

Global Space Strategies and Best Practices

*Research Paper for Australian
Government, Department of Industry,
Innovation and Science by Bryce Space
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The goal of this paper is to assist the Australian Government in a review to of Australia's space industry capability to enable the nation to capitalise on the increasing opportunities within the global space sector.

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Executive Overview

Economic growth and diversification are increasingly important as drivers of government space activity. Three key aspects of any national approach to space development for economic growth and diversification:

- Resourcing desired initiatives
- Targeting capabilities
- Structuring governance

Significant successes:

- Direct funding of Canadarm creates space robotics dominance for Canada
- Largest global satellite services companies headquartered in Luxembourg through incentives, laws, regulations
- UK/South Korea cooperation helped build South Korea capability; South Korea/UAE cooperation helping to build UAE capability
- SpaceX growth fostered in part by NASA program to acquire launch to ISS; SpaceX has increased US market share in international commercial satellite launch market

Case studies of nations with some similarities to Australia show diverse approaches and some initial benefits from space initiatives

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Drivers of Space Development

Nations invest in space capabilities to fulfil national objectives: military success and defence strategy, leadership and prestige, development and resource management, and economic growth and diversification. Economic growth and diversification are increasingly important as drivers of government space activity.

Capturing a larger share of the global space economy is a desirable goal for multiple reasons. Space is a reliable growth industry that has proven resilient in the face of economic downturns, including the 2008 global recession.¹ Space-enabled services boost productivity to other sectors of the economy, from agriculture to mining to commerce of all types.

Space Development Strategies

Any national approach to space development for economic growth and diversification has three key aspects: resourcing desired initiatives, targeting capabilities, and structuring governance.

Resourcing

Funding for space-related development can come from government, the private sector, or a combination of the two. The simplest model is **direct government investment** in specific capabilities or missions. Another model is **targeted investment** in specific capabilities. Often, multiple governments will pursue **international cooperation** as a way to pool their investment in a mutually desired capability or mission.

Governments also can **encourage private sector investment** in space through incentives such as tax breaks, access to publicly funded facilities, government expertise, and other non-cash resources. **Anchor tenancy**, or guaranteed government business, has been a particularly important approach to encouraging the private sector to invest in space-based capabilities. Anchor tenancy often is a key element of **public-private partnerships** in which the government and private sector co-invest in a certain capability.

Capabilities

National space capabilities may encompass the full space value chain, though most governments target capabilities in which to invest, ranging from **manufacturing** of various types (satellites, launch vehicles, components), **ground infrastructure, services, and downstream applications**. These choices will depend on available resources—different capabilities require different levels of investment—and objectives.

Governance

At the most basic level, space governance can take two forms: **centralised** and **decentralised**. In a centralised construct, government space functions—development, operations, regulation—are consolidated under a single agency. In a decentralised structure, these functions are the responsibility of different agencies, usually with some degree of coordination. A **dedicated space** agency is typical, though not an absolute, and also is not necessarily indicative of a centralised governance structure.

Best Practices and Lessons Learned

All of the approaches described have been applied in some form to space development initiatives by governments, with varying outcomes. The examples below highlight approaches that have worked, a few that have not, and some where outcomes are not yet known.

Funding Space Development

The most obvious and straightforward way for governments to develop a space capability is through **direct funding** of a program. Canadarm, the robotic arm that was used to manoeuvre hardware in and out of the cargo bay of NASA's Space Shuttle, was developed—essentially from scratch—in the late 1970s by a Canadian industrial consortium with funding from the Canadian government. Success with Canadarm led to Canada's role in the International Space Station (ISS) as supplier of the robotic Mobile Servicing System, which played a key role in ISS assembly and is now used to move equipment and supplies around the facility. Canada today is recognised as a world leader in space robotics. The direct funding approach is most appropriate in the case of capabilities for which the government has identified a clear requirement.

A more open-ended approach is **targeted investment** in capabilities with demonstrated or anticipated economic potential. As part of its decision to focus on space as an economic growth engine, the United Kingdom (UK) increased its annual investment in the European Space Agency (ESA) by 25% starting in 2013. This investment was directed primarily toward ESA programs and technologies with the potential to generate economic returns, such as satellite communications and Earth observation (EO). Most of this investment flowed back to British industry per ESA's geographic return policy, under which program work is assigned to different member states in proportion to their annual contribution to the agency. The ESA funding increase paid fast dividends in the agency's agreement to relocate its telecommunications directorate, the European Centre for Space Applications and Telecommunications, from the Netherlands to an existing UK ESA facility in Harwell. The Centre employs about 100 people and has drawn a significant domestic and foreign industry presence.

Another approach to targeted investment is to directly invest in companies developing promising technologies. Canada's economic development ministry, Innovation, Science and Economic Development Canada, in February 2017 invested \$13.6 million² in EO satellite operator and services provider UrtheCast. The investment will support the company's development of a constellation of optical and radar satellites, which can make observations day or night and in all types of weather.³ The UK invested \$81 million in Reaction Engines, a company developing propulsion technology that has the potential to dramatically reduce the cost of access to space.⁴

Governments also can seek to **attract private investment** via favourable taxation policies and through incubators, or clusters, that draw on non-cash public resources to nurture budding industries. Luxembourg provides good examples of both. In 2009, Intelsat, which along with rival SES sits atop the list of global commercial satellite operators, relocated its corporate headquarters from Bermuda to Luxembourg, describing its new host as “a stable jurisdiction that is familiar with the fixed satellite services sector and has established tax treaties with the countries in which Intelsat does business.”⁵ Luxembourg also is host to SES, which was created by the government in 1985.

Luxinnovation, a government-managed economic development organisation, established the Luxembourg Space Cluster that fosters collaboration in fields such as satellite communications, environmental monitoring, global navigation satellite services (GNSS), and space technology development. The UK and Canada also have created space clusters to support nascent companies. Luxembourg has gone a step further, setting up a fund to assist companies interested in mining resources on celestial bodies and even taking a stake on one such company, Planetary Resources.⁶ In 2017, Luxembourg passed a law giving companies the right to sell resources extracted from asteroids and other celestial bodies.

Government export credit agencies, which provide or back loans on attractive terms to help foreign entities buy goods and services from domestic industry, are an important tool in capital intensive industries. Coface of France, the US Export-Import Bank, and Export Development Canada all have been active in the space market; export credit has reportedly been a deciding competitive factor in a number of large deals.

Public-private partnerships are common in the space economy, and can be an effective method for overcoming barriers such as high capital requirements, technology risk, and longer development timelines. These barriers can prevent establishment of viable and valuable commercial space capabilities. Public-private partnerships can take several forms, but typically involve some co-investment between government industry, government anchor tenancy, or some combination thereof.

An example of a successful partnership is NASA's effort to nurture commercial cargo and crew transportation services for the ISS via co-investment and a guaranteed market for the resulting services.⁷ One company in particular, SpaceX, has built a growing and highly competitive satellite launch business, to the benefit of commercial and government satellite owners; while NASA's program focused on ISS cargo launches, NASA resources helped SpaceX develop capability, enhance its infrastructure, and build its workforce, which contributed to its competitiveness in satellite launch. Another example is commercial EO satellite operator DigitalGlobe, where the US National Geospatial-Intelligence Agency (NGA) used a similar co-investment/anchor tenancy arrangement. DigitalGlobe has built a successful global business and is a vital source of satellite imagery and related products to the US defence and intelligence community. In both of these cases, the government remains a significant customer. It is also worth noting that originally this partnership model involved two providers (DigitalGlobe and GeoEye), but the limited market forced a consolidation down to one.

There also are other examples of public-private partnerships that did not turn out the way the government had hoped. Among the more notable is Europe's Galileo GNSS satellite program. As originally structured, the program featured a considerable financial investment in the ground and applications segments from an industrial consortium whose reward was to be a robust commercial market for the resulting services. However, the consortium, composed of many of Europe's top space contractors, did not meet the goals set by the European Union (EU), throwing the entire program into a financial crisis that was resolved only after the EU stepped in with new financing and took control of the program.⁸

In the US, the Evolved Expendable Launch Vehicle (EELV) program illustrates the risk of putting broader market forces on the critical path to meeting national strategic objectives. Based on projections from launch providers and others in the late

1990s for soaring commercial demand for launch services, the US Air Force (USAF) opted to partially fund two competing EELV rocket families rather than fully fund one as originally planned. The providers were expected to recoup their share of the investment on the commercial market, while the USAF would maintain competition and redundancy in its own market. But the projected commercial market collapsed—part of the broader telecom meltdown at the turn of the century—just as the resulting launchers began operations, putting the USAF in the position of having to pay the entire cost of keeping both in business. The cost of national security launches soared because the market was not large enough for two providers to produce rockets efficiently, and the USAF ultimately forced them to merge, creating the very monopoly it had hoped to avoid.

Public-private partnerships are most successful when the government has a clear understanding of the market for the capability it is seeking to develop, and is prepared to reduce market risk as an anchor customer or with appropriate investment commitments. Government decision-makers benefit from rigorous, independent analysis of market dynamics from sources other than the parties to partnership negotiations. Public-private partnerships are less successful when the government places bets on markets it does not fully understand, and over which it has no control, in an effort to defray its own costs.

For countries seeking to build up a domestic space capability, working with established space powers has proven to be a successful pathway. Such international cooperation might take the form of agreements between governments to pursue a specific mission or set of missions. The ISS, of course, is a massive cooperative effort among the world's leading space powers, resulting in a unique space capability as well as creating relationships (generally viewed as positive) that help to shape today's complex geopolitical dynamics.

A perhaps more relevant example is the China-Brazil Earth Resource Satellite (CBERS) program, in which Brazil has worked with China to gain hands-on experience building and operating a series of environmental monitoring satellites. China views space cooperation as one of several avenues to strengthening economic and political relationships with developing countries.

Governments also work directly with foreign companies to learn how to build and operate satellites. The Korea Advanced Institute of Science and Technology (KAIST), a publicly funded research university, built South Korea's first satellite with hands-on assistance from Surrey Satellite Technology Ltd. (SSTL) of the UK. Several aspiring spacefaring countries have taken a similar route with SSTL, which was spun out of the University of Surrey and now is part of the pan-European Airbus Defence and Space conglomerate. The United Arab Emirates (UAE), in turn, established its satellite capability through a partnership with Korea.

Regional cooperation has enabled European nations to collectively become global space leaders, through the ESA. Other regional efforts include the Regional Centre for Space Science and Technology Education for Latin America and the Caribbean (known by its Spanish acronym, CRECTEALC), set up to explore options for regional cooperation in space, with the potential for setting up a regional space agency not unlike ESA. In Asia, there is the Asia-Pacific Space Cooperation Organization (APSCO), headquartered in China, with eight member space agencies, mostly from South and South East Asia, and also Peru. In addition, there is the Asia-Pacific Regional Space Agency Forum (APRSAF), established

in 1993 to enhance space activities in the region. Australia is a participant in APRSAF, a venue where government space agencies, international organizations, companies, and academic organizations to meet to discuss cooperation, primarily in four areas: Earth observation, communications, education and space environment utilization.

Capabilities Focus

Other than the largest global powers, most countries do not have the resources to develop the full range of **space capabilities**, including satellite manufacturing, launch, operations, services, and downstream applications, and so (more or less intentionally), tend to focus on specific capabilities.

Israel is unique among smaller space nations in that it does have capability across the **full value chain** of the space economy. It operates the Shavit launch vehicle for some national defence missions; manufactures communications and EO satellites; is home to satellite communications and EO services providers, as well as a major ground systems supplier; and has a vibrant tech sector that has developed several space related downstream applications. Israel's case is unique, however, due to its geopolitical situation.

One of the first questions governments seeking to boost their space industry face is whether to **build or buy launch vehicles**. For countries that regard independent orbital launch as a must-have strategic capability, there is no choice. But launcher development programs can be very challenging and expensive—any government contemplating such an undertaking must weigh that against the potential gain. Generally, even the most successful commercial launch capabilities rely on government funding, with the government providing resources for development, operations, or capability enhancement, in addition to paying for launches as a customer. This is the case for the high performing US launchers operated by ULA and SpaceX and the European Ariane vehicles. Smaller national programs have often struggled for viability. Brazil's long-running effort to develop a satellite launcher, despite economic issues that have limited its spending power, is a cautionary tale. Brazil's Veiculo Lancador de Satellites-1 (VLS-1), built from sounding rocket motors, experienced multiple in-flight failures and one on-pad explosion that resulted in 21 fatalities before being abandoned.⁹ While South Korea successfully launched its Naro-1 rocket, developed with help from Russia, in 2013 after two test failures, it has not conducted any launches since. Although some have tried to make an economic case for launch vehicle development, the commercial market is already crowded and prone to demand swings. The UK took a different route, opting to buy launch services despite having developed a rocket that successfully launched—from Australian territory—a satellite in 1971. Note that the UK is now considering development of a launch facility and is seeking a relationship with a launch provider.

New Zealand appears to be seeing launch-related success. Orbital launches from New Zealand began in 2017 with the launch of an Electron vehicle developed by Rocket Lab. (Rocket Lab, founded in New Zealand by New Zealand native Peter Beck, is a subsidiary of a US company.) In 2014, the government of New Zealand awarded research grant funding for Rocket Lab in the amount of \$25 million over five years. The country's government has also allocated a modest budget of \$15 million over four years for a space office with the Ministry of Business, Innovation and Employment.¹⁰ Rocket Lab's future market performance is to be seen. An indicator of potential success is that it attracted more than \$100 million in commercial investment to date.

The upshot: absent a compelling strategic rationale, countries should be wary of undertaking a program to field an indigenous launch capability.

Up and coming space powers have had better success in developing an independent **satellite and component manufacturing** capability. The payoffs come in the form of economic diversification and the potential export revenues. In South Korea, for example, the government has promoted cooperation between the Korea Aerospace Research Institute (KARI), universities and the private sector as part of a broader economic policy of nurturing selected industries with the expectation that they eventually will generate export revenue.¹¹ The SaTReC Initiative, a satellite and sensor manufacturer spun out of KAIST, has done just that, with a customer base that includes Spain (Deimos 2 satellite, later purchased in orbit by Canadian company UrtheCast), the UAE, and Malaysia. The UAE, after working closely with the SaTReC Initiative on two EO satellites that launched in 2009 and 2013, is now building its first all-domestic satellite, KhalifaSat, with a launch targeted for 2018.

Israel, whose satellite manufacturing capability stems from military programs, has an investment program specifically geared toward promoting satellite exports. Government-owned Israel Aerospace Industries (IAI) builds highly capable satellites for operational use, but aside from a recently launched imaging satellite for the Italian Ministry of Defence¹² has struggled to gain traction in the export market.

Several countries, including Canada, India, and Australia, have invested in **satellite services**, specifically telecommunications providers, primarily as a way to keep their far-flung populations connected. In the case of Canada and Australia, these companies are now privatised. As noted, Luxembourg has built a large satellite services ecosystem through incentives and business-friendly policies.

Downstream applications offer the potential for high economic returns for a relatively low level of government investment. One area of focus for the UK space incubator, the Satellite Applications Catapult, is intelligent transport and autonomous vehicles, according to the organisation's website. Intelligent transport has a high economic impact and will benefit from satellite based services including communications and GNSS, the website says. Similarly, the Catapult's Blue Economy Programme aims to leverage satellite technology to enable sustainable growth of maritime industries including fisheries, aquaculture, and shipping and port efficiency.

Investment in **early stage research and development**, while not necessarily space directed, can pay off down the road in the form of space capability. The UK's SSTL, which is among the world's most successful small satellite makers, with a long history of exports, was spun out of the University of Surrey, a public research university.

Governance Models

Perhaps the best example of a **centralised** space governance structure is India, where the basic responsibilities—research and development, operations, regulation, economic development, and launch—all fall under the Indian Space Research Organisation (ISRO). Other examples are Russia, where civilian-run Roscosmos oversees the country's entire space industrial complex and the UAE.

Most space governance structures are more **decentralised**. A good example is the US: military, intelligence, and civil activities are funded and managed by different agencies

(primarily the Department of Defence and NASA, respectively) while regulatory functions are spread among multiple agencies, some of which also have promotional or operational roles. Economic development and regulatory functions are sometimes aligned. The UAE Space Agency, for example, has a promotional and regulatory role for the nation's space sector. In the United States, the Federal Aviation Administration (FAA) both regulates and promotes the commercial launch industry. Military and civil programs are often separated. Japan's civilian space programs are managed by the Japan Aerospace Exploration Agency, while Japan's Information Gathering Satellite system, deployed to keep tabs on North Korea, is managed by an office in the prime minister's cabinet. Europe also has multiple agencies with differentiated functions, particularly distinguishing between civil and military space activities. In China and Russia, the distinction between military and civil space organisations is less clear. Russia's Roscosmos is a civilian-run agency but has broad oversight authority. China has a civilian space agency, but some analysts believe it is closely tied to the People's Liberation Army.

Although most nations with substantial space activity have **dedicated space agencies**, this is not always the case. Turkey and Malaysia, for example, are exceptions. Other nations have operated substantial space programs prior to establishing a space agency. The National Research Council of Canada oversaw the development of Canadarm; the Canadian Space Agency (CSA) was not established until 1989. The UK also had a sophisticated and growing space industry well before it established the UK Space Agency in 2011, a move that was designed to consolidate the space efforts of nearly a dozen different agencies, and raise the country's clout within ESA. Similarly, the UAE already was home to two telecommunications satellite operators and was developing an independent satellite manufacturing capability when it created a space agency in 2014 to better coordinate those efforts. Singapore is active in space, with a domestic satellite manufacturing capability, but does not have a separate space agency.

Arguments against a dedicated space agency typically hinge on concerns about costs and the expansion of government bureaucracy. Prior to the creation of the UK Space Agency, Britain had a user-driven model that advocates said prevented investments in space activities lacking a practical, real-world purpose or application. In the US, there is currently a push to create a dedicated space corps within the USAF. Opponents of the move, including several top USAF officials, say the change would add bureaucracy and undermine efforts to better integrate space into military operations.

Governance Case Studies

These case studies are focused on nations relevant to Australia based on national attributes and space objectives.¹³

United Kingdom

The UK is Europe's third largest economy with a gross domestic product (GDP) of \$2.8 trillion, triple that of Australia, and a national budget of about \$1 trillion, double that of Australia.¹⁴ Its territory is a fraction of Australia's and its 65 million population is three times Australia's. The UK space budget is \$500 million.¹⁵

Space Growth Initiative

The UK has long possessed sophisticated space industrial and operational capabilities, mostly serving military purposes. A government-commissioned report dubbed the Space Innovation and Growth Strategy (IGS) was released in 2010 that identified space as an important engine of economic growth and recommended that the government take steps to increase its share of the global space economy from 6% in 2007 to 10% by 2030.¹⁶

Resources

As noted, a key result of the IGS report was a UK commitment to increase its annual investment with ESA—a primary outlet for members' development activities—by 25% starting in 2013.

Another outcome of the IGS report was the creation of the Satellite Applications Catapult, a not-for-profit company that promotes the development and advancement of commercial space applications. Specific services offered by the Catapult include assistance with raising private capital and grant funding, technical support, access to facilities and information exchange. The Catapult is funded by the government's innovation agency, Innovate UK, which along with the UK Space Agency has a member serving on the company's board.

Capability

UK space industry capabilities include manufacturing of most of the classes of satellites and components, as well as ground systems, and downstream space enabled products and services. The new investment has been targeted primarily toward satellite communications and EO, two areas that the IGS report identified having strong commercial potential. In addition, the UK has invested in engine technology, building on existing national capability.

The UK does not have its own launch capabilities and primarily accesses space via European launch provider Arianespace, though it is currently considering a launch site for a small launchers.

Governance

Until fairly recently, civil activities were coordinated by the British National Space Centre, with funding provided by a collection of 11 agencies with disparate missions and agendas.

Following the IGS report, a UK Space Agency was established in 2011 that consolidated civil space funding and development responsibilities and embraced the report's growth goal.

Outcome

To measure industry's progress toward meeting the goals outlined in the IGS report, the UK Space Agency commissions reports every two years that survey all organisations in the country that supply or consume space products and services.

According to the latest Summary Report: Size & Health of the UK Space Industry released in December 2016, the UK space industry generated revenue of \$17 billion in 2014/15, with a growth rate of 6.5% per year. Although the growth rate was down slightly from 7.3% in 2012/13, the report noted that 2014/15 was a difficult year for the global space industry as a whole.¹⁷

Direct space employment increased 6% during the period, to 38,522 jobs, representing 0.12% of the total UK work force. Space exports, meanwhile, grew to \$6.2 billion, or 36.4% of space-related income. This represents an increase of 31% compared to 2012/13 and is 30% higher than the overall UK economy.

Finally, the UK accounted for 6.5% of the global space economy for 2014/15, up only slightly from the 6% for 2007 identified in the IGS report. However, if the significant changes in the exchange rate for the British pound are factored out, the UK's share would be above 8%, which was the interim goal for 2020 laid out in the IGS report.

Canada

Canada has a territory that is a third larger than Australia's and a population of 35.6 million, 57% larger than Australia. Its GDP of \$1.7 trillion and national budget of \$632 billion are both roughly 46% larger than Australia's.¹⁸ Canada's space budget is about \$400 million.¹⁹

Space Growth Initiative

In contrast to the UK, Canada has not yet seen a clarion call to elevate the profile and competitiveness of its space program. Although Canada boasts a well-developed space industry sector, including a leading global satellite operator and several major hardware suppliers, there is a sense among stakeholders in the Canadian space program that the lack of an overarching space strategy has caused Canada to lose ground in space.²⁰

Resources

The CSA funds civilian space programs while the Department of National Defence funds military programs. Canada also has created a space start-up incubator, Max Q, and invested in EO company UrtheCast. Commercial revenues are extremely important to

Canada's space industry. Its flagship space company, MDA, has substantial commercial business as an owner of US satellite manufacturer Space Systems Loral and imagery services provider DigitalGlobe. Canada is an associate member of ESA, participating in selected projects, and is home to Telesat, a major commercial satellite operator.

Capabilities

Canada possesses the full range of space capabilities with the exception of launch. MDA is a diversified company with expertise in space robotics, satellite manufacturing and services. MDA operates the CSA funded Radarsat series of day-night EO satellites, the first of which launched in 1995. Canada's advancement in space robotics resulted in Canada's signature contributions to human spaceflight: the Canadarm series of robotic arms installed on the Space Shuttle orbiters and the International Space Station (in which Canada is a partner).

The Canadian military has long relied heavily on its close ties to the United States for space capabilities but appears poised to step up its own efforts, particularly in satellite communications and space surveillance. The year 2013 saw the launch of Canada's first operational military satellite, Sapphire, a space surveillance satellite whose data has been integrated into the US Space Surveillance Network (SSN).

Governance

Canadian government space activities are divided between the CSA, which is responsible for civilian missions, and the Canadian Armed Forces (CAF).

What appears to be lacking in Canada is a formal mechanism for coordinating its military, civil and commercial programs, despite overlapping requirements in areas including remote sensing and communications.

Outcome

An August 2017 Canadian government report,²¹ based on surveys of the stakeholders, highlighted concern that successive governments have not fully recognised or appreciated space as a national asset. "Participants felt there was a need to elevate the space program to the national level once again and for the government to take a whole-of-government approach to designing and implementing a national space program," the report said.

The report, intended to inform a forthcoming space strategy, also noted a drain in Canadian talent due to a lack of opportunities in Canada and said government support for space was fragmented and insufficient to support the needs of what inherently is a long-term enterprise. Some of these concerns appear to be validated in the CSA's most recent report on the state of the Canadian space industry.²² According to that report, Canadian space revenues declined slightly in 2015, and were flat for the five-year period ending in 2015. Domestic revenues declined 3% in 2015, the report said.

Meanwhile, the long-awaited Canadian space strategy is behind schedule; its release had been expected in June 2017 but has been delayed. Canada's space strategy currently is embodied in a Space Policy Framework, released in 2014, which outlines five core principles to guide future Canadian space activities: Canada first, support for industry, partnerships, key areas of technical excellence, and inspiring Canadians.²³

United Arab Emirates

The UAE, located on the Arabian Peninsula, is a tiny territory with a population slightly above 6 million. Once almost fully reliant on oil and gas exports, the UAE has carried out a successful economic diversification program, reducing the energy sector's portion of GDP to 30%. The UAE's GDP is \$669 billion and annual budget is \$113 billion (about a half and a quarter of Australia's, respectively).²⁴ The UAE space budget is about \$150 million.²⁵

Space Growth Initiative

The UAE had long been active in space when, in 2014, it became the first among the Gulf Cooperation Council states to create a dedicated space agency (UAESA). UAE has identified space not only as a way to diversify its traditionally oil-based economy but also as a source of inspiration to disaffected elements of the broader Arab world. The UAESA has been given a mandate to carry out a mission to Mars, which it hopes to launch in time for a 2021 arrival at the Red Planet.

Resources

Targeted investments are made in UAE's space program by the government as well as private and semi-private organisations. Beside direct investment in its own space activities, UAE had engaged in international space partnerships. UAE-based Aabar Investment has funded in Virgin Galactic (37.8% share of the company), and the UAE has signed Memoranda of Understanding with space programs in several nations, including China, France, Russia, the UK, India, and Japan (for knowledge-transfer and other resource sharing) and an Agreement to Collaborate with NASA.²⁶

Capabilities

UAE has worked closely with SaTReC Initiative of South Korea on EO satellites, and is now working to build its first all-domestic satellite. Building capabilities through spacecraft R&D is vital for UAESA, which is also mandated with launching a Mars orbiter by 2021.

Governance

In addition to serving as a focal point for outreach and education initiatives, the UAESA plays a coordinating role in activities of the country's other main space organisations that predate its establishment: satellite operators Thuraya and Yahsat, and the Mohammed bin Rashid Satellite Centre (MBRSC). Specifically, the agency sets policies for these semi-autonomous organisations and negotiates government-to-government agreements that facilitate their goals. The agency contracts its satellite development work to the MBRSC, which can initiate projects on its own.

Outcome

As the result of UAE collaboration with SaTReC Initiative, two EO satellites successfully launched in 2009 and 2013. The MBRSC is now building its first all-domestic satellite, KhalifaSat, with a launch targeted for 2018 and is working on elements of the Hope Mars mission under contract to the UAESA.

Singapore

Singapore has a successful free-market economy with a population approaching 6 million. Its GDP is \$493 billion, with an annual budget of \$45 billion.²⁷ The country's space budget is estimated to be \$26 million.²⁸

Space Growth Initiative

The Singapore Economic Development Board established the Office for Space Technology and Industry (OSTIn) in 2013 to pursue economic opportunities primarily in the field of small satellite technologies and applications. The long-term strategic vision is to create a vibrant space ecosystem where companies can tap Singapore's engineering and research capabilities to innovate and export space products and services. Apart from economic growth, space is seen as a way to draw students into science, technology, engineering, and mathematics (STEM) disciplines.

Resources

In addition to its space budget, OSTIn expects space to draw resources from adjacent industries such as aerospace engineering, electronics, communications, and information technology. OSTIn also is bullish on applications enabled by satellite imagery. OSTIn encourages public-private partnerships in space development and supports foreign companies interested in leveraging Singapore to innovate and develop new space applications and services.²⁹ A number of international satellite operators maintain offices in Singapore.

Capabilities

The Nanyang Technological University (NTU) and the National University of Singapore pioneered the nation's nanosatellite manufacturing capability. NTU collaborated with DSO National Laboratories (a defence technology research organisation) on Singapore's first indigenously built satellite, launched in 2011. ST Electronics Satellite Systems, a joint venture of NTU, Singapore Technologies Electronics, and DSO National Laboratories, opened a satellite-manufacturing centre in 2014.³⁰

Governance

Singapore's space activities are coordinated by OSTIn, which coordinates closely with a host of other agencies responsible for defence, trade, the economy, foreign affairs, education, and science and technology.

Outcome

Singapore's first commercial EO satellite, TeLEOS-1 built by ST Electronics Satellite Systems with help from the SaTReC Initiative, was launched along with five other domestically built satellites aboard an Indian rocket in December 2015.

Norway

Norway has a population of 5.3 million people, with an economy that features a highly developed private sector and a large state sector. Norway opted out of the EU in a referendum in 1994; however, it remains a member of the European Economic Area and makes substantial contributions to the EU budget. Norway's GDP is \$364 billion, and its budget is \$188 billion. Norway has been active in space since the 1960s. Its space budget is about \$134 million.

Space Growth Initiative

Given its geographic location, low population density, and activities in the maritime and offshore energy sectors, Norway is a natural consumer of space services. The country's far-northern location is ideally suited for hosting ground stations for polar-orbiting satellites, which are used primarily for meteorology, environment monitoring, and land imaging. In 2013, a government-issued White Paper set priorities and goals for space in addressing economic growth and societal needs. The paper stressed Norway's strengths in space industry niches and applications and said increased space activity is necessary for the country to maintain its role as a leader in shipping, technology and environmental stewardship. Norway's strategic goal for space has always been consistent: profitable companies, growth, employment, meeting needs of society and key user groups, greater return on international collaboration, and high quality national administration.³¹

Resources

A large portion of Norway's space budget goes to international activities, including contributions to ESA (\$33 million), and to the EU for the Galileo GNSS and Copernicus environmental monitoring satellite programs (operated by ESA for the EU). Norway also has bilateral programs with Canada, Switzerland, Germany, France and Sweden. Lastly, Norway is a dues-paying member of the European Organisation for the Exploitation of Meteorological Satellites. Of its entire space budget, Norway spent 13% on the Norwegian Space Centre and on its national industry and infrastructure.³² Participation in ESA helped raise the technological level of Norwegian companies.

Capabilities

Norway's space industry has historically had close ties to the defence, offshore, and maritime sectors. Satellite telecommunications are an important industry segment, represented by national operator Telenor, which has four satellites in orbit. Norway also hosts a substantial number of ground stations for polar-orbiting satellites. Norwegian industry produces high-tech equipment for ground stations, satellite components, and booster separation mechanisms for the European Ariane 5 launch vehicle. In 2012, Norwegian space related revenues were roughly \$1 billion, with 70% coming from the telecommunications sector. About 40 Norwegian companies participate in space activity, although few do so exclusively. Many leverage ESA-developed technology in other sectors. Space manufacturing employed an estimated 364 full-time equivalents in 2013, but including university researchers could significantly increase that number.³³

Norway's geography has helped it succeed in several space niches: research balloon and sounding rocket launches, and ground stations, including in Antarctica for communicating with polar-orbiting satellites. These facilities are fully equipped with

Norwegian-made hardware including antennas, receivers and demodulator systems, satellite checkout and test systems, environmental data downlinks, and tracking, telemetry, and control systems.

The Norwegian Space Centre, in cooperation with Norway-based Kongsberg Group and the University of Toronto's Institute for Aerospace Studies, has built multiple Automatic Identification System satellites for maritime surveillance and has follow-on spacecraft in development.

Governance

The Norwegian Space Centre operates under the Ministry of Trade, Industry and Fisheries. It is responsible for the Norwegian space policy and coordinates all space-related activities and represents Norway in ESA. Through a public-private partnership with Kongsberg, it operates Kongsberg Satellite Services, which operates ground stations and develops space applications. According to the 2013 White Paper, the Centre manages the state's ownership interests on behalf of the Ministry of Trade and Industry.

Outcome

The 2013 White Paper proposed several adjustments to Norway's space policy aimed at maximising the economic benefit of international collaboration, including greater participation in EU space programs outside of ESA, and ensuring that Norwegian downstream companies gain more from participation in ESA. The paper also called for assured access to international EO data, promotion of opportunities in the Norwegian space sector, addressing Norwegian user needs in the most cost-effective manner, and a review of how to best address communications needs in Norwegian High North. In general, these recommendations present more of a fine-tuning of the existing space policy, including a better balance between ESA and EU program participation to maximise their performance in the Norwegian areas of interest.

South Korea

South Korea is a globally integrated, high-tech industrialised economy. The country's area is small relative to Australia, and its population is slightly over 51 million. GDP is \$1.9 trillion and annual budget is about \$286 billion. Korea's space budget is \$318 million.

Space Growth Initiative

South Korea has long pursued indigenous launch capability motivated at least in part by national security considerations. At the same time, the government treats space in the context of a broader economic policy of nurturing selected industries to ultimately generate export revenue.

In 2007, Korea established its first Space Development Basic Plan, which covered space development matters, including policy, organisational structure, financial and human resources, infrastructure expansion, and international cooperation. The Basic Plan was consolidated by a host of government ministries responsible for functions including education, science, defence, intelligence, economic competitiveness, and transportation. The primary budget item under this plan was the development of an

indigenously built Korea's Space Launch Vehicle (KSLV) and the Naro Space Center, followed by satellite development and operations.³⁴

Resources

The First Basic Plan allocated some \$1.3 billion for the period from 2007 to 2011. In 2012, the Second Basic Plan for 2012-16 was launched, with an estimated total allocation of \$2 billion. It was revised in November 2013 with an increase to accelerate development of the KSLV-2. In 2013, the space budget was about \$318 million, with 40% allocated to launch vehicle development and 30% to satellite development and operations.³⁵

Capabilities

KSLV-1, whose first stage was supplied by Russia's Khrunichev State Research and Production Space Center, successfully launched in 2013 after failing in the first two attempts. The Korean government plans to develop a launch vehicle built entirely with Korean technology by 2019.³⁶

The country's first satellite, Kitsat-1 (launched in 1992), was developed by KAIST, a public research university that established a Satellite Technology Research Centre in 1989. Engineers from the centre hatched the SaTReC Initiative, a commercial manufacturer that has built satellites and components for several countries.

South Korea's capabilities in non-space high-tech sector positions it well in the market for space-related products, services, and downstream applications.

Governance

Space activities in South Korea are managed primarily by the Korean Aerospace Research Institute (KARI), established in 1989. Residing within the Ministry of Science, ICT and Future Planning, KARI has responsibility for developing satellites, launch vehicles, and unmanned aerial vehicles. SaTReC notwithstanding, space activities are primarily funded by the government. Companies in the space sector (about 100, most notably Korean Aerospace Industries) act primarily as contractors to KARI.³⁷ Outside of the Ministry of National Defence, which relies heavily on the United States for military space capabilities, several Korean government ministries have budgets for space-related activities including those responsible for weather forecasting, the environment and agriculture.

Outcome

To date, South Korea has 18 satellites in orbit, both indigenously built and purchased from foreign suppliers. In addition to SaTReC, South Korea has at least one start-up nanosatellite company (SatByul Co Ltd.) engaged in international cooperation in developing, producing, and marketing CubeSat-type nanosatellites.

South Korea continues to pursue a fully indigenous launch capability, hoping to eventually be a provider of commercial launch services.³⁸

Israel

Israel has a technologically advanced, free-market economy, while its national security situation is defined by the ongoing Arab-Israeli conflict. Its GDP is \$301 billion, with an annual budget of \$88 billion. Israel's civil space budget is estimated at \$90 million.³⁹

Space Growth Initiative

Israel's space program is a by-product of a national security policy dictating the need for independent access to space and a satellite reconnaissance capability. The Shavit family of launch vehicles is derived from the country's ballistic missile program. Its first successful launch, in 1988, deployed the first Israeli-made reconnaissance satellite, Ofeq-1. Israel has pushed hard to generate export sales for its primary satellite manufacturer, government-owned Israel Aerospace Industries (IAI).

Resources

Israel's civil space budget does not include launch vehicle development, and most satellite programs are funded separately as well. Israel's international cooperative programs, including environmental satellites built in cooperation with the French and Italian space agencies, also are separately funded, with \$50 million and \$116 million budgets, respectively.⁴⁰

Capabilities

Leveraging its national security programs, Israel has built a small but sophisticated space program with the independent ability to launch small satellites and manufacture imaging and telecommunications satellites of all sizes. Its private industry includes world-class ground equipment and network services provider Gilat, satellite telecommunications operator Amos Spacecom, and satellite imagery provider ImageSat. Israel's information technology sector produces sophisticated satellite-enabled applications, including mapping service Waze, acquired by Google in 2013 for a reported \$1.3 billion.⁴¹

Governance

The Israel Space Agency oversees civilian programs but coordinates closely with the Ministry of Defence, whose space budget is larger. The space agency also works closely with IAI and manages a budget intended to leverage IAI's military satellite work to boost its commercial competitiveness. The latter effort has been criticised in Israel as insufficient and potentially leading to a decline of national space industry that cannot be supported solely by domestic demand.⁴²

Outcome

Unlike service and applications, Israel faces difficulties in selling satellites internationally, a situation that likely is due at least in part to its geopolitical situation. Israel has recorded at least one imaging satellite export sale, to the Italian Defence Ministry, and reportedly is in the running to supply imaging satellites to Poland.⁴³

Efficacy of Government Space Investment

Government investment in space activities has complex economic outcomes, from revenue and competitiveness in global space industries, to productivity and efficiency gains in diverse sectors, to broader socio-economic impacts.

Market Share

Considering simply market share in major space sectors, government investment has supported the leading nations in the global space economy. Europe has long made a concerted effort to be a prominent player in commercial launch services, investing in rockets optimised to launch geostationary-orbiting communications satellites. Europe, via ArianeGroup, has consistently been a leader in commercial launch services. For the five year period from 2012 through 2016, Arianespace, the ArianeGroup subsidiary responsible for conducting launches, captured 42% of this market, as measured by the number of satellites whose launches were subject to international competition. Ariane operations have generally required additional annual support from ESA. SpaceX in the United States captured 22% of the launch market in this period, and based on its backlog, its market share is on track to increase; as noted, SpaceX has received significant government contracts.

Similarly, in commercial satellite manufacturing, US and European companies have dominated, and have received significant government resources. ESA has made targeted investments intended to improve the competitiveness of European companies, while major US commercial satellite makers participate in government programs focused in US defence objectives, including substantial development and manufacturing work for US government agencies. For 2012 to 2016, US companies captured a 57% share of the global competitive market, while European firms had a 37% share.

Less successfully, Japan has long invested in satellite technology to boost its industrial competitiveness. Its share of the 2012 to 2016 global market was about 2% and confined largely to its domestic commercial programs.

Economic Impact

Some countries conduct evaluations of investments in space programs, either on a regular basis or as part of one-off studies. (Norway has been evaluating its industry every year since the 1990s, for example.⁴⁴) The Organisation for Economic Cooperation and Development (OECD) published the following selected national assessments of economic returns, measured in economic activity resulting from a given level of government expenditure on space programs in various years: Belgium 1:1.4 (2010), Denmark 1:3.7 up to 4.5 (2008), Ireland 1:3.63 (2012), Norway 1: 4.75 (2013), Portugal 1:2 (2011), and UK 1:1.91 (2010).⁴⁵ Impacts from institutional space investments were grouped by the OECD into:

- New products and services
- Productivity/efficiency gains in diverse economic sectors

- Cost avoidance (e.g. costs avoided and lives saved thanks to weather forecasts)⁴⁶

Frequently, US economic impact studies focus on the straightforward transactional impacts that result from a government agency spending money in a given region. Such studies use well-established input-output models (such as IMPLAN) and measure economic impacts of policy changes, industrial or infrastructural developments, and other economic events. Generally, all government spending has positive transactional impacts. Space-related activities in the United States have slightly higher impacts. A NASA-commissioned study of NASA socio-economic impacts,⁴⁷ prepared by Bryce (then Tauri) in 2013, indicated regional activity by NASA (80% of NASA's annual budget is spent in industry and at universities) generates \$2.60 of economic output, compared to the federal non-military average of \$2.30 and military average of \$2.00.

Studies sometimes consider specific space markets or jobs created by a particular technology, measuring impact in terms of jobs. For example, Australia has recently conducted such studies, e.g. *The Value of Augmented GNSS in Australia (2013)*⁴⁸ and *The Value of Earth Observations from Space to Australia (2015)*,⁴⁹ both by ACIL Allen Consulting.

Broader Impacts

Beyond direct economic impacts, measuring the broader impact of knowledge creation is more complex. Some studies have sought to capture all types of economic impact of space activity. A report conducted in the 1970's, *Economic Impact of NASA R&D Spending*,⁵⁰ by Chase Econometrics generated a widely reported estimate that NASA expenditure generated a multiplier effect of up to 14 times the original investment. This estimate was challenged on several occasions, including in a 1977 Government Accountability Office Report.⁵¹ Generally, it is no longer regarded as a credible basis for policy decisions.

Bryce's 2013 study *NASA Socio-Economic Impacts* identified and quantified different types of impacts of space spending. The categories were

- Scientific knowledge, measured in terms including scientific data sets maintained, visits to data websites, and academic citations.
- Investment in space-related research and technology development produces innovations that stimulate the economy, measured in terms of new technologies and transferred technologies. (One very limited study suggested that the median annual revenue generated by each technology spun out of NASA may be as high as \$1 million.)
- Advancement of overall national space capabilities, measured in terms of specific industries (such as, for example, weather forecasting).
- Technology innovation, measured by the extent to which space funding maps to key emerging technologies.
- Inspiration and STEM education, measured in terms of internships, fellowships, and social media metrics.
- Relevance to foreign policy and national security goals of the government, measured in terms of international agreements and joint programs.

Country	Govt Space Budget (\$B)	National Budget (\$B)	% Nat'l Budget to Space	GDP Growth Rate	Selected Organizations	Space Sector Employees	Governance Model	Major projects/ focuses
China**	\$10.80	\$2,708	0.40%	6.70%	CNSA; CAST; CAST; CASIC; CGWIC; Chinasat; APT Satellite Holdings	25,000	Centralized (Government owned space industry dominated by People's Liberation Army (PLA))	Full spectrum of self-sufficient national space activities: launch; human spaceflight; satellites technology for the full range of applications; science and planetary studies. Limited commercial space activities
France*	\$2.40	\$1,392	0.17%	1.10%	CNES; France MoD; Airbus Group; Arianespace; Thales Group; Safran Group; Eutelsat	16,000	Disaggregated (Space agency CNES, MoD, cooperation within ESA, mature private industry, manufacturing and sat. services, public/private partnerships for EO, launch)	Full range of space activities (significant part via ESA participation): launch (via ESA); satellite technology; full range of satellite applications; science and planetary studies. Exception: human spaceflight. Substantial commercial space sector.
Germany*	\$1.60	\$1,494	0.11%	1.70%	DLR; Germany MoD; Airbus Defence and Space; Kayser-Threde; OHB System	6,837	Disaggregated (Space agency DLR, MoD, cooperation within ESA, mature private industry, manufacturing and sat. services, public/private partnerships for EO, launch)	Full range of space activities (significant part via ESA participation): launch (via ESA); satellite technology; full range of satellite applications; science and planetary studies. Exception: human spaceflight.
India	\$4.30	\$273	1.57%	7.60%	ISRO/Antrix	14,700	Centralized within ISRO	Full spectrum of self-sufficient national civil space activities: launch; satellites technology for the full range of applications; science and planetary studies. Exceptions: human spaceflight; military space. Substantial commercial satellite services, majority provided by government-owned entities
Indonesia	\$0.14	\$138	0.10%	5.00%	LAPAN; PT Datacom; PT Pasifik Satelit Nusantara; PT Telkom; Bank Rakyat Indonesia	2,000	Centralized (Space agency LAPAN encompasses virtually all aerospace R&D activities civil and military, two semi-privatized PTT type companies operate communication satellites), in late development a large bank entered satellite business by buying and launching BRISat comsat	Achieve indigenous satellite development and manufacturing, some efforts on developing a launch vehicle
Israel	\$0.09	\$88	0.10%	2.80%	ISA; Israel MoD; IAI; Amos/Spacecom; ImageSat International; Golat	1,200	Hybrid (Space Agency, MoD, and industry independent but closely coordinated)	Indigenous launch and satellite development and manufacturing capability. Vibrant ground system and downstream application sectors. Focus on national security and economic returns.

Table 2. Emerging space markets.

Country	Govt Space Budget (\$B)	National Budget (\$B)	% Nat'l Budget to Space	GDP Growth Rate	Selected Organizations	Space Sector Employees	Governance Model	Major projects/ focuses
Italy*	\$1.20	\$890	0.13%	0.80%	ASI; Italy MoD; Avio; Thales Alenia Space; Telespazio; GAUSS Srl; OHB Italia SpA (former carlo gavazzi Space)	6,000	Disaggregated Disaggregated (Space agency ASI, MoD, cooperation within ESA, mature private industry, manufacturing)	Full range of space activities (significant part via ESA participation): launch (via ESA); satellite technology; full range of satellite applications; science and planetary studies. Exception: human spaceflight.
Japan	\$3.50	\$1,931	0.18%	0.50%	JAXA; Japan MoD; MHI; MELCO; NEC Toshiba; SkyPerfect JSAT	31,000	Disaggregated (JAXA, Cabinet Satellite Information Center, mature industry, manufacturing and satellite services)	Launch and satellite industry; science and planetary studies. Large commercial satellite services and ground equipment sectors
Malaysia	\$0.12	\$63	0.19%	4.20%	National Space Committee (JANGKA); Binariang Sdn. Bhd. (MEASAT)	19,500	Centralized (under new space policy adopted in 2017 all space activities civil and military overseen by National Space Committee (JANGKA); also private satcom operator MEASAT	Achieve indigenous satellite development and manufacturing, technology development, education of workforce
Russia**	\$3.58	\$230	1.56%	-3.70%	Roscosmos (holding company for entire space manufacturing); Russia MoD (Space Forces/ VKS); Russian Satellite Communications Company (RSCC); Gazprom Space Systems	200,000	Centralized, civil and military space closely intertwined	Early Space Age power. Full spectrum of self-sufficient national space activities: launch; human spaceflight; satellites technology for the full range of applications; science and planetary studies. Limited commercial space activities.
Singapore	\$0.03	\$45	0.06%	2.00%	OSTIn, Centre for Remote Imaging, Sensing and Processing (CRISP); SingTel	500	Hybrid (Office for Space Technology and Industry (OSTIn) closely coordinates other agencies responsible for defense, trade, the economy, foreign affairs, education, and science and technology)	Achieve indigenous satellite development and manufacturing, become leader in specific space-related technologies and downstream applications, use space as a stimulus to promote STEM education
South Korea	\$0.40	\$286	0.14%	2.80%	KARI; KAIST; SaTReC; KT	3,600	Disaggregated: KARI, KAIST, Satrec, several govt ministries have space-related budgets	Launch capability, satellite and satellite component development and manufacturing, ground systems and satellite-enabled electronics; focus on export growth opportunities
Taiwan	\$51.00	\$84	60.75%	1.50%	NSPO	11,500	Centralized under National Space Organization (NSPO)	Indigenous satellite development and manufacturing; focus on earth observation and national security

Table 2. Emerging space markets.

Country	Govt Space Budget (\$B)	National Budget (\$B)	% Nat'l Budget to Space	GDP Growth Rate	Selected Organizations	Space Sector Employees	Governance Model	Major projects/ focuses
Turkey	\$0.10	\$151	0.07%	2.90%	Tubitak Uzay; Aselsan; Turkish Aerospace Industries; Ctech; Turk Telecom	32,368	Hybrid: Turkish Space Agency introduced by a 2017 bill to help develop indigenous competitive space industry. Unclear if current satellite program participants will go under the agency	Achieve indigenous satellite development and manufacturing, possibly to pursue indigenous launch capability. Focus on defence, national security
UAE	\$0.15	\$113	0.13%	2.30%	UAESA; MBRSC; Thuraya; Yahsat	400	Centralized: space agency coordinates activity, including commercial satellite operators and Mohammed bin Rashid Satellite Center	Indigenous satellite development and manufacturing; focus on economic development, diversification, promoting STEM education. Substantial commercial satellite services sector.
UK*	\$0.50	\$1,097	0.05%	1.80%	UKSA; UK MoD; Innovate UK (funding Catapult), other government agencies with space-related budgets, Airbus/SSTL, Inmarsat	29,000	Disaggregated. Space Agency established in 2011 to consolidated activities of numerous civil agencies; MoD space still separate	Full range of space activities (significant part via ESA participation): launch (via ESA); specific space (propulsion) and satellite technologies; full range of satellite applications; science and planetary studies. Substantial commercial space sector. Focus on maximizing economic returns.
USA**	\$47.50	\$3,688	1.29%	2.40%	NASA; US DoD; NOAA; FAA; FCC; ULA; Lockheed Martin; Boeing; SSL; SpaceX; Rocket Lab; Planet; Spaceflight Industries; DigitalGlobe; Echostar; ViaSat	350,000	Disaggregated (National Space Council reinstated under Pres. Trump to coordinate)	Early space age power. Full spectrum of self-sufficient national space activities. Sophisticated industrial base encompassing satellites, space and Earth science platforms, GNSS, human spaceflight and emerging space sectors. Large commercial space sector.
GLOBAL	\$76.00	\$22,020	0.35%	3.00%	--	900,000		
European Space Agency (ESA)**	\$6.80	--	--	--	Space agencies of ESA member countries	60,000		

Table 2. Emerging space markets.

* These countries contribute a percentage of their annual space budgets to ESA. France contributes about 23%, Germany 23%, Italy 14%, and the UK 9%.

Space budgets and space sector values: OECD Space Economy at a Glance (2014) except noted otherwise, national budget data and national GDP growth rates from CIA Fact Book, and U.S. budget data from the Congressional Budget Office.

Employment data: OECD Space Economy at a Glance (2014).

Appendix: Selected Space Terms and Acronyms

Terms

Geosynchronous orbit (GEO): a circular orbit at an altitude of 35,852 km (22,277 mi) with a low inclination (i.e., near or on the equator). Geostationary orbit (GSO) is a subset of GEO in which a satellite has an orbital period equal to the Earth's rotational period and thus appears motionless from the ground

Launch vehicle: a rocket used to carry a payload from Earth's surface into space

Stage (of a launch vehicle or a rocket): in order to lighten the weight of the launch vehicle to achieve orbital velocity, most launchers discard a portion of the vehicle (a stage). Each stage contains its own engines and propellant (fuel)

Orbit: a trajectory of an object, such as the trajectory of a planet about a star or a moon or a satellite around a planet

Satellite constellation: a number of satellites with coordinated ground coverage, operating together under shared control

Remote sensing: acquisition of information about an object (such as a planet) or phenomenon without making physical contact

Acronyms

NASA: National Aeronautics and Space Administration

ESA: European Space Agency

UK: United Kingdom

ISS: International Space Station

SES: Societe Europeenne de Satellite

EO: Earth observation

US: United States

SpaceX: Space Exploration Technologies

NGA: National Geospatial-Intelligence Agency

EU: European Union

EELV: Evolved Expendable Launch Vehicle

USAF: US Air Force

CBERS: China-Brazil Earth Resource Satellite

KAIST: Korea Advanced Institute of Science and Technology

SSTL: Surrey Satellite Technology Ltd.

UAE: United Arab Emirates

CRECTEALC: Regional Centre for Space Science and Technology Education for Latin America and the Caribbean

APSCO: Asia-Pacific Space Cooperation Organization

ULA: United Launch Alliance

VLC-1: Veiculo Lancador de Satellites-1

KARI: Korea Aerospace Research Institute

IAI: Israel Aerospace Industries

ISRO: Indian Space Research Organisation

CSA: Canadian Space Agency

GDP: gross domestic product

GNSS: global navigation satellite system

IGS: Innovation and Growth Strategy

MDA: MacDonal, Dettwiler and Associates

CAF: Canadian Armed Forces

UAE: United Arab Emirates

UAESA: UAE Space Agency

MBRSC: Mohammed bin Rashid Satellite Centre

STEM: science, technology, engineering, and mathematics

OSTIn: Office for Space Technology and Industry (Singapore)

NTU: Nanyang Technological University (Singapore)

OECD: Organisation for Economic Cooperation and Development

CONAE: Comisión Nacional de Actividades Espaciales (Argentina, space agency)

CSA: Canadian Space Agency

CNSA: China National Space Agency

CAST: China Academy of Space Technology

CNES: Centre national d'études spatiales (France, space agency)

DLR: Deutsches Zentrum für Luft- und Raumfahrt (Germany, space agency)

LAPAN: National Institute of Aeronautics and Space, Indonesia

ISA: Israel Space Agency

ASI: Italian Space Agency

JAXA: Japan Aerospace Exploration Agency

UKSA: UK Space Agency

KSLV: Korean Space Launch Vehicle

FAA: Federal Aviation Administration

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Bryce Space and Technology is an analytic consulting firm serving government and commercial clients. Bryce provides unique, integrated expertise on the space economy.

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