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Commercial Space Industry Launches a New Phase

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Summary

Rockets, satellites, and the services they provide, once the domain of governments, are increasingly launched and managed by privately owned companies. Although private aerospace firms have contracted with federal agencies since the onset of the Space Age six decades ago, U.S. government policy has sought to spur innovation and drive down costs by expanding the roles of satellite manufacturers and commercial launch providers.

Global spending on space activity reached an estimated $323 billion in 2015. Of this amount, nearly 40% was generated by commercial space products and services and 37% by commercial infrastructure and support industries. The U.S. government—including national security agencies and the National Aeronautics and Space Administration (NASA)—accounted for about 14% of global spending; government spending by other countries was responsible for the remaining 10%.

The satellite and launch vehicle supply chains are global, with a small number of manufacturers. In 2015, global satellite manufacturing revenues were $6 billion; launches booked $2.6 billion in revenue. Ground stations—the largest part of the commercial space infrastructure—generated more than $100 billion in revenue, largely from geolocation and navigation equipment.

The face of the U.S. space industry is changing with a government shift toward use of fixed price contracts for commercial services, new entrants with new launch products, and an increase in the use of smaller satellites:

- NASA's commercial cargo program and other federal contracts are supporting the growth of the commercial launch industry, with less expensive rockets, some of which are planned to be reusable. Many of the new space-related companies are attracting rising levels of venture capital.
- Aggressive pricing by U.S. entrants is cutting into the international launch market once dominated by foreign providers.
- A renewed interest in low-cost satellites, some of which are small enough to be held in one hand, is prompting a range of start-ups and providing new accessibility to space by educational institutions, small businesses, and individual researchers.

In order to spur innovation and growth, the commercial space industry has been purposely insulated from some types of federal regulation often applied to other industries. Nevertheless, three broad federal issues will affect the industry's future development. One is the structure of federal regulation and management; those responsibilities currently are dispersed among many agencies, and there is congressional interest in reorganizing commercial space functions at NASA and the Departments of Defense, Commerce, Transportation, and State. A second issue is the extent to which U.S. export controls are hampering U.S. satellite industry sales abroad. Export controls have recently been revamped to enable export of more commercial space products and services, but impediments may remain to reestablishing U.S. space product competitiveness. A third concern is that new Federal Communications Commission (FCC) regulations allowing wireless communication providers to share spectrum previously dedicated to satellite transmissions may result in interference. The commission has pledged to continue studying the issue.

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Introduction

Rockets, satellites, and the services they provide, once the domain of governments, are increasingly launched and managed by privately owned companies. Until 1982, the U.S. government launched all civil and commercial payloads into orbit, and U.S. launch vehicle manufacturers produced vehicles only under contract to the National Aeronautics and Space Administration (NASA) or the Department of Defense (DOD). Most of the satellites they carried into orbit were owned by U.S. or foreign government agencies. Now, commercial payloads are generally launched by private providers, and the payloads themselves are increasingly likely to be owned by private entities: Of the 576 U.S.-owned satellites currently in orbit, 286 were launched for commercial reasons and another 12 on behalf of academic users.[1]

The growth of the commercial space sector is a result of a deliberate shift in federal policy. The Commercial Space Launch Act of 1984[2] states the following:

> [T]he United States should encourage private sector launches, reentries, and associated services and, only to the extent necessary, regulate those launches, reentries, and services to ensure compliance with international obligations of the United States and to protect the public health and safety, safety of property, and national security and foreign policy interests of the United States.[3]

That law was amended in 2004 to provide that "the regulatory standards governing human space flight ... evolve as the industry matures so that regulations neither stifle technology development nor expose crew or space flight participants to avoidable risks as the public comes to expect greater safety for crew and space flight participants from the industry."[4]

National security agencies have emphasized the importance of the commercial space industry, in particular the space industrial base.[5] To foster its growth, the commercial space industry has purposely been insulated from some types of federal regulation often applied to other industries. For example, the Commercial Space Launch Act directs the Secretary of Transportation to issue regulations affecting the design and operation of launch vehicles only to protect the safety of crew, thereby giving launch vehicle manufacturers and operators wide leeway in developing new rockets. An initial eight-year "learning period" for this limited regulation has been twice extended, most recently until 2023.[6]

The Commercial Space Industry

Global spending on space activity reached an estimated $323 billion in 2015. Of this amount, nearly 40% was generated by commercial space products and services and 37% by commercial infrastructure and support industries. The U.S. government—including military and national

[1] Union of Concerned Scientists, *UCS Satellite Database*, http://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database#, viewed October 25, 2016.

[2] P.L. 98-575.

[3] P.L. 98-575, §2.

[4] §2(a) of Commercial Space Launch Amendments Act of 2004 (CSLAA), P.L. 108-492.

[5] Department of Defense and Office of the Director of National Intelligence, *National Security Space Strategy*, (Unclassified Summary), January 2011, p. 4, http://www.defense.gov/Portals/1/features/2011/0111_nsss/docs/NationalSecuritySpaceStrategyUnclassifiedSummary_Jan2011.pdf.

[6] The initial eight-year "learning period" was enacted in CSLAA and most recently extended by the Commercial Space Launch Competitiveness Act of 2015, P.L. 114-90.

security agencies and NASA—accounted for about 14% of global spending, and government spending by other countries the remaining 10%.[7]

The commercial space industry has distinct subsectors. Most commercial payloads are placed in orbits around Earth by launch vehicles that have the thrust to escape Earth's gravity. Typically, the firms that provide commercial launch services also design and assemble the rockets they launch. The payloads, such as satellites and manned space capsules, are manufactured by other firms. Service providers (such as television broadcasters) may design and build their own satellites, or purchase them from third-party manufacturers. The ground stations that control and communicate with the payloads, which form an integral part of the spacecraft operations, may be operated by the launch services, the payload owners, or entirely separate entities.

Satellites

The satellite supply chain is global, with a small number of manufacturers. Satellites are custom-made for their users, using specialized parts, which require extensive testing to ensure they will operate in a space environment where replacement and repair are generally not options. Because there are a limited number of rocket launches each year, supply chain deadlines are governed by a satellite launch window; if that window is missed because of production or regulatory delays, it may be many months or even years before another launch vehicle will be available to carry the satellite into orbit. Minimizing the mass and physical dimensions of a satellite is critically important, because heavier or bigger satellites are likely to require larger, more costly launch rockets. **Appendix A** shows a range of existing satellites, their weight, and corresponding familiar objects that approximate the same mass.

The United States is the largest manufacturer of spacecraft, followed by the European Union and Russia. The global commercial satellite manufacturing sector, with $6 billion in revenues in 2015, attempted 86 launches carrying 262 spacecraft. Of these, 126 were satellites weighing less than 22 pounds (10 kilograms). The growing use of these smaller satellites has led to a doubling in the number of satellites launched. However, smaller satellites comprise a tiny portion of the mass of vehicles sent into space: Of 392 tons of satellites launched in 2015, the total weight of satellites under 22 pounds was barely half a ton.[8]

Regardless of their size and type, satellites generally utilize similar types of components and instruments (**Figure 1**), including the following:

- *Solar panels* generate electricity that is stored in onboard *rechargeable batteries*.
- A *propulsion tank* adjusts altitude and orbit control and assists in placing the satellite into final orbit; several *thrusters* assist with these maneuvers and may be used later to move the satellite into a new orbit or, when the satellite's useful life is over, into a "graveyard" orbit farther away from Earth.
- *Thermal control* is the skin that prevents damage to the internal components in the extreme temperatures of space. Satellites pass through a wide range of temperatures, ranging from about -300°F to +200°F. Certain components, such as batteries, have an optimum operational range of about +50°F to +85°F.[9] The skin is composed of a

[7] Space Foundation, *The Space Report*, 2016, p. 16.

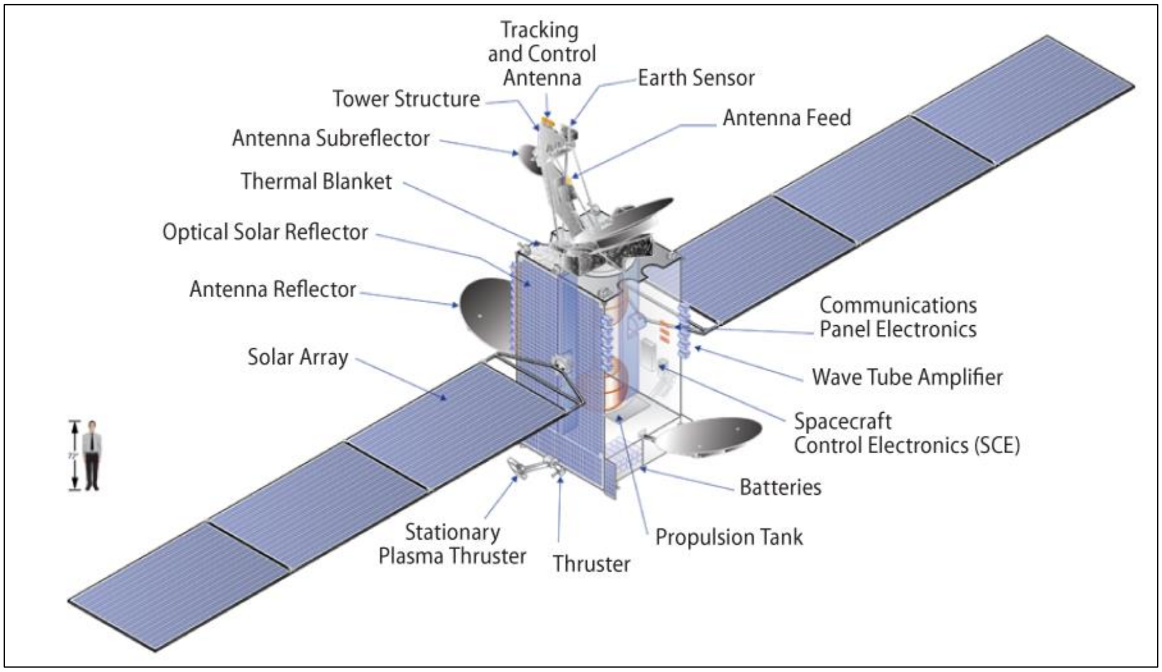
[8] Ibid., p. 17.

[9] James Wertz, David Everett, and Jeffrey Puschell, "Spacecraft Subsystems V: Structural and Thermal," in *Space Mission Engineering: The New SMAD* (Space Technology Library, Hawthorne, CA, 2011), p. 686, Table 22-9.

multilayer thermal blanket made of lightweight reflective films. In addition, a coated or mirrored optical solar reflector may be used, which acts like a radiator to keep the components from overheating due to solar energy and radiation.

- An *electronics system* controls satellite functions, such as flight operations, the direction in which the satellite points, and mathematical analysis.
- A *communications system* includes a transmitter, a receiver, *antennae* that send data to and receive instructions from ground stations, and an amplifier that produces high-power radio frequency signals.
- Specialized components are determined by the core mission of the satellite. For example, a remote sensing satellite might include an image sensor, a telescope, and a digital camera.

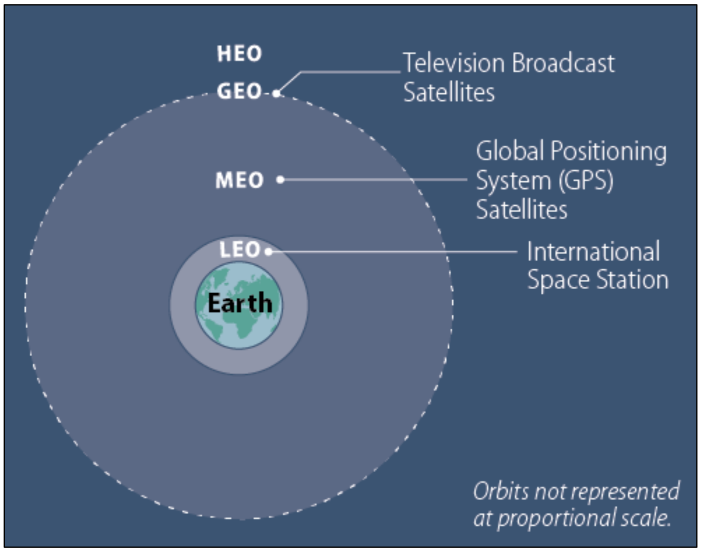
Figure 1. Typical Satellite Components



Source: Image courtesy of Space Systems Loral (SSL), http://www.sslmda.com.

Satellites are placed into different types of Earth orbits depending on their planned use: low Earth orbit, medium Earth orbit, geosynchronous Earth orbit, and high Earth orbit (**Figure 2**). The altitude of the orbit determines how frequently the spacecraft orbits the Earth. Some types of space activities require closer proximity to Earth for supply and maintenance and to provide higher-resolution images of Earth. Others operate farther in space to more effectively deploy their services. The International Space Station (ISS), for example, is in low Earth orbit, taking 90 minutes for a full orbit, while a television or weather satellite in geosynchronous orbit will take a full day. A satellite in geosynchronous orbit matches the Earth's rotational speed, so unlike other types of satellites, it will remain in the same place above the Earth and can therefore provide the same locations with weather monitoring or telecommunications.

Figure 2. Earth Orbits



Source: CRS.

At the end of June 2016, 1,419 satellites were in operation, with 55% in low Earth orbit, 36% in geosynchronous orbit, 7% in middle Earth orbit, and the remainder in high Earth orbit. Of these, 576 are U.S. satellites, 140 Russian, 181 Chinese, and 522 from other countries. Of the U.S. satellites, 286 are commercial, 146 military, 132 government, and 12 civil.[10]

Launch Services and Vehicles

The commercial launch industry booked $2.6 billion in revenues in 2015, when it attempted 86 rocket launches. Of these, 83 launches successfully placed payloads into orbit. Twenty-two launches carried commercial satellites and 64 carried government payloads; some carried both. It has been estimated that total costs of global launches for commercial, civil, and military purposes (including servicing the ISS) in 2015 were about $8 billion.[11] The U.S. Government Accountability Office (GAO) identified three factors spurring the growth of the U.S. launch industry:

- the NASA commercial cargo program and other federal contracts;
- aggressive pricing by SpaceX and some other private providers, which are "more price competitive compared with foreign launch providers"; and
- the emerging space tourism and small satellite industries.[12]

Launch Services

A traditional spaceport was a facility owned by the federal government, such as Kennedy Space Center and Cape Canaveral Air Force Station (both in Florida) and Vandenberg Air Force Base (in California). The federal government has used these facilities for its own launches and also

[10] Ibid.

[11] Ibid., p. 17.

[12] U.S. Government Accountability Office, *Commercial Space: Industry Developments and FAA Challenges*, GAO-16-765T, June 22, 2016, pp. 11-12.

promoted their use for commercial space access. Several private providers of launch services have chosen to build their own facilities. The Federal Aviation Administration (FAA) has licensed 10 spaceports in seven states: California, Florida, Texas, Oklahoma, Alaska, Virginia, and New Mexico.[13] California, Florida, and Texas each have two licensed spaceports. Additional launch sites have been proposed in other states.

Spaceports are configured for specific uses.[14] Some are planned only to launch large vertical rockets, while others hope to lure space tourism with facilities for winged launch vehicles.[15] Regardless of the type of launch vehicles using the sites, they have common infrastructure needs, including access for delivery of large launch vehicle components; room to assemble rocket parts into a launch vehicle; facilities for receiving and storing propellants and loading them aboard rockets; secure facilities for storing cargo, payloads, and scientific experiments; work space for crews, engineers, and launch personnel; and meteorological equipment to monitor weather patterns prior to scheduled launches.[16]

The ISS[17] also increasingly offers certain types of launch services; part of it is designated as a national laboratory, a shared resource for NASA and private industry;[18] astronauts have used its robotic arm to launch small satellites into orbit, many of them only 4-inch cubes.[19] In 2015, 42 small satellites, primarily with commercial functions, were launched as cargo to the ISS for later deployment into individual orbits.[20] U.S. crew members and cargo were transported to the ISS in NASA's Space Shuttle from 2000 until 2011, when the shuttle was retired. Since then, the ISS has been resupplied by commercial launches through NASA's Commercial Orbital Transportation Services (COTS) program—the companies SpaceX and Orbital ATK are participants—as well as launches by the Japan Aerospace Exploration Agency (JAXA) and Russian Soyuz rockets.[21]

Launch Vehicles

Launch vehicles have the primary function of putting a spacecraft into an orbit or a suborbital trajectory. In the process of launching a satellite, most of the rocket stages fall away in sequence

[13] Federal Aviation Administration, *Active Launch Site Operator Licenses*, September 17, 2013, https://www.faa.gov/data_research/commercial_space_data/licenses/. FAA licensing authority is specified in 14 C.F.R. Part 420.

[14] Richard Rogers, "Commercial Spaceports: Building the Foundation of a Commercial Space Transportation Network," *TR News (Transportation Research Board)*, No. 300 (December 2015), p. 9.

[15] Some launch vehicles are expected to be shuttle-like vehicles, such as Virgin Galactic's SpaceShipTwo and Sierra Nevada's Dream Chaser.

[16] Other countries with spaceports are Australia, Brazil, China, EU, India, Iran, Israel, Japan, North Korea, Norway, Russia, South Korea, and Sweden. Space Foundation, *The Space Report*, 2016, p. 61.

[17] The ISS has been in operation since 2000 as a habitable satellite in LEO. It has a rotating multinational crew who conduct scientific research and demonstrate new technologies. NASA pays Russia $82 million for each roundtrip crew transport aboard Soyuz. NASA Office of Inspector General, *NASA's Commercial Crew Program: Update on Development and Certification Efforts*, IG-16-028, September 1, 2016.

[18] In 2005, Congress designated part of the ISS as a national laboratory in the NASA Authorization Act of 2005 (P.L. 109-155), §507.

[19] NASA, "Deploying Small Satellites From ISS," press release, November 10, 2015, https://www.nasa.gov/mission_pages/station/research/benefits/cubesat.

[20] Federal Aviation Administration, *The Annual Compendium of Commercial Space Transportation*, January 2016, p. 36.

[21] In January 2016, NASA awarded a contract to Sierra Nevada Corporation to be third participant in its Commercial Resupply Services beginning in 2019. NASA, "NASA Awards International Space Station Cargo Transport Contracts," press release, January 14, 2016, https://www.nasa.gov/press-release/nasa-awards-international-space-station-cargo-transport-contracts.

until the spacecraft reaches its planned orbit; the first stage of the rocket propels the rocket from the launch pad, and then the second-stage rocket boosts the payload to orbit. Launch vehicles generally are used only once, although some commercial providers are developing vehicles that are intended to be reusable. **Figure 3** is a cross section of a typical launch vehicle, the United Launch Alliance Atlas V. Its major components—from top to bottom—include the following:

- The *nose cone or fairing*, a structure made with a vented aluminum-honeycomb core and graphite epoxy covering, carries the payload. Manufacturers offer clients a choice of three payload fairings, depending on the size of the payload.[22] The fairing protects the payload from atmospheric pressure changes and aerodynamic heating during launch.
- The *second-stage rocket* consists of fuel and oxygen tanks, control systems, and a rocket engine that carries the payload to orbit. The Atlas V is propelled by a single RL 10 Centaur engine and stainless steel fuel tanks, providing 22,300 pounds-force (lbf)[23] of thrust, fueled by liquid hydrogen and liquid oxygen. The walls of the stainless steel tanks are insulated and so thin that they cannot support their own weight before they are pressurized, a design developed to maximize engine performance.[24] The Centaur second stage also includes flight and guidance computers that autonomously control all aspects of the flight.
- *Adapters* connect the first and second stages of the rocket and provide the structure for housing vehicle electronics.
- The *first stage* consists of additional fuel and oxygen tanks, control systems, and rocket engines, sometimes supplemented with strap-on boosters. The Atlas V main booster is made of a special aluminum and, unlike the stage-two tanks, is structurally stable. The launch vehicle is fueled by rocket propellant (or highly purified kerosene) and liquid oxygen that provide 860,300 lbf of thrust. The RD 180 engine was developed in Russia and is produced by a U.S.-Russian joint venture.[25]

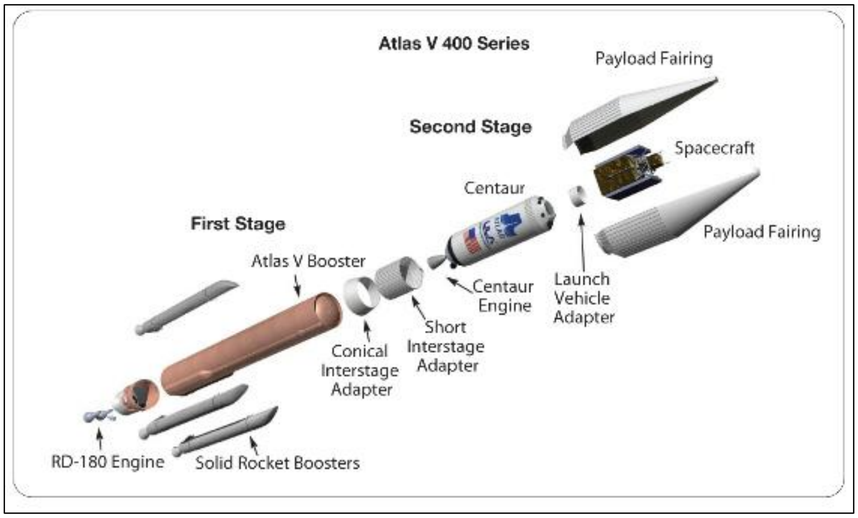
[22] The height of an Atlas V rocket with a short fairing is 196 feet; with a medium fairing, 205 feet; and a long fairing, 215 feet. United Launch Alliance, http://www.ulalaunch.com/uploads/docs/Atlas500_Cutaway.pdf.

[23] The abbreviation *lbf* represents pound-force. As a measurement unit of force, it equals one pound multiplied by the standard acceleration due to gravity on Earth.

[24] The Centaur is the name of the second stage rocket used on Atlas rockets; variations of it have been in use since 1963. See http://www.nasa.gov/centers/glenn/about/history/centaur.html. The Aerojet Rocketdyne RL 10 engine has been used for more than 50 years as the second-stage engine on many commercial, civil, and military rockets. See http://www.rocket.com/rl10-engine.

[25] The engines are produced in Russia by NPO Energomash and sold by the U.S.-Russian joint venture, known as RD AMROSS, a joint venture between Pratt & Whitney and NPO Energomash. See http://www.ulalaunch.com/faqs-rd-180.aspx.

Figure 3. Cross Section of a Typical Launch Vehicle



Source: Image courtesy of United Launch Alliance, http://www.ulalaunch.com/products_atlasv.aspx.

Ground Systems

Ground systems are the Earth-bound infrastructure that transmits directions to satellites and receives data they collect.

Ground systems include *antenna services* for transmission and reception of satellite radio frequency (RF) signals. There has been experimentation with optical communications (using lasers), but most satellite communication is through RF, generally using 30 megahertz (MHz) to 30 gigahertz (GHz) bands.[26] Antenna services decode embedded data streams before passing them on for distribution and analysis.[27] Ground service options are customized for each satellite program and may include government-owned and commercial antenna assets to maximize a satellite's communications capability. A satellite that is in frequent contact with ground stations will need smaller amounts of onboard data storage than a spacecraft that has limited opportunities to transmit data to the ground.[28]

Ground facilities include *user terminals*, which can be handheld mobile terminals, rooftop dish antennae for satellite television, satellite radios in cars, or large corporate dish antennae.[29]

Ground systems also include *data accounting and distribution services* and *data processing* services. In addition to data storage, these services identify data missing from transmissions and take action to retrieve it from the satellite.[30] These services are highly automated "lights-out" systems that function around the clock with only occasional monitoring by employees. As the

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[26] Australian Space Academy, *Radio Frequencies for Space Communication*, http://www.spaceacademy.net.au/spacelink/radiospace.htm.

[27] James Wertz, David Everett, and Jeffrey Puschell, "Spacecraft Subsystems V: Structural and Thermal," in *Space Mission Engineering: The New SMAD* (Space Technology Library, Hawthorne, CA, 2011), p. 879.

[28] Satellites with continual links to ground stations are built with no onboard storage. Ibid., pp. 880 and 897.

[29] Roger Cochetti, *Mobile Satellite Communications Handbook*, 2nd ed. (Hoboken, NJ: Wiley, 2015), pp. 31.

[30] James Wertz, David Everett, and Jeffrey Puschell, "Spacecraft Subsystems V: Structural and Thermal," in *Space Mission Engineering: The New SMAD* (Space Technology Library, 2011), p. 879.

global space economy continues to expand, the need for international standards is growing to ensure interoperability among systems from different countries and service providers.[31]

With more than $100 billion in revenue, ground stations and related equipment comprise the largest part of commercial infrastructure. This subsector provides consumer products such as satellite phones and television, navigation chips in mobile phones, and many other products. Three-quarters of the revenue stems from geolocation and navigation equipment, such as Global Positioning System (GPS) receivers.[32]

Space-Related Products and Services

Global commercial space products and services generated $126 billion in revenue in 2015. The space component of some of these products and services is not always well understood by the users, who may take some of them—such as GPS—for granted. The major commercial categories include the following:

- *Communications systems* relay radio and television signals sent from a point on the ground to a satellite and then to another ground point. These signals may carry such content as television programs, in-flight calls from airplane passengers, and some smartphone data. Satellite television alone accounts for almost a third of all space-related commercial activity.[33]
- *Earth observation* provides environmental monitoring of oceans, forests, deserts, wildlife habitats, and natural disasters.
- *Global atmospheric monitoring* includes data collected for meteorological use to help predict weather patterns, hurricanes, and El Niño. It also measures soil water content to assist in prediction of droughts and floods.
- *Transportation* uses provide geolocation services to delivery trucks and ride-sharing services and their passengers.
- *Safety enhancement* provides data to first responders at oil spills and forest fires and prevents train collisions with geolocation services.

Satellites also have noncommercial, national security purposes, including detecting the launch of missiles; detecting nuclear explosions in the ground or atmosphere to monitor nuclear treaty compliance; and providing global jam-resistant communications for strategic and tactical forces during a conflict.

Insurance

Space launches are risky: three of the 86 commercial launches attempted in the United States in 2015 failed, resulting in the destruction of launch vehicles and costly payloads. Given the potential losses, insurance coverage is likely to play an important role in the development of a commercial space industry. Worldwide space insurance premiums were more than $700 million in

[31] Several international protocols have been implemented through the Consultative Committee on Space Data Services. See https://public.ccsds.org/default.aspx; ibid., p. 894.

[32] Space Foundation, *The Space Report*, 2016, pp. 17-19.

[33] The U.S. satellite industry, comprising satellite manufacturing, telecomm services (including television, mobile data, remote sensing), launch vehicles, and ground equipment, is estimated as having $208 billion in revenue in 2015. See Satellite Industry Association, *State of the Satellite Industry Report*, June 2016, p. 5.

2015, and insured losses exceeded $600 million in 2014.[34] Major insurers such as American International Group, Munich Re, and Allianz compete in the market.

Nonetheless, insurance on space-related risks appears to have limitations. In September 2016, a rocket owned by SpaceX exploded while on the launchpad at Cape Canaveral, Florida, destroying the satellite it was preparing to launch. The Falcon 9 rocket was reportedly not insured. The owner of the satellite it was attempting to launch held $300 million of coverage. However, the policy[35] may not be applicable because the rocket explosion took place during a prelaunch test and not during the actual launch.[36]

New Entrants Change the Industry

Three developments are changing the shape of the commercial space industry: a shift in government space activities toward the use of commercial services, an increase in private financing, and an increase in the launch of small satellites. These changes are supporting the development of new entrants with new launch products.

U.S. Government Redefines Procurement

Whereas NASA once owned the spacecraft produced for it by suppliers like Boeing, it now is in some cases transferring risk by contracting out for services, leaving the ownership of the launch vehicles to commercial entities. Its choice of traditional procurement or a more commercially oriented approach (**Table 1**) depends on the program mission.[37] With the commercially oriented approach, NASA agrees on a fixed price for the services a contractor is to provide, rather than using a cost-plus methodology that reimburses the contractor's allowable expenses and adds an additional payment to ensure a profit.

One example of the new approach is procurement of transportation of astronauts to the ISS. NASA traditionally would have provided detailed descriptions of each step in development of a launch vehicle and funded it as well. Now, however, more project development is left to the contractor, which shares the cost.[38] The commercial partner is expected to meet project milestones. If it does, it is paid and the project moves to its next stage.

[34] Ibid., p. 20.

[35] The satellite destroyed in the SpaceX explosion was built by Israeli-based Space Communication for Facebook and Eutelsat; it was designed to provide Internet service to sub-Saharan Africa. Dana Hull and Julie Johnsson, "SpaceX Explosion Draws Attention to Insurance for Rocket Science," *Insurance Journal*, September 2, 2016.

[36] Ian Salisbury, "Elon Musk's SpaceX Rocket Could Have Been Insured, But Wasn't," *Time*, September 2, 2016.

[37] NASA has worked with private companies almost from its inception, developing the first civil communications satellites in cooperation with AT&T, Radio Corporation of America (RCA), Hughes Aircraft, and others. Roger Cochetti, *Mobile Satellite Communications Handbook*, 2nd ed. (Hoboken, NJ: John Wiley & Sons, Inc., 2015), p. 3.

[38] NASA's Commercial Orbital Transportation Services (COTS) is an example of a public-private partnership using the approaches in **Table 1**. SpaceX and Orbital LEO transportation systems were developed jointly: SpaceX invested 53% and the U.S. government invested 47% for the development and demonstration of a commercial transportation system; Orbital invested 58% and the U.S. government invested the remaining 42%. NASA, *Commercial Orbital Transportation Services: A New Era in Spaceflight*, February 2014, p. 95, https://www.nasa.gov/sites/default/files/files/SP-2014-617.pdf.

Table 1. Distinct Approaches for Distinct Missions at NASA

Program Characteristics	Traditional Approach	Commercial-Oriented Approach
Owner	NASA	Industry
Contract type	Cost-plus	Fixed price
Contract management	Prime contractor	Public-private partnership
Customers	NASA	Government and nongovernment
Funding for capability development	NASA procures capability	NASA provides "milestone" payments as agreed goals are reached
NASA's role in capability development	NASA defines "what" and "how"	Industry defines "how" and NASA approves
Requirements definition	NASA defines detailed requirements	NASA defines only higher-level requirements
Cost structure	NASA incurs total cost	NASA and industry share costs

Source: NASA, Human Exploration and Operations Mission Directorate.

During the final years of the space shuttle program, NASA encouraged and funded commercial providers to develop systems that could transport crew and cargo to the ISS. The first of these was the SpaceX Dragon capsule and Falcon 9 rocket, which has ferried supplies to the ISS since 2012. Last year, four ISS cargo launches were conducted by Orbital ATK and three more by SpaceX. (Boeing and SpaceX are each developing ISS crew transportation capabilities for first use in the next few years.)

New entrants are changing the economics of launches by reuse of rocket boosters. SpaceX's entry into the launch market provides NASA and DOD with new options, and it is also cutting into the international launch market formerly dominated by foreign providers. SpaceX has had several successful launches and relandings. Blue Origin has to date launched several prototypical rockets that have returned to their launchpads.

Private Financing Increases

Space-related industries[39] are taking advantage of a range of private financing options, including venture capital, debt financing, and acquisition, receiving more than $13 billion in such investments between 2000 and 2015. According to Tauri Group, a space industry research organization, this trend has accelerated over the past five years, with 2015 recording $2.3 billion in space-related capital investment, a record level for one year.[40] Several wealthy business owners—some with ties to Silicon Valley—and corporations are also investing in space-related companies,[41] as are banks, including the U.S. Export-Import Bank.[42] These combined capital sources have spurred the establishment of new companies: In the last five years, an average of

[39] Including satellite, launch vehicle, and ground equipment manufacturing; satellite-based services such as television, radio, and broadband; and data collection and analytical services. Tauri Group, *Start-Up Space: Rising Investment in Commercial Space Ventures*, January 2016, p. 2.

[40] Of the $2.3 billion invested in space-related companies in 2015, $1.8 billion was venture capital. Ibid., p. iv.

[41] So-called space billionaires Jeff Bezos, Elon Musk, and Richard Branson have formed start-up space ventures. Large companies such as Google, Qualcomm, AT&T, Coca-Cola, and Monsanto are also investing. Ibid., p. 9.

[42] Ex-Im Bank has provided debt funding for satellite systems. Ibid., p. 10.

eight new space ventures were established annually, almost triple the level of such firm creation in the early 2000s.[43] According to Tauri Group, investors find space attractive because launch vehicle costs are forecast to drop with the use of new types of launch hardware, including reusable rockets, and because they anticipate the development of new products and services,[44] such as space tourism and new satellite sources for collecting and analyzing data obtained in space.

Growing Deployment of Small Satellites

The development of small satellites[45] for Earth imaging and establishing space-based Internet networks from LEO is now possible because satellite components have been miniaturized and standardized. Groups of small satellites are referred to as constellations; Planet Labs, for example, has a constellation of 36 small satellites in orbit, with customers paying for the images it can capture at less distance from Earth than is possible with larger satellites in higher orbits.[46] Some observers argue that demand for data may be driving the market for small satellites, as much as the new technologies.[47]

Small satellites allow access to space by researchers, companies, and governments that cannot afford larger spacecraft. Because small satellites can travel as a secondary payload on many launch vehicles, launch costs may be only a few million dollars per satellite, although multiple small satellites may be required for many purposes.[48]

The small satellite market is addressed by a number of startup firms that hope to succeed in providing broadband, remote imaging, or communication services, such as Firefly Space Systems in Texas, Rocket Lab in California, and OneWeb in Virginia. While small satellites are normally launched on rockets with other, larger payloads, Virgin Galactic is proposing a new type of launcher: a rocket attached to the wing of a modified commercial 747 jet will launch a payload into orbit when the plane reaches an altitude of 35,000 feet. Virgin Galactic believes this form of launch vehicle, using smaller rockets, will significantly reduce the cost of putting small satellites into orbit.[49]

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[43] The availability of private funding can affect NASA's commercial space resources. In 2006, NASA chose SpaceX and Rocketplane Kistler (RpK) to provide future space transportation services to the ISS. In 2007, NASA terminated its contract with RpK because the company was unable to raise enough private funding to continue its vehicle development. NASA, *Commercial Orbital Transportation Services*, NASA/SP-2014-617, February 2014, p. v.

[44] Long-established aerospace firms are not part of the Tauri Group analysis, even if they obtain private equity investments; new space ventures and capital directed to them are the focus of that analysis. The Tauri Group, *Start-Up Space: Rising Investment in Commercial Space Ventures*, January 2016, p. 3.

[45] Small satellites are categorized as picosatellites (under 1 kilogram [kg]), nanosatellites (1-10 kg), and microsatellites (10-100 kg). CubeSats, which generally weigh less than 1.3 kg, are in the shape of a cube that can fit in a person's hand. In the last 50 years, 38 picosatellites, 680 nanosatellites, and 860 microsatellites have been launched worldwide. Henry Helvajian and Siegfried W. Janson, eds., *Small Satellites: Past, Present and Future* (El Segundo, CA: Aerospace Press, 2009).

[46] Clay Dillow, "Here's why small satellites are so big right now," *Fortune*, August 4, 2015.

[47] Prateep Basu, *'Big Data' Leap in EO Markets*, Northern Sky Research, October 1, 2016, http://www.nsr.com/news-resources/the-bottom-line/big-data-leap-in-eo-markets/.

[48] Aerospace Press, "Small Satellites: Past, Present, and Future," press release, June 1, 2008, http://www.aerospace.org/publications/aerospace-books/small-satellites-past-present-and-future.

[49] Samantha Masunaga, "Small satellites are back, with down-to-earth expectations," *Los Angeles Times*, May 27, 2016.

NASA is also utilizing small so-called CubeSats to address scientific questions and broaden the involvement of students and researchers. In 2015, 42 small satellites, primarily with commercial functions, were launched as cargo to the ISS for later deployment from there.[50] NASA has announced that it will help develop new CubeSat technologies and will launch six small Earth-observing satellite missions.[51]

Commercial Space Workforce Declines

The space industry workforce includes employees in private-sector firms as well as those working at NASA, DOD, and other government agencies. The increasing public attention given to the commercial space industry belies a dichotomy: the commercial and civil space workforces are declining, while national security workforces remain steady.

Commercial employment in the space industry peaked in 2006 at about 267,000 employees and has declined steadily since then.[52] The termination of NASA's space shuttle program[53] in 2011 resulted in the loss of many private-sector jobs. Other major reasons for the decline in space industry employment may be many skilled workers reaching retirement age and difficulties in recruiting young talent.[54]

Jobs in this industry generally require advanced skills, such as engineering, differentiating them from the average U.S. manufacturing or service-industry job. The Space Foundation has identified six industry sectors that collectively approximate the space industry. Bureau of Labor Statistics (BLS) data show that employment in these six sectors dropped by 16% in the 10 years from 2005 to 2015 (**Table 2**).[55]

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[50] Federal Aviation Administration, *The Annual Compendium of Commercial Space Transportation*, January 2016, p. 36.

[51] NASA, "New CubeSats to Test Earth Science Tech in Space," press release, February 22, 2016, http://www.nasa.gov/press-release/nasa-selects-instruments-to-study-air-pollution-tropical-cyclones; NASA, "NASA Small Satellites Set to Take a Fresh Look at Earth," press release, November 7, 2016, http://www.nasa.gov/press-release/nasa-small-satellites-set-to-take-a-fresh-look-at-earth. The new satellites will reach orbit on an Orbital ATK Pegasus XL rocket.

[52] Bureau of Labor Statistics, *Quarterly Census of Employment and Wages (QCEW)*.

[53] The United Space Alliance was formed by Boeing and Lockheed Martin in 1996 as the major contractor for the shuttle and the ISS. See http://www.unitedspacealliance.com.

[54] U.S. Department of Commerce, Bureau of Industry and Security, *U.S. Space Industry "Deep Dive" Assessment: Employment in the U.S. Space Industrial Base*, September 2014, p. 13.

[55] These six categories also include jobs that are not in the commercial space industry. For example, NAICS 334511 also includes workers in broader aerospace and nautical industries, so some of the decline in that category could have been in those industries, not commercial space. Data from the Bureau of Labor Statistics (BLS) do not go into that greater level of detail.

Table 2. Space Industry Employment

(2005-2015)

Industry Sector	Employment in Sector 2005	Employment in Sector 2015	Percent Change
Search, Detection, and Navigation Instruments (*334511*)[a]	155,492	124,578	-19.9%
Guided Missile and Space Vehicle Manufacturing (*336414*)[b]	53,316	55,825	+ 4.7
Guided Missile and Space Vehicle Propulsion Unit and Parts Manufacturing (*336415*)[c]	13,115	9,729	-25.8
Other Missile and Space Vehicle Manufacturing (*336419*)[d]	7,423	5,309	-28.4
Satellite Telecommunications (*517410*)[e]	16,349	8,633	-47.2
Space Research and Technology (*927110*)[f]	18,371	17,293	-5.9
TOTAL	**264,066**	**221,367**	**-16.2%**

Source: Bureau of Labor Statistics, *Quarterly Census of Employment and Wages (QCEW)*.

Notes: Industry categories are based on the North American Industry Classification System (NAICS); NAICS codes are shown italicized above.

a. Manufacturing of search, detection, navigation, guidance, aeronautical, and nautical systems and instruments.

b. Manufacturing of complete guided missiles and space vehicles and/or developing and making prototypes of such missiles and vehicles.

c. Manufacturing of guided missile and/or space vehicle propulsion units and parts and/or developing and making prototypes of such units and parts.

d. Manufacturing of guided missiles and space vehicle parts and auxiliary equipment (except guided missile and space vehicle propulsion units and parts) and/or developing and making prototypes of guided missile and space vehicle parts and auxiliary equipment.

e. Telecommunications services provided to other establishments in the telecommunications and broadcasting industries by forwarding and receiving communications signals via system of satellites or reselling satellite communications.

f. Government establishments primarily engaged in the administration and operations of spaceflights, space research, and space exploration, including government establishments operating spaceflight centers.

These data do not show the full scope of the space industry workforce. The categories listed in **Table 2** include both space and nonspace activity,[56] while employees in other sectors who are working on space-related tasks are excluded because most of the employment in the sector is not related to space.[57]

An alternative approach to assessing the size and breadth of the space industry workforce is the 2012 space industry report by the U.S. Department of Commerce (DOC), based on a survey of 3,780 respondents in 16 different manufacturing and service segments of the space economy, including spacecraft and launch vehicles, communications systems, ground systems, electronic equipment, and software.[58] This survey, conducted once and covering the years from 2009 to

[56] For example, NAICS 334511 includes manufacture of space guidance systems, but also the manufacture of nonspace equipment such as aircraft airspeed measurement instruments.

[57] For example, NAICS Surveying and Mapping Services (54137) includes imagery obtained by satellites, but the larger part of the category is based on aerial photography.

[58] U.S. Department of Commerce, Bureau of Industry and Security, *U.S. Space Industry "Deep Dive" Assessment: Employment in the U.S. Space Industrial Base*, September 2014, pp. 18-19.

2012, shows a somewhat larger workforce of 254,179 employees in 611 commercial companies that viewed themselves as dependent on federal space programs.[59]

In addition to commercial employment, DOC identified 13,897 space-related jobs in the U.S. government, 19,630 in nonprofit organizations, and 60,533 at universities, for a total of 348,239 workers dependent on space-related programs. The report shows shrinkage of nearly 7% in employment at companies dependent on commercial space programs from 2009 to 2012.[60]

Wages in the commercial space industry are higher than average U.S. wages. The average space industry salary of $111,000 (in 2014)[61] is double what the average private-sector employee receives.[62] Average salaries vary within the six industry categories cited in **Table 2**, from about $92,000 in missile and vehicle propulsion (NAICS 336415) to more than $124,000 in missile and vehicle manufacturing (NAICS 336414).[63]

Policy Issues for Congress

Three overarching issues will affect the development of commercial space in the future: how the industry is regulated by diverse federal agencies, the effects of new export control laws and regulations that seek to increase U.S. space industry competitiveness, and the allocation of spectrum for satellite use.

Regulating and Managing Commercial Space

The commercial space industry is governed by federal agencies with diverse regulatory interests. The major federal agencies with commercial space policy responsibilities are as follows:

- *FAA's Office of Commercial Space Transportation* regulates launches and reentries of space vehicles, as well as the U.S. launch and reentry sites, including rerouting aircraft that may interfere with a nearby rocket launch.[64]
- The *Department of Commerce* has two major space industry interests. The National Oceanic and Atmospheric Administration (NOAA) licenses commercial imaging satellites and utilizes commercial space capabilities for improved weather forecasting and environmental data collection,[65] and also oversees the Office of Space Commerce, which promotes the U.S. commercial space industry's economic growth and technological advancement.[66] DOC's Bureau of Industry and Security (BIS) administers export controls and licensing for strategic technologies, including space industry components.[67]

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[59] Employment estimate is for 2012, with 611 of the 3,780 respondents saying they were dependent on federal space-related programs for their viability. Each company determined its own standard of dependency. Ibid.

[60] Ibid.

[61] Space Foundation, *The Space Report*, 2016, p. 65.

[62] In 2015, the average U.S. private sector job paid $52,876, and the average U.S. manufacturing job paid $64,305. Bureau of Labor Statistics, *Quarterly Census of Employment and Wages*.

[63] Space Foundation, *The Space Report*, 2016, p. 66.

[64] https://www.faa.gov/about/office_org/headquarters_offices/ast/regulations.

[65] http://www.noaanews.noaa.gov/stories2016/images/NOAA%20Commercial%20Space%20Policy.pdf.

[66] http://www.space.commerce.gov/about/mission.

[67] Most space technologies are covered by U.S. export control laws and regulations. Export Administration Regulations (EAR) cover dual-use products that could be used for either commercial or military purposes. https://www.bis.doc.gov/ (continued...)

- *NASA* provides infrastructure and operations support and encourages private-sector investment in its launches and other activities through its Commercial Crew and Cargo Programs.[68]
- *Department of Defense* utilizes commercial space systems and technologies for national security purposes. Through the Air Force, it provides infrastructure, operations support, and safety oversight for government and commercial launches at its launch sites.[69] Additionally, through the Defense Technology Security Administration (DTSA), it reviews and comments on applications for export licenses, in conjunction with Department of State review.[70]
- *Department of State* (DOS) is responsible for the export and temporary import of defense articles and services—including some commercial space components—through the International Traffic in Arms Regulations (ITAR).[71]
- *Federal Communications Commission* licenses commercial satellite radio frequencies and determines placement of satellites in geostationary orbit.[72]

The current regulatory and management structure may require changes if the commercial space industry grows. Private firms may take on more responsibilities for launching government satellites (including military satellites), offer space flights for tourists, undertake mining operations on asteroids and the moon, and attempt to explore and even settle Mars. This could lead to greater commercial demand for FAA to process licenses, permits, and safety reviews. Congress may need to set additional legal parameters to establish a legal basis for regulation of passenger safety in space tourism and space traffic management. In addition, the current legal provision for liability risk-sharing between launch companies and the U.S. government may require changes as the industry matures and more private individuals become passengers or crew.

A better system for integrating commercial space launches into the air traffic control system is a particular concern for FAA. Currently, when a launch or reentry is planned, FAA closes airspace near the site because equipment onboard aircraft often cannot track rockets and spacecraft moving at very high speeds. Since launch times may vary from initial plans, FAA may close the airspace for a long period, causing both commercial and military aircraft to be delayed or rerouted. The FAA alert system utilizes email and phone calls to commercial and military airspace users. As the number of rocket launches increases, FAA may face pressure to reduce the length of air space closures. The agency plans to use an automated system to deliver alerts to aircraft pilots to minimize air traffic impact.[73]

In the 114th Congress, H.R. 4945 has been proposed to change federal oversight of commercial space. In addition to making organizational changes within DOD, the legislation would direct NASA to develop a 20-year plan to land astronauts on Mars, and would require the Department of

(...continued)

index.php/about-bis.

68 https://www.nasa.gov/exploration/commercial/index.html.

69 http://archive.defense.gov/home/features/2011/0111_nsss/docs/Fact%20Sheet%20DoD%20Space%20Policy.pdf.

70 http://www.dtsa.mil/SitePages/assessing-and-managing-risk/space-launch-technology.aspx.

71 http://www.pmddtc.state.gov/regulations_laws/itar.html.

72 https://www.fcc.gov/licensing-databases/licensing and https://www.fcc.gov/approved-space-station-list.

73 Michael Lopez-Alegria, Former Astronaut and Vice Chairman, Commercial Space Transportation Advisory Committee (COMSTAC), *FAA Oversight of Commercial Space Transportation*, Subcommittee on Aviation, House Committee on Transportation and Infrastructure, June 22, 2016, pp. 5-6.

Transportation to establish an Office of Commercial Space Transportation and an Office of Spaceports and also to designate a lead government agency for space traffic management. DOC would be directed to develop a plan to coordinate space-related economic and regulatory activities, and DOS would be required to begin developing an international traffic management regime.

Export Controls

Spacecraft, ground stations, and some unique components are regulated by the U.S. export control system. They are considered dual-use items, as even those developed primarily for commercial or civil purposes have possible military applications. During the Cold War era, these space industry products were regulated exclusively by DOS[74] and were considered munitions, as many of them were then designed specifically for military purposes. Although the regulation of these dual-use space products was transferred to DOC[75] in the 1990s, Congress returned regulatory authority to DOS in 1998 after some satellite designs were improperly transferred to China.[76]

DOS's administration of export controls came under strong criticism from manufacturers of space-related equipment. The satellite industry asserted that the long licensing process led to a loss of sales abroad, and the Aerospace Industries Association (AIA) claimed that the U.S. share of the global commercial satellite market fell from 63% before export controls were transferred to DOS to 30%.[77] A DOC survey of manufacturers found that many believed that the DOS export controls "eroded U.S. competitiveness in the international space market."[78] In 2013, Congress transferred export control responsibilities for 80% of satellites and related items back to DOC regulation for sales to most countries.[79] AIA and others are calling for controls on some commercial items that are still under DOS, such as apertures on electro-optical satellites used for remote sensing, integrated propulsion systems, and plasma thrusters, to be transferred to DOC.[80]

AIA also has raised concerns about the launch vehicle restrictions in the international Missile Technology Control Regime (MTCR), which regulates missile proliferation. As space tourism becomes a possibility, some MTCR rules—as incorporated into U.S. export controls—could affect the development of this commercial activity, including limitations on the type of rocket that could be used to boost space tourists into suborbital space. In addition, a space tourism rocket that is launched in one country and descends in another country could be considered a missile export subject to strict MTCR controls.[81]

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[74] Department of State licensing program is through the International Traffic in Arms Regulation (ITAR).

[75] The Department of Commerce administers Export Administration Regulations (EAR) through the Bureau of Industry and Security.

[76] Before 1990, commercial communications satellites and related items were on the State Department's U.S. Munitions List (USML). For more information on the U.S. export control system and regulation of satellites and related equipment, see CRS Report R41916, *The U.S. Export Control System and the President's Reform Initiative*, by (name r edacted) and (name redacted)), p. 19.

[77] David Melcher, "Tick Tock," *Space News*, October 10, 2016, http://www.spacenewsmag.com.

[78] Bureau of Industry and Security, Department of Commerce, *U.S. Space Industry "Deep Dive" Assessment: Impact of U.S. Export Controls on the Space Industrial Base*, February 2014, p. 14.

[79] National Defense Authorization Act of 2013, P.L. 112-239; satellites exports remain prohibited to China, North Korea, and countries designated as state sponsors of terrorism (currently Iran, Sudan, and Syria).

[80] Aerospace Industries Association and Satellite Industry Association, industry analysis submitted to Department of State, *Satellite Export Control Priorities*, 2015.

[81] CRS conversation with staff of Aerospace Industries Association, November 2, 2016, and Peter de Selding, "U.S. (continued...)

Spectrum Allocation

The satellite industry[82] is concerned that sharing of certain bands for future wireless 5G use—some of which are currently used solely for satellite transmissions—could jeopardize the reliability and cost-effectiveness of their service.[83]

For decades, satellites have communicated on dedicated frequency bands assigned by the International Telecommunications Union (ITU). The specific band used by a satellite depends on its purpose.[84] For example, lower frequencies—the L-, S-, and C-bands—are not affected by heavy rainfall and are therefore used in tropical regions; they can also simultaneously serve large areas of the globe. The Ku and Ka bands are used for television broadcasting and data services. Satellites are built to transmit a specific frequency and cannot be reprogrammed after launch.[85]

The Obama Administration directed the FCC to identify spectrum that could be used to expand Wi-Fi services in the future. To address that goal, FCC and the National Telecommunications and Information Administration (NTIA) collaborated in identifying 500 MHz of spectrum suitable for wireless broadband use, including future domestic 5G terrestrial mobile providers.[86] Some of this spectrum was obtained by sharing frequencies in the 28 GHz band previously dedicated to satellite transmissions.[87]

The satellite industry expressed concern over sharing spectrum, particularly the 28 GHz band, contending that current satellite services could be undermined without a deeper understanding of how future 5G services will be used:

> [S]atellites are providing vital services to all Americans using spectrum bands above 24 GHz. Satellites "distribute point-to-multipoint video and other high bandwidth services more efficiently and more cost effectively than any other technology." In addition, high-throughput satellites are bringing competitive broadband services to all of the United States. Satellites also provide advanced services to ships, aircrafts and motor vehicles.... Consideration of repurposing spectrum access from existing users with a supporting record would result in the loss of critical services to U.S. consumers, and to vital enterprise users such as first responders and the U.S. military.[88]

(...continued)

Satellite Export Regs Remain a Frustration for European Industry," *SpaceNews*, February 7, 2014, http://spacenews.com/39414us-satellite-export-regs-remain-a-frustration-for-european-industry/.

[82] Letter from Tom Stroup, President, Satellite Industry Association, to Marlene Dortch, Secretary, Federal Communications Commission, October 5, 2012; Monica Alleven, "O3b throws water on idea of near-term solution for 28 GHz sharing," *FierceWireless*, April 29, 2016.

[83] The commercial space industry is not alone in arguing against spectrum sharing; other industries, including nascent autonomous motor vehicles, railroads, and federal weather satellite services, have made similar arguments to the FCC.

[84] Satellite frequency bands range from 1,467 gigahertz (GHz) to 30 GHz. EMEA Satellite Operators Association (ESOA), *Satellite Spectrum*, viewed November 4, 2016, https://www.esoa.net/spectrum/satellite-spectrum.asp.

[85] Ibid.

[86] Department of Commerce, *Plan and Timetable to Make Available 500 Megahertz of Spectrum for Wireless Broadband*, October 2010, p. ii, https://www.ntia.doc.gov/files/ntia/publications/tenyearplan_11152010.pdf.

[87] Federal Communications Commission, "Use of Spectrum Bands Above 24 GHz," 81 *Federal Register* 79894-79945, November 14, 2016, https://www.gpo.gov/fdsys/pkg/FR-2016-11-14/pdf/2016-25765.pdf.

[88] Letter from Tom Stroup, President, Satellite Industry Association, to Federal Communications Commission, February 18, 2015, http://www.sia.org/wp-content/uploads/2015/02/SIA_Reply_Comments_Spectrum_Frontiers_2015_02_18.pdf.

The FCC contends that its approach in its July 2016 ruling struck a balance between wireless services and satellite operations and that the spectrum sharing provided in the decision would "ensure that diverse users—including federal and non-federal, satellite and terrestrial, and fixed and mobile—can co-exist and expand."[89] The FCC also noted that there had been "dueling studies" from affected industries and said it would continue to study the issue and make adjustments if necessary.[90]

There has been congressional interest in the FCC's activities with regard to satellite spectrum. H.R. 4945 (114th Congress) would direct the FCC to preserve primary electromagnetic access in the 27.5-28.35 GHz band for satellite operators.[91] The FCC is also evaluating a proposal by Ligado Networks, a satellite-communications company developing a network to support 5G service, for sharing the 1675-1680 band with NOAA. DOC, the Air Force, and the Aerospace Industries Association have expressed concern that this sharing arrangement might interfere with GPS signals and the emergency response, homeland security, and aviation safety sectors that rely on them.[92]

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[89] Federal Communications Commission, "FCC Takes Steps to Facilitate Mobile Broadband and Next Generation Wireless Technologies in Spectrum Above 24 GHz," press release, July 14, 2016, https://apps.fcc.gov/edocs_public/attachmatch/DOC-340301A1.pdf. GN Docket No. 14-177.

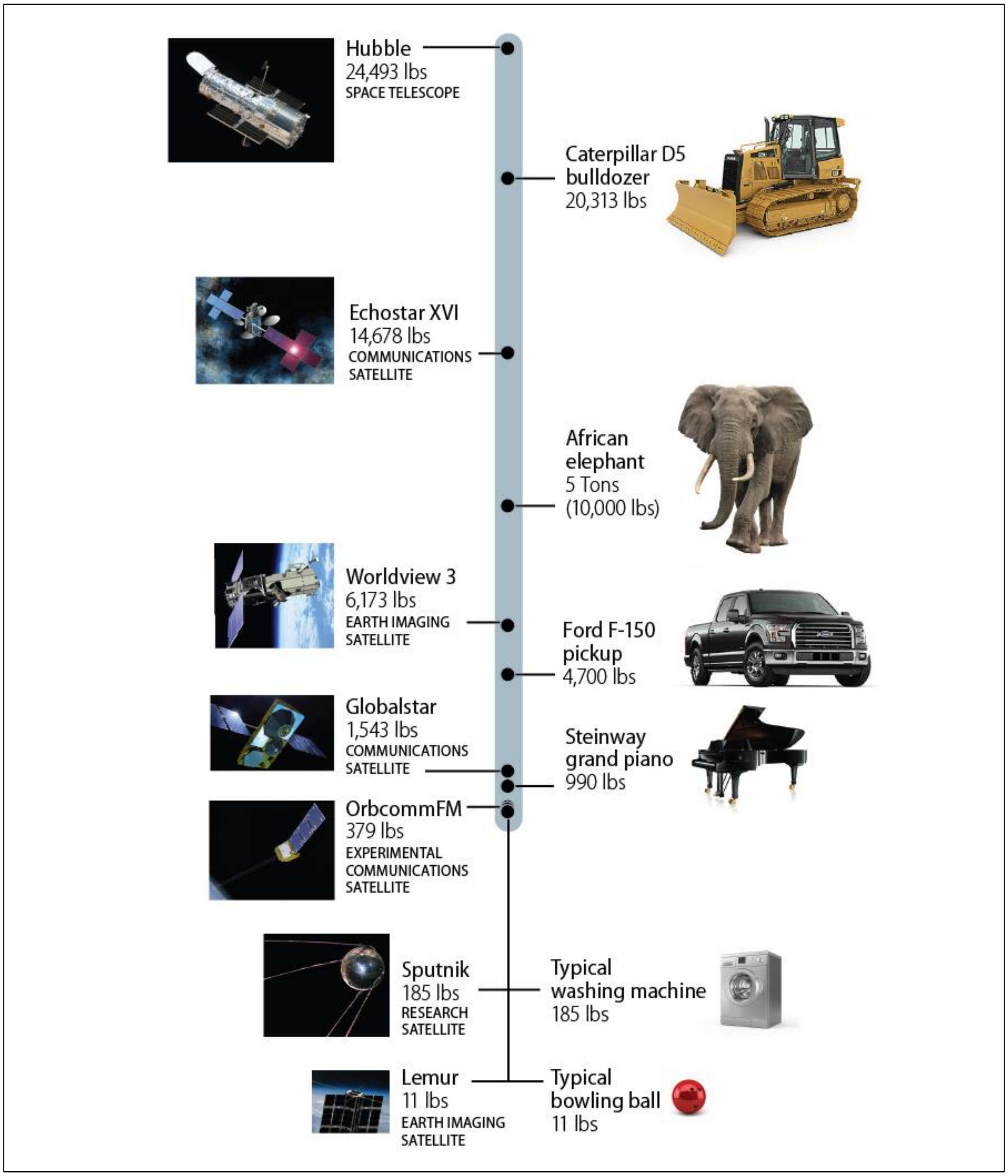
[90] John C. Tanner, "What the FCC's 5G Spectrum Plan Means for Ka-band Satellite," telecomasia.net, July 20, 2016.

[91] H.R. 4945, American Space Renaissance Act. The comprehensive legislation was referred to several committees.

[92] The Commander of the Air Force Space Command mentioned his concern during a March 15, 2016, hearing by the House Subcommittee on Strategic Forces. Letter from Ali Bahrami, Vice President, Civil Aviation, Aerospace Industries Association, to Federal Communications Commission, June 21, 2016, https://ecfsapi.fcc.gov/file/10621054184363/Ligado%20-%20IB%20Docket%20No%20%20RM-11681_AIA-FINAL.pdf; Dee Ann Divis, "FCC Opens GPS-Adjacent Ligado Proposal for Comment," *Inside GNSS News*, May 1, 2016, p. http://www.insidegnss.com/node/4933.

Appendix A. Satellite Size Comparison

Figure A-1. Types of Satellites Based on Mass, Compared to Earth-Bound Objects



Source: CRS.

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