications with the ISS U.S. National Laboratory. Between 1982 and 2013, there were 34 publications regarding ISS stem cell research. Since 2014, that number has nearly doubled, the data show.

Stem Cells Grow Better in Space

Stem cells are capable of self-renewal — the process of dividing to create additional cells — and differentiation into mature cell types.[8] Research on these cells has posited the theory of being able to create the basic building materials needed in the body in an unlimited amount, which opens the door for testing therapeutics and new transplantation methods. Successfully



using stem cells in transplants eliminates the risk of the body rejecting the transplant,[9] and could eliminate the use of donors, which are already in limited supply.[10]

Human-derived mesenchymal stem cells (MSCs) assist in the activation of immune cells and promote tissue repair and regeneration.[11] They have the ability to differentiate into many types of cells, including bone, cartilage, and connective tissue.[12]

Scientists face several obstacles when attempting to grow enough cells on Earth. Most therapies require a large amount of stem cells to be effective — about 200 to 500 million cells.[13] Stem cells grown on Earth in a culture are less resilient and can lose their ability to differentiate into other types of cells.[14] They also don't expand as well in a two-dimensional cell culture environment because it differs from the way stem cells naturally develop inside the body.[15]

Cells that develop naturally inside the human body grow within support structures made of proteins and carbohydrates, allowing organs to maintain their three-dimensional shape.[16] In labs, cells are grown in sheets and spread out flat, posing problems for scientists who study cancer by looking at genetic changes affecting cell growth and development.[17]

The microgravity environment aboard ISS offers the unique ability to grow stem cells in a three-dimensional way that more closely replicates natural cell growth in the body.[18] Observing cells in a three-dimensional structure allows scientists to improve models to study cell behavior, test drugs, and accelerate advances in tissue engineering.[19]

Scanning Electron Micrograph of a human Muellerian ovarian cancer cell nurtured in microgravity conditions. The three-dimensional structure shown is much closer in true size and form to natural tumor cells found in cancer patients.
Credit: NASA

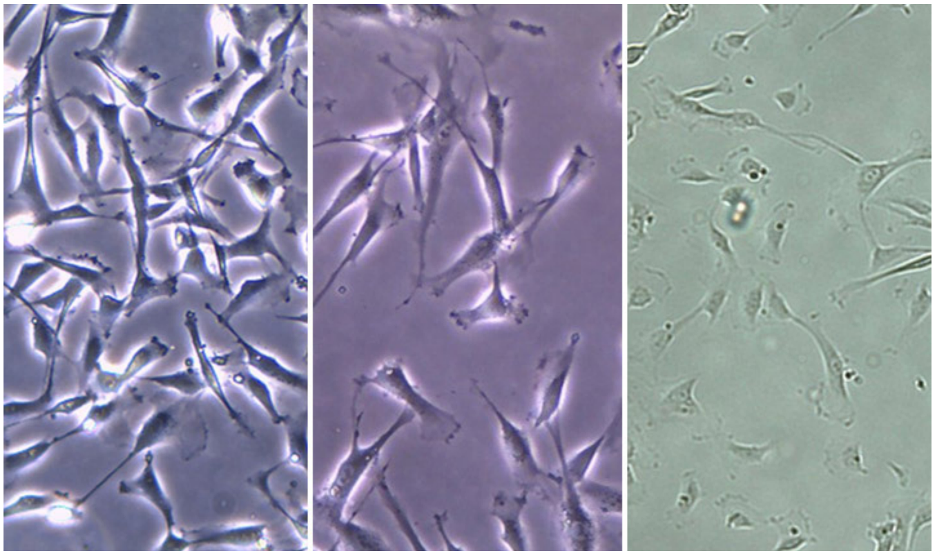
Earlier this year, researchers led by Dr. Abba Zubair, director of Transfusion Medicine and Stem Cell Therapy at the Mayo Clinic, published results from an ISS experiment on the feasibility of growing MSCs in space for clinical applications. The MSCs were imaged every 24 to 48 hours, and the cells were harvested at seven and 14 days, according to the researcher's publication.

The experiment was a success. Results showed that microgravity significantly altered MSC secretion of cytokines and growth, the paper stated. They also seemed to be more immunosuppressive than the ground-controlled cells, with no evidence of cancer development.[20] Additionally, the cells demonstrated a better ability to develop into different types of cells.

The feasibility of growing more viable stem cells in space has opened the door to potential human clinical applications on Earth that could significantly help victims of chronic health conditions and cancer. Dr. Zubair noted at an October conference hosted by the ISS U.S. National Laboratory that stem cells can be used to reduce the effects of cancer treatments and assist with organ repair and regeneration. The ability to grow three-dimensional models also allows pharmaceutical companies to decrease their reliance on using animal test subjects, according to data provided by Tomlin of the ISS U.S. National Laboratory.

One fascinating development is that scientists believe they may soon have the technology to manufacture human organs and tissues aboard the ISS for use on Earth. Using the 3D BioFabrication Facility,[21] a space-based automated human tissue printing system developed by Techshot and launched into space aboard the SpaceX CRS-18 cargo mission in July 2019,[22] ISS crew members made their first and second prints using human cells one month later.[23]

The waiting list for a donor organ includes about 75,000 people on any given day, according to the Centers for Disease Control and Prevention.[24] Scientists have experimented with a process similar to 3D printing to engineer human tissues that would someday lead to creating whole human organs in space.[25] Without microgravity, "printing" human tissues requires



Neonatal CPCs cultured in the BioCell hardware.
Credit: Kearns-Jonker Laboratory, Loma Linda University

scaffolding to keep the structures from collapsing, and that material must be able to dissolve as the tissue matures.[26] However, aboard the ISS, technology such as the BioFabrication Facility can more seamlessly create the tiny, complex structures found inside human organs.[27]

Studying Heart Cells in Near-Zero-Gravity Conditions

With extended stays becoming more common on the ISS, scientists have sought to study how microgravity conditions affect different parts of the body, including the heart. In addition to helping astronauts with knowns risks of spaceflight, their research can be used to address heart conditions on Earth, where about 735,000 Americans have a heart attack and about 610,000 die from heart diseases yearly.[28]

Using an experiment launched onboard SpaceX's ninth commercial resupply services mission in July 2016,[29] a Stanford University research team led by Dr. Joseph Wu and Dr. Arun Sharma examined how near-zero-gravity conditions would affect the functional properties and gene expression of specialized cardiac muscle cells derived from human-induced pluripotent stem cells (iPSC).[30]

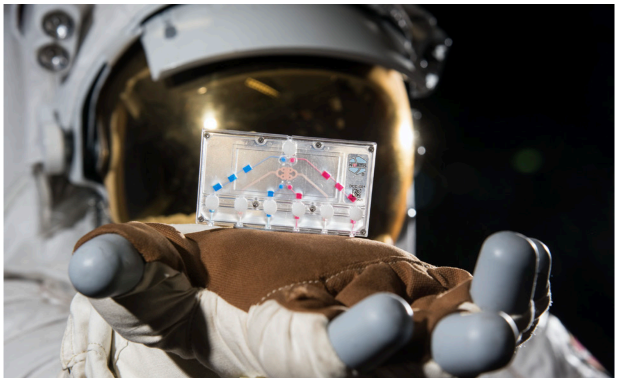
The investigation found that microgravity alters cardiac function at the cellular level,[31] a discovery that could help astronauts on future long-duration spaceflight missions, as well as patients with cardiovascular diseases on Earth. Human heart cells, the study found, change their functional properties in space and compensate for the loss of gravity by altering their gene-expression patterns. The ability to produce three-dimensional tissue-like structures could provide a more accurate model that would allow researchers to study interactions between cell types.[32] When a person experiences a blockage in a coronary artery, heart tissue rapidly begins to die and remains damaged even after blood flow is restored.[33] Scientists working with the ISS are studying whether heart tissue can be regenerated to restore cardiac function.[34] Some are specifically focusing on human cardiovascular progenitor cells (CPCs) — immature heart cells that can develop into several different types of cells.[35]

Loma Linda University researcher Mary Kearns-Jonker and her team in June 2017 sent cultures of CPCs to the ISS lab on board SpaceX's 11th commercial resupply mission to study the effects of microgravity on neonatal CPCs and adult CPCs.[36] Among their discoveries, the team found that neonatal cells exhibited enhanced "stemness" compared to the adult cells — making them behave more like stem cells with the ability to change into other types of cells.[37] Their findings could significantly help with advancing cell-based regenerative therapies for heart attacks and other injuries.[38]

With the help of findings aboard the ISS, scientists could potentially be able to use a less-perfect ground-based simulated microgravity as a way to adapt CPCs for new therapies.[39]

Using Tissue Chips to Study Bone Loss and Muscle Atrophy

In 2016, Dr. Siobhan Malany, director of Translational Biology at Sanford Burnham Prebys Medical Discovery Institute and founder of Micro-gRx, was awarded a grant from the Center for the Advancement of Science in Space (CASIS) to study atrophy in muscle cells aboard the ISS.[40] Her team collected human skeletal muscle cell samples that were integrated onto a lab-on-a-chip — a single integrated circuit that can perform several lab functions — to replicate muscle



An astronaut holds a type of NIH Tissue Chip
Source: NASA/Josh Valcarcel

weakness associated with aging.[41] They were launched to the ISS in 2018 aboard a Cygnus cargo ship atop a Northrop Grumman Antares rocket at NASA's facility at Wallops Island, Virginia.[42] The researchers hope to determine whether muscle loss induced by microgravity in spaceflight is similar to immobility in older adults to learn more about how cells can affect clinical therapies.[43]

A growing need for relevant models to study disease pathology and gain preclinical efficacy and toxicity data has led to an expanding interest in tissue engineering.[44] Technology such as lab-on-a-chip and tissue chips — also known as Microphysical Systems (MPS) or organs-on-chips — are being used to exploit the unique microgravity environment aboard the ISS.[45] Tissue chips are practically the size of a thumb drive, but they carry living human tissues and cells within their three-dimensional structure that simulate human organs such as the lungs, heart, and liver.[46] This new technology is being used to study a multitude of effects on human cells and tissue, including responses to stressors, drugs, different genetics, and more.[47]

Exciting New Possibilities

While the use of the ISS lab for regenerative medicine research is relatively new, the potential it holds is remarkable. The near-zero-gravity conditions offer the ability to study pure phenomena that can be evaluated without the influence of gravity.[48] New phenomena have also been discovered because of the lack of gravity's influence.[49] It's also allowed for new manufacturing processes to be developed,[50] such as the 3D BioFabrication Facility that prints human tissue.

These discoveries and more could lead to new ways on the final frontier to treat, prevent, and cure diseases on Earth.

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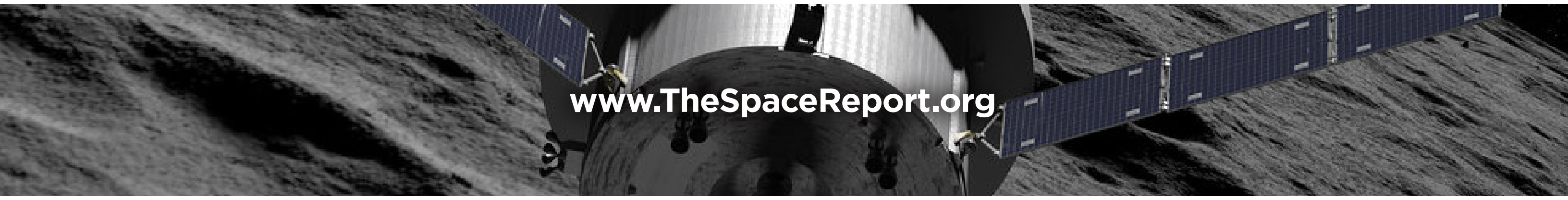

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The Role Of Intellectual Property In Space Innovation

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5 "The Protocol Relating to the Madrid Agreement Concerning the International Registration of Marks" is actually the result of previous failed treaty attempts to create an international trademark registration system. As the U.S. Patent and Trademark Office notes, "The protocol is a filing treaty and not a substantive harmonization treaty." That is, although it does offer a means for the filing of an "international" trademark application, each nation has the right to determine its own protection rights to be granted by the filing, with the strength of such rights varying across a very wide spectrum. (https://www.uspto.gov/trademark/laws-regulations/madrid-protocol)

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Section 4 | Space Products and Innovation

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