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


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.


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 90 minutes.

- Medium Earth Orbit (MEO) is the region of space around the Earth above LEO (2,000 km) 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 the satellite orbits at approximately 35,790 kilometers above the Earth’s surface. At this altitude, the orbital period is equal to the period of 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 the satellite passes over the equator and each latitude on the Earth’s surface at the same local time every day, meaning 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 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 dwell times at a point on the planet’s surface; visibility near apogee can exceed 12 hours. 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.).
Introduction to *The Space Report* | Quarter 1

Beginning with this issue, the Space Foundation is publishing *The Space Report* (TSR) quarterly, instead of annually. This new reporting schedule is an attempt to provide a more comprehensive and timely awareness of activities and developments in the global space industry, publishing documented industry changes and trends sooner than possible with an annual report. The switch to a quarterly publication also means the report’s content and emphasis will be a little different each quarter.

For example, instead of covering all the topics normally covered in the annual report, the Economy section in this quarter’s release of *The Space Report* covers only U.S. government and military investments. In Workforce, the report covers only the U.S. Space Workforce. Satellites and spacecraft are the only topic focused on in the Infrastructure section. Moreover, Products and Services will be a little lighter. Next quarter’s publication will cover different topics within those same categories.

Readers of *The Space Report, Quarter 1* will notice more detail in certain topics within. Additionally, there are a few analyses providing perspectives of trends happening within the global space industry. The Space Index, which had a place in *The Space Report* until 2014, is back as well. Necessarily, some of the information in this quarter’s report will change over the next few quarters, reflecting changes in official reporting updates of the global space industry. Publications in future quarters will also contain summaries of data updates, whether for Economy, Infrastructure, or other categories.

Over the years, *The Space Report’s* clear, researched, and accessible reporting has provided a service to the space industry and to others interested in understanding it. Quarterly versions of *The Space Report* will do the same, but with over ten years of data collection informing the research, *The Space Report, Quarter 1*, is data dense.

For those wishing to access the datasets used to create these quarterly reports, or to access datasets not published in *The Space Report, Quarter 1*, subscribing to *The Space Report Online* provides access to the data repository behind these quarterly publications.

### 1 | The Space Economy: U.S. Government Space Investments

The U.S. government continued significant spending on space activities in 2018, increasing its investment in space. This spending gave the U.S. government a greater share of global space economy investment than any other nation. The largest beneficiaries of the increase were the Department of Defense (DoD) and elements within it and the National Aeronautics and Space Administration (NASA); however, six other U.S. government agencies have a stake in space. As readers will note comparing the U.S. civil government and military economy section and the U.S. space workforce section, the spending increases and decreases for NASA and the DoD don’t necessarily correlate with increased or decreased employment in the workforce.

### 2 | Workforce: U.S. Space Workforce

There are hundreds of thousands of employees in the global space industry. The U.S. space workforce significantly contributes to the global industry, providing highly skilled individuals with the knowledge of and experience operating cutting edge technology. The U.S. space workforce has faced significant drops in employment for over a decade, but last year’s data show slight workforce increases. More workforce challenges face space industry companies beyond employment—diversity foremost among them. Low gender diversity and minority representation seem to mirror the diversity challenges of Google or Apple.

State-level space industry employment focuses on hubs within certain states, such as Florida or California. Workforce trends in these states mirror the national trend, experiencing losses during the past decade. But, like the national space workforce, in 2018 some states saw a reversal to these losses.
3 | Space Infrastructure: Spacecraft and Satellites

As of March 6, 2019, 38 nations deployed and operated 465 spacecraft during 2018. Since this report is a snapshot of 2018 activities and not intended as a comprehensive list, not all 38 of those nations are covered. Data regarding the spacecraft of those countries is available to subscribers of The Space Report Online, the data repository for these quarterly TSR releases. The data within the sections of Infrastructure in this TSR release (Communications Satellites; Positioning, Navigation and Timing (PNT) Satellites; Earth Observation/Remote Sensing (EO/RS) Satellites; and Exploration Spacecraft and Probes) will focus on the three countries, organizations, and companies with the largest share of spacecraft activities within each section.

4 | Space Products and Services

The Space Report, Quarter 1 provides insights into the commercial, civil government and military interests creating, expanding, and using space-based technologies and services. Commercial enterprises are expanding the uses and customers for space-based systems, such as the Global Positioning System, that were initially designed and deployed for other space segments or users. Earth observation data, once the domain of government intelligence agencies, are integrated with smartphone software applications, and combined with space-based navigation data to create a virtual infrastructure for burgeoning businesses, such as electric scooter rental companies.

While this category once belonged to products resulting from the technology transfer and spinoff programs of civil space agencies, larger swaths of entrepreneurs are combining existing space services to keep humans safer and more comfortable, and to provide previously inconceivable conveniences.
1.0 Introduction | The U.S. government increased spending on space activities in 2018. This spending represents a greater share of global space economy investment than any other nation. The U.S. government allocated the majority of funding to the Department of Defense (DoD) and its subordinate agencies and the National Aeronautics and Space Administration (NASA). Six additional U.S. government agencies with space components are examined.

The U.S. National Space Council meets in front of the possible future of commercial space travel, NASA's Commercial Crew Program capsules. Credit: NASA/Kim Shiflett

1.1 U.S. Government Space Investment

The United States (U.S.) spent USD $48.3 billion on space activities in Fiscal Year (FY) 2018, which ran from October 1, 2017, through September 30, 2018. 2018 represented an increase of 10.0% from USD $43.4 billion in FY 2017, which was USD $4.8 billion (2.5%) lower than FY 2016. The Department of Defense (DoD) and National Aeronautics and Space Administration (NASA) accounted for 93.7% (USD $45.2 billion) of U.S. government space spending in 2018, with six other entities splitting the remaining 6% (USD $3.0 billion).

1.1.1 U.S. Military Space

Space technologies are a vital asset to the United States military across air, land, sea, and cyberspace. All four branches under the Department of Defense (DoD) – the Air Force (USAF), the Army (USA), the Navy (USN), and the Marine Corp (USMC) - have space assets. DoD agencies with space assets and operations include the Missile Defense Agency (MDA), the Defense Advanced Research Projects Agency (DARPA), the National Reconnaissance Office (NRO) and the National Geospatial-Intelligence Agency (NGA). The U.S. Coast Guard (USCG), which operates under the Navy during wartime and under the Department of Homeland Security during peacetime, also manages and operates a satellite. Three U.S. military branches/agencies (USAF, NRO, DARPA) and the USCG launched military payloads in 2018.

EXHIBIT 1b. U.S. Government Agency Space Budgets, 2018

<table>
<thead>
<tr>
<th>Agency</th>
<th>Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>Department of Defense (DoD)*</td>
<td>$24.526 B</td>
</tr>
<tr>
<td>National Aeronautics and Space Administration (NASA)</td>
<td>$20.736 B</td>
</tr>
<tr>
<td>Department of the Interior (DOI) (including USGS)*</td>
<td>$0.112 B</td>
</tr>
<tr>
<td>Department of Energy (DOE)*</td>
<td>$0.027 B</td>
</tr>
<tr>
<td>National Science Foundation (NSF)*</td>
<td>$0.502 B</td>
</tr>
<tr>
<td>National Oceanic and Atmospheric Administration (NOAA)</td>
<td>$2.187 B</td>
</tr>
<tr>
<td>Department Of Transportation (DOT)</td>
<td>$0.020 B</td>
</tr>
<tr>
<td>United States Department of Agriculture (USDA)*</td>
<td>$0.199 B</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$48.308 B</strong></td>
</tr>
</tbody>
</table>

*Space Foundation estimate
Source: Space Foundation database

EXHIBIT 1c. U.S. Government Space Budget, 2018

<table>
<thead>
<tr>
<th>Agency</th>
<th>Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>Department of Defense</td>
<td>42.92%</td>
</tr>
<tr>
<td>National Aeronautics and Space Administration</td>
<td>4.53%</td>
</tr>
<tr>
<td>National Oceanic and Atmospheric Administration</td>
<td>.33%</td>
</tr>
<tr>
<td>National Science Foundation</td>
<td>.23%</td>
</tr>
<tr>
<td>Department of Agriculture</td>
<td>.06%</td>
</tr>
<tr>
<td>Department of Interior</td>
<td>.04%</td>
</tr>
<tr>
<td>Department of Energy</td>
<td>.04%</td>
</tr>
<tr>
<td>Department of Transportation</td>
<td>.04%</td>
</tr>
</tbody>
</table>

Total: $48.31 B
The DoD had the largest share of U.S. government space spending in 2018, 50.8% (USD $24.5 billion); this represents an 18.6% (USD $3.8 billion) increase over the 2017 DoD figure of USD $24.5 billion. The classified portion of the DoD budget grew by 10.7% from 2017 to 2018, but the unclassified space portion grew by 25.2%. Programs funded under the unclassified portion of the 2018 DoD space budget included the U.S. Air Force’s (USAF’s) space situational awareness (SSA) programs Combined Space Operation Center (CSpOC) (formerly Joint Space Operations Center (JSpOC)3) and North American Aerospace Defense Command (NORAD)4 and as well as the joint DoD/Department of Energy (DoE) Nuclear Detonation (NUDET) Detection System.5

2018 saw the launch of satellites for three USAF space programs covered by the unclassified portion of the DoD space budget: SBIRS (Space Based Infrared System), the missile warning system; Advanced Extremely High Frequency System (AEHF),6 a secure communications constellation; and Global Positioning System (GPS), the positioning, navigation, and timing (PNT) constellation.7 DoD spending on NUDET and SSA activities and ground systems combined comprised less than 5% (USD $350 million) of the unclassified DoD space budget. Communications operations and equipment made up 16.5% of the unclassified DoD space budget (USD $1.8 billion), and GPS operations and equipment constituted 7%, (USD $800 million). The SBIRS program made up 11.0% ($1.0 billion) of the unclassified DoD space budget.8

Classified space programs encompassed almost USD $22 billion, about two thirds, of the DoD’s 2018 space budget.9 The estimated share of space-based classified programs is calculated by assessing the rate of change between 2016 and 2017 figures in the Aeronautics and Space Report of the President,10 as well as the average shift in unclassified line-item figures in the same timeframe.

The President’s FY2020 Budget requested USD $72.4 million in the DoD budget for the “initial establishment of the United States Space Force.”11 A presidential memo issued on December 18, 2018, directed military leaders at the Pentagon to take the first step and establish the United States Space Command. The Space Force will be placed by statute within the Department of the Air Force as the “sixth branch of the United States Armed Forces.”12 Congress has yet to act on these directives due to a provision in the 2019 National Defense Authorization Act that positions the Space Force under the United States Strategic Command, one of several DoD unified commands,13 whereas the administration envisions an independent unified command.14

### 1.1.2 U.S. Civil Government Space

Seven U.S. civil government agencies have space line items, if not subordinate space agencies, in their budget: NASA, the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), the United States Department of Agriculture (USDA), the Department of Interior (DOI), the Department of Energy (DOE), and Department of Transportation (DOT). Civil government agency budgets combined make up 49.2% (USD $23.8 billion) of the U.S. space budget, a 4.2% (USD $998.3 million) increase from 2017. NASA has the lion’s share of this budget, 83%, with 17% going to all of the other agencies/departments.
1.1.2.1 National Aeronautics and Space Administration (NASA)

NASA programs comprised the second largest share, 43%, of the U.S. government space budget (USD $19.7 billion). The NASA budget grew by 5% in 2018; its top-level line items are: Science; Aeronautics; Exploration Technology; Deep Space Exploration Systems; Space Operations; STEM Engagement; Safety, Security, and Mission Services; Construction and Environmental Compliance and Restoration; and Inspector General.

The most significant budgetary gains were in Planetary Science (21.3%), under the Science budget, and Construction and Environmental Compliance and Restoration, also known as ECR (17.4%). The majority of budgetary growth in Planetary Science was directed towards the Europa Clipper/Lander project, due to launch as early as 2023, and the continuation of the missions under the Mars Exploration Program. The ECR Program is dedicated to cleaning up chemicals released into the Earth’s environment, such as Trichloroethylene (TCE), from past NASA activities. Although human studies are limited, studies in animals have found that consuming TCE-contaminated water over a long period of time (several years or more) can cause “kidney, liver, and lung damage and potentially increase cancer risk.”

NASA’s continued and growing investment into the Space Launch System (SLS) and its accompanying initiatives appear in three line items: Exploration Technology (USD $687 million), Deep Space Exploration Systems (USD $4.9 billion), and Exploration Systems Development (USD $3.9 billion). Each of those three line items grew by over 10% from 2017 to 2018. Nonetheless, NASA is reportedly “reassessing” the now already delayed 2020 initial launch date. An audit of the SLS Exploration Systems Development (USD $3.9 billion). Each of those three line items grew by over 10% from 2017 to 2018. Nonetheless, NASA is reportedly “reassessing” the now already delayed 2020 initial launch date. An audit of the SLS program in October 2018 found that it was projected to run out of funds three years early due to “poor performance” and “weak oversight.”

<table>
<thead>
<tr>
<th>Budget Authority, dollars in millions</th>
<th>FY 2016 Actual¹</th>
<th>FY 2017 Actual²</th>
<th>FY 2018 Actual ³</th>
<th>FY 2019 Enacted ⁴</th>
<th>FY 2020 NASA Request ⁵</th>
<th>FY 2020 Presidential Request ⁶</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science</td>
<td>5,589.4</td>
<td>5,762.0</td>
<td>6,221.5</td>
<td>6,905.7</td>
<td>6,303.7</td>
<td>6,304.0</td>
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<tr>
<td>Earth Science</td>
<td>1,927.0</td>
<td>1,908.0</td>
<td>1,921.0</td>
<td>1,931.0</td>
<td>1,779.8</td>
<td>1,780.0</td>
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<tr>
<td>Planetary Science</td>
<td>1,628.0</td>
<td>1,828.0</td>
<td>2,217.9</td>
<td>2,758.5</td>
<td>2,622.1</td>
<td>2,622.0</td>
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<tr>
<td>Astrophysics</td>
<td>762.0</td>
<td>783.0</td>
<td>850.4</td>
<td>1,191.6</td>
<td>844.8</td>
<td>845.0</td>
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<tr>
<td>Heliophysics</td>
<td>647.0</td>
<td>675.0</td>
<td>688.5</td>
<td>720.0</td>
<td>704.5</td>
<td>705.0</td>
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<tr>
<td>James Webb Space Telescope</td>
<td>620.0</td>
<td>569.0</td>
<td>533.7</td>
<td>304.6</td>
<td>352.6</td>
<td>353.0</td>
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<tr>
<td>Aeronautics</td>
<td>642.0</td>
<td>656.0</td>
<td>690.0</td>
<td>725.0</td>
<td>666.9</td>
<td>667.0</td>
</tr>
<tr>
<td>Exploration Technology</td>
<td>686.5</td>
<td>687.0</td>
<td>760.0</td>
<td>926.9</td>
<td>1,014.3</td>
<td>1,014.0</td>
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<tr>
<td>Deep Space Exploration Systems</td>
<td>4,030.0</td>
<td>4,324.0</td>
<td>4,790.0</td>
<td>5,050.8</td>
<td>5,021.7</td>
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<tr>
<td>Exploration Systems Development</td>
<td>350.0</td>
<td>3,929.0</td>
<td>4,395.0</td>
<td>4,092.8</td>
<td>3,441.7</td>
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<tr>
<td>Advanced Exploration Systems</td>
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<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
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<tr>
<td>Exploration Research and Development</td>
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<td>395.0</td>
<td>958.0</td>
<td>1,580.0</td>
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<tr>
<td>Space Operations</td>
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<td>4,749.2</td>
<td>4,639.1</td>
<td>4,285.7</td>
<td>4,426.0</td>
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<tr>
<td>Space Shuttle</td>
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<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
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<tr>
<td>International Space Station</td>
<td>1,436.0</td>
<td>1,451.0</td>
<td>1,493.0</td>
<td>–</td>
<td>1,458.2</td>
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<tr>
<td>Space Transportation</td>
<td>2,668.0</td>
<td>2,589.0</td>
<td>2,345.8</td>
<td>–</td>
<td>1,828.6</td>
<td>–</td>
</tr>
<tr>
<td>Space and Flight Support</td>
<td>923.0</td>
<td>903.0</td>
<td>910.3</td>
<td>–</td>
<td>848.9</td>
<td>–</td>
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<tr>
<td>Commercial LEO Development</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>40.0</td>
<td>150.0</td>
<td>–</td>
</tr>
<tr>
<td>STEM Engagement</td>
<td>115.0</td>
<td>100.0</td>
<td>100.0</td>
<td>110.0</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Safety, Security, and Mission Services</td>
<td>2,772.0</td>
<td>2,769.0</td>
<td>2,826.9</td>
<td>2,755.0</td>
<td>3,084.6</td>
<td>3,685.0</td>
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<tr>
<td>Center Management and Operations</td>
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<td>–</td>
<td>1,983.4</td>
<td>–</td>
<td>2,065.0</td>
<td>–</td>
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<tr>
<td>Agency Management and Operations</td>
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<td>843.5</td>
<td>–</td>
<td>1,019.6</td>
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<tr>
<td>Construction and Environmental Compliance and Restoration</td>
<td>446.0</td>
<td>485.0</td>
<td>569.5</td>
<td>348.2</td>
<td>604.0</td>
<td>–</td>
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<tr>
<td>Construction of Facilities</td>
<td>–</td>
<td>–</td>
<td>483.1</td>
<td>–</td>
<td>517.5</td>
<td>–</td>
</tr>
<tr>
<td>Environmental Compliance and Restoration</td>
<td>–</td>
<td>–</td>
<td>86.4</td>
<td>–</td>
<td>82.9</td>
<td>–</td>
</tr>
<tr>
<td>Inspector General</td>
<td>37.0</td>
<td>38.0</td>
<td>39.0</td>
<td>39.3</td>
<td>41.7</td>
<td>–</td>
</tr>
<tr>
<td>NASA Total</td>
<td>19,285.0</td>
<td>19,762.0</td>
<td>20,736.1</td>
<td>21,500.0</td>
<td>21,019.0</td>
<td>21,000.0</td>
</tr>
</tbody>
</table>

Year-to-Year Change¹: 7.1% 2.5% 5.5% 3.7% -2.2% -2.3%

¹ FY 2015 reflects funding amounts specified in the September 2015 Operating Plan per Public Law 113-235. FY 2016 reflects funding amounts specified in Public Law 114-113, Consolidated Appropriations Act, 2016, as executed under the Agency’s FY 2016 Operating Plan. FY 2017 reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017, as executed under the Agency’s FY 2017 Operating Plan. FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as executed under the Agency’s FY2018 Operating Plan. Table does not reflect emergency supplemental funds also appropriated in FY 2018, totaling $81.3 million. FY 2019 reflects only funding amounts specified in Public Law 115-254, Consolidated Appropriations Act, 2019. FY 2020 reflects only funding amounts specified in NASA FY 2020 Budget Request. FY 2020 reflects only funding amounts specified in the FY2020 Budget Request of the President.

Source: NASA
The 2018 budget for U.S. crew transportation services to the International Space Station (ISS) on Russian transportation systems decreased by USD $79 million (9.4%).\(^{24}\) The U.S. has bought seats on the Russian Soyuz spacecraft at a cost of $80 million each since the end of the Space Shuttle program in 2011. There are no designated seats for U.S. astronauts on Soyuz launches past 2019; however, NASA is considering reserving two additional seats for 2020 as a contingency plan should complications emerge in the 2019 test flights of the commercial SpaceX Crew Dragon and Boeing Starliner CST-1000.

The other significant decrease in the NASA 2018 budget was the James Webb Space Telescope allocation. An independent review board reported that “human errors, excessive optimism and the complexity of the spacecraft” delayed the launch twice and have already taken the program nearly USD $800 million, 10% over the capped $8 billion budget before its new launch date in 2023.\(^{25}\) The administration also proposed cutting the Wide Field Infrared Survey Telescope (WFIRST) astrophysics program in 2018;\(^{26}\) however, Congress did not act on the proposal, instead growing the program’s budget by 8.6% to USD $783 million.\(^{27}\)

### 1.1.2.2 National Oceanic and Atmospheric Administration (NOAA)

NOAA operates the National Environmental Satellite, Data, and Information Service (NESDIS), a global environmental monitoring system, and its components: the Environmental Satellite Observing Systems, the National Center for Environmental Information, and Procurement, Acquisition, and Construction (PAC) activities. The NESDIS budget decreased by 0.4% in 2018 to a total of almost USD $2.2 billion.\(^{28}\)

Of this decline, the National Center for Environmental Information's allocation decreased 4.3% to USD $58.7 million and the Environmental Satellite Observing Systems’ budget fell by 2.5% to USD $162.3 million. The National Center for Environmental Information program encompasses the operation of the ocean monitoring satellite Jason-3,\(^{29}\) and space weather monitoring satellite DSCOVR.\(^{30}\) The National Center for Environmental Information also incorporates the Office of Space Commerce, which the U.S. government utilizes to “facilitate commercial space marketplace.”\(^{31}\)

The majoriy of NESDIS funding, nearly 90% (USD $1.9 billion), was allocated to PAC activities. These activities include initiatives such as the Joint Polar Satellite System (JPSS) and Compact Coronagraph Development (CCOR) as well as satellite ground services (SGS).\(^{32}\) Under PAC, NOAA launched one satellite in 2018: GOES-17, the latest contribution to the Geostationary Operational Environmental Satellites-R (GOES-R) constellation.\(^{33}\)

### 1.1.2.3 National Science Foundation (NSF)

The NSF’s budget reached USD $7.4 billion in 2018, with an estimated 6.8% (USD $502.3 million) allocated to space applications under its Division of Atmospheric and Geospace Science (AGS). NSF funding overall decreased by 1.1% (USD $5.7 million) from 2017,\(^{34}\) a percentage that is then applied to the 2017 NSF figure in the Aeronautics and Space Report of the President to create an estimated 2018 NSF space budget figure.\(^{35}\)

The NSF funds surface-based space observation and telescope operations around the world: the Atacama Large Millimeter/Submillimeter Array (ALMA) in Chile; the Laser Interferometer Gravitational Wave Observatory (LIGO) in Louisiana; the twin Gemini Observatory telescopes located in China and Hawaii; the South Pole Telescope (SPT) in Antarctica; the Daniel K. Inouye Solar Telescope (DKIST) coming online in Hawaii in 2020; and, the Large Synoptic Survey Telescope (LSST) coming online in Chile in 2023.\(^{36}\)
Another AGS-funded program is the International Space Station (ISS) National Lab (formerly The Center for the Advancement of Science in Space, or CASIS) collaborations aboard the ISS. A third is the IceCube Neutrino Observatory located at the South Pole, which in 2018 discovered the “first evidence of one source of high-energy cosmic neutrinos.”

1.1.2.4 Department of Energy (DOE), Department of Interior (DOI), United States Department of Agriculture (USDA)

Three U.S. government agencies with space budgets comprise 0.7% (USD $337.2 million) of the total U.S. space budget: DOE, DOI, and the USDA). Estimates of the space-focused spending of each of these agencies are accomplished by applying the rate of change between the 2016 and 2017 figures for each agency in the Aeronautics and Space Report of the President to the 2017 figure for each agency.

Of the USD $337.2 million allocated between these three agencies, 59%, or almost USD $200 million, went to spinoffs such as Veggie, a deployable and expandable growth chamber on the ISS. Congress allocated an additional third (USD $111.3 million) of the USD $337.2 million to the DOI, whose U.S. Geological Survey (USGS) uses data from the Landsat Earth Observation constellation. The final 8% (USD $27.0 million) constitutes DOE space spending, including joint sponsorship and funding of NUDET with the USAF, and a NASA partnership supplying radioisotope power systems (RPSs), nuclear devices that power deep space exploration spacecraft.

1.1.2.5 Department of Transportation (DOT)

The DOT oversees the Federal Aviation Administration (FAA), the organization responsible for activities in the Office of Commercial Space Transportation (AST). AST issues commercial space transportation licenses and experimental permits. The Office also conducts safety inspections for the commercial space industry. The AST budget grew by 0.7% to USD $19.8 million.

1.2 The S-Network Space Index℠ Q4 2018 Performance

1.2.1 Introduction to the S-Network Space Index℠

Investor interest in the space industry has become more widespread in recent years, partly due to high-profile efforts to advance technology and create exciting new commercial services, and partly because of reports from major financial institutions that project annual space revenues in the trillions of dollars within the next two decades. However, most regular investors lacked a convenient way to participate in this growth because many of the companies that dominate media coverage today are private companies with limited opportunities for investment except by accredited investors, venture capital firms, or institutional investors. Although there are numerous publicly traded companies with activities in the space sector, investors unfamiliar with space were potentially at a disadvantage in terms of finding such companies and (in some cases) assessing the role that space activities play in the business operations of diversified companies that are primarily engaged in non-space business.

The S-Network Space Index℠ was established to address this information gap by tracking a portfolio of companies from around the world that are active in space-related businesses such as satellite-based telecommunications; transmission of television and radio content via satellite; rocket 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. Unlike other indexes that combine space with other sectors such as defense or deep sea exploration, the S-Network Space Index is considered a “pure-play” space index. 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.
The creators of the S-Network Space Index are pleased to announce that it is the first Certified Space Data Product™ under the Space Foundation’s Space Certification Program™. The Space Data Products category is the newest addition to the Space Certification Program, recognizing products and services that either use data collected from space systems or provide data about space and the space industry.

1.2.2 Index Methodology
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 volume 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.

1.2.3 Index Performance
As was the case with the broader global market, the S-Network Space Index (SNET SPACE) trended downward in the fourth quarter of 2018, declining by 18.0%. This trend was greater than the 14.8% decline experienced by the S-Network US Equity 3000 Index (SNET 3000), which tracks the 3,000 largest (by market capitalization) U.S. stocks. Of the three indexes shown in Exhibit 1j, the best fourth-quarter performance was seen in the 13.3% decline of 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.

EXHIBIT 1j. S-Network Space Index vs. Benchmark Indexes, Q4 2018
Assessing the performance of the S-Network Space Index since live calculation began on May 7, 2018, the picture is a little different—SNET SPACE outperformed both of the other indexes as shown in Exhibit 1k. Despite the downward market trend in the fourth quarter of 2018, SNET SPACE ended 2018 with only a 5.4% decline due to its stronger performance earlier in the year, as compared to a 6.3% drop for the SNET 3000 and a 9.6% drop for the SNET Global 2500.

1.2.4 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. As of September 2018, when the index underwent quarterly rebalancing, U.S. companies comprised 62.7% of the weight of the overall index, with France in second place at 14.5%. The United Kingdom, Canada, Japan, Australia, and Italy were also represented in the index.

The constituent companies of the index as of September 21, 2018, are listed in Exhibit 1m. Although this list was in effect throughout most of the fourth quarter, changes were made at two points in time:

- After Sky was acquired by Comcast, it was removed from the index when its stock was delisted from the London Stock Exchange in November 2018. This deal was similar to AT&T’s acquisition of DIRECTV, completed in July 2015, as both transactions consisted of major terrestrial television providers adding direct-to-home satellite television to their portfolio of services.

- The index underwent its semi-annual reconstitution—adding new companies and dropping current companies according to the index rules—on December 21, 2018. At that time, Global Eagle Entertainment was removed from the index as it no longer met the financial criteria for inclusion. Four companies were also added to the index, all of which are listed on U.S. exchanges: Raytheon (RTN), Harris (HRS), Honeywell (HON), and L3 (LLL). In October 2018, Harris and L3 announced plans for a merger of equals that is expected to be complete sometime in mid-2019, subject to shareholder approvals, regulatory clearances, and other customary closing conditions.

The performance of the constituent companies was generally downward in the fourth quarter, but there were two notable outliers:

- Globalstar (up 28%): the increase was almost entirely due to a bump during the last few trading days of 2018. However, the stock was down 50% for the year as a whole.

- Maxar Technologies (down 61%): the company reported a substantial quarterly loss in its Q3 2018 earnings report, as well as a 31% year-over-year decline in GEO communications satellite revenue. Despite positive results in other lines of business, these factors contributed to an immediate drop in the company’s stock, which did not recover by the end of 2018.
1.2.5 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.

This document is provided solely for informational and educational purposes and is neither an offer to sell nor a solicitation of an offer to buy the securities described herein. S-Network Global Indexes Inc. and Space Investment Services LLC do not guarantee the accuracy and/or the completeness of the S-Network Global Index(es) or any data included therein and shall have no liability for any errors, omissions, or interruptions therein. S-Network Global Indexes Inc. makes no express or implied warranties, and expressly disclaims all warranties of merchantability or fitness for a particular purpose or use with respect to the S-Network Global Index(es) or any data included therein. Without limiting any of the foregoing, in no event shall either company have any liability for any special, punitive, indirect, or consequential damages (including lost profits), even if notified of the possibility of such damages.

EXHIBIT 1k. S-Network Space Index Constituents as of 21 September 2018

<table>
<thead>
<tr>
<th>Company</th>
<th>Ticker</th>
<th>Country</th>
<th>2018 Q4 Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerojet Rocketdyne Holdings</td>
<td>AJRD US</td>
<td>United States</td>
<td>6%</td>
</tr>
<tr>
<td>Airbus</td>
<td>AIR FP</td>
<td>France</td>
<td>-22%</td>
</tr>
<tr>
<td>AT&amp;T</td>
<td>T US</td>
<td>United States</td>
<td>-15%</td>
</tr>
<tr>
<td>Ball</td>
<td>BLL US</td>
<td>United States</td>
<td>5%</td>
</tr>
<tr>
<td>Boeing</td>
<td>BA US</td>
<td>United States</td>
<td>-16%</td>
</tr>
<tr>
<td>Dish Network</td>
<td>DISH US</td>
<td>United States</td>
<td>-30%</td>
</tr>
<tr>
<td>Echostar Holding</td>
<td>SATS US</td>
<td>United States</td>
<td>-19%</td>
</tr>
<tr>
<td>Eutelsat Communications</td>
<td>ETL FP</td>
<td>France</td>
<td>-16%</td>
</tr>
<tr>
<td>Garmin</td>
<td>GRMN US</td>
<td>United States</td>
<td>-9%</td>
</tr>
<tr>
<td>Global Eagle Entertainment</td>
<td>ENT US</td>
<td>United States</td>
<td>-3%</td>
</tr>
<tr>
<td>Globalstar</td>
<td>GSAT US</td>
<td>United States</td>
<td>28%</td>
</tr>
<tr>
<td>Inmarsat</td>
<td>ISAT LN</td>
<td>United Kingdom</td>
<td>-23%</td>
</tr>
<tr>
<td>Intelsat</td>
<td>I US</td>
<td>United States</td>
<td>-31%</td>
</tr>
<tr>
<td>Iridium Communications</td>
<td>IRDM US</td>
<td>United States</td>
<td>-18%</td>
</tr>
<tr>
<td>Leonardo</td>
<td>LDO IM</td>
<td>Italy</td>
<td>26%</td>
</tr>
<tr>
<td>Lockheed Martin</td>
<td>LMT US</td>
<td>United States</td>
<td>-25%</td>
</tr>
<tr>
<td>Loral Space &amp; Communications</td>
<td>LORL US</td>
<td>United States</td>
<td>-20%</td>
</tr>
<tr>
<td>Maxar Technologies</td>
<td>MAXR CN</td>
<td>Canada</td>
<td>-61%</td>
</tr>
<tr>
<td>Northrop Grumman</td>
<td>NOC US</td>
<td>United States</td>
<td>-23%</td>
</tr>
<tr>
<td>Orbcomm</td>
<td>ORBC US</td>
<td>United States</td>
<td>-24%</td>
</tr>
<tr>
<td>SES</td>
<td>SESG FP</td>
<td>France</td>
<td>-14%</td>
</tr>
<tr>
<td>Sirius XM Holdings</td>
<td>SIRI US</td>
<td>United States</td>
<td>-9%</td>
</tr>
<tr>
<td>Sky Perfect Jsat Holdings</td>
<td>9412 JP</td>
<td>Japan</td>
<td>-14%</td>
</tr>
<tr>
<td>Sky</td>
<td>SKY LN</td>
<td>United Kingdom</td>
<td>Acquired by Comcast</td>
</tr>
<tr>
<td>Speedcast International</td>
<td>SDA AU</td>
<td>Australia</td>
<td>-26%</td>
</tr>
<tr>
<td>Thales</td>
<td>HO FP</td>
<td>France</td>
<td>-17%</td>
</tr>
<tr>
<td>Trimble Navigation</td>
<td>TRMB US</td>
<td>United States</td>
<td>-24%</td>
</tr>
<tr>
<td>Viasat</td>
<td>VSAT US</td>
<td>United States</td>
<td>-6%</td>
</tr>
</tbody>
</table>
Snapshots: The U.S. Government Space Budget in 2018 | Total $48.31 B
These visualizations illustrate the composition of U.S. government space spending in 2018, totaling USD $48.3 billion. In the graphic below, each square block represents USD $1 billion and each circle represents USD $10 million.

U.S. Government Space Budgets

- Department of Defense (DoD) – $24.53 B
- National Aeronautics and Space Administration (NASA) – $20.74 B
- National Oceanic and Atmospheric Administration (NOAA) – $2.19 B
- National Science Foundation (NSF) – $0.50 B
- Other – $0.36 B

Global Government Space Spending, 2018

- U.S. Government Space Spending
  - $28.91 B (37.44%)
- Non-U.S. Government Space Spending
  - $48.31 B (62.56%)

Total: $77.22 Billion

Rate of Change in U.S. Government Space Spending, 2009–2018

- 2009
- 2010
- 2011
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
- 2018

Rate of Change Relative to 2009

- 10%
- 5%
- 0%
- -5%
- -10%
- -15%
2.0 Introduction  |  The global space industry employs hundreds of thousands of highly-skilled individuals to design, produce, and operate cutting-edge technology. This workforce, in turn, contributes to thriving local economies, with clusters of innovative companies and service support industries. Understanding trends in the space workforce, including its overall size and composition, provides a way to track the health of the industry. This data can help to identify current and future challenges and opportunities for local communities and the entire space industry.

Engineers ensure a protective aeroshell is properly installed around NASA's Mars InSight lander. Credit: NASA/JPL-Caltech/Lockheed Martin

2.1 U.S. Space Workforce

The U.S. space workforce consists of more than 179,000 workers across the commercial*, civil, and national security sectors. The majority of these professionals, 135,000, are working in the private sector, focused on development and manufacturing of new space systems, as well as providing services such as satellite telecommunications. The U.S. government employs 44,000 space professionals, with 17,000 working for the National Aeronautics and Space Administration (NASA), and more than 27,000 working in the Defense and Intelligence communities. Although trends vary among and within each of these areas, as a whole, U.S. space employment grew from 2017 to 2018.

2.1.1 Space Industry Employment

The U.S. Bureau of Labor Statistics (BLS) publishes information about employment in the United States in its Quarterly Census of Employment and Wages. This survey covers more than 95% of U.S. jobs and provides a reliable and consistent measure with which to identify and evaluate employment trends over time. As of January 2019, the most recent data available includes full-year employment estimates for 2017 and preliminary estimates for the first half of 2018.1

BLS categorizes the U.S. workforce using the North American Industry Classification System (NAICS). There are more than 15 NAICS codes that include some space activity. However, for most of these, space constitutes only a small portion of the category. For example, workers involved in direct broadcast satellite services and direct-to-home satellite services are included in the Wired Telecommunications Carriers code, but this code also includes internet service providers and telephone carriers using wired telecommunications infrastructure – activities that are much larger in scope.2

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* Throughout this section the terms ‘private’ and ‘commercial’ are used interchangeably to refer to workers that are not employed by federal, state, or local government.
For this analysis, five NAICS designations are used to represent the commercial U.S. space industry workforce: Broadcast and Wireless Communications Equipment Manufacturing, Guided Missile and Space Vehicle Manufacturing, Space Vehicle Propulsion Units and Parts Manufacturing, Other Guided Missile and Space Vehicle Parts, and Satellite Telecommunications. Space workers likely make up a large portion of each of these categories, allowing them to be used to gain insight into trends in the U.S. space industry as a whole.1

2.1.1 National Employment Trends
The commercial U.S. space industry workforce grew 3.1% from 2016 to 2017, reaching 132,086 workers. This increase reverses a trend stretching back nearly a decade, to 2008. Preliminary numbers from 2018 suggest that this increase will continue. Growth in the space industry from 2016 to 2017 was nearly double the rate of the total U.S. private industry, which grew 1.6% over that same period. Still, the space industry remains significantly smaller than it was 10 years ago, with significant growth needed to match trends in the overall economy. While the overall U.S. private industry workforce is 7.3% larger in 2017 than it was in 2007, the commercial space workforce remains 15.1% smaller.2

Growth in the space industry from 2016 to 2017 occurred across four of the five sectors considered in this analysis. Guided Missile and Space Vehicle Manufacturing added the largest number of workers, increasing by 3,669 professionals to reach a total of 59,634 workers in 2017. Although the absolute gains were smaller, the growth rates within the Other Guided Missile and Space Vehicle Parts, and Satellite Telecommunications sectors were the highest among the five sectors, at 8.2% and 7.2%, respectively. Only Broadcast and Wireless Communications Equipment Manufacturing experienced a decline from 2016 to 2017, falling by 562 individuals, a decrease of 2.1%.3


<table>
<thead>
<tr>
<th>Category Name and NAICS* Code</th>
<th>2007</th>
<th>2012</th>
<th>2016</th>
<th>2017</th>
<th>10-Year Change</th>
<th>5-Year Change</th>
<th>1-Year Change</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadcast and Wireless</td>
<td>66,809</td>
<td>61,872</td>
<td>49,494</td>
<td>48,470</td>
<td>-27.4%</td>
<td>-21.7%</td>
<td>-2.1%</td>
<td>Includes manufacturing search, detection, navigation, guidance, aeronautical, and nautical systems and instruments.</td>
</tr>
<tr>
<td>Communications Equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing (NAICS Code: 334220)</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Guided Missile and Space</td>
<td>53,068</td>
<td>54,583</td>
<td>55,965</td>
<td>59,634</td>
<td>12.4%</td>
<td>9.3%</td>
<td>6.6%</td>
<td>Includes manufacturing complete guided missiles and space vehicles and/or developing and making prototypes of guided missiles or space vehicles.</td>
</tr>
<tr>
<td>Vehicle Manufacturing</td>
<td></td>
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<td></td>
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<tr>
<td>(NAICS Code: 336414)</td>
<td></td>
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</tr>
<tr>
<td>Guided Missile and Space</td>
<td>14,875</td>
<td>10,867</td>
<td>9,735</td>
<td>10,030</td>
<td>-32.6%</td>
<td>-7.7%</td>
<td>3.0%</td>
<td>Includes manufacturing guided missiles and/or space vehicle propulsion units and propulsion unit parts and/or developing and making prototypes of guided missile and space vehicle propulsion units and propulsion unit parts.</td>
</tr>
<tr>
<td>Vehicle Propulsion Unit and</td>
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<td></td>
<td></td>
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<tr>
<td>Propulsion Unit Parts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing (NAICS Code: 336415)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Other Guided Missile and Space</td>
<td>7,557</td>
<td>6,751</td>
<td>5,132</td>
<td>5,553</td>
<td>-26.5%</td>
<td>-17.7%</td>
<td>8.2%</td>
<td>Includes manufacturing guided missile and space vehicle parts and auxiliary equipment (except guided missile and space vehicle propulsion units and propulsion unit parts) and/or developing and making prototypes of guided missile and space vehicle parts and auxiliary equipment.</td>
</tr>
<tr>
<td>Vehicle Parts and Auxiliary</td>
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<tr>
<td>Equipment Manufacturing (</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>NAICS Code: 336419)</td>
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<td></td>
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</tr>
<tr>
<td>Satellite Telecommunications</td>
<td>13,226</td>
<td>10,266</td>
<td>7,837</td>
<td>8,399</td>
<td>-36.5%</td>
<td>-18.2%</td>
<td>7.2%</td>
<td>Includes telecommunications services provided to other establishments in the telecommunications and broadcasting industries by forwarding and receiving communications signals via a system of satellites or reselling satellite telecommunications.</td>
</tr>
<tr>
<td>(NAICS Code: 517410)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Space Industry Employment</td>
<td>155,535</td>
<td>144,339</td>
<td>128,163</td>
<td>132,086</td>
<td>-15.1%</td>
<td>-8.5%</td>
<td>3.1%</td>
<td>Total</td>
</tr>
</tbody>
</table>

*North American Industry Classification System
Source: U.S. Bureau of Labor Statistics

Overall space employment increases align with the Bureau of Labor Statistics’ predictions published in its Occupational Outlook Handbook (OOH). Unlike the BLS industry statistics reported above, which use the NAICS codes, the OOH classifies workers into occupational categories. According to the Bureau’s analysis, employment of Aerospace Engineers, as well as Aerospace Engineering and Operations Technicians, is expected to grow by 6% and 7%, respectively, from 2016 to 2026. Employment for those in the sciences, including astronomers and atmospheric scientists, is expected to grow even more rapidly over this period, at rates of 10% and 12%, respectively.4

BLS notes that opportunities for employment with private space companies are expected to increase as spaceflight activity continues to shift from government agencies to the private sector. The rising demand for and greater commercial viability of small satellites are also driving this trend.
Salary trends also suggest that space industry jobs remain in high demand. The average space salary is nearly $118,000, more than double the average salary for all U.S. private sector jobs of $55,000. Individuals working in the Guided Missile and Space Vehicle sector, which saw significant growth from 2016 to 2017, had an average salary of $134,853 in 2017. With the exception of Other Guided Missile and Space Vehicle Parts and Auxiliary Equipment Manufacturing, all sectors saw real growth in wages from 2012 to 2017.

2.1.1.2 State Space Industry Employment Trends

In addition to federal-level information, the BLS Quarterly Census of Employment and Wages provides space employment data at the state level. This analysis focuses on the same five NAICS codes identified above and thus does not include workers in the many NAICS codes in which space constitutes only a small portion of the category.

The state-level data underestimate the true number of space workers in an additional way: the Bureau of Labor Statistics does not disclose the number of workers in cases where doing so may reveal information about individual employers — for example, in cases where one or two companies make up the majority of the employment for a particular state and sector. This non-disclosure rule can help to explain why, for instance, BLS data shows total space employment in Alabama to include only about 400 workers in 2017, even though United Launch Alliance alone employs more than 600 workers in its Decatur, Alabama, facility. The number of Guided Missile and Space Vehicle Manufacturing (NAICS Code: 336414) employees in Alabama is not disclosed, and thus not included in the overall count, likely because the majority of these workers are those employed by ULA.

Many states have economic development and other agencies that provide estimates of the number of space workers in their area, but the definitions and processes used to develop these estimates differ from organization to organization, making inter-state comparisons and assessments difficult. For example, the Los Angeles County Economic Development Corporation (LAEDC) estimates that more than 90,000 individuals worked in the aerospace industry in southern California in 2016. However, this total includes aircraft manufacturing and other aviation-related activity, in addition to space workers. Similarly, the Metro Denver Economic Development Corporation estimates that Colorado employed more than 21,000 aerospace workers in 2016, but this number seems to include workers beyond those working strictly on space-related efforts. The Colorado Space Coalition reports nearly 200,000 space-related jobs in the state, which likely includes military and civil government workers, in addition to private space employment.
While the state-level BLS data has its limitations, it is useful for providing information regarding the geographic distribution of the space industry and the changes over time within these states. The following analysis discusses these trends.

BLS data shows space professionals working in nearly every state, with large clusters of space professionals in selected states. California tops the list with nearly 40,000 employed in the private space industry in 2017. The space industry in California remains strong, despite setbacks, such as the 10% cut to SpaceX’s workforce announced in early 2019, which occurred primarily within the company’s Hawthorne, California, headquarters. An expert at LAEDC expressed confidence that the employees leaving SpaceX would have no difficulty finding new jobs in the area, with Northrop Grumman, Boeing, Lockheed Martin, and others continuing to hire.

Florida represents another major space employment hub, with approximately 11,000 private-industry space workers. Florida’s Space Coast was selected “Turnaround of the Year” for the 2018 Awards for Excellence & Innovation by SpaceNews. The Space Coast unemployment rate dropped from 11.8% in 2010, coinciding with the end of the Space Shuttle program, to 3% in 2018. Part of Florida’s strategy was to attract new, entrepreneurial space companies, augmenting its existing strengths in government space activity. Florida officials noted that despite the SpaceX layoffs in California, the company was continuing to hire in Florida. The state has also welcomed the development of facilities by Blue Origin and OneWeb.

EXHIBIT 2g. State-Level Space Industry Employment, 2018

California and Florida are home to the largest number of space workers. However, many other states have a strong and growing space industry presence. As an example, Colorado, home to Space Foundation headquarters, has long been a hub for military space activity. The Air Force Space Command is headquartered at Peterson Air Force Base in Colorado Springs, attracting many space defense companies to the area. In recent years, the state has also been encouraging the growth of private space enterprise, with a goal of becoming the Silicon Valley of aerospace. The Metro Denver Economic Development Corporation states that more than 50% of Colorado aerospace companies employ 10 people or fewer, reflecting this entrepreneurial focus.
Similar to national trends, the five states with the largest space employment have experienced decreases in their workforce over the past decade. However, many are also experiencing the recent reverse in this trend. California, Florida, and Virginia saw increases from 2016 to 2017. Average annual salaries are high in each of these locations, as well: California space workers make an average of nearly $140,000 and Virginia space workers make $128,000 on average.19

2.1.3 Workforce Diversity
Diversity and inclusion are an important aspect of maintaining a cutting-edge workplace. In addition to its intrinsic value, diversity has been found to increase company productivity.20 Despite growing attention to the need for diversity, females and minorities remain underrepresented in the space industry. The 2018 Aviation Week Workforce Study reports that within the Aerospace and Defense Industry, about 24% of the workforce is female, and minorities make up 26.7% of the workforce. Black, Hispanic, and Asian-Americans are represented at 6.8%, 7.6%, and 10.0%, respectively. All of these values fall approximately by half when considering representation in executive-level roles.21

The U.S. Equal Employment Opportunity Commission (EEOC) offers another source for examining this issue. While they do not provide data associated with the full 6-digit NAICS codes used in the employment analysis above, data is available at the higher-level 3-digit NAICS designation. This data shows that in 2016 in the field of Transportation Equipment Manufacturing (NAICS code 336), women made up 23.3% of the workforce while minorities accounted for 29.5% of the workforce. In the Telecommunications sector (NAICS code 517), females made up 37.6% of the workforce and minorities made up 37.3% of the workforce.22

Similar to the finding in the Aviation Week Workforce Study, EEOC data shows that representation drops significantly when looking at women and minorities in senior-level positions. In Transportation Equipment Manufacturing, women make up 13.9% of senior-level officials, while minorities account for 13.2% of these positions. In Telecommunications, women and minorities make-up 21.5% and 15.9% of these positions, respectively.23

The challenges faced by the space sector mirror those of the tech sector more broadly. Many tech firms, such as Apple, Google, and Microsoft, have similarly low representation of women and minorities, according to diversity reports released by these companies. At Apple, women make up 32% of the workforce and African Americans make up 9% of the workforce.24 Google’s workforce is 31% female and 2.5% African American, and Microsoft’s workforce is 36% female and 4% African American.25 These and many other companies in the tech industry have put programs in place aimed at improving this situation, including annual public reporting on workforce statistics.

Within the space industry, many companies – Boeing, Lockheed Martin, and Northrop Grumman, for example – have diversity and inclusion initiatives that aim to increase the number of women and minority employees.26 However, only Northrop Grumman publicly releases statistics on workforce demographics (27% female, 24.5% people of color).27 Others, particularly SpaceX, have been criticized for their lack of attention to this issue as a whole.28 Diversity and inclusion in the space industry are only likely to improve to the extent that companies prioritize these efforts.

2.1.2. NASA Workforce
NASA employed 17,373 workers as of the beginning of FY 2019. This total has remained steady in recent years, in part because of a hiring freeze instituted in early 2017.29 Overall, the NASA workforce has declined by 9.0% since 2014. The agency is nearly a third smaller than it was 25 years ago in 1994.30

Still, the agency is an important source of space jobs around the United States, particularly at Goddard Space Flight Center in Maryland and Johnson Space Center in Texas, each home to more than 3,000 NASA employees, and at Kennedy Space Center in Florida and Marshall Space Flight Center in Alabama, which each exceed 2,000 workers. Virginia, Ohio, California, Mississippi, and Washington, D.C., also house significant portions of the NASA workforce.31
Based on responses to the Federal Employee Viewpoint Survey administered by the Office of Personnel Management, NASA was named the best place to work in the federal government by the nonprofit Partnership for Public Service for the seventh straight year in a row. Rankings are based on an assessment of employee engagement, which includes job satisfaction, satisfaction with the organization as a whole, and the percentage of workers who would recommend their organization as a good place to work.³²

Satisfaction about salary is one of the few areas in which NASA survey responses in 2018 were lower than in previous years.³³ In 2017, the average salary at NASA was $122,551. While this is still slightly higher than the average private sector space salary, it represents a decrease in real terms from the average NASA salary in 2016. NASA salaries were about 1% lower in 2017 than they were in 2016.³⁴

NASA was one of only 13 federal agencies that ranked higher than the private sector average in terms of overall employee engagement. However, many worry that the type of high-skilled workers employed at agencies such as NASA may choose to transition to the private sector due to growing challenges for government workers, including hiring and salary freezes, and, most recently, the longest U.S. government shutdown in history. Approximately 95% of NASA employees were furloughed during the shutdown in December 2018 and January 2019.³⁵

Disillusionment with government service may also affect recruiting efforts, a particular concern for NASA as the agency continues to actively work to restore balance to an aging workforce. In FY 1994, 31.3% of the NASA workforce was under 35, and 18.1% was over 54. At the beginning of FY 2019, the opposite was true: 36.6% of NASA’s workforce was over 54, while only 16.1% was under 35. Part of this trend is due to the choice of many employees to work past the traditional age of retirement; 21.8% of NASA’s workforce is eligible to retire as of the beginning of FY 2019.³⁶

NASA continues to make efforts to improve diversity as well. In FY 2017, minorities made up 28.3% of the overall NASA workforce but only 13.7% of senior-level employees. Women made up 34.2% of the overall NASA workforce in FY 2017 and 16.1% of senior-level employees.³⁷ NASA continues to execute its diversity and inclusion strategic implementation plan to recruit and retain workers with a wide variety of backgrounds.³⁸

NASA also tries to support women and minorities through its Office of Small Business Programs (OSBP). NASA contracts with hundreds of businesses throughout the country. In doing so, they aim to ensure that Women-Owned Small Businesses account for 5% of total prime and subcontract value and that Historically Black Colleges and Universities and Minority Institutions (HBCU/MI) account for 1%.³⁹

Throughout 2018, NASA continued its HBCU/MI Technology Infusion Road Tour, helping to make connections between NASA officials and HBCU and MI representatives to raise awareness about opportunities to work with NASA.⁴₀
2.1.3 U.S. National Security Space Workforce

The U.S. National Security Workforce includes military professionals and civilians working in the Department of Defense and the Intelligence Community. In 2018, there were more approximately 27,000 national security space professionals in the United States.

The importance and organization of military space activities have received significant attention in the past year, following President Trump’s June 2018 statement that he would direct the Pentagon to establish a Space Force as a sixth branch of the armed forces.41 A plan released by the Pentagon in August 2018 noted that one of the steps the Defense Department will take in preparation for standing up a Space Force would involve building an elite group of space officers called the “Space Operations Force.” This group will provide space expertise in times of crisis and conflict.42 As of the beginning of 2019, however, the military space workforce continues to be managed within each of the existing services.

2.1.3.1 United States Air Force

The Air Force is home to the largest portion of the U.S. military space workforce. In 2018, 11,622 officer, enlisted, and civilian employees made up the Air Force Space Cadre, which includes astronauts, space operations officers, space systems operation enlisted duty, geospatial intelligence enlisted duty, and Air Force Space Command civilians. The Air Force Space Cadre decreased by more than 800 individuals from 2017 to 2018, a reduction of about 6.5%. Most of the decreases occurred among Space Operations Officers, which fell by 158 individuals, nearly 10%, and Geospatial Intelligence Enlisted Duty, which decreased by 571 individuals over that time, an 18.4% decrease. The decrease seen over the previous year continues a trend that began following a high of 14,589 space workers in 2011. The Air Force Space Cadre is about 20% smaller now than it was at that time.43

Despite this downward trend in total size, the Air Force remains committed to training the highest quality space professionals. In 2018, the Air Force inaugurated the first class for a new space immersion concentration at the Air Command and Staff College. Referred to as Schriever Scholars, these individuals are being trained to be experts in the integration of space and space-based capabilities into joint warfighting efforts.44

2.1.3.2 United States Army

The U.S. Army has seen significant growth of its space workforce in recent years, aided by the introduction of a new Army Space Training Strategy in 2013. The strategy has helped to raise awareness and interest in space capabilities.45 In FY 2018, the Army had 4,948 billets composing its space workforce. That is more than double the number in FY 2011, the earliest year for which data is publicly available when there were 2,350 space cadre billets.46

As of 2018, the Army maintains a space cadre nearly half as large of that of the U.S. Air Force. About 8% of these individuals, 404 in FY 2018, are Space Operations Officers, with responsibility for formulating policy, developing operational concepts, conducting research, developing technologies and planning, and evaluating and implementing the tactics and techniques for the operation and use of space systems.47
The Army is one of the largest users of space – more than 70% of the Army’s major weapons, and equipment need satellites to function. It is also a provider of space-based capabilities, operating a constellation of small communications satellites as well as a remote sensing satellite used by Army commanders. Training and maintaining a large space cadre ensures that the Army will have individuals that understand how space assets are integrated into warfighting capabilities and that there are individuals able to manage Army space systems.

2.1.3.3 United States Navy

The U.S. Navy maintains a much smaller, but still significant, space cadre, made up of 488 Naval Officers in 2018. The professionals include those who have received education, training, and some experience in space-related missions over the course of their careers. A small fraction of these individuals are conducting direct space operations or space acquisitions at any given time. The majority of them are executing their primary duties day-to-day, at sea and ashore, as Information Officers, Surface Warfare Officers, Naval Aviators, and Submariners. The U.S. Navy Space cadre is in the process of reviewing and updating its space cadre billet list.

The Marine Corps also maintains a space cadre, made up of Space Operations Officers and Space Operations Staff Officers. Marines in these specialty areas have completed required courses and training related to space, and are involved in the integration of space operations within Marine Corps operations. As of January 2019, 84 billets required or recommended the Marine Corps space designators, including 14 billets requiring the Space Operations Officer skill and 70 billets that require or recommend the Space Operations Staff Officer skill. More than 200 Marines hold one of these skill designators.

2.1.3.4 United States Coast Guard

The U.S. Coast Guard does not have an official space designation within its workforce. However, it has begun working on space-related projects within its Research and Development Center. On December 3, 2018, the Coast Guard launched two CubeSats designed to detect signals from emergency distress beacons in the Arctic and evaluate the effectiveness of space-based sensors in support of Arctic search and rescue missions. It has also initiated an assessment to evaluate all potential satellite sensor and payload combinations that could help the Coast Guard accomplish its missions.

2.1.3.5 Intelligence Community

The intelligence community includes numerous space professionals, primarily concentrated within the National Geospatial-Intelligence Agency (NGA), the National Reconnaissance Office (NRO), and the Defense Intelligence Agency (DIA). These organizations employ military professionals, including the service professionals certified in space discussed previously, intelligence agencies, civilians, and contractors.

NGA is the nation’s primary source of geospatial intelligence, which it provides in support of U.S. national security and defense, as well as disaster relief. The agency employs approximately 14,500 people, and about 48% of these individuals – 6,960 people – work with satellite data in some capacity.

The NRO designs, acquires, launches, and operates the U.S. space reconnaissance satellites. To do so, it maintains a workforce of approximately 3,000 scientists, engineers, communications systems specialists, mission support personnel, and program and acquisition managers.

DIA provides military intelligence to the Department of Defense and the Intelligence Community to support military planning and operations and weapon system acquisitions. The agency is home to the Missile and Space Intelligence Center, which provides insight into space-related developments. However, DIA does not disclose the portion of its 16,500-person workforce that is focused on space issues. For this reason, its workforce is not included in the calculation of totals for the purposes of this report.
3.0 Introduction | As of March 6, 2019, information was available about 38 nations that deployed and operated 465 spacecraft during 2018. The number of nations operating spacecraft grew 10% from 2017 to 2018, with 75 total nations operating spacecraft. While the 465 deployed spacecraft is a record number, beating 2017’s 443, the percentage growth of spacecraft deployed from 2017 to 2018 did not match the percentage growth of launch attempts that year.

The Parker Solar Probe sits atop its ride to the Sun, one half of the launch vehicle’s fairing positioned behind.
Credit: NASA/Johns Hopkins APL/Ed Whitman

3.1 Spacecraft/Satellites
3.1.1 Spacecraft Overview
Space launch vehicle (SLV) launch attempts in 2018 grew to 114, a 25% increase from 2017’s 91. The increase in spacecraft deployments during that same period was 5%.

Before further considering these numbers, readers should be aware that a full 20% (92) of the 465 spacecraft deployed in 2018, have not yet been identified officially in The Space Report’s (TSR) primary source, the United States (U.S.) Air Force’s (USAF) online spacecraft data repository, Space-Track.org. All numbers reported in the Spacecraft/Satellite portion of this release of the Report are based on data from Space-Track.org as of March 6, 2019.

These numbers will change as spacecraft are identified during 2019. The number of unidentified objects may indicate the challenges the USAF is facing given the limited assets it has compared to the annual growth in the number of spacecraft deployed; complicating this identification process are the challenges of identifying small satellites such as cubesats (and even smaller ones) from hundreds to thousands of miles away.

The next quarter’s publication of TSR will provide an updated spacecraft overview and summary.

As noted above, 38 nations deployed and operated spacecraft in 2018. As this report is a snapshot of 2018 activities and not intended as a comprehensive list, not all 38 of those nations are covered in the Infrastructure sections for spacecraft and satellites. Data regarding the spacecraft of those countries is available to subscribers of The Space Report Online, the data repository for these quarterly TSR releases.

The data within the following sections of Infrastructure in this TSR release (Communications Satellites; Positioning, Navigation and Timing (PNT) Satellites; and Earth Observation/Remote Sensing (EO/RS) Satellites) will, more often than not, focus on the three countries, organizations, and companies with the largest share of spacecraft activities within each section.
3.1.1.1 Spacecraft Mission Segment Breakdown

There were 465 spacecraft deployed from 112 successful launches as well as deployments from the International Space Station (ISS) in 2018. Of those, commercial missions were the largest share, accounting for a 36% share of deployed spacecraft (166). While the highest 2018 share, the number and share of commercial spacecraft deployed last year fell from 2017’s deployment of 272 commercial spacecraft, a 61% share of the spacecraft deployed that year and a drop of 39% from 2017. The next-highest share went to civil government missions, with 29% (136) of spacecraft deployed for that mission segment. The military mission segment accounted for 15% (71) of all spacecraft deployed in 2018. The remaining 20% (92) of the 465 spacecraft deployed in 2018 had not been identified as of March 6, 2019.

The three satellite operators with the largest shares of commercial spacecraft deployments in 2018 were Planet, Spire Global, and Iridium. The 38 satellites Planet deployed in 2018 netted a 23% share of the 166 commercial spacecraft. Spire’s 28 satellites accounted for a 17% share of the total number of commercial spacecraft deployed in 2018. Iridium’s 25 satellites took a 15% share of the deployments.

Three civil government operators, Russia’s Roscosmos, the European Space Agency (ESA), and the U.S.’s National Aeronautics and Space Administration (NASA), had the largest shares of 2018’s civil government spacecraft deployments. Roscosmos deployed ten civil government spacecraft, a 7% share of the 136 civil government spacecraft deployed in 2018. ESA and NASA each deployed eight civil government spacecraft in 2018 (6% each of all civil government spacecraft deployed that year).

Twelve nations deployed military satellites in 2018. Of those, the four organizations with the largest shares of military satellites deployed came from three nations—China, Russia and the U.S. China’s Satellite Navigation Office launched the largest share of military satellites in 2018, 25% (18). The USAF deployed the next largest share, 13% (9). The Chinese Academy of Sciences and Russia’s Ministry of Defense each deployed six military satellites (a 9% share each).

3.1.1.2 Spacecraft Payload Type Breakdown

Optical payloads made up the largest share of the 465 spacecraft deployed in 2018 (31%). These 144 optical satellites were deployed for collecting images of the Earth’s surface and weather. Automated maritime tracking communications systems followed with 8% (36) of 2018’s total spacecraft deployments. A new weather forecasting satellite payload, Global Positioning System-Radio Occultation (GPS-RO), accounted for 7% (31) of those deployments.
Multiple payloads are increasingly residing on the same satellite. For example, EUMETSAT’s Sentinel-3B hosts both optical and synthetic aperture radar (SAR) payloads. Spire Global’s Lemur-2 cubesats host at least five different payloads, including optical, Automated Information Systems (AIS; for maritime tracking), and GPS-RO.

### 3.1.3 Spacecraft Country Breakdown

Three nations accounted for 58% (271) of the 465 spacecraft deployed in 2018: the U.S., China, and Russia. The U.S. was the nation with the largest share of spacecraft deployed through its agencies, companies, and other organizations. U.S. space operators deployed 180 spacecraft, 39% of the 465 spacecraft deployed in 2018. This percentage is a drop in the U.S.’s overall spacecraft deployment activity when compared to 2017, when the U.S. accounted for 65% (286 spacecraft) of that year’s total number of deployed spacecraft. China’s space operators followed, deploying 73 spacecraft in 2018, 16% of all spacecraft deployed in 2018. Russia accounted for the remaining 18 spacecraft (4% of 2018’s spacecraft deployments).

The three spacecraft operators with the largest shares of 2018’s deployed spacecraft are based in the U.S.: Planet, Spire Global, and Iridium. These three commercial operators accounted for 20% (91) of all spacecraft deployed that year.

The three spacecraft manufacturers with the largest share of the 465 deployed spacecraft in 2018 were Planet (U.S.), Thales Alenia Space (France), and Spire Global (U.S.). Together, the three manufactured 21% (96) of all spacecraft deployed in 2018. Planet’s share, 8%, was the largest of the three: 36 of the cubesats it manufactured were deployed that year. Thales Alenia Space manufactured 32 spacecraft deployed in 2018, a 7% share of 2018’s total. Spire Global manufactured 6% (28) of the 465 spacecraft deployed in 2018.

### 3.1.4 Spacecraft Masses

Spacecraft mass statistics in 2018 continued to be dominated by satellites in the small satellite category (mass: .01-180 kilograms/equivalent launch weight: .022-397 pounds). Of the 465 spacecraft deployed last year, 37% (171) had a mass of less than 180 kilograms (397 pounds). Nanosatellites, a sub-category of small satellites with a spacecraft mass of 10 kilograms (22 pounds) or less, accounted for 5% of satellites deployed. Satellites within that mass range accounted for 22% (101) of spacecraft deployed in 2018.
While the number of nanosatellites took the largest share of small satellite deployments, multiplying those 130 spacecraft by the highest mass possible within the category (10 kilograms) results in an aggregate mass of 1,300 kilograms. That mass is 18% of the mass of the largest commercial satellite deployed in 2018, a Telstar communications satellite with a mass of 7,080 kilograms (launch weight: 15,609 pounds).

### 3.1.1.5 Spacecraft Data Insights

#### 3.1.1.5.1 Focusing on Small Satellite Growth and Manufacturing in 2018

As readers review the data within the spacecraft section of the Quarter 1 2018 issue of *The Space Report*, they will probably notice that one company keeps showing up as a significant contributor in the industry of spacecraft manufacturing and operations: Planet. Considering the number of dedicated small satellite manufacturers, such as Clyde Space, ISIS, or Pumpkin, the data surrounding Planet’s spacecraft output is worthy of further analysis. As it happens, 2018 is the latest year in a half-decade of spacecraft manufacturing and operations in which Planet has been prominent.

For each of the past five years, including 2018, Planet had the largest share of manufactured spacecraft. It also had the largest share of spacecraft operations in each of those years. Planet, founded very late in 2010, achieved within five years of its founding, status as a space operator with the largest satellite constellation and a satellite manufacturer with the largest share of satellites deployed each year in the same period.¹ Data collected by *The Space Report* shows that one other U.S. company, Spire Global, is doing something very similar, albeit with very diverse payloads on each of its satellites.

No dedicated small satellite manufacturer has come close to Planet’s satellite deployment numbers or share of spacecraft deployments in the past five years. These dedicated small satellite manufacturing companies follow similar business models as their larger counterparts, who were generally very successful in attracting new business. However, the relative rarity of satellites deployed that these dedicated small satellite manufacturing companies produced, at least when compared to Planet’s deployments, indicates a challenge exists for those manufacturers. Even when their small satellites are comparatively inexpensive to traditional and larger spacecraft.

The allure of building small satellites, such as cubesats, might be explained by a few inherent cubesat characteristics. Cubesats, as stated before, are inexpensive and very small with the most prevalent size being a little larger than a tissue box with half the weight of carry-on luggage. They are also customizable, with some companies using commoditized consumer electronics for processing and power for installation into uniform satellite platforms (busses). Cubesats also allow for flexibility in launch schedule, as they can be deployed from many space launch vehicles—a critical characteristic for startups on a tight schedule.

Manufacturers like Planet seem to understand less obvious reasons to build small satellites. The manufacturing facilities do not require much space when compared to the larger satellite manufacturing facilities of traditional companies. This small manufacturing footprint allows a company to “go where the talent is.” Planet builds its satellites near downtown San Francisco, even as it moved to a larger facility in 2018 to build them.² A quick map search reveals other technology-focused companies such as Splunk, Wired Magazine, SquareTrade, and LinkedIn, are within a few blocks of Planet. Google and Apple headquarters are about an hour’s drive away. Being situated in such a locale means if Planet is looking for talented software and hardware engineers, the company does not have to look very far.

Some of the dedicated small satellite manufacturers plant flags in regions with similar talent pools. For example, Clyde Space, is headquartered in Glasgow, Scotland, a city known to be a regional technology hub, thereby giving Clyde almost immediate access to the talented workforce that is available there. The company was founded five years before Planet, 2005, and while data shows the company has customers deploying its satellites, they have not approached the same share of spacecraft deployments as Planet.³ *The Space Report’s* data also shows other dedicated small satellite manufacturers are in similar predicaments.
That begs the question: “Why is it that dedicated small satellite manufacturers have not achieved the high level of spacecraft shares that combined manufacturer/operators possess?”

One of the starkest differences are the offerings of each business. Companies like Planet and Spire Global do not offer their satellites for sale. Instead, they offer services and products surrounding the data their satellites collect. To offer the data that they do, the scope of collected data and meeting advertised collection/analysis turnarounds, those companies require large satellite constellations.

The dedicated small satellite manufacturers offer satellites, satellite components, and other related products or services. Those companies’ products are necessarily more complicated to understand, require more interaction on the customer’s part, and the options lists may even discourage a few possible customers. Universities, governments or military segments may take advantage of these offerings. However, the uptake of manufactured small satellites from dedicated small satellite manufacturers to commercial companies seems very slow.

So, what is the future of small satellite manufacturing? Is it dependent on companies who build and operate small spacecraft? Alternatively, do the dedicated small satellite manufacturers have a say? Or is there another way?

Companies such as Swarm Technologies are going the route of Planet and Spire Global, building the satellites the company will operate, and then providing an Internet of things (IoT) communications network from space. In 2018, Swarm Technologies deployed seven satellites and intends to operate 150 satellites by mid-2020. On the other hand, in 2018 a company with a similar mission, Hiber Global, deployed and operated two satellites manufactured by a dedicated small satellite manufacturer, Innovative Solutions in Space (ISIS). Hiber intends to deploy 48 satellites by 2023.

Three questions appeared during this analysis that may aid to companies interested in deploying large constellations of satellites into space: “Is my company offering data? If so, do I let someone build my satellites? Or is it cheaper for me to build my own satellites?”

Five years of recent history points to a willingness of companies to use do it yourself (DIY) solutions, including small satellite manufacturing, to provide an end-product-data, to customers. But it also shows some customers are open to having someone else build their satellites. Just not as many.

Tell us what you think – Give us your feedback! Contact us at Research@SpaceFoundation.org.

3.1.1.5.2 Market Vibrancy

One look at the number of spacecraft deployed over the past year, as well as the nations’ deploying them, makes it appear that U.S. manufacturers supplying those assets are doing quite well.

In 2018, the number of spacecraft deployed that were manufactured by U.S. space companies totaled 158. That number equated to 34% of the total 465 spacecraft deployed last year. In 2017, 240 of 443 spacecraft deployed were U.S.-manufactured, with an even-higher market share of 54%. These numbers from the last two years leave no doubt how well U.S. spacecraft manufacturers are faring when compared to the competition offered by other nations.

The closest competitor to U.S. spacecraft manufacturers is China, who accounted for 16% of all the spacecraft deployed in 2018. That share represents the most spacecraft deployed in a year from that nation, 74. Together, U.S. and Chinese spacecraft manufacturers accounted for 50% of 2018’s deployed spacecraft. The shares of manufactured spacecraft deployed by these two nations indicates vibrant manufacturing sectors for both countries.

That last statement may be true. But there are layers in this data. The type of customers buying and operating these assets may give an idea of the health and robustness of manufacturers in both of these nations. In this case, the type of customer stems from a basic question:
“How many of the customers of these countries’ spacecraft manufacturers come from other nations?”

Why focus on that question?

Recent history demonstrates what happens when markets are fairly open. For example, smartphone manufacturers from around the world have constantly one-upped each other annually. Each year smartphone manufacturing companies from around the world showcase their offerings, producing new batches of these devices with the newest features, better performance, and more capable and efficient processors and sensors. Some of these performance and technologies tend to be leveraged in other products for significantly less cost. Even better, many of these devices are interoperable on different networks, including those overseas.

The very brief smartphone history points to signs of healthy and mature markets; any markets, including spacecraft manufacturing. There were 38 nations with space operations organizations deploying spacecraft in 2018. While notable, not all of them are able to manufacture spacecraft on their own.

For China’s spacecraft manufacturers, the number of customers from nations other than China is very low: two. One of those customers, Pakistan, is operating an Earth observation satellite. The other, France, operates its spacecraft jointly with China. There were 24 other customers using Chinese-manufactured spacecraft, all of them from China. This means 8% of Chinese manufactured spacecraft that were deployed in 2018 were operated by foreign customers.

In the U.S., the number of foreign customers deploying U.S. manufactured spacecraft in 2018 was also very low. Of the 158 spacecraft manufactured by U.S. companies, 13 were deployed for customers from 10 other nations. Those 10 nations were 17% of all 58 customers that deployed spacecraft from U.S. spacecraft manufacturers. The remainder were deployed from U.S. spacecraft operators.

Compared to Russia and India, whose spacecraft manufacturers from each nation relied wholly on indigenous spacecraft operators as their customers, U.S. and Chinese manufacturer foreign customer shares seem relatively average. However, looking at other spacecraft manufacturers from other nations paints a slightly different picture.

European spacecraft manufacturers from Germany, France, and the United Kingdom come into focus when discussing the share of foreign customers compared to indigenous ones. The spacecraft manufacturers from these nations accounted 64 of the spacecraft deployed in 2018. Fifteen foreign customers/agencies were accounting for 68% of the 22 customers of the spacecraft manufacturers of those three nations.

Germany’s spacecraft manufacturers had 14 spacecraft deployed in 2018. Of the six customers buying German-manufactured spacecraft, 33% (2) of the customers were foreign spacecraft operators. One of Germany’s foreign spacecraft operators was the European Space Agency (ESA), an international space agency.

France had eight foreign spacecraft operators deploy 39 spacecraft from the country’s spacecraft manufacturers. Those eight foreign customers represented 80% of the 10 total customers for France’s spacecraft manufacturers. Going even further, 95% (39) spacecraft were deployed from foreign customers out of a total 41 that were manufactured in France. Two of France’s foreign space operations customers belonged to international organizations such as EUMETSAT and ESA.

When compared to Germany and France, the United Kingdom (UK) deployed the least number of spacecraft manufactured in that country—11. However, out of all UK spacecraft manufactured and deployed in 2018, 83% of that industry’s six customers were foreign.

The overall share of these spacecraft manufacturers is small when compared with the 158 spacecraft deployed that were manufactured in the U.S. However, their contribution is not small when compared with China’s space manufacturers.
Despite the increased activities from those two nations, European manufacturers managed to gain more foreign customers in 2018 than the U.S. and China combined.

Foreign customers also bring different points of view to the business of space. They keep the industry from becoming an echo-chamber and that puts pressure on assumptions and untouchable industry traditions. If we were to take the U.S. automobile industry as a historical example, lack of foreign points of view helped U.S. automobile manufacturers create Barca-lounger-type, inefficient, underperforming cars that were considered the pinnacles of American engineering in the late 1960s. However, Europeans, whose roads rarely run straight and true, facing high fuel costs, helped point in a different direction. The same is true for Japan.

Whether U.S. spacecraft manufacturers acknowledge these types of market pressures or not, other nations’ spacecraft manufacturers are showing a willingness to court customers from other nations—some specifically successfully courting U.S. spacecraft operations businesses. If U.S. spacecraft manufacturers are attempting to court foreign spacecraft operators to their products, the 2018 data certainly shows low gains for their attempts.

Moreover, there may be reasons why European spacecraft manufacturers seem to be much more successful than their U.S. counterparts. Especially when U.S. spacecraft operations companies are using European-manufactured spacecraft. For those interested in increasing the vibrancy and diversity of the types of customer spacecraft manufacturers are courting, identifying those reasons may be key in attempts to do so.

3.1.2 Communications Satellites Overview
There were 128 communications satellites deployed in 2018, a 28% share of the 465 satellites deployed that year. That number was a 42% increase from 2017’s 90 communications satellite deployments. The 128 satellites were diverse in physical size, mass, and mission capabilities, from relatively simple amateur radio efforts on cubesats to traditional large, complex, and heavy communications satellites. Some deployed satellites, such as the “Internet of Things (IoT)” communications relay satellites from companies such as Swarm Technologies, were a quarter of a 1U cubesat’s physical size and mass.

At the other end of the 2018 spectrum was a Telstar geosynchronous communications satellite with a mass of 7,080 kilograms (equivalent to a launch weight of 15,609 pounds). It was the heaviest commercial communications satellite ever deployed.6

Data collected for the 2019 TSR regarding communications satellites showed shifts in the kinds of communications satellites deployed. Except for Iridium’s space-based cellular network, the primary nature of satellite communications historically has been the business of broadcasting from large satellites in geosynchronous orbit; in 2018, small satellites in low Earth orbit relaying automated broadcasts from various devices became the largest share of the segment. There was also an increase in the number of broadband-dedicated satellites orbiting the Earth. Additionally, while not great in number, deep space relay small satellites were deployed in 2018.

The following breakdowns will only cover the three entities with the largest portions in each subsection.

3.1.2.1 Communications Satellites Mission Segment Breakdown
The majority of communications satellites deployed in 2018, 66% (85), were for commercial purposes (or “missions”). Civil government missions ranked second with a 28% share (36). The seven satellites launched for military communications missions took a 4% share of communications satellites deployed in 2018. This is consistent with 2017 statistics.

The top three operators of the 86 communications satellites deployed for commercial missions in 2018 were Spire Global, Iridium, and SES. Spire and Iridium are U.S. companies, while SES is headquartered in Luxembourg. These three companies operated 69% (59) of the commercial communications satellites deployed in 2018.
The top three operators of the 36 civil government-focused communications satellites deployed in 2018 were Swarm Technologies, the Indian Space Research Organisation (ISRO), and the Technical University of Berlin. The communications satellites of those three organizations accounted for a 42% share of the civil government missions (15 satellites), dominated by the experimental communications satellites from Swarm and the Technical University of Berlin.

Five nations deployed the seven military communications satellites in 2018: Denmark, Japan, Luxembourg, Russia, and the U.S. Denmark deployed the GOMX4-A/Ulloriaq for demonstrating inter-satellite linking and maritime and aircraft tracking. The SKY Perfect JSAT Corporation deployed the DSN-1 communications satellite for the Japanese military. Luxembourg deployed the SES-16/GOVSAT-1 telecommunication satellite. Russia’s Ministry of Defense deployed the Cosmos 2526 communications satellite. The U.S. Air Force (USAF) deployed an Advanced Extremely High Frequency (AEHF) communications satellite and USA-283, a classified communications satellite. The U.S. Coast Guard (USCG) deployed a search and rescue test demonstration satellite, Polar Scout Yukon. With the exception of the Danish and USCG satellites, all military communications satellites were deployed into geosynchronous orbits in 2018.

**3.1.2.2 Communications Satellites Payload Type Breakdown**

Of the 128 communications satellites deployed in 2018, 28% of them (36) involved communications for maritime tracking; the greatest number of these were the Spire Global’s satellites discussed below. The next largest share fell to a space-based cellular-style network of satellites, taking a 20% share of that category (25). Traditional broadcast and direct-to-home (DTH)-type satellites had the third-largest share with 14% (18).

A growing presence of Internet of Things (IoT) data relay satellites were deployed in 2018, accounting for a 12% share of the communications satellites deployed (15). Another type of communications satellite relies on amateur radio frequencies for communications. Eleven of these were deployed, taking a 9% share of the 2018 communications spacecraft deployments.

2018 was also a year in which two U.S. and one Chinese deep space communications relay satellites were deployed. In the middle of 2018, NASA’s InSight lander was launched toward Mars. Sharing the launch with Insight were two 6U technology demonstration communications relay cubesats, MarCO-A and MarCO-B (Mars Cube One—also known as EVE and WALL-E). The two satellites were designed to relay the lander’s status to NASA as they passed by Mars, which they accomplished following InSight’s successful landing in late 2018.7

A Chinese deep space communications relay satellite, Queqiao, was launched in May 2018. The satellite was deployed into a stable orbit between the Earth and the Moon, with a primary mission to serve as a relay communications satellite for China’s Chang’e 4 Moon lander. The lander was successfully launched in December 2018 and landed on the Moon in January 2019.8

**3.1.2.3 Communications Satellites Country Breakdown**

The top three operators of the overall number of communications satellites deployed in 2018 are headquartered in the United States.

Spire Global, a company with a relatively recent and large constellation of multi-payload cubesats, deployed 22% of all of 2018’s communications satellites (28). The company’s cubesats have a maritime tracking payload, commonly referred to as automatic identification system (AIS).9
Iridium, a company operating interlinked communications satellites for point to point communications (a cellular network that orbits the Earth), deployed 25 new Iridium NEXT satellites in 2018, accounting for 20% of all communications satellites deployed in 2018.10

U.S. start-up company Swarm Technologies deployed its SpaceBEE communications satellites in 2018, taking a 5% share of all deployed communications satellites that year (7). The SpaceBEEs are very small 1/4U cubesats, with general-purpose communications relay payloads linking IoT devices on Earth.11

As in 2017, France’s Thales Alenia Space company manufactured the greatest share of communications satellites deployed in 2018 with 23% (30). Most of those satellites, 25, were deployed as part of the Iridium NEXT constellation. Spire Global was the next with 22% (28). Swarm Technologies manufactured the seven satellites it deployed in 2018, taking a 5% share of all the communications satellites deployed that year. Both Spire and Swarm build and operate their satellites.

### 3.1.2.4 New Communications Satellites Challenges

January 2018 marked the first time a U.S. communications satellite operator deployed satellites without the U.S. Federal Communications Commission’s (FCC) permission.12 In April 2017, nine months before the launch, the company had applied to the FCC for permission to operate its very small satellites, but the FCC denied Swarm’s application nine months later.13 Despite the denial, Swarm Technologies deployed four satellites from an Indian Polar Satellite Launch Vehicle (PSLV) in January 2018.

Soon after the launch, the FCC charged Swarm with violations of of U.S. space and communications policies. Nearly a year after the launch of its satellites, the FCC and Swarm Technologies settled the FCC charges with a Consent Decree in December 2018, which included Swarm’s paying the FCC a civil penalty of $900,000.14 The agreement allows the company to conduct operations but under FCC scrutiny.

### 3.1.3 Positioning, Navigation, and Timing (PNT) Satellites Overview

Of the 465 spacecraft deployed during 2018, 6% (27) were for Positioning, Navigation, and Timing (PNT) missions. These new PNT satellites were added to existing PNT constellations belonging to five nations and the European Union (EU)/European Space Agency (ESA). PNT satellite deployments in 2018 increased the overall number of dedicated PNT satellites by 22% from 2017. By the end of 2018, 147 PNT satellites orbited the Earth in six constellations.

The Space Report’s data about PNT satellites show shifts in just how active nations were in 2018 with respect to building out or maintaining these crucial infrastructure constellations. For example, while 27 PNT satellites were deployed in 2018, 69% of those were for China’s BeiDou constellation. Details of the acceleration of China’s PNT satellite deployment and constellation size increase are available in the BeiDou section below.

The nations operating these satellites are creating opportunities here on Earth and continued reinforcing a small but critical piece of space-based infrastructure during 2018. Examples of such opportunities are documented in this report’s Products and Services section. Consider: The economic impacts of this satellite type, PNT, which in 2018 only had 6% share of global spacecraft deployments, were considerable.

Products and services based on PNT satellite signals continue to grow, while the share of this sector in the global space economy reflects the commercial interest and growing investment. Though military missions drive the deployment of satellites in the three largest PNT constellations, the commercial benefits derived from them continue to dwarf the military’s investment in those systems.

The following breakdowns will only cover the three entities with the largest portions in each subsection.
3.1.3.1 PNT Satellites Mission Segment Breakdown
Like PNT deployments in previous years, the majority of the 27 PNT satellites deployed in 2018, 81% (21) were for military missions. Four satellites (15% of the total) were deployed for civil government missions. And one commercial satellite accounted for the remaining 4% share of PNT satellites deployed in 2018.

China, India, Russia, and the United States (U.S.) accounted for all 21 military PNT satellites deployed in 2018. Of the military PNT satellites deployed last year, China’s share was the largest at 81% (17). Russia deployed two PNT satellites (9% of the PNT satellites deployed). India and the U.S. each deployed one PNT spacecraft (about a 5% share each). The EU/ESA accounted for all four civil government PNT satellites deployed in 2018. China deployed the single commercial PNT satellite.

3.1.3.2 PNT Satellites Country Breakdown
Of the 146 PNT satellites in Earth orbit during 2018, 101 were operational, up 11% from 2017’s total of 91 operational PNT satellites. The U.S. maintained the highest share of operational PNT satellites, slightly above 30%, with its Global Positioning System (GPS) constellation. The Russian GLONASS PNT constellation kept Russia ranked second with 24%. The EU/ESA’s share ranked third in 2018, with 18% of the operational PNT satellites. China’s 2018 PNT satellite deployment efforts pushed its rank to four, with a 17% share. India and Japan each had less than a 10% share of operational PNT satellites in 2018.

BeiDou/CentSiSpace
Of all the nations deploying and operating PNT satellites in 2018, China was the busiest. At the beginning of 2018, the nation’s PNT system, known as BeiDou (Compass), consisted of 26 satellites. By 2018’s end, the number of satellites in the BeiDou constellation had grown to 42, a 69% increase. The overall number of BeiDou satellites exceeds the numbers in each of its U.S., Russian, and EU/ESA constellation counterparts.

The 18 BeiDou satellites China deployed in 2018 were an 800% increase from the two BeiDou satellites deployed in 2017. As of January 2019, 30 of the 42 BeiDou satellites in orbit were considered operational. While China reported that not all of its BeiDou satellites were operational, the total deployed as of this report is well above the number the nation has stated as required for global operations (35). Some of the BeiDou satellites continue to undergo testing.

During the 10 years prior to 2018 (2008-2017), China deployed 26 BeiDou satellites, averaging an annual 2.6 deployments per year. From 2009-2018, China’s annual average BeiDou satellite deployment rate (including the 18 deployed in 2018) rose to 4.4. China announced plans in January 2019 to launch 11 more BeiDou satellites throughout 2019.

Unlike other PNT systems, BeiDou serves as a text messaging platform as well.

China was also the only nation with a commercial company experimenting in the PNT satellite field. The company, China Academy of Sciences (CAS), deployed CentiSpace-1 to Low Earth Orbit (LEO).

Galileo
In contrast to the PNT systems operated by other nations (except Japan), two European civil government organizations (the EU) and the ESA) share acquisition, management and operation of the Galileo PNT constellation. During 2018, EU/ESA deployed four Galileo satellites, bringing the total number in the constellation to 26.
The operational constellation size now exceeds by two the minimum required number of 24 satellites required for effective global coverage. As of December 2018, the four satellites launched this past year are not yet considered operational as they are still undergoing testing. These satellites are planned to enter service in early 2019, which will also mark a milestone for the constellation as it comes online for global coverage at that time.

In late 2018, the United States Federal Communications Commission (FCC) granted a waiver for devices in the U.S. to receive specific signals from the Galileo system. The waiver allows users in the U.S. to receive the signals, which will provide more accuracy for positioning purposes.

**Navigation with Indian Constellation (NavIC)**

India launched one Indian Regional Navigation Satellite System (IRNSS) satellite to complete its Navigation with Indian Constellation (NavIC) in 2018. This new satellite brings the number of operational IRNSS satellites to seven. The constellation provides regional positioning, navigation, and timing service to India and neighboring countries such as Pakistan and Bangladesh. The Indian Space Research Organisation’s (ISRO) Navigation Centre (INC) operates the IRNSS satellites. There are eight IRNSS satellites in NavIC. One, however, suffered an onboard clock failure in early 2017, making the satellite inoperative for PNT purposes. India’s share of the world’s operational PNT satellites remains at the 2017 level of 7%; this equates to a global ranking of #5.

**QZSS**

Japan’s Cabinet Office continues to operate all four satellites of QZSS (also known as Michibiki), the country’s PNT constellation. QZSS is a regional PNT system solely catering to Japan’s population. As of November 2018, Japan considered all four QZSS satellites operational.


<table>
<thead>
<tr>
<th>Country</th>
<th>System Name</th>
<th>Minimum Constellation Requirement</th>
<th>Currently Operating Constellation</th>
<th>Operational Date Coverage</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>BeiDou/Compass</td>
<td>35</td>
<td>331</td>
<td>2011</td>
<td>China in 2011, global coverage by 2020</td>
</tr>
<tr>
<td>Europe</td>
<td>Galileo</td>
<td>242</td>
<td>223</td>
<td>2015</td>
<td>Europe in 2016, full global in 2020</td>
</tr>
<tr>
<td>India</td>
<td>Navigation with Indian Constellation (NavIC)—formerly named Indian Regional Navigation Satellite System (IRNSS)</td>
<td>7</td>
<td>74</td>
<td>2016</td>
<td>South Asia</td>
</tr>
<tr>
<td>Japan</td>
<td>Global Navigation Satellite System (GLONASS)</td>
<td>4</td>
<td>4</td>
<td>2017</td>
<td>Japan</td>
</tr>
<tr>
<td>Russia</td>
<td>Global Positioning System (GPS)</td>
<td>21</td>
<td>26</td>
<td>2011</td>
<td>Global</td>
</tr>
<tr>
<td>United States</td>
<td>Wide Area Augmentation System (WAAS)</td>
<td>24</td>
<td>31</td>
<td>1995</td>
<td>Global</td>
</tr>
</tbody>
</table>

The nation plans to launch four more QZSS satellites by 2023. The satellites also use their assigned PNT frequencies to relay messages during emergencies. The messages are relayed to specialized radio receivers and then retransmitted through emergency broadcast systems.
GLONASS
For 2018, Russia maintained its 2017 number of operational GLONASS PNT satellites, 24; these satellites are also known as Uragan. However, because China and the EU/ESA increased their overall numbers of operational PNT satellites, the Russian share of operational satellites at the end of 2018 dropped from 26% in 2017 to 24%. The Information and Analysis Center for Positioning, Navigation, and Timing in Korolyov, Russia operates the GLONASS satellites.

The total number of GLONASS satellites at the end of 2018 included the operational satellites (24), one spare satellite, and one satellite undergoing flight testing. All 24 operational Russian PNT satellites are the GLONASS-M type, the first of which was launched in 2003. Russia launched two GLONASS-M satellites in 2018 to replace older satellites. The older, replaced GLONASS satellites remain on orbit as spares. There are no significant updates available on the GLONASS-K satellites which Russia had started to add to their system in 2017.

GPS
The U.S. maintained 31 operational GPS satellites during 2018, the same number operational during 2017. While that number of operational satellites is seven more than the minimum number of GPS satellites required to meet military requirements (24), the United States Air Force (USAF), the military organization responsible for acquiring, deploying, and operating the satellites, has consistently maintained on orbit more than the minimum for at least a decade (there are three GPS satellites on orbit as spares as of October 8, 2018). The average age of operational U.S. GPS satellites is 11 years, with the oldest being 20. All are variations of the GPS-II satellite family.

While the number of operational GPS satellites has not changed, the U.S.’s share of the world’s operational PNT satellites shrank to 30%. The change in share is due to the increased PNT satellite deployment activities of the EU/ESA and China during 2018.

The USAF launched its first GPS-III satellite in 2018. As of mid-March, 2019, it is not yet operational. The USAF will be able to use the GPS-III satellite’s full capabilities, including a secondary Search and Rescue (SAR) payload, when the GPS
The constellation’s new ground segment, Next Generation Operational Control System (OCX), becomes operational in 2022.\textsuperscript{34} The top three manufacturers of PNT satellites in 2018, from an overall share perspective, came from China and Russia. The China Academy of Space Technology (CAST) manufactured 35\% (9) of all PNT satellites deployed in 2018. Another Chinese company, the Innovation Academy for Microsatellites of CAS (SECM), followed CAST’s manufacturing share closely, manufacturing 31\% (9) of 2018’s deployed PNT satellites.

The two GLONASS-M satellites manufactured for the Russian military were from the JSC Academician M.F. Reshetnev Information Satellite Systems manufacturing floor. The company’s two satellites took an 8\% share of 2018’s PNT satellite deployments.

### 3.1.3.3 Spacecraft Data Insights

#### 3.1.3.3.1 China’s Increased Spacecraft Deployments and Shifting Missions

China’s space industry significantly increased the nation’s share of 2018 space launches and spacecraft deployments. Highlights of these activities include the successful deployment of a lunar rover and a communications relay spacecraft that allows for communications between the rover and China. Other activities, such as the number of spacecraft deployed, as well as that nation’s shift in mission focus, are also notable.

From 2014 through 2017, China’s annual average space deployment rate was 34 spacecraft. The nation’s operators deployed 74 spacecraft in 2018, an 118\% increase. That was the most spacecraft China’s space operators deployed, ever.

Although China’s operators hit a record with spacecraft deployments, the diversity of spacecraft customers for its manufacturers appear to be quite small – 3\% of 26 spacecraft operators. Specifically, China had two foreign customers, France and Pakistan, each buying one Chinese-manufactured spacecraft. By comparison, United States spacecraft operators deployed 180 spacecraft in 2018. Of those, 158 were manufactured by U.S. companies, which in turn were sold to 13 customers from 10 other nations. Those 13 foreign customers represent a 17\% share all the customers who bought U.S. manufactured spacecraft.

Both foreign and Chinese customer sets are small shares within all customers of each nation’s spacecraft manufacturers. Considering China’s considerable diplomacy efforts through programs such as the Belt and Road Initiative, the return on investment seems marginal, at least for its space industry.\textsuperscript{47} This seeming lack of foreign interest in Chinese-manufactured spacecraft may be attributable to many scenarios or a combination thereof. One reason for the low number of foreign customers may be the shift in mission segments in 2018.

China shifted towards deploying many more spacecraft for its military mission segment. In 2018, the nation deployed 38 spacecraft for military purposes. From 2014 through 2017, they averaged 11.5 military spacecraft deployments annually. The 38 military spacecraft deployed in 2018 represented a 230\% increase from the annual average of the previous four years.

The largest portion of military spacecraft deployments for China in 2018 went to its positioning, navigation, and timing (PNT) spacecraft, BeiDou. BeiDou spacecraft deployments numbered 18, a 47\% share of all of China’s military spacecraft in 2018. The high number of BeiDou spacecraft deployed in 2018 is also a departure for the annual deployments of BeiDou spacecraft in the years leading up to 2018. From 2008 through 2017, China deployed 26 BeiDou satellites, averaging an annual 2.6 deployments per year.

There may be several reasons for the acceleration of PNT spacecraft deployments in China, some with military implications. However, there may be a very good economic incentive as well: GPS. It could be that China has watched the U.S. Global Positioning System’s (GPS) impact on the global space economy very closely. The positive impacts, both on societies and economies around the world, may be a very good reason for rapid PNT satellite deployments. The number of BeiDou satellites operating after 2018 allows the constellation to provide global instead of regional (Asia-Pacific) coverage.
China has been encouraging its smartphone industry to build phones that use BeiDou as one of the PNT constellations referenced in their chipsets for many years. But, at least until recently, the lack of global availability of BeiDou signals would not have motivated China’s smartphone manufacturers as they provided phones globally through companies like Apple.

There are questions that must be asked, perhaps the most pertinent being, “What’s the hurry?”

It may be typical Chinese behavior in that that nation’s manufacturers take their time and learn, before creating products that seemingly explode onto the world’s stage. It may be because China really would like a part of the PNT pie. It may all be part of China’s plans to ensure it remains independent of outside influences. It could also be a combination of those reasons, or something else that may reveal itself in the future.

Regardless, it will still be a reason to watch what China will do next because its impact will resonate around the globe.

### 3.1.3.4 PNT Satellite Ground Networks

For PNT satellites to function reliably and in some cases provide more than just the basic function of timing signals from space to the ground, a ground network is necessary. Software updates, fixing troublesome satellites, or ensuring their orbit paths are consistent, requires, ideally, a global network of ground stations for transmitting commands and receiving satellite health information. This section provides updates on and challenges faced by the ground segments for two PNT constellations.

In 2018, the USAF continued GPS operations with ground equipment that is decades old. The number of command and control antennas (which the USAF uses to send GPS satellite commands and receive data) in the current GPS ground control network remained at 11. The number of sites the USAF uses to monitor GPS satellites status remained at 16. Antennas and monitoring stations are positioned all over the globe, but the whole network is controlled by one master control center in the U.S. state of Colorado.

The USAF’s current ground network is fully capable of working with the service’s GPS-II satellite family. However, the GPS satellite launched in 2018 was the first GPS-III satellite. While the current ground control segment has gone through upgrades over the decades since its inception, it can control the GPS-III satellites but cannot take advantage of some of their new capabilities.
A new ground system architecture, GPS Next Generation Operational Control System (OCX), was supposed to be operational in 2016. The program has missed a number of schedule deadlines and has exceeded cost estimates by 250%. The most recent year now given for the GPS ground segment to become fully operational is 2022, six years after the original date for operations.

Responsibility for the operation of the Galileo constellation’s ground system moved in 2018 from the European Space Agency (ESA) to the European Global Navigation Satellite System (EGNSS) Agency (GSA). The ground control segment is run from the Oberpfaffenhofen Control Centre in Germany. A backup control center resides in Fucino, Italy. Both are able to control all 14 uplink stations around the world.

3.1.4 Earth Observation/Remote Sensing (EO/RS) Satellites Overview

Of the 465 spacecraft deployed in 2018, 38% (176) were deployed for Earth Observation/Remote Sensing (EO/RS) missions. While this is a significant share of all deployed spacecraft, it is a decrease in share and number of spacecraft deployments from the 52% (232) in 2017.

The shift to EO/RS satellites with smaller volumes and masses seen in 2017 continued throughout 2018. However, EO/RS payloads further diversified into other types of remote sensing payloads. Satellites designed to monitor and track changes to, and developments on, the Earth’s surface and in the atmosphere were using a wider variety of electronic, infrared, radar, and optical payloads and technologies, or combinations of them, to provide observation and sensing capabilities.

The following breakdowns will only cover the three entities with the largest portions in each subsection.

3.1.4.1 EO/RS Satellites Mission Segment Breakdown

Of the 176 EO/RS satellites deployed in 2018, a majority, 56% (98), were deployed for commercial purposes. The 98 satellites are a decline from the number of commercial EO/RS satellites deployed the previous year (194). Civil government EO/RS satellites accounted for 29% (51) of total deployments. Military satellites took the smallest share of EO/RS satellites deployed in 2018 with 15% (27).

The three satellite operators with the largest shares of commercial EO/RS satellites were Planet (U.S.), Spire Global (U.S.), and Zhuhai Orbita Control Engineering Co., Ltd. (China). The 71 satellites of those three companies made up a 73% share of the commercial EO/RS satellites deployed in 2018. Planet had the largest share of 2018 EO/RS satellite deployments, 39% (38). Spire Global’s 27% (28) represented the second-largest share. Zhuhai Orbita’s five commercial EO/RS satellites took 5%.

During 2018, three civil government satellite operators combined for the largest share of civil government EO/RS satellites deployed with 28% (14). The China National Space Administration deployed and operated seven civil government EO/RS spacecraft that year, a 14% share of that mission segment. Russia’s Roscosmos accounted for 8% (4) of the civil government EO/RS spacecraft deployed. Three civil government EO/RS satellites were deployed and operated by the Indian Space Research Organisation, a 6% share.

Nine nations deployed 2018’s 27 probable military/reconnaissance EO/RS satellites. This number was a 50% increase from 2017’s 18 probable military deployments. The nation with the largest share of military EO/RS satellites deployed in 2018 was China, with 59% (16). The 16 satellites represent a 100% increase over that nation’s eight military EO/RS satellites deployed in 2017.

The only other nations of the remaining eight who deployed more than one probable military/reconnaissance EO/RS satellite in 2018 were Japan, Russia, and the United Kingdom, each of which deployed two.
There have always been a number of similarities/equivalences and differences between military/reconnaissance EO/RS satellites and their commercial/civil government counterparts. Like those counterparts, military EO/RS satellites carry a variety of payloads, depending on their missions, and they use technologies similar to those of their counterparts. The greater cost to acquire and operate each military EO/RS satellite (as well as other types) because of security and hardening requirements drives many of the differences. This translates to significantly fewer military/reconnaissance EO/RS satellites deployed annually than their commercial/civil government EO/RS equivalents.

Descriptors for many of the military/reconnaissance missions (imagery intelligence (IMINT), signals intelligence (SIGINT), and measurements and signatures intelligence (MASINT), provide some clues as to the nature of those satellites, as do the types of orbits into which they are deployed. At least two of those missions, IMINT and SIGINT, had equivalents in the commercial segment in 2018. Two MASINT, Synthetic Aperture Radar (SAR), and Light Detection and Ranging (LIDAR) payloads were deployed on commercial EO/RS satellites in 2018. However, there are other specific military missions, such as missile warning satellites with infrared (IR) payloads, with no general commercial equivalent. The U.S. Air Force (USAF) deployed a Space Based Infrared System (SBIRS) missile warning satellite in 2018, but there were very few commercial satellites with IR payloads deployed during that timeframe.

3.1.4.2 EO/RS Satellites Payload Type Breakdown

Optical payloads constituted the largest share of the payloads of the 176 EO/RS satellites deployed during 2018, 82% (144); they were deployed primarily to collect images of Earth’s surface and weather. Another weather-focused remote-sensing satellite payload, Global Positioning System - Radio Occultation (GPS-RO) (see Spacecraft Overview for additional details), accounted for the next-highest 2018 share, 18% (31).

IR payloads accounted for 19% (35) of the payloads on all EO/RS satellites deployed in 2018. Twenty-eight of those payloads were on Spire Global’s Lemur-2 cubesats. Current Spire documents do not reference products or services resulting from the Lemur-2 IR sensors. This lack of information may indicate that while there are significant numbers of IR sensor payloads on orbit, 74% of them appear to not have been in use in 2018.

SAR payloads on nine satellites deployed in 2018 took a 5% share of all 2018 EO/RS satellites. Companies from Finland, the United Kingdom (UK), and the U.S. deployed commercial surface imaging satellites with SAR payloads. These payloads observe objects on the Earth’s surface using radio waves that bounce off certain kinds of objects and return to a SAR receiver. The SAR payloads can “see” objects on the Earth’s surface through clouds. Some are sensitive enough to detect changing levels of caps on oil storage containers.56

Four satellites, a 2% share of EO/RS satellites, were deployed in 2018 with the ability to monitor for particular types of radio frequencies emanating from the Earth. Three met commercial demands while the fourth was fulfilling a civil government demonstration.

3.1.4.3 EO/RS Satellites Country Breakdown

The countries with spacecraft operators operating the most EO/RS satellites deployed in 2018 were in the U.S. and China. Combined, operators from these two countries accounted for 42% (73) of all EO/RS satellites deployed during 2018.

Two U.S. companies, Planet and Spire Global, accounted for a 38% (66) share of all EO/RS satellites deployed in 2018, and 85% of all 78 U.S. commercial EO/RS satellites deployed that year. Planet’s 2018 deployment efforts netted the company a 22% share (38) of all EO/RS satellites deployed, while Spire’s 28 satellite deployments gave that company a 16% share. Both companies’ combined 2018 satellite deployments fell shy of their total satellite deployments in 2017.

Note: As of March 6, 2019. Satellites may have multiple types of earth observation/remote sensing payloads.
The China National Space Administration (CNSA) deployed and operated seven EO/RS satellites in 2018, accounting for 4% of all EO/RS satellites deployed that year. Five of those seven are part of the China High-Resolution Earth Observation System (CHEOS), that nation’s effort to build more advanced sensors and Earth observation capabilities.

Three manufacturers accounted for 47% (83) of all EO/RS satellites deployed in 2018: Planet, Spire Global, and the China Academy of Space Technology (CAST). Planet and Spire also operate the satellites they build, while CAST is primarily a satellite manufacturer. Identical in number and share to the statistics in the “EO/RS Satellite Operators” section, Planet and Spire completed manufacture of 38% (66) of all EO/RS satellites deployed in 2018, with Planet accounting for 22% (38) and Spire accounting for the remaining 28 satellites (a 16% share). Government-run CAST completed manufacture of 17 EO/RS satellites in 2018, giving it a 10% share of the 176 EO/RS spacecraft deployed that year.

3.1.4.4 EO/RS Meteorological Focus

In 1900, a hurricane defied U.S. Weather Service predictions and destroyed Galveston, Texas. The highest part of the island on which the city rests is about 2.75 meters (9 feet) above sea level.57 Death toll estimates vary, but at least 6,000 Galveston residents died, and over 3,600 buildings were destroyed as the hurricane hit the city.58 The magnitude of the hurricane surprised all residents as it hit Galveston with wind speeds estimated at 193+ kph (120+ mph), and with tides and storm surges that pushed ocean water as high as 4.5+ meters (15+ feet) above sea level.59

At that time, the Weather Service relied immensely on historical data and barometric readings. So confident was the Weather Service about the track of the hurricane that eventually hit Galveston, that it predicted the storm would instead move over Florida and then up the Atlantic seaboard. The unexpected movement toward Galveston showed that humankind still had a lot to learn about weather prediction in general and hurricane formations in particular.

The desire to learn more about hurricanes and their behavior is a significant driver of why companies and governments deployed in 2018 more satellites with instruments focused on hurricane formation than in any previous year. Combined, the total number of deployed commercial, military, and civil government meteorology satellites grew 14% in 2018 to 49 satellites from 2017’s 43. The share of EO/RS satellites deployed in 2018 with a meteorological focus was 28%.

Commercial satellites with meteorology payloads accounted for 65% (32—28 from Spire Global alone) of all satellites deployed with meteorological capability during 2018. Deployed civil government meteorology satellites made up 22% (11) of 2018’s meteorological satellites, while military meteorology satellites accounted for the remaining 13% (6).

One of the largest shares of meteorological payload types deployed in 2018 has been GPS-RO receivers primarily on commercial satellites. Of the 49 meteorological satellites deployed, 63% (31) have a GPS-RO receiver. The GPS-RO payloads on their host satellites work by receiving positioning, navigation, and timing signals from GPS satellites. The signals have traveled through the Earth’s atmosphere from GPS satellites to the GPS-RO payloads on various satellites, bending in response to the varying thicknesses of the atmosphere as they travel. The more the signals bend, the more particles there are between the GPS and GPS-RO satellites (i.e., atmospheric density variations can help calculate temperature, humidity, atmospheric pressure, and more).

These satellites are proving to be very effective in lessening track and intensity errors for hurricane predictions—by as much as 50%.60 This improvement in forecasting provides communities in a hurricane’s potential track to evacuate earlier than in the past. Had the U.S. Weather Bureau had this tool in 1900, Galveston would still have been impacted, but many more lives would likely have been saved.

3.2 Exploration and Research Spacecraft, Landers, and Rovers—Overview

Of the 465 spacecraft deployed in 2018, 4% (17) were for exploring and understanding the space environment, other worlds, and the universe. The missions of these spacecraft are diverse. Some, like China’s Chang’e 4 lunar lander, are well-known, while others performing research missions are not as well publicized. While not all the probes and spacecraft deployed and
operating during 2018 will be covered in this section, more data about these spacecraft are available from The Space Report Online’s database. This section also covers exploration and research spacecraft and probes with missions that came to an end, as well as those that arrived at their destinations, in 2018.

### 3.2.1 Exploration and Research Spacecraft, Landers, and Rovers Breakdown by Mission Segment

If there is a trend in the exploration and research spacecraft, landers, and rovers deployed, it is that civil government entities conduct most of these types of missions. Of the 17 spacecraft in this category deployed in 2018, 16 (94%) were for civil government missions, with 11 of those spacecraft operated by universities and observatories. The remaining six civil government spacecraft deployed in 2018 were operated by national space agencies, such as the United States (U.S.) National Aeronautics and Space Administration (NASA) and the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt (DLR)).

Only one spacecraft, Arkyd-6A, was deployed in 2018 for a commercial operator. Operated by Planetary Resources, the 6U cube satellite's mission is to search for water-containing asteroids.

### 3.2.2 Exploration and Research Spacecraft, Landers, and Rovers—A Mission Sampling

#### Exploring Other Solar Systems from Near-Earth: TESS

NASA deployed the Transiting Exoplanet Survey Satellite (TESS) into a highly elliptical orbit around the Earth; it began operations in July 2018. The orbit provides TESS a greater field of regard of space viewable from Earth orbit than the Kepler planet-hunting spacecraft, 85% versus 0.25%.\(^61\)

The elliptical orbit allows TESS to observe stars 30-100 times dimmer than the stars Kepler observed during its mission. TESS’s mission is planned for two years. NASA retired the Kepler spacecraft in October 2018 after a little over nine years in orbit.\(^62\)

#### Exploring the Moon: Chang’e 4

In December 2018, China launched a lunar exploration mission, Chang’e 4 (named after the Chinese Moon Goddess). The Chang’e 4 mission complement consists of a lander and a rover (Yutu-2—Jade Rabbit), as well as tools for scientific experiments and data collection. Chang’e 4’s mission is to take photos of the dark side of the moon and study lunar geology, specifically that in the Von Karman crater. The mission also includes searching for water or ice, which scientists suspect to be below the moon’s surface.

Upon successfully landing on the Moon’s far side in January 2019, Chang’e 4’s deployed the Yutu-2 rover.\(^63\) The rover carries instruments for collecting lunar geologic data, studying the early universe, and detecting radiation levels on the moon to aid in a future long-term human lunar mission.\(^64\)

Before the Chang’e 4 spacecraft launch, China deployed a communications relay satellite, Queqiao (Magpie Bridge), into an orbit around a stable Earth-Moon Lagrange point. The satellite’s orbit allows it to serve as a communications relay satellite between ground stations on Earth and Chang’e 4/Yutu-2 on the Moon. Queqiao also carries equipment to study the early universe.

As the first spacecraft to land on the far side of the moon, Chang’e 4 has recorded low temperatures of -190 degrees Celsius (\(^9\)C) (-310 degrees Fahrenheit (\(^9\)F)), much lower than the anticipated -173\(^9\)C (-280\(^9\)F).\(^65\) The mission is expected to last a total of about one year. However, Yutu-2 is planned to roam the Moon’s surface for only about three months before it becomes inoperable because of exposure to the harsh conditions of the Moon’s dark side.\(^67\)

#### Exploring Mars: InSight

NASA’s InSight, a lander to study Mars’ interior structure and chemical makeup, was launched in May 2018. Six months later, in November 2018, InSight successfully landed on Mars and took a picture of itself on Mars’ surface.\(^68\)
Shortly after it landed, InSight deployed a seismometer onto the surface of Mars to begin data collection. The instrument was placed on the surface to investigate whether Mars is seismically active. The lander continues collecting geological data from the planet such as seismic activity, the planet’s wobble, and interior samples from the first 5 meters (16 feet) below the planet’s surface. NASA expects InSight’s mission to last at least two years.

Exploring Mercury: Bepi-Colombo

ESA and the Japan Aerospace Exploration Agency (JAXA) launched the Bepi-Colombo spacecraft in October 2018 to learn more about Mercury. The spacecraft consists of three parts: Mercury Magnetospheric Orbiter (MMO), Mercury Planetary Orbiter (MPO), Mercury Transfer Module (MTM).

MMO and MPO will observe and record data from Mercury while MTM transports them there. JAXA’s MMO will observe Mercury’s magnetic field as well as the sun’s influence on the planet. ESA’s MPO component will observe the planet’s gravitational field, its planetary makeup and surface environment. Bepi-Colombo reaches Mercury in late 2025 and will begin orbiting the planet upon arrival, deploying both MMO and MPO from the MTM into [what type of] orbits. The two orbiters will collect data for a year once in orbit around Mercury.

Exploring the Sun: Parker Solar Probe

A NASA exploration mission, the Parker Solar Probe, launched in August 2018. The probe’s mission is to fly through the Sun’s corona via a highly elliptical orbit, sampling the surrounding environment, and subsequently providing the data to scientists with the goal of gaining a better understanding of the Sun’s chemical makeup, as well as its age. This analysis may provide scientists and researchers a more accurate estimate of where the Sun is in its lifecycle. The satellite conducted the first of 24 planned encounters with the Sun in October 2018.

Before the Parker Solar Probe, the probe Helios 2 had made the closest approach to the sun, in 1976, coming within 43 million kilometers (26 million miles) of the Sun’s surface. The Parker Solar Probe broke that 42-year old record at the end of October 2018. The Parker Solar Probe is expected to come within 6.2 million kilometers of the sun's surface during in 2024 but planned to pass by the Sun twice more in 2025.

Exploring the Solar System (and Beyond)

NASA launched OSIRIS-Rex, an Asteroid Study and Sample Return probe, to asteroid 101955 Bennu in September 2016. The probe started its approach towards Bennu in mid-2018 and by December 2018, had matched Bennu’s velocity. OSIRIS-Rex began orbiting the asteroid on December 31st, 2018 and will continue orbiting Bennu for a year, before it lands on the asteroid to collect samples. Once sample collection is complete, OSIRIS-Rex will return to Earth with the samples by 2023.

JAXA launched Hayabusa-2 in December of 2014 on an asteroid sample return mission as well. The spacecraft’s destination was the near-Earth object and asteroid, Ryugu. Hayabusa-2 slowly approached the asteroid, taking pictures as it moved closer, and arrived near Ryugu in June 2018. In December 2018, it moved into an orbit around Ryugu. Hayabusa-2 will land on the asteroid in 2019 to collect samples before returning to Earth by 2020.

The Dawn probe, a NASA satellite with the mission of exploring the asteroid belt between Mars and Jupiter, stopped responding to commands from Earth in late 2018. The satellite had been inserted in orbit around Ceres before going mute. Launched in 2007, its original goal was to help scientists understand the early stages of Solar System development. Its mission focused on two dwarf planets in the asteroid belt, Ceres and Vesta. Dawn provided substantial data on the formation of planets, which helped update the models of solar system development.

NASA launched its New Horizons mission in 2006. The probe’s original goal was to observe and record data about Pluto and its moons, which it accomplished as the spacecraft flew by Pluto in 2015. However, it had a secondary mission: exploring Kuiper Belt objects and other interesting objects as it traveled to the edge of the solar system and beyond.
In late 2018, New Horizons passed what scientists expected to be two Kuiper Belt objects. However, subsequent photos and data from New Horizons revealed the two objects to be fused as one object, Ultima Thule. Geologists and geophysicists hope to learn more about planetary formation through the study of Ultima Thule. New Horizons continues toward Kuiper Belt object 2014 MU.

Voyager 2, now a 42-year mission launched by NASA in 1977, was originally intended to observe the Solar System’s gas giants. In November 2018, Voyager 2 was the second spacecraft to observe the universe beyond the Earth’s solar system as it reached interstellar space by passing through the heliosphere. Voyager 2’s distance from Earth of 18 billion kilometers (10.8 billion miles) makes it one of two Voyager spacecraft traveling beyond the solar system. Voyager 1 is currently 2 billion kilometers (1.2 billion miles) further from Earth than Voyager 2 even though they were both launched in the same year, continuing its journey beyond the heliosphere.

3.2.3 Exploration and Research Spacecraft, Landers, and Rovers by Country
While there were five national and international entities operating the 17 spacecraft and probes deployed in 2018 for space exploration and research purposes, two nations, the U.S. and China, were responsible for the largest mission shares. The United States was responsible for 10 of these types of missions (59%), and China accounted for three (18%). The other nations and organizations (ESA, France, Germany, and South Korea) each had one spacecraft or probe deployed in 2018 for space exploration and research.
4.0 Introduction

Companies and individuals are using positioning, navigation and timing (PNT), Earth observation (EO), and communication satellite technologies and data to humanity’s benefit. From commercial transportation to natural disaster relief, these products and services are changing, for the better, the way humans interact with others and the environment. The expansion of space infrastructures is creating new opportunities and products and services for those willing to use their imaginations.

Global PNT availability allows companies and organizations to create large networked vehicle fleets to enhance automobile safety and reliability. Earth observation imaging technologies are being used to observe pipeline and gas storage infrastructures, providing scientists and engineers the ability to assess and react much faster. Aid groups used Earth observation imagery analysis techniques to locate safe drinking water and accessible transportation routes during natural disasters. Combining these technologies allows humans to deal with complex challenges, such as conserving vast swaths of open ocean for shark populations.

Parking for European Truck Drivers

European truck drivers can only drive so long in a day before they are legally required to rest. If drivers, and the companies they work for, don’t comply with time-limiting driving regulations, they are subject to fines. Conservative drivers, combined with this mandate, can cause truck parking facilities to fill up quickly in the evening. This situation causes issues, because the drivers need to stop no matter where they are and pull over to the road’s shoulders. This can slow traffic and create potentially unsafe road conditions.

European drivers can employ smartphone applications like Traxpert’s Parckr app, which tracks thousands of different truck parking areas. These applications also query for availability of services in parking areas, including gas stations, fast food restaurants, and parking spaces. Applications like these guide drivers in finding a safe parking space when they need to end their day or take a break. The application provides a forecast of when particular popular parking stops will be full, so truck drivers can plan ahead.

Smartphone applications like Parckr use EO and PNT satellite data, providing overhead images of truck stops along a driver’s projected route. In the case of Parckr, the European Space Agency (ESA) Space Applications Business Incubation Center in Noordwijk, Netherlands, provided assistance to the app developer.

By monitoring data about moving trucks with the help of PNT satellites, ESA provides models for parking based on historical patterns by time of day and day of the week. This technology is using satellite data to help truck drivers work more safely and avoid fines, and to improve the safety of the rest of the drivers on the road.

Autonomous Vehicle

Autonomous vehicles have been in development since the 1930s with the goal of creating safer travel by road and providing the driver freedom to focus on other tasks while in the car. These types of cars have steadily been experimented with over the years, though have not been made available to the public until recently.
Early autonomous cars used radio frequencies for navigating the streets. Current autonomous vehicles rely on, and cannot operate safely without, PNT satellites and related technologies. 2018 saw an increase in the availability of the autonomous car to the public on an expanded scale, slowly introduced based on their state of maturity and usefulness.

National supermarket chains in the United States such as Kroger are experimenting with autonomous vehicles. Kroger, with the help of the autonomous vehicle start-up Nuro, launched the first delivery service for groceries in Scottsdale, Arizona in mid-2018. Scottsdale has a higher than national average age demographic; 22.4% of its residents are over 65 years old, compared to the national average of 15.6%.

Kroger and Nuro are attempting to answer a need for Scottsdale’s older residents: gaining free time by having something else accomplish their grocery-getting. Supermarket customers order groceries through a smartphone application, choosing whether to have a delivery arrive the same day or the next day.

The autonomous vehicles come equipped with GPS chips, allowing them to navigate and time arrivals based on local data from global imaging, similar to Google traffic alerts. This helps the autonomous vehicle avoid traffic delays while providing timely delivery of goods. Fleet management personnel also use PNT and EO data from satellites to monitor and control the vehicles.

**Electric Scooters**

Entrepreneurs are using space infrastructure to offer alternative transportation modes in cities for reasonable prices. This type of service fills the need for cost-effective transportation without the hassle of commuting by car and clogging up the streets. Historically, alternatives to driving in cities have been utilization of mass transit (taking a bus or train with dozens of other people), ride a bicycle, or walk. In June 2018, electric scooters were initially offered for rent in Paris.

Renting an electric scooter may be attractive as a commuting alternative because it removes dealing with rush hour crowds on buses and trains and minimizes the physical exertion of riding a bike or walking. Two companies launched this service in Paris around the same time: Lime and Bird. Both rely on radio signals from PNT satellites.

Both companies offer similar services: scooter rentals, paid using a smartphone application. One of the biggest advantages provided to these companies are that their businesses don’t need “docks,” physical locking stands, for their scooters. This allows the companies’ scooters to be placed nearly anywhere within the city, to be used by anyone—so long as they have a smartphone. This convenience is why cities other than Paris are also experiencing an increase in commuters using rented electric scooters.

The services use their smartphone applications on renters’ phones, along with PNT satellite signals, to manage real-time scooter locations and monitor fares. These smartphone applications provide users with directions to nearby scooters as well as unlocking the scooters for use. Once a rider starts to move, the app monitors the time (adding up charges by the minute) and the location of the scooter. When the rider is finished, they will indicate this on the smartphone application, and the rider’s account is charged.

These companies offer services to municipalities as well as college campuses. The feature of powering transportation with an electric motor enables the scooters to cut down on carbon emissions and total environmental pollution (e.g., air quality and noise) compared with the average car.

**Shark Conservation**

Every year, 73 million sharks are killed, primarily for their fins as an ingredient in shark fin soup. This drive for shark fins by fishermen has put more than 70 varieties of sharks at risk of extinction. Exacerbating the problem of extinction is the species-wide characteristic of slow reproduction and maturity cycles. Satellite data is providing help with solving the shark overfishing problem before they are fished into extinction.
Historically, sharks have been tracked visually, with bright tags attached to fin-tops so trackers could see the tags when sharks surfaced. This process was limited as trackers could only observe these sharks from the coasts, leaving the shark’s entire ocean journey an unknown. Eventually, radio wave technology helped track sharks as researchers attached radio signal and acoustic signal tags to the animals. The land-based receivers, however, were few, and could not detect radio signals when sharks were further out to sea. The result of these receivers showed activity gaps, primarily because of where the receivers were located, which produced inconsistent shark activity data.

However, now, radio receivers on satellites are being used to do more than their terrestrially-based counterparts. One of the main steps being taken today to identify areas being overfished is to tag sharks with trackers tied to satellites. Satellite tagging started in the early 1980s and has provided ecologists with consistent data that helps track the movement of sharks in the Earth’s oceans where radio tags cannot be monitored and visual sightings are not possible. Current satellite radio emitter tags use PNT signals from PNT constellations in space, such as the Global Positioning System (GPS), to track and monitor the sharks in zones that are protected against fishing.

Location data gathered from these new types of tags led to the understanding that shark-poaching was occurring in sanctuaries. Biologists then tracked and monitored the captured tagged sharks, identifying where they were being taken (e.g., the Philippines and Guam). Then, using EO imagery satellites with PNT data correlation, biologists surveilled and identified ships fishing illegally in these protected areas. The ship information is sent to local authorities, who can investigate the ships and enforce local illegal fishing laws.

**Monitoring Pipelines from Space**

Pipeline leaks are harmful to the environment, costly to repair, and can lead to serious injuries or death to those living and working around them. For years, workers used helicopters, ground vehicles, and horses to monitor the health of pipelines. Inspecting pipelines through each of these methods were limited by the type of terrain through which the pipelines were installed, the sheer thousands of miles the pipelines traverse, weather conditions, and more. Even helicopters carrying sensors to detect the amount of methane in the air (indicating a leak) could only inspect a small pipeline section. While it could get to an area quickly, the inspection was still time- and human power-intensive. Additionally, helicopters must revisit an area every couple of weeks, requiring additional time and resources.

Satellites, however, can revisit large observation areas once every three to four days. In the past few years, satellite imagery and other remote sensing capabilities have gained some use for pipeline monitoring. More recently, the combined data of sensors from EO and PNT satellites, make it possible to provided monitoring services and data about pipelines. Satellites with synthetic aperture radars (SAR), for example, can obtain high-resolution data of observed areas in sunlight, but also provides data in more challenging areas covered in darkness and clouds. With SAR, multiple images are taken over a period of time; then these images are compared to discover differences in the condition of the observed pipelines.

Scientists and petroleum engineers identify any small changes between images, such as ground elevation changes caused by leaks, or changes in the pipeline structures themselves. These changes are then transmitted in real time over mobile satellite communication links, instantly informing system maintainers of any changes. Navigation satellites direct the workers to the exact location of the potential problem so that it can be assessed and ultimately fixed.

**Enabling Relief in the Aftermath of Natural Disasters**

A massive earthquake hit Indonesia in September 2018. The California Wildfire afflicted the state’s residents in November of 2018. In each disaster, residents and emergency teams dealt with extreme changes in the environment and faced areas that appeared inaccessible as a result of fire. Local resources, such as unmanned aerial vehicles (UAVs), were no use against the wildfire’s high temperatures. Earth observation (EO) spacecraft were used to help provide data to those who needed it.

Companies such as Maxar’s DigitalGlobe provided satellite imagery to relieve workers involved in both disasters, as the satellites captured images of the aftermath. Images from satellites assisted teams of relief workers in locating people...
trapped within collapsed houses, by crumbling bridges, or other unfortunate circumstances inside disaster zones. These images also helped local authorities identify sources of safe drinking water and determine which transportation routes were still open to provide access to impacted areas.18

Communications satellites were also critical in the hours and days after the disasters. Each disaster impacted local communications infrastructures. Space based communications satellites helped move satellite imagery data to the hands of local relief workers and organizations such as Earthrise Media, Team Rubicon, and the Red Cross.19
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Section 2 | Workforce


### The Space Economy

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