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China Dream, Space Dream

China's Progress in Space Technologies and Implications for the United States

A report prepared for the
U.S.-China Economic and Security Review Commission

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CONTENTS

ACRONYMS

A2/AD	Antiaccess/area denial
APAS	Androgynous Peripheral Attach System
APSCO	Asia Pacific Space Cooperation Organization
ASAT	Anti-satellite
ASB	Air-sea battle
ASBM	Antiship Ballistic Missile
ASLV	Aerospace Solid Propellant Launch Vehicle Company
C4ISR	Command, control, communications, computers, intelligence, surveillance, and reconnaissance
CALT	China Academy of Launch Vehicle Technology
CAS	Chinese Academy of Sciences
CASC	China Aerospace Science and Technology Corporation
CASIC	China Aerospace Science and Industry Corporation
CAST	Chinese Academy of Space Technology
CBERS	China-Brazil Earth Remote Sensing Satellite
CCD	Charge-coupled device
CCP	Chinese Communist Party
CEOS	Committee on Earth Observation Satellites
CFOSAT	China-France Oceanography SATellite
CGWIC	China Great Wall Industry Corporation
CMC	Central Military Commission
CNP	Comprehensive national power
CMSA	China Manned Space Agency
CNSA	China National Space Agency
CRESDA	Center for Resources Satellite Data and Application
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
EO	Electrooptical
EOS	Earth Observation System
ESA	European Space Agency
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EVA	Extravehicular activity
FAA	U.S. Federal Aviation Administration
FYP	Five-Year Plans
GAD	General Armament Department
GEO	Geosynchronous Earth orbit
GEO	Group on Earth Observations
GF	Gaofen
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning Systems
GSD	General Staff Department
GTO	Geosynchronous transfer orbit
IADC	Inter-Agency Space Debris Coordination Committee
IRMSS	Infrared multispectral scanner

ISR	Intelligence, surveillance, and reconnaissance
ITAR	International Traffic in Arms Regulations
JPL	Jet Propulsion Laboratory
LEO	Low Earth orbit
MEO	Medium Earth orbit
MLP	Medium and Long-term Plan for Science and Technology Development
MOST	Ministry of Science and Technology
NASA	National Aeronautics and Space Administration
NOSS	Naval Ocean Surveillance System
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NDRC	National Development and Reform Commission
NSOAS	National Satellite Ocean Application Service
NSRCC	National Remote Sensing Center of China
PGM	Precision guided munitions
PLA	People's Liberation Army
PLAAF	People's Liberation Army Air Force
PRC	People's Republic of China
RADI	Institute of Remote Sensing and Digital Earth
RDSS	Radio determination satellite service
RF	Radio frequency
SASMAC	Satellite Surveying and Mapping Application Center
SAR	Synthetic aperture radar
SASTIND	State Administration for Science, Technology, and National Defense
SBIRS	U.S. Space-based Infrared System
SSO	Sun synchronous orbit
SVOM	Space Variable Objects Monitor
TDRS	Tracking and Data Relay Satellite
TT&C	Telemetry, tracking, and control
VISR	Visible and infrared scanning radiometer
WFI	Wide field imager

EXECUTIVE SUMMARY

China's position in the world has been evolving. It seeks increased influence and independence from foreign powers with the ultimate goal of preserving China's sovereignty, independence, territorial integrity, and political system. Over the long term, China seeks to transform the international system to better suit its interests, but seeks to integrate itself into the existing international system over the short term with the goal of reshaping the Asia-Pacific political environment into one in which its interests must be given greater attention.

China's pursuit of space power is intended to support this strategy. China views the development of space power as a necessary move for a country that wants to strengthen its national power. Indeed, China's goal is to become a space power on par with the United States and to foster a space industry that is the equal of those in the United States, Europe, and Russia. China takes a comprehensive, long-term approach to this goal that emphasizes the accrual of the military, economic, and political benefits space can provide. By placing much of its space program in a 15-year development program and providing ample funding, the Chinese government provides a stable environment in which its space program can prosper. Although China is probably truthful when it says that it is not in a space race, such statements mask the true intent of its space program: to become militarily, diplomatically, commercially, and economically as competitive as the United States is in space.

For China's military, the use of space power can facilitate long-range strikes, guide munitions with precision, improve connectivity, and lead to greater jointness across its armed forces. Economically, space technologies can create markets for new technologies and result in "spin-off" technologies for commercial uses that will make its industry more competitive. Politically, space power provides "carrots and sticks" that China can use to influence the international situation. Internally, China's rise as a space power is designed to demonstrate to the Chinese people that the Chinese Communist Party is the best organization to lead the country.

In examining China's use of its space program to advance its national security, economic, and diplomatic interests, this study finds that China has made much progress, particularly in serving its national security interests, but that its goals of using space to advance its economic and diplomatic interests remain underdeveloped. As a result, China is a "partial space power"; that is, a global actor that has yet to translate its power into comprehensive influence.

This conclusion should not be unexpected, however. China is a latecomer as a serious space power. China's rapid progress in space technology, although impressive, is also the result of starting from a low base and a reliance on the pioneering work of the United States and Russia. The United States remains the world's leading space power, and Chinese space technologies still lag behind the United States.

Nevertheless, China's efforts to use its space program to transform itself into a military, economic, and technological power may come at the expense of U.S. leadership and has serious implications for U.S. interests. Even if U.S. space power continues to improve in absolute terms, China's rapid advance in space technologies will result in relative gains that challenge the U.S. position in space. At its current trajectory, China's space program, even if not the equal of the U.S. space program, will at some point be good enough to adequately support modern military operations, compete commercially, and deliver political gains that will serve its broader strategic interest of again being a major power more in control of its own destiny.

Military Benefits

China's space program has made the most progress in addressing its national security needs. China's space program assists the People's Liberation Army (PLA) in its efforts to achieve information superiority, defined as the ability to use information freely and to deny the use of information by an adversary. Based on their analyses of U.S. military operations, Chinese military researchers view space as a critical component in making the PLA into a force capable of winning "informatized" wars and recognize the role space plays in the collection and transmittal of information and the need to deny those capabilities to an adversary.

Indeed, nearly every Chinese source describes space as the "ultimate high ground," leading many Chinese analysts to assess that space warfare is inevitable. Because of the preeminence of the space battlefield, analysts writing on space argue that it will become *the* center of gravity in future wars and one that must be seized and controlled. In fact, these analysts argue that the first condition for seizing the initiative is to achieve space supremacy.

China's space program plays a central role in its effort to possess antiaccess/area denial (A2/AD) capabilities. Chinese analysts writing on space argue that the development of long-range precision strike weapons "cannot be separated from space power." Long-range anti-ship cruise and ballistic missiles require the ability to locate, track, and target enemy ships hundreds or thousands of kilometers from China's shores. Such capabilities could also be used to attack U.S. bases and the bases of its allies in Asia as well as targets within the 50 states.

Chinese writings also devote much attention to the need to develop counterspace capabilities and offer multiple rationales for why China must develop counterspace weapons. China must be able to protect its own space-based assets from attack and prevent an adversary from using space to attack terrestrial targets. A second reason is to deny an adversary the use of space. Chinese military analysts have noted the dependence of the U.S. military on space and have concluded that the degradation of U.S. space capabilities may result in decisive losses for the U.S. military. Third, counterspace capabilities can be used against space-based missile defense to preserve China's nuclear deterrent. Finally, space can be used to deter real and potential adversaries from using force, both in space and in other domains.

Economic and Commercial Benefits

China's rise as a space power also appears to have potential negative economic consequences for the United States, although that impact will be felt more in the long-term. China has embraced its space program as a driver of economic growth and technological advancement that can help change its economy from a low-cost manufacturer to a high-tech competitor. According to Chinese analysts, investments in space technologies can produce a ten-fold return. The demand created by space projects can spur advances in high technologies that not only can be applied to other uses but also can create new markets. The creation of high technology space products is also intended to support the development of other industries through the introduction of spin-off technologies—technologies originally developed for the space industry that have found a civilian application. Progress in space technologies can create new markets, such as satellite communications, radio and television, remote sensing data, and satellite navigation products as well as those related to new materials and information technology.

Space can also aid economic growth directly through commercial launch services and satellite exports. Because of U.S. export control laws, China realizes that it must also develop satellites for other countries if it is also to provide commercial launch services. China aims to capture 10 percent of the world's commercial satellite market and 15 percent of the global space launch business by 2015.

To date, China has built and launched satellites for Nigeria, Venezuela, Pakistan, and Bolivia. It has also signed contracts for satellites with Belarus, Laos, and Sri Lanka, and Venezuela for an additional satellite. In addition to offering lower-priced satellites, China offers a competitive package that includes launch services, training for local operators, and low-cost loans through its export-import bank.

In addition to satellite exports, China has also provided launch services to Indonesia, Turkey, Ecuador, Argentina, and Luxembourg and has signed contracts with Bolivia, Laos, Belarus, Sri Lanka, Congo, and Algeria. In 2011, CASC launched a satellite for European satellite communications provider Eutelsat. This was the first time that China had launched a foreign-made satellite for a foreign client since 1999.

Political Benefits

The Chinese government also uses its space program for domestic and international political gain. By developing a robust space program and participating in high-profile activities such as human space flight and lunar exploration, the Chinese Communist Party can demonstrate that it is the best provider of material benefits to the Chinese people and the best organization to propel China to its rightful place in world affairs. Outwardly, China conducts numerous cooperative activities with other countries and holds international exchanges and cooperation to improve its international position, which increases its influence among less developed countries and facilitates technology transfer to China. These activities build China's reputation as a reliable and attractive space partner and could help to achieve China's goal of establishing a multi-polar world.

The importance of China's space diplomacy should not be overstated, however. Cooperation in space do not drive relations on Earth. International cooperation on space activities usually follows progress in the overall relationship and is more of an indicator of the state of a relationship than a critical component. Although China's increasing space power does play a role in advancing its diplomatic interests, there is no evidence that it has directly produced tangible political benefits in other areas besides space.

China conducts cooperative activities with numerous countries and as China's space program continues to improve, countries without the security concerns of the United States will increasingly look upon space as another venue for interacting with China. China cooperates with many countries in space and looks to Europe in particular for access to technology and expertise denied by the United States.

China's longest cooperative space relationship is with Russia and its predecessor, the Soviet Union. China has a long-term cooperation plan with Russia that has resulted in technology transfer and agreements on joint space science and deep space exploration. Russia is also receptive to cooperating with China on human spaceflight and the exploration of the moon and Mars.

European countries and the European Space Agency are also seeking opportunities for greater cooperation with China in space technologies, space exploration, and human spaceflight in order to facilitate greater economic ties between Europe and China and to compensate for the reduced funding of the European Space Agency. Europe and China have conducted a variety of cooperative activities since 2000. These include an agreement to develop China-based applications of the Galileo satellite navigation system and cooperative activities on monitoring space weather and Earth remote sensing. Europe is also interested in collaborating with China on human spaceflight and is considering providing experiments on

China's space station as well as having European astronauts conduct Chinese experiments on the International Space Station.

China's relationship with the United States space program has been turbulent, with successive NASA administrators considering cooperative activities with China. In 2004, the head of the China National Space Administration visited NASA for the first time, and in 2006, a NASA administrator for the first time visited the China National Space Administration. This was followed four years later by a visit to China by NASA Administrator Charles Bolden. All visits were described as familiarization tours, and no substantive agreements on cooperation resulted. In 2011, Congress prohibited NASA from conducting many types of activities with China. Since then, NASA's activities with China's space program have been restricted to multinational fora.

Organization

China's space program is inherently dual-use. The main organizational actor is the military's General Armament Department (GAD). The GAD is responsible for overseeing the research and development of spacecraft and runs the country's launch centers, satellite control centers, and human spaceflight program. Responsibility for providing missions for China's spacecraft can come from a variety of organizations. Military tasking can come from the General Staff Department, but civilian missions, such as weather forecasting, and other remote sensing missions can be led by civilian organizations, such as China's National Meteorological Administration.

The plethora of organizations responsible for space-related activities has led some Chinese authors to argue that China needs an executive agent in order to respond efficiently to crises. Officers from the PLA Air Force have been most vociferous in advocating for this role. They argue that the Air Force is best suited to manage the space portfolio since it is the most high-tech of the services, and other air forces of the world are responsible for space. But other services have also indicated that they may be tasked with space missions. In particular, the Second Artillery may play a role in conducting counterspace missions, especially those involving direct ascent capabilities.

Space Technologies

China has made impressive progress in space technologies since 2000. With the exception of missile early warning, China now has nearly a full range of satellites to accomplish a variety of missions. These include remote sensing satellites with various resolutions and covering various spectrums, a satellite navigation system, communication satellites, and robust human spaceflight and lunar exploration programs. China places a priority on the development of space technologies: three of the sixteen mega-projects of the Medium and Long-term Plan for Science and Technology Development involve space. China's space mega-projects have been unofficially dubbed the "221 Program," which refers to the human spaceflight program and lunar exploration programs, the Earth remote sensing and Beidou satellite navigation programs, and a next generation of launch vehicles.

Human Spaceflight

China's human spaceflight program has conducted a total of ten missions, five of them manned. The first Shenzhou space capsule was launched in 1999. Since then, the space capsule and the missions have increased in complexity. In 2008, China conducted its first spacewalk and in 2011 conducted its first docking. China has also launched a small station, Tiangong-1, in 2011. The ultimate goal of China's human spaceflight program is to complete a large, long-term space station by 2023.

China conducts human spaceflight for a variety of reasons. The main reason is political. As demonstrated by the U.S. Apollo program, human spaceflight can have immense domestic and international political benefit. Large space projects, like those necessary for human spaceflight, can also create a skilled workforce and produce high technology. Militarily, Chinese analysts regard human-operated spaceflight as having advantages over robotic missions, and they often discuss manned ISR and counterspace missions.

Lunar Exploration

China has conducted four lunar exploration missions. The first two missions, Chang'e 1 and 2, orbited the moon to take images of the lunar surface. A third lunar mission landed a robotic rover, Jade Rabbit, on the moon in December 2013 to analyze the lunar surface. This rover experienced mechanical difficulties after the first lunar night and became nearly unusable. The fourth mission was launched in October 2014 and involved a flyby of the moon and the return of the orbiter to Earth. The ultimate goal of China's lunar exploration program is to conduct a mission that will collect lunar soil samples and return them to Earth by 2020. Although China is conducting feasibility studies of manned missions to the moon, no official approval has been given.

A primary purpose of China's lunar exploration program is to analyze the lunar soil for possible economic exploitation. Foremost is speculation about the mining of helium-3, an element that could be used in a future fusion reactor. According to Chinese analysts, 100 tons of helium-3 could supply the world's electrical needs for one year, and they estimate that the moon has one to five million tons. At a price of $4–10 billion per ton, these analysts conclude that mining helium-3 could be profitable.

Satellite Navigation

China's Beidou satellite navigation system is planned to provide a global service by 2020. Designed to be similar to the U.S. Global Positioning System (GPS), Beidou will consist of 35 satellites in medium Earth and geosynchronous orbits that will provide positioning accuracies of less than 10 meters. With the use of a nation-wide system of differential Beidou, accuracy will be improved to one meter. Unlike GPS, Beidou has a short messaging service in which messages as long as 120 characters can be sent to other Beidou receivers.

Similar to GPS, Beidou is first and foremost a military system that has extensive civilian applications. Seeing the need to eliminate their reliance on GPS, Chinese scientists and military officers have advocated since the early 1980s for China to have its own satellite navigation system. Beidou is now being increasingly used by the Chinese military at the regiment level and above and is reportedly being integrated into weapon guidance systems.

China also sees great economic benefit in promoting Beidou for domestic civilian use. The Chinese market for satellite navigation products is projected to reach to 400 billion yuan ($65.14 billion) by 2020. Currently, products for GPS have 95 percent of the market. China plans for Beidou products to capture 70–80 percent of the domestic market by 2020 and has enacted preferential policies, including the mandatory installation of Beidou receivers on certain vehicles, to achieve that end.

Remote Sensing

The stated purpose of China's satellite remote sensing project is to build an all-weather, 24-hour, global Earth remote sensing system by 2020 capable of monitoring the ground, atmosphere, and oceans. China has a variety of remote sensing satellites, including four new series of satellites introduced since 2000:

the Gaofen, Yaogan, Huanjing, and Tianhui satellites. This is in addition to legacy satellite series such as the Ziyuan Earth remote sensing satellite and the Fengyun meteorological satellite. Although China has many remote sensing satellites, the first official satellite to be launched under the remote sensing mega-project is the Gaofen-1, launched in 2013.

With these satellites, China can serve a variety of remote sensing needs. Chinese imagers have stated resolutions of one to thirty meters and can image in the visible, infrared, and multispectral ranges. The Yaogan and Huanjing satellites also use synthetic aperture radar (SAR) to be able to image through cloud cover or at night. Certain Yaogan satellites are also rumored to have electronic intelligence capabilities.

Accessing information from these satellites is facilitated by a network of three satellites, designated Tianlian, that relay communications and data between satellites and ground stations anywhere on the Earth regardless of the position of the satellite in orbit or the location of the unit on the ground. As such, the Tianlian satellites play a critical role in facilitation of real-time intelligence collection to China's military.

Launch Vehicles

China is also developing a new generation of launch vehicles. These new rockets will use "non-polluting" fuel and are planned to be more reliable and cost effective. The Long March 5 will be able to launch 14 metric tons into low Earth orbit, which is more than three times the current payload capacity. This heavier lift capacity will allow China to orbit its larger space station and launch heavier remote sensing and communication satellites. The Long March 6 will be a light lift rocket capable of launching one metric ton into low Earth orbit. The Long March 7 will be a medium lift rocket capable of launching 13.5 metric tons into low Earth orbit and will eventually replace the Long March 2F as the launch vehicle for human spaceflight missions. The first launch of these rockets is scheduled to occur in 2015.

China has also developed the solid-fueled Long March 11, Kuaizhou, and Feitian-1 launch vehicles. These light lift rockets are intended to provide China with a rapid response capability that could be used to quickly launch satellites in response to disasters or military conflict.

INTRODUCTION

China's growing military, economic, and political power has been of increasing concern to the United States. The expansion of its interests, coupled with increasingly assertive behavior, has led to a perception of many in the West that the United States is a country on the decline while China is a country on the rise. At a time when China's rapid economic growth continues, its military swiftly modernizing, and its political clout increasing, the economic growth of the United States remains slow, and its ability to shape world affairs appears to be on the decline. This has led some to conclude that the Chinese model based on an authoritarian-directed form of capitalism is replacing global acceptance of an American model built on democracy and free markets or that China will replace the United States as the most powerful country.[1]

China's rise as a world power has been accompanied by its rise as a space power. China's ambition to become a space power is driven by a belief in the benefits of space power to contribute significantly to China's national power. China regards its space program as an important expression of its comprehensive national power and is intended to portray China as a modernizing nation committed to the peaceful uses of space while at the same time serving its political, economic, and military interests.[2] It contributes to China's overall influence and provides capabilities that give China more freedom of action and helps maintain national security. Indeed, China has the ultimate goal of transforming itself from a "major space power to a strong space power" on par with the United States and Russia. In recent years, China has made important progress across a broad range of space technologies, including launchers, satellites, lunar exploration, human space flight, and counterspace technologies.

The rise of China's space program presents military, economic, and political challenges to the United States. As the *U.S. National Security Space Strategy* states, "Space is vital to U.S. national security and our ability to understand emerging threats, project power globally, conduct operations, support diplomatic efforts, and enable global economic viability."[3] China's efforts to use its space program to transform itself into a military, economic, and technological power may thus come at the expense of U.S. leadership in both absolute and relative terms.

Uncertainty over China's pathway to potential major power status, the possibility of a conflict over its territorial claims, and the inherent dual-use nature of space technologies means that China's improving space capabilities could be used against the U.S. military. China's space program contributes to the Chinese military's antiaccess/area denial (A2/AD) capabilities by providing critical C4ISR (command, control, communications, computers, intelligence, surveillance, and reconnaissance) support to long-range precision strikes weapons and providing the ability to threaten U.S. space-based assets.

Space is also becoming more economically competitive. China's space program officials believe that space technology is the highest of high technologies, the mastery of which can have positive consequences far beyond the realm of space power to produce tangible benefits for the Chinese people and the national interests of the country. To carry out this plan, China's space industry has been designated as one of

[1] Stefan Halper, *The Beijing Consensus: How China's Authoritarian Model Will Dominate the Twenty-First Century* (Philadelphia: Basic Books, 2010), X; Martin Jacques, *When China Rules the World: The End of the Western World and the Birth of a New Global Order* (New York: Penguin Press, 2009), 363.
[2] Information Office of the State Council, China's Space Activities in 2011, December 2011,http://www.gov.cn/english/official/2011-12/29/content_2033200.htm.
[3] Department of Defense and the Office of the Director of National Intelligence, *National Security Space Strategy*, January 2011, 1.

China's strategic emerging industries, and space technologies figure prominently in China's science and technology modernization plans. Indeed, China's space industry has the goal by 2020 to become a "world-class" aerospace industry on par with Boeing, Lockheed Martin, and Airbus Group.

China has also been able to use its space program to further its diplomatic objectives and to increase its influence in the developing world and among second-tier space powers. China conducts numerous international cooperative activities that provide leadership opportunities, improve bilateral relations, and open up avenues for technology transfer.

Sources

This report is supported by hundreds of sources, ranging from Chinese language news sources, journals, and space industry and military publications to English language news and analysis. Although individual facts may not be a cause for debate, the larger epistemological question of the intent of China's space program and its implications may be. Most controversial will be the use of space for military purposes. This work builds upon the principal author's previous work and reaffirms the finding that Chinese researchers are unanimous in their belief that space war is inevitable, a belief also stated by the Vice Chairman of the Central Military Commission, Xu Qiliang. China's commitment to this vision is exemplified by the large amount of theoretical and technical research being carried out in China by the PLA, defense industrial research institutes, and civilian research organizations. While such writings do not necessarily reflect official Chinese military strategy, the near unanimity of opinion by Chinese writers on this topic suggests a consensus within the defense community.

China's Space Policy

According to one Chinese source, space policy is determined by the overall strategy of a country and its political, economic, military, science and technology, and societal goals. The main investor in space technologies is the government and, as a result, the highest level of government leadership determines space policy. As this source states, "Our country's strategic goals for space development and the policies to realize those goals have consistently received the attention of the highest leadership and have received the support of every organization. It can be said that the country's space policy is the lifeline for space development."[4]

To date, China has released three space "white papers," in 2001, 2006, and 2011. Entitled "China's Space Activities," these documents can be considered nominal statements of policy but are primarily geared towards China's technological accomplishments and goals and not to how the government and military use or plan to use space, nor to the organizations that are charged with carrying out space policy and how they are funded. As a result, even though China's space program is much more open than before, much more work needs to be done to equal the transparency of the U.S. space program.

Each white paper contains an "aims and principles" section that is akin to a broad policy statement. The purposes of China's space program have remained consistent in all three white papers:

> to explore outer space and to enhance understanding of the Earth and the cosmos; to utilize outer space for peaceful purposes, promote human civilization and social progress, and to benefit the whole of mankind; to meet the demands of economic development,

[4] Geng Yandong, 军事航天系统工程 [*Military Space System Engineering*] (Beijing: National Defense Industry Press, 2007), 138.

> scientific and technological development, national security and social progress; and to improve the scientific and cultural knowledge of the Chinese people, protect China's national rights and interests, and build up its national comprehensive strength.[5]

All three white papers have stated a commitment to independent and self-reliant development while at the same time welcoming cooperation with international partners. Reflecting the progress its space program has made since the initial white paper in 2001, the principles by which China has sought to achieve these aims have been revised to reflect its modernization goals. The 2001 white paper, for example, stated that China would only select a "limited number of targets" in which to make breakthroughs according to its national situation and strength.[6] By 2006, China would instead "maintain comprehensive, coordinated, and sustainable development," and in 2011 China would also concentrate on making breakthroughs in key technologies for leapfrog development.

China's Grand Strategy

Because China's explanation of its space policy is limited and because China has not issued a space strategy, determining the direction of its space program can be difficult. This does not mean, however, that China's space strategy is unknowable. In order to address this challenge this study will position China's space strategy within the context of its grand strategy. Although it is important to stress that China does not appear to have an official grand strategy, there is a consensus that China desires to increase its power and position in the world and that this desire is based on several principles. First is the Chinese concept of *fuqiang* (富强), or "wealth and power." The term *fuqiang* is a shortened version of *fuguo qiangbing* (富国强兵) meaning "rich country and strong army." The goal of having a rich country and strong army was first expressed by the Legalist philosopher Han Feizi during the Warring States Period of the fifth century BC when he stated, "If a wise ruler masters wealth and power, he can have whatever he desires."[7]

The pursuit of wealth and power has taken on new impetus with the rise to power of Chinese President Xi Jinping in 2012 and his call for China and the Chinese people to chase the "China Dream." Although the concept of the China Dream remains ill-defined, Xi has described it as "improvement of people's livelihoods, prosperity, construction of a better society, and military strengthening."[8] The concept of the China Dream and China's pursuit of wealth and power also ties closely to the Chinese idea of national rejuvenation. Chinese history stresses China's role as a world power that was lost to the hands of foreigners beginning in 1839 with the first Opium War. From then until the founding of the People's Republic of China in 1949, described as the "one hundred years of humiliation," China was engulfed in domestic turmoil, civil war, and foreign invasion that rendered it weak, with no real standing in the world order. Since 1839, Chinese politicians and intellectuals sought to restore China to its previous periods of

[5] Information Office of the State Council, China's Space Activities in 2011, December 2011, http://www.gov.cn/english/official/2011-12/29/content_2033200.htm.
[6] Information Office of the State Council, *China's Space Activities*, November 2000, http://www.china.org.cn/e-white/8/index.htm.
[7] Orville Schell and John Delury, *Wealth and Power: China's Long March to the Twenty-First Century* (New York: Random House, 2013), 21.
[8] For example, Xi Jinping's first mention of the China Dream was at the National Museum of Chinese History at the permanent exhibition "Road to Rejuvenation." See 习近平：承前启后 继往开来 继续朝着中华民族伟大复兴目标奋勇前进 [Xi Jinping: Inherit the Past and Usher in the Future, Carry Forward the Revolutionary Cause and Forge Ahead into the Future, Continue Forging Valiantly Ahead Toward the Chinese People's Mighty Goal of Rejuvenation], Xinhua, November 29, 2012, http://news.xinhuanet.com/politics/2012-11/29/c_113852724.htm.

economic and military power,[9] with little success until the founding of the People's Republic of China (PRC) in 1949 when the Communist Party rid China of foreign influence and later sought greater prosperity through economic reform started by Deng Xiaoping.

This legacy of China's downfall into foreign subjugation, economic stagnation, and national humiliation is seen today in China's pursuit of wealth and power. According to David Lampton, Hyman Professor and director of SAIS-China and China Studies at the Johns Hopkins School of Advanced International Studies, "One almost universally shared goal in the PRC—indeed in China for the last 150 years or more, since the Qing Dynasty went into decline—is to make China rich and powerful and to regain the nation's former status as a great power that controls its own fate."[10] As Ye Zicheng of Peking University writes, "China is a unique country in the history of world civilization. Nearly all the more than 20 great civilizations in world history have vanished…Unlike all these other civilizations, China is the only country that has continuously maintained its historical civilization for some 5,000 years…This unique continuity expresses its creativity for self-renewal."[11] He continues, "That China was able to become a great power many times over the course of more than 2,000 years was due to its strong points and the superiority that it enjoyed. This also confers on contemporary China some cultural and historical resources that can be made use of today to expedite growth."[12]

According to David Finkelstein, vice president and director of the China Studies Division at the Center for Naval Analyses, China's grand strategy can be summarized as "the attainment of a strong, modern, and prosperous China."[13] Avery Goldstein further elaborates, writing that China aims to engineer its

> rise to great power status within the constraints of a unipolar international system that the United States dominates. It is designed to sustain the conditions necessary for continuing China's program of economic and military modernization as well as to minimize the risk that others, most importantly the peerless United States, will view the ongoing increase in China's capabilities as an unacceptably dangerous threat that must be parried or perhaps even forestalled. China's grand strategy, in short, aims to increase the country's international clout without triggering a counterbalancing reaction.[14]

The basis for China's rise to great power status is a strong economy. Chinese scholars point to the Soviet Union as proof that merely having a strong army is not sufficient for maintaining a country's position in the world. Not only will a growing economy give China more influence in the world, it will also enable it to afford the capabilities it needs to wield that power.

The ultimate goal of becoming a rich country with a strong army is to preserve China's sovereignty, independence, territorial integrity, and political system by integrating itself into the existing international system,[15] while at the same time working to transform the system to better suit China's interests.[16] But

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[9] For a discussion of "wealth and power" see Schell and Delury, *Wealth and Power*, 5–10.
[10] David Lampton, *The Three Faces of Chinese Power: Might, Money, and Minds* (Berkeley: University of California Press, 2008), 25.
[11] Ye Zicheng, *Inside China's Grand Strategy,* (Lexington: The University Press of Kentucky, 2011), 30–31.
[12] Ibid., 37.
[13] David Finkelstein, "Commentary on China's External Grand Strategy," Center for Naval Analyses, January 2011, 2.
[14] Avery Goldstein, *Rising to the Challenge: China's Grand Strategy and International Security* (Stanford, CA: Stanford University Press, 2005), 17.
[15] Ye Zicheng, *Inside China's Grand Strategy* (Lexington: The University Press of Kentucky, 2011), 79.
[16] Ibid., 260.

because the United States remains the world's lone superpower, China must not derail its economic modernization effort by coming into military or economic conflict with the United States. As a result, even though China is becoming more assertive in defending what it sees are its legitimate interests, it will try to do so in a way that does not fundamentally harm its economic interests and lead it into a military conflict with the United States.

Although China does not seek conflict with the United States, it must at the same time act in ways to bring about its goal of becoming a world power.[17] As Peking University's Ye writes, "there is a close connection between the rejuvenation of the Chinese nation and China's becoming a world power. If China does not become a world power, the rejuvenation of the Chinese nation will be incomplete. Only when it becomes a world power can we say that the total rejuvenation of the Chinese nation has been achieved."[18] Although President Xi Jinping has stated that China "must strive to make our neighbors more friendly in politics, economically more closely tied to us, and we must have deeper security cooperation and closer people-to-people ties,"[19] he has also stated that China "would never sacrifice its legitimate rights or basic interests" and that "no foreign country should expect us to make a deal on our core interests and hope we will swallow the bitter pill that will damage our sovereignty, security, and development interests."[20] As Bonnie Glaser, senior adviser at the Center for Strategic and International Studies, concludes:

> China appears to believe that growing Chinese economic and military clout will over time persuade its neighbors that there is more to gain from accommodating Chinese interests than from challenging them. In handling relations with its neighbors, China is employing both carrots and sticks to deter countries from pursuing policies that inflict damage on Chinese interests.[21]

This strategy will require a careful balancing act. China must learn to minimize confrontation with potential foes while at the same time strengthening its economic ties with them. As Peking University's Wang Jisi writes, "All this means that it is virtually impossible to distinguish China's friends from its foes. The United States might pose political and military threats, and Japan, a staunch U.S. ally, could be a geopolitical competitor of China's, but these two countries also happen to be two of China's greatest economic partners."[22]

The Pursuit of Comprehensive National Power and China's Grand Strategy

In order to carry out this grand strategy, China must build up what it calls comprehensive national power (CNP). There is no set definition of comprehensive national power. According to a report written by the Chinese Academy of Sciences, comprehensive national power refers to "the complete power and international influence that a sovereign country uses and develops…It includes societal, material, and spiritual factors. It also includes real power and potential power and mechanisms to turn potential power

[17] Ibid., 73.
[18] Ibid., 74.
[19] Mu Xuequan, "Xi Jinping: China to Further Friendly Relations with Neighboring Countries," Xinhua, October 26, 2013, http://news.xinhuanet.com/english/china/2013-10/26/c_125601680.htm.
[20] "No Compromises Over China's Sovereignty: Xi," Xinhua, January 30, 2013, accessed September 1, 2014, http://english.sina.com/china/2013/0129/555233.html.
[21] Bonnie S. Glaser, "China's Grand Strategy in Asia," Statement before the U.S.-China Economic and Security Review Commission, March 13, 2014.
[22] Wang Jisi, "China's Search for a Grand Strategy," *Foreign Affairs*, March/April 2011, http://www.foreignaffairs.com/articles/67470/wang-jisi/chinas-search-for-a-grand-strategy.

into real power. It is the organic integration and interactive use of a country's politics, economy, science, culture, education, national defense, diplomacy, national resources, and national will.[23] It is also the representation of a country's ability to protect and garner its national interests."[24]

Ye Zicheng defines CNP as the "power of a sovereign country, including both hard power, such as economic and military power, and soft power, such as spiritual, cultural, national historical tradition, and national cohesiveness. National power also includes both present power and potential power."[25] In short, Ye writes that CNP is best understood "as comprising a country's survival ability, development capacity, and international influence."[26] David Lampton uses a more political science-oriented description of CNP as "the sum total of coercive, economic, and ideational power of a nation."[27]

CNP is difficult to operationalize due to the difficulty in appropriately measuring resources and their relative importance, and then combining them into one measurement while at the same time taking into account both real and potential power.[28] The purpose here, however, is not to debate the merits of using CNP, but rather to explore how it guides Chinese analysts in their conception of China's grand strategy. As George Washington University professor David Shambaugh writes, "The Chinese have wisely learned one key lesson from studying the experiences of other previous powers: genuine powers possess multidimensional strength."[29] This includes "the economy, science, technology, education, culture, values, military, governance, diplomacy, and other sectors" as well as a strong component of soft power.[30]

A critical part of China's quest to increase its CNP and become a world power is the ability to develop high technology independently. China's leadership understands that its growth model based on being the world's low cost manufacturer is not sustainable over the long term and that it must move up the value chain by being able to manufacture its own high technology products. The importance of technological innovation was highlighted in a June 2014 speech by Xi Jinping in which he urged China's scientists and engineers to "innovate, innovate, and innovate again."[31] According to Xi, China "is closer than at any other time in its history of reaching its mighty goal of the rejuvenation of the Chinese people" and that China "must continue by resolutely implementing the strategy of using science and education to rejuvenate the country and innovation to drive development and unswervingly continue on the road of making China into a strong science and technology power."[32] Drawing on lessons from history, Xi states that science and technology are the basis of a strong and prosperous country and that since the sixteenth century every science and technology revolution has influenced the global power structure. Drawing on China's own history since the end of the Ming Dynasty, Xi states that the strength of a country cannot simply be based on the size of its population or territory and that the reason China "took a beating" between 1839 and 1949 was that it was backwards in science and technology. Xi concludes that China "cannot lag in the

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[23] Jiang Zhou, "国家战略性产业生命路径及其拐点分析" [An Analysis on the Life Path and Inflexion Point of the National Strategic Industry], master's thesis, University of Science and Technology of China June 28, 2009, 4.
[24] Ibid., 4–5.
[25] Ye Zicheng, *Inside China's Grand Strategy*, 17.
[26] Ibid., 19.
[27] Lampton, *Three Faces of Chinese Power*, 21.
[28] Ibid.
[29] David Shambaugh, *China Goes Global: The Partial Power* (New York: Oxford University Press, 2013), 5.
[30] Ibid., 6.
[31] Xi Jinping, "在中国科学院第十七次院士大会、中国工程院第十二次院士大会上的讲话" [Speech at the Chinese Academy of Sciences Seventh Academician Congress and China Academy of Engineering Twelfth Academician Congress], June 9, 2014, http://politics.people.com.cn/n/2014/0610/c1024-25125483.html.
[32] Ibid.

competitive arena of science and technology" and must catch up to and eventually surpass the current science and technology leaders by first focusing on core technologies. Consequently, China can only maintain its economic and military security through original innovation and not on relying on "dressing up" foreign technologies into Chinese products.[33]

China's Space Strategy

China's grand strategy is reflected in its pursuit of space power. Indeed, China's space program has received high-level endorsement from China's leadership. Mimicking the China Dream slogan, members of China's space program are encouraged to chase the "Space Dream" (航天梦). According to Xi Jinping, "the dream of space flight (飞天梦) is an important part of the strong country dream (强国梦)" [34] and "the space dream is an important component of realizing the Chinese people's mighty dream of national rejuvenation."[35]

The importance of the space program is rooted in the importance of the role high technology plays in China's development. According to one researcher, "building China as a strong space power is the only way that China can rejuvenate to have wealth and power."[36] According to this view, space technologies are both high risk yet a high value added strategic industry that places great demands on a country's research and development apparatus across many different industries.[37] As a result, the development of space technologies is both a display of a country's technological capability and by extension a display of its military, economic, and scientific capabilities, but also a necessary move for a country that wants to strengthen its national power.[38]

SPACE POWER'S CONTRIBUTION TO CHINA'S COMPREHENSIVE NATIONAL POWER

China's space program furthers its grand strategy ambitions by adding to China's CNP. Although space power is not a main contributor to China's CNP, it nevertheless is considered an important component. Space activities increase China's hard power by improving its military capability and economy and its soft power by enhancing its political status. As one analyst writes, "For a country, space activities not only can expand its strategic space, but also can also help it to gain the initiative in international political, economic, technological, military and diplomatic arenas.[39]

The Role of Space in China's Military

China's space program assists the People's Liberation Army (PLA) in its transformation into a military reliant on information for winning wars. According to China's 2013 defense white paper, "China's armed

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[33] Ibid.

[34]"习近平"天地通话"激励中国飞天梦" [Xi Jinping: 'Space to Earth Communications' Encourages China's Dream of Spaceflight], http://www.chinanews.com/gj/2013/06-25/4964690.shtml.

[35]"航天梦与中国梦" [The Space Dream and the China Dream], 中国航天报 [*China Space News*], July 31, 2013, 3.

[36] Wu Weiqiang, "浅谈航天强国评价体系研究" [A Brief Discussion on Research on the Analysis of Strong Space Power Evaluation System], 航天工业管理 [*Space Industry Management*], 2013/3, 37.

[37] Wu Weiqiang, "浅谈航天强国评价体系研究" [A Brief Discussion on Research on the Analysis of Strong Space Power Evaluation System], 航天工业管理 [*Space Industry Management*], 2013/3, 34.

[38] Ibid., 33.

[39] Feng Shuxing, 我国空间力量发展与空间安全的思考 [Reflection on Development of Space Power and Space Security] 装备学院学报 [*Journal of Academy of Equipment*], October 2012, 9.

forces firmly base their military preparedness on winning local wars under the conditions of informatization." Indeed, information superiority is seen now by the PLA as a primary component for winning future wars. The side that can best collect and process information and deny that ability to an adversary will be better able to detect and exploit battlefield opportunities and counter enemy movements.

Chinese writings on space and counterspace indicate that China sees that it has widespread economic and military interests in space and that these interests must be protected. Underlying this analysis is the belief that "whoever controls space controls the Earth." This belief is based on the premise that space is the new high ground on which success on the terrestrial battlefield is based. Indeed, space is so important to battlefield success that conducting modern war is not possible without its effective use. In November 2009, then People's Liberation Army Air Force Commander and now Vice Chairman of the Central Military Commission General Xu Qiliang stated that space had become a "new commanding height for international strategic competition" and that having control of the air and space "means having control of the ground, oceans, and the electromagnetic space, which also means having the strategic initiative in one's hands."[40]

Space can be used for a variety of national security applications, including reconnaissance, meteorology, missile early warning, communication, and navigation. These technologies can provide critical capabilities to monitor the activities of potential adversaries, facilitate communication between far-flung forces, and provide navigation data to naval and air forces. Weapons can also be placed in space. These include ballistic missile defenses to intercept incoming nuclear-armed missiles, anti-satellite weapons to destroy orbiting satellites, and orbital bombardment systems that can conduct strikes against terrestrial targets.

A robust, space-based C4ISR system is often described as a critical component of a future networked PLA. The necessity to develop space-based C4ISR systems is based on the requirement to develop power-projection and precision-strike capabilities. The development of long-range cruise missiles and anti-ship ballistic missiles for over-the-horizon attacks requires the ability to locate, track, and target enemy ships hundreds of kilometers away from China's shores, as well as the ability to coordinate these operations with units from multiple services. In doing so, remote sensing satellites can provide intelligence on the disposition of enemy forces and provide strategic intelligence before a conflict begins. Communication satellites can provide global connectivity and can facilitate communications between far-flung forces. Navigation and positioning satellites can provide critical information on location and can improve the accuracy of strikes.

However, the PLA also recognizes that it must deny the use of information to its opponents. Chinese analysts assess that the employment of space-based C4ISR capabilities by potential adversaries, especially the United States, requires the PLA to develop capabilities to attack space systems. Based on this assessment, Chinese analysts surmise that the loss of critical sensor and communications capabilities could imperil the U.S. military's ability to achieve victory or to achieve victory with minimal casualties. According to the U.S. Defense Department, China is developing a wide range of counterspace technologies to include direct-ascent kinetic-kill vehicles, directed energy weapons, and jammers.[41]

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[40] "奋飞在新世纪的天空: 中央军委委员、空军司令员许其亮答本报记者问" [Flying with Force and Vigor in the Sky of the New Century—Central Military Commission Member and PLA Air Force Commander Xu Qiliang Answers Reporter's Questions in an Interview], 解放军报 [*PLA Daily*], November 1, 2009.

[41] Office of the Secretary of Defense, "Military and Security Developments Involving the People's Republic of China 2014," 32.

Despite the importance China's military places on space, PLA military doctrine does not designate space as a unique operational campaign.[42] Nevertheless, space operations play an important role in supporting other PLA campaigns and in the PLA's anti-access/area denial operations. As a result, China's military strategy, the missions given to the PLA, its thinking on modern war, and its concept of operations play a central role in how Chinese military analysts conceive of space operations and its role in Chinese military operations.

National Military Strategy

China's national military strategy is served by the PLA's military strategic guidelines, which in turn guide the PLA's reform and modernization efforts. These guidelines represent a "capabilities-based and contingency-based strategy" that provides a direction "for the development of warfighting capabilities as well as professional and other institutional capacities…that are subject to larger-order national objectives."[43] In doing so, the military strategic guidelines are "pragmatic, deliberate, and based on the types of calculations that any professional military establishment would undertake."[44] According to David Finkelstein, based on this, China's military strategy has four main components:

1. Provide for the defense of strategic assets on the mainland in light of twenty-first century precision-guided munitions and other high-tech weapons that could be used to threaten China or actually be employed against the mainland;
2. Strengthen the deterrent value of its nuclear forces;
3. Fight and win high-tech joint campaigns in the maritime, aerospace, and electromagnetic battle spaces off its littoral if need be; and
4. Field credible operational capabilities to deter potential aggression against the mainland or its interests (political or economic), support the diplomatic element of national power with real "teeth," and provide options to China's leaders across the full spectrum of operations, from "show of force" to the application of force in such a manner that any required escalation control can be managed.[45]

In 2004, the PLA was given more specific guidance to the types of operational capabilities it needed to develop and to the types of operations it is expected to conduct. Known as the "new historic missions" (新历史使命), these missions give priority to certain responsibilities and guide the PLA in training and weapons and equipment acquisition. They also reflect China's growing economic and security interests around the world and the PLA's mission in protecting them. The new historic missions are:

- *Guarantee Chinese Communist Party rule.* The PLA remains the ultimate backer of the Communist Party.
- *Safeguard the strategic opportunity for national development.* The PLA is to deter aggression against China and protect its national sovereignty and territorial integrity so that China may develop economically.

[42] Office of the U.S. Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China* (2014), 32.
[43] David Finkelstein, "China's National Military Strategy: An Overview of the "Military Strategic Guidelines," in *Right Sizing the People's Liberation Army: Exploring the Contours of China's Military*, ed. Roy Kamphausen and Andrew Scobell (Carlisle, PA: Strategic Studies Institute, September 2007), 132.
[44] Ibid., 131–32.
[45] Ibid., 130–31.

- *Safeguard national interests.* The PLA must defend China's interests, not only within its land borders, territorial waters, and territorial air space, but also in international waters, outer space, and in the electromagnetic sphere.
- *Play an important role in world peace.* China will maintain a defensive military strategy and will participate in United Nations peacekeeping missions and international cooperation on counterterrorism.[46]

The most important of the historic missions for the purposes of this paper is the third, devoted to safeguarding China's national interests. This mission not only charged the PLA with defending China's interests within its land borders, territorial waters, and territorial air space, but then expanded its responsibilities to defend China in international waters, outer space, and cyber space. Based on these missions, the PLA could be expected to develop operational concepts and weapons to carry out these missions.

Chinese Military Concept of Operations

A second factor that affects PLA space operations is its concept of operations. Chinese writings place a heavy emphasis on gaining the initiative at the outset of a conflict, including during the U.S. military's deployment stage. The PLA, like most militaries, would prefer to fight a "quick war with a quick resolution" (速战速决). Based on the their study of war since the 1982 Falklands War, PLA analysts assess that the relatively quick conclusion of modern wars places an emphasis on seizing the initiative at the outset of a campaign. Looking at the 1991 Gulf War, and the initial invasions of Afghanistan in 2001 and Iraq in 2003, Chinese military analysts assess that the PLA cannot allow the U.S. military to become fully prepared lest they cede victory.

In carrying out this concept of operations, the Chinese government states that its national defense policy is "purely defensive in nature" and that it "places the protection of national sovereignty, security, territorial integrity, safeguarding of the interests of national development, and the interests of the Chinese people above all else."[47] In doing so, China follows a military strategy of active defense (积极防御), which was been described by Mao Zedong as "offensive defense or defense through decisive engagements…for the purpose of counter-attacking and taking the offensive."[48]

At face value, an adherence to a defensive national defense policy would seem to be counter to the goal of fighting a quick war with a quick resolution and the need to take the initiative at the beginning of an operation. In fact, there is little operational difference between China's active defense strategy and an offensive military strategy. Chinese analysts assert that, within the context of protecting China's national interests, the full range of offensive actions are possible. As a result, active defense is best thought of as a politically defensive but operationally offensive strategy in which China will maintain a rhetorically defensive posture up until the time that war appears imminent. Thus, any U.S. military support or deployment that is deemed a precursor to U.S. action could be grounds for a preemptive strike. In this case, the United States would be considered to have taken a "first shot" at the strategic level that would allow China to conduct first strikes at the operational and tactical levels.

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[46] Liberation Army Daily editorial department, "论新世纪新阶段我军的历史使命——写在《解放军报》创刊 50 周年之际"[On Our Military's Historic Missions in the New Century, New Stage—Written on the 50th Anniversary of the Founding of the Liberation Army Daily], *Liberation Army Daily* (*解放军报*), 9 January 2006.
[47] Information Office of the State Council of the People's Republic of China, *China's National Defense*, December 2009.
[48] Mao Zedong, *Selected Military Writings of Mao Zedong* (Beijing: Foreign Languages Press, 1967), 105.

Chinese thinking on active defense can be seen in writings on space operations. A 2013 textbook on space operations, for example, argues that China's space strategy is defensive in nature and thus it will "do all it can at the *strategic* level to avoid firing the first shot" (emphasis added).[49] In other places, however, the authors recommend conducting first strikes at the operational and tactical levels, writing that one should "strive to attack first at the campaign and tactical levels in order to maintain the space battlefield initiative"[50] and argue that fighting a quick war with a quick resolution is one of the "special characteristics of space operations" and that a military should "conceal the concentration of its forces and make a decisive large-scale first strike."[51]

Striking Centers of Gravity and Assassin's Mace Weapons

A third factor influencing the conduct of space operations is the focus on striking centers of gravity. China's military is no longer focused on fighting wars of annihilation in which the PLA will concentrate on killing large numbers of enemy troops. Instead, similar to how the U.S. military fights wars, the PLA now focuses on operational centers of gravity whose destruction or debilitation could have a direct impact on the overall battlefield situation. By striking these targets, the PLA hopes to create a cascade effect that will open up windows of opportunity that it can exploit to achieve a decisive effect on the battlefield. The PLA has identified these centers of gravity as those targets involved in collecting and processing information.

Indeed, information warfare and achieving information superiority is seen now as the main determiner of success on the battlefield. In fact, the PLA is now tasked with fighting and winning "local wars under conditions of informatization." Under this goal, the PLA must not only be able to effectively use information but also deny information to an enemy. Information superiority, however, does not have to be achieved permanently across all battlefields and can be achieved locally for short periods of time. The goal, again, is to create windows of opportunity that can be exploited for overall success.

One important factor in the development of a force capable of striking centers of gravity and fighting informatized warfare is the requirement to develop 'assassin's mace weapons' (杀手锏). While Chinese writers often use the term loosely to describe any technology, tactic, or strategy that could give the PLA an advantage, Chinese writings on space state that the term is more narrowly defined, and their development was ordered by then President Jiang Zemin, who encouraged the PLA to go from "fighting with the weapons it has" to "developing the weapons it needs."[52] In this context, assassin's mace weapons are described as a

> type of weapon that can be used suddenly with good effect and can deliver a fatal blow to the enemy. It can effectively deter and hinder an enemy from going to war, effectively strike against the enemy's weaknesses, and restrain an enemy's strike configuration. Towards a side that is in a disadvantageous position, developing "assassins' mace" weapons is very significant.[53]

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[49] Jiang Lianju, 空间作战学教程 [*Space Operations Textbook*], (Beijing: Military Sciences Press, 2013), 42.
[50] Ibid., 52.
[51] Ibid., 142–43.
[52] Li Zhichong, Sun Qiangyin, and Li Rongkun, 高技术条件下非对称作战研究 [*Asymmetric Operations Under High Technology Conditions*] (Beijing: National Defense University Press, 2000), 225.
[53] Ibid.

The impetus to build assassin's mace weapons is the result of policy guidance from the highest levels of the Chinese leadership. According to the biography of Chinese general and former vice chairman of the Central Military Commission, Zhang Wannian, the roots of the assassin's mace weapons program lie in the accidental U.S. bombing of the Chinese embassy in Belgrade. On the day of the bombing an emergency meeting was held to discuss the event, which was followed by an expanded meeting of the Central Military Commission (CMC) in which the PLA was ordered to develop strategic capabilities that could deter the United States.[54] Although no details are given as to which specific weapons were approved, according to guidance given by Jiang Zemin, "what the enemy is most fearful of is what we should be developing." Furthermore, Zhang instructed the PLA to look at the requirements of future war and solve the problems of "seeing far, striking far, and striking accurately."[55] The capabilities space technologies offer in strengthening C4ISR systems to better enable precision strikes and the ability to threaten enemy space-based assets with counterspace technologies suggest that they were likely candidates for inclusion in Zhang's directive.

Space Warfare

The PLA does not appear to have one official definition of space war, but all Chinese definitions of space war have the following characteristics:

- Military offensive and defensive operations in outer space
- Attacks against targets in air, ground, sea, or space from space
- Attacks against targets in space from air, ground, sea, or space

The PLA's interest in the use of space gained momentum after the 1991 Gulf War, which has been referred to as the first space war, and has only increased since. Chinese analysts noticed the increasing dependency on space by the U.S. military. According to some Chinese analysts, the U.S. military relies upon space for 70–80 percent of its intelligence and 80 percent of its communication.[56] Some Chinese writings also attribute an almost omnipotent quality to U.S. space-based intelligence, surveillance, and reconnaissance (ISR) and conclude that the U.S. receives exquisite intelligence from these platforms.

Without a doubt, space has become more integrated with U.S. military operations and now plays a vital role at the strategic, operational, and tactical levels of war. During the Gulf War, 50 satellites supported the U.S. war effort. In the 2003 Iraq War, that number had increased to more than 74.[57] The Gulf War was the first conflict to feature the use of the Global Positioning System (GPS) for navigation, which has since become a critical component of precision guided munitions. During the Gulf War, just eight percent of munitions used were precision guided munitions (PGM) and those PGMs used were laser guided. Eight years later, during Operation Allied Force in the former Yugoslavia, three percent of munitions dropped

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[54] Wu Qiong. "A Preliminary Exploration of Our Army's Military Deterrent Thinking," *Military Historical Research*, no. 2 (2002), 16.

[55] Guo Xiangjie, 张万年传 [*The Biography of Zhang Wannian*] (Beijing: PLA Press), 163.

[56] Chang Xianqi, 军事航天学 [*Military Astronautics*] (Beijing: National Defense Industry Press, 2002), 257–58; and Chi Yajun and Xiao Yunhua, 信息化战争与信息作战理论精要 [*The Fundamentals of Informationized Warfare and Information Operations Theory*] (Beijing: Military Science Press, 2006), 38–39.

[57] "Satellites Provide Vital Reconnaissance, Communications to War Effort," *Post-Gazette*, April 2, 2003, http://old.post-gazette.com/nation/20030402spacewar0402p4.asp.

were guided by GPS.[58] This percentage had increased to 22 percent during the initial invasion of Iraq with 90 percent of the munitions dropped on Baghdad being precision guided.[59]

During this time, the U.S. military also acquired a massive need for connectivity. During the 1991 Gulf War, the U.S. military used 99 megabits per second (Mbps) of bandwidth. During the Iraq War that number had jumped to 3.63 gigabits per second (Gbps), even though fewer than one-quarter of the troops were involved in that conflict as compared to the Gulf War.[60] From 2000–2012, U.S. military satellite capacity usage had increased fivefold, due, in part, to an increase in the number of remotely piloted vehicles. Indeed, the number of remotely piloted vehicles the U.S. military is able to deploy may be limited by available satellite bandwidth.[61] The need for more bandwidth has resulted in the Defense Department relying on commercial satellite providers for 40 percent of its satellite communication needs.[62]

The increasing reliance on space by the U.S. military has resulted in an increasing interest by Chinese analysts in counterspace technologies to deny potential adversaries the use of space. Counterspace technologies include kinetic- kill vehicles that destroy their targets by ramming them at high speeds, directed energy weapons such as lasers that can degrade or disable satellites, and co-orbital technologies that can orbit to a satellite and ram it or grab it for nefarious purposes. The most recent well-known example of an anti-satellite test was the 2007 Chinese test of a direct ascent kinetic-kill vehicle that destroyed a defunct weather satellite.

Because of this, Chinese sources conclude that space warfare will follow the evolution of air warfare. Initially air power was used for reconnaissance over the European trenches of World War I. To deny access to this intelligence, airplanes were equipped with weapons to shoot down other aircraft. Other aircraft were assigned to bomb and strafe ground forces. During World War II, air power became more decisive and strategic, with air power playing a key role in naval operations and in the invasion of northern Europe. In recent conflicts, air power has played a critical role in achieving victory for the U.S. military.

According to Chinese sources, space warfare is now at the equivalent stage of the state of air power in World War I in which intelligence gathering was the main mission of air forces.[63] But just as with air power, space power will become so vital to military operations that militaries will seek to control space, resulting in a contest over its supremacy. As a result, Chinese analysts conclude that space war is inevitable and that the Chinese military must not only develop space-based C4ISR assets, but also develop the means to

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[58] George C. Marshall Institute, "A Day Without Space: Economic and National Security Ramifications," October 16, 2008, 26, http://marshall.org/wp-content/uploads/2013/08/Day-without-Space-Oct-16-2008.pdf.
[59] T. Michael Moseley, "Operation IRAQI FREEDOM—By the Numbers," *USCENTAF*, April 30, 2003, http://www.afhso.af.mil/shared/media/document/AFD-130613-025.pdf; "Smart Bombs' Move to Center Stage in U.S. Arsenal," *The Christian Science Monitor*, March 20, 2003, http://www.csmonitor.com/2003/0320/p06s01-woiq.html.
[60] The George C. Marshall Institute, "A Day Without Space: Economic and National Security Ramifications," 2008, 22–27.
[61] "Satellite Shortages May Choke off Military Drone Expansion," *National Defense*, April 2013, http://www.nationaldefensemagazine.org/archive/2013/April/Pages/SatelliteShortagesMayChokeOffMilitaryDroneExpansion.aspx.
[62] "Report to the Secretary of Defense: Taking Advantage of Opportunities for Commercial Satellite Communications Services, Report FY13-02," *Defense Business Board*, http://dbb.defense.gov/Portals/35/Documents/Reports/2013/FY13-02%20Taking%20Advantage%20of%20Opportunities%20for%20Commercial%20Satellite%20Communications%20Services.pdf.
[63] Cai Fengzhen and Tian Anping, 空天战杨与中国空军 [*The Air-Space Battlefield and China's Air Force*] (Beijing: Liberation Army Press, 2004), 36.

protect those assets and to deny an enemy access to its space-based C4ISR assets.[64] In this regard, Chinese writers on space advocate the PLA to prepare to achieve space supremacy, defined as the ability to use space and to deny the use of space to its adversaries.

Space-based C4ISR

Space-based C4ISR figures prominently in Chinese writings on C4ISR systems and is often considered a critical component in extending China's power projection capabilities. Indeed, as China's military is increasingly called to conduct operations farther from its shores, the utility of space becomes more important (see Figure 1). As Jesse Karotkin, Senior Intelligence Officer (SIO) for China at the Office of Naval Intelligence (ONI), writes

> In order to characterize activities in the "near seas," China must build a maritime and air picture covering nearly 875,000 square nautical miles (sqnm). The Philippine Sea, which could become a key interdiction area in a regional conflict, expands the battlespace by another 1.5 million sqnm. In this vast space, many navies and coast guards converge along with tens of thousands of fishing boats, cargo ships, oil tankers, and other commercial vessels.[65]

Figure 1. The Chinese coastline and near seas

[64] See, for example, Liu Xinde, "空间战" [*Space Warfare*], in China Strategic Rocket Force Encyclopedia Department, 中国战略导弹部队百科全书 [*China Strategic Rocket Unit Encyclopedia*] (Beijing: China Encyclopedia Press, 2012), 60; and Zhang Zhiping, ed., 空军战略 [*Air Force Strategy*] (Beijing: China Encyclopedia Press, 2007), 122–23.

[65] Jesse Karotkin, "Trends in China's Naval Modernization," Testimony before the U.S.-China Security and Economic Review Commission, January 30, 2014.

As a result, space becomes more important in regards to targeting naval assets and the requirement to develop A2/AD capabilities against the U.S. Navy. The development of long-range cruise missiles and anti-ship ballistic missiles for over-the-horizon attacks requires the ability to locate, track, and target enemy ships hundreds or thousands of kilometers from China's shores. In fact, Chinese analysts argue that development of this capability "cannot be separated from space power."[66] Such capabilities could also be used to attack U.S. bases and the bases of its allies in Asia.

The capabilities derived from a space-enabled, networked force will also better integrate disparate services into a joint force, an essential prerequisite for winning informatized wars. Space-enabled operations allow a service to better support other services, for example, through precision strikes. Additionally, space-based C4ISR capabilities will allow services to share a common battlefield picture and better communicate.[67]

Counterspace Capabilities

Because space holds such a preeminent position on the battlefield and because overall victory flows from space superiority, many authors advocate the development of space weapons to achieve space superiority. In the words of one source,

> The development of anti-satellite weapons (ASATs) will greatly enhance China's prospects of winning a regional high-tech war….It is not only necessary, but also feasible to develop such weapons…. To make certain the credibility of deterrence, and to safeguard its security and national interests in the 21st Century, China must apply an asymmetric strategy in accordance with its particular condition, actively researching and developing ASAT weapons.[68]

Many analysts argue that space will become *the* center of gravity in future wars and one that must be seized and controlled.[69] In fact, analysts argue that the first condition for seizing the initiative is to achieve space supremacy. Because space will become the center of gravity in future wars, they argue, the first shots of a war will take place in space as adversaries vie for its control.[70]

Chinese military writers point to U.S. space policy and tests of counterspace technologies as evidence that the PLA needs to develop its own weapons. Chinese analysts point to the 2006 U.S. National Space Policy, which stated that "the United States will oppose the development of new legal regimes or other restrictions that seek to prohibit or limit access to or use of space," and the 2010 U.S. National Space Policy, which states that "the United States will employ a variety of measures to help assure the use of

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[66] Wu Xiaopeng, Feng Shuxing, Zhang Yan, and He Zhonglong, 剖析一体化联合作战对空间力量的信息需求 ["Anatomizing the Integrative Joint Operations Information Requirement for the Space Force"], 装备指挥技术学院学报 [*Journal of the Academy of Equipment Command and Technology*], June 2006, 44; and Guan Qingbo, Luo Xiaoming, and Zhang Rong, 军事卫星信息支援下导弹攻防作战仿真系统的研究与实现 ["The Research and Practice of the Simulation of Military Satellite Information Support to Offensive and Defensive Missile Operations"], 装备指挥技术学院试验指挥系 [*Journal of the Academy of Equipment Command and Technology*], March 2001, 32.

[67] Zhu Hui, ed., 战略空军论 [*Strategic Air Force*] (Beijing: Blue Sky Press, 2009), 39.

[68] Yuan Liwei and Yang Jianjun, "反卫星武器装备发展探过" [An Exploration of Anti-Satellite Weapon Development], 飞航导弹 [*Winged Missiles*], December 2004, 46.

[69] Chang Xianqi, 军事航天学 [*Military Astronautics*], (Beijing: National Defense Industry Press, 2005), 259–60.

[70] Ibid.

space for all responsible parties, and, consistent with the inherent right of self-defense, deter others from interference and attack, defend our space systems and contribute to the defense of allied space systems, and, if deterrence fails, defeat efforts to attack them" as evidence that the U.S. government supports the development of counterspace weapons and their use.[71] According to Chinese analysts, these include the 1985 test involving the launch of a kinetic-kill vehicle from an F-15, the 1997 test of the MIRACL laser, the 2008 shoot down of an errant satellite with an SM-3 missile, and the test of the XSS-11 satellite to test close proximity maneuvers.[72]

Chinese analysts offer four reasons why China must develop counterspace weapons. The first reason is to deny an adversary the use of space. In this context, the Chinese military would seek to deny the U.S. military use of information from its space-based assets. Chinese military analysts have noted the dependence of the U.S. military on space and have concluded that the loss of the use of space for the U.S. military may cause it to lose the conflict.

A second reason is in response to U.S. missile defenses. Chinese analysts regard the deployment of missile defense systems as giving the United States a de facto counterspace capability. Chinese analysts may also be concerned that the United States will deploy space-based interceptors.[73] In this context, China may be concerned that space-based interceptors would negate its nuclear deterrent and require China to develop countermeasures to ensure the viability of its nuclear missile force.

A third reason is to protect Chinese space-based assets from attack and to prevent an adversary from using space to attack terrestrial targets.[74] In this context, space weapons would protect Chinese spacecraft from attack through the interception of interceptors or co-orbital weapons. It could also include attacking the source conducting attacks against Chinese spacecraft. In addition, Chinese counterspace technologies would defend Chinese territory and forces from space-based attack.

In addition to actual warfighting, space power can also be used to coerce. Chinese analysts write that having the ability to destroy or disable an opponent's satellites may deter an adversary from conducting counterspace operations against Chinese satellites. Space power can also improve the overall capabilities of a military and serve as a deterrent force not just against the use of specific types of weapons, but also as a general capability that can deter a country from even becoming involved in a conflict.[75]

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[71] Hou Menglan, Mu Yongming, and Peng Hui, "美国反卫星武器发展方向及启示" [Direction and Implication of the Development of the U.S. Anti-Satellite Weapons], 国防科技 [*National Defense Science and Technology*], 2013/1; and Yang Caixia and Ai Dun, "论中国发展反卫星武器的合法性," [On the Legality of the Development of ASATs for China], 北京航空航天大学学报(社会科学版) [*Journal of Beijing University of Aeronautics and Astronautics* (Social Sciences Edition)], March 2010/2.

[72] See, for example, Xu Jun, Weng Xiaodong, Zhou Wenming, "美俄激光反卫星武器的发展现状" [Development of American and Russian Laser Anti-Satellite Weapons], 激光与光电子学进展 [*Advances in Laser and Opto-electtronics Studies*], August 2003; Li Daguang, "由美国"导弹打卫星"看其反卫星武器发展" [Using the U.S. 'Missile to Hit a Satellite' to View Its Development of Anti-Satellite Weapons], 国防技术基础 [*National Defense Technology Basics*], 2008/7; and Song Yanxue, Zhang Zhifeng, and Qi Lihui, "美国反卫星武器最新发展动态" [The Most U.S. Anti-Satelllite Weapons Recent Developments], 飞航导弹[*Winged Missile Journal*], 2008/1.

[73] Jiang Lianju, 空间作战学教程 [*Space Operations Textbook*], (Beijing: Military Sciences Press, 2013), 127.

[74] Chang, *Military Astronautics*, 260; and Zhang Zhiwei and Feng Chuangjiang, "Analysis of Future Integrated Air and Space Operations [空天战长与国家空天安全战略]," 中国军事科学 [*China Military Science*], no. 2 (2006): 58.

[75] Jiang Lianju, *Space Operations Textbook*, 127.

In carrying out these missions, Chinese analysts discuss a combination of both hard and soft attacks. Soft attacks refer to attacks whose effects are often temporary and do not create debris. These can include the use of electromagnetic radiation, infrared, or laser interference and jamming methods. They can also include computer network operations to infiltrate space information systems in order to steal, tamper with, and delete computer code and information in an attempt to deceive or obstruct adversary operations.[76] According to another author:

> A military satellite cannot connect with the Internet. Therefore, some people think "hackers" cannot attack a satellite's command and control [system]. But in actuality, the microwave antenna of the satellite control is open, so one can intercept satellite information through technological means and seize the satellites command and control [system]. Using this as a springboard to invade the enemy's independent network systems is entirely possible.[77]

Hard attacks, on the other hand, refer to the employment of weapons systems to destroy space- and terrestrially-based space assets. Kill methods include nuclear weapons, kinetic weapons such as missiles and satellites, and high power directed energy weapons such as lasers, particle beams, and microwaves.[78]

Even before China's 2007 ASAT test, Chinese analysts preferred soft attack methods to hard attacks because they do not produce debris and often produce temporary effects that can be useful when trying to limit escalation or when targeting third-party satellites. Moreover, the effects of soft methods may be less observable than hard kill methods, which may enable China to attack satellites covertly and thus may be more prone to use in politically sensitive situations.[79] Hard kill methods, however, are still considered to be of value and can be used when soft kills are ineffective or unsuitable for the mission.[80]

Manned Platforms

Chinese analysts also see a role for manned platforms in space warfare. Manned platforms are described as more responsive than unmanned platforms and able to employ a variety of weapons.[81] Other authors write that manned platforms are "the best space weapon for attacking satellites in low Earth orbit, synchronous orbit, and high orbit."[82]

Manned space platforms include space capsules, space stations, and space planes. Space capsules and space planes can transport goods and people between ground and space, carry out space rescue missions, and conduct reconnaissance and surveillance against targets.[83] According to an article written by the current director of the China Manned Space Agency, space stations can service military satellites in orbit,

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[76] Chang, *Military Astronautics*, 295–96.
[77] Xiao Wenguang and Li Yuanlei. "计算机网络于未来战争" [Computer Networks in Future Wars], 江苏航空 [*Jiangsu Aviation*] 1 (2007), 31.
[78] Qi Xianfeng, 空间信息系统防护探讨 ["Study on the Protection of Space Information System"], 装备指挥技术学院学报 [*Journal of the Academy of Equipment Command and Technology*], 2007/5, 62.
[79] Ibid, 173.
[80] Ibid, 258.
[81] Li Yiyong, Li Zhi, and Shen Huairong, "临近空间飞行器发展与应用分析" [Analysis on Development and Application of Near Space Vehicle]," 装备指挥技术学院学报 [*Journal of the Academy of Equipment Command and Technology*], 2008/2, 64 and Chang, *Military Astronautics*, 118–19.
[82] Li, Cheng, and Zheng, *Integrated Aerospace Information Operations*, 218.
[83] Chang, *Military Astronautics*, 123, 145.

including repair, maintenance, fueling, and replenishment of ammunition, as well as serve as platforms for kinetic and directed energy weapons.[84]

Co-orbital Counterspace Technologies

Chinese researchers also discuss the use of co-orbital counterspace technologies. As one researcher states, the "ample use of the superiority and characteristics of modern small satellites (satellites with a mass between 100 and 500 kg), ingeniously applied to space attack and defense, will cause small satellites to become a space weapon assassin's mace."[85] Co-orbital satellites are those satellites that come within a close distance to another satellite to interfere with, disable, or destroy the target satellite. Co-orbital satellites can be armed with kinetic energy weapons, lasers, radio frequency weapons, jammers, or robotic arms that can dismember the satellite. Co-orbital satellites can also be armed with unusual weapons, such as "spray paint" that can be used to paint over optical lenses or even "umbrellas" that can block the view of sensors. Finally, co-orbital satellites can crash into another satellite or self-destruct close to the target satellite. Moreover, co-orbital satellites do not have to be dedicated to the counterspace role and instead can serve legitimate peacetime functions.[86]

Co-orbital satellite weapons can come in the form of operational satellites performing legitimate peacetime missions, free-floating dedicated co-orbital weapons such as space mines, and satellites that can be released from a "mother" satellite. Co-orbital space weapons can orbit alone, in constellations, or be hidden among debris, and can be deployed in four ways. "Trailing ASATs" follow close to their target satellite, mimicking their orbital movements. This type of weapon would be easy to detect and would probably not be used unless a country were attempting to signal. So-called parasitic satellites, on the other hand, can attach themselves to the target satellite to be employed at an appropriate time. A third type of deployment is to place the attacking satellite in a distant part of the same orbit as the target satellite, though this method would increase the chances of detection as it maneuvered to its target. The final method is to place the attacking satellite in the crossing orbit of the target satellite so that its orbit approaches the target satellite at a certain time and place.[87]

Given the variety of employment methods and the possibility of covert peacetime employment, the use of co-orbital ASAT weapons potentially complicates the ability of the U.S. military to defend its satellites. Moreover, even if a satellite was identified as being a co-orbital weapon during peacetime, the U.S. military would have to detect its employment during wartime far enough in advance, so as to issue repositioning commands to the target satellite. A country unaware that its satellites are the targets of a co-orbital attack could not take steps to defend itself. A country with an effective space surveillance network, however, could detect an attack and take relatively simple steps that due to orbital dynamics would make it difficult for a co-orbital attack to be successful. Thus the effectiveness of co-orbital satellites is somewhat dependent on the "cooperativeness" of the target satellite.

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[84] Wang Zhaoyao, "军事航天技术及其发展" [Military Space Technology and Its Development], 航天器工程 [*Spacecraft Engineering*] 1 (2008): 17.

[85] Lin Laixing, "Study on the Overseas Microsatellite Application in Space Attack-Defense (国外微小卫星在空间攻防中的应用研究)," *Journal of the Academy of Equipment Command and Technology* (装备指挥技术学院学报), 2006/6, 49.

[86] See, for example, Huang Siyong and Xu Peide, "空间武器平台潜伏轨道分布模型研究" [Study of Distributed Model of Hidden Orbits for Space Weapons Platforms], 航天控制 [*Aerospace Control*], June 2007; and Ma Wendi, 小卫星编队与反卫星卫星 ["Small Satellite Formations and ASAT Satellites"], 中国航天 [*Aerospace China*], April 2006.

[87] David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security: A Reference Manual* (Cambridge: American Academy of Arts and Sciences, 2005), 151.

China's View on Outer Space Weapons and Arms Control

China maintains that "outer space is common heritage of all mankind, and the benefits of space development should be enjoyed by all," and that "for any country, to maximize the military and security value of outer space, or even seek to place weapons there, would yield no benefit to the security of its own or the world."[88] Before China's 2007 ASAT test, Chinese policy was widely regarded as unconditionally opposed to all types of ASAT weapons. Official Chinese policy, however, only expresses opposition to the "deployment of weapons in outer space and the threat or use of force against objects in outer space, so as to ensure that outer space is used purely for peaceful purposes."[89]

With this formulation, the Chinese stance on space weapons neither prohibits the development, testing, and deployment of terrestrially-based counterspace weapons, such as direct-ascent kinetic-kill vehicles and directed energy weapons nor the development of any type of counterspace weapon or their storage, including space-based weapons, as long as they are not deployed in space. Moreover, China's stance does not prohibit "use of force" or the "threat of force" against objects in space during armed conflict. According to a Chinese and Russian draft "Treaty on Prevention of the Placement of Weapons in Outer Space and of the Threat or Use of Force against Outer Space Objects" nothing in the proposed treaty "may be interpreted as impeding the exercise by the States Parties of their right of self-defense in accordance with Article 51 of the Charter of the United Nations."[90] This last condition renders the treaty useless considering the emphasis of China's military strategy on striking first and since most countries claim the right of self-defense before going to war.

Economic and Commercial Benefits

In addition to military utility, China has also embraced its space program as a driver of economic and technological advancement. China's 2006 space white paper states: "Since the space industry is an important part of the national overall development strategy, China will maintain long term, steady development in this field."[91] China sees much potential in developing the space market. Revenue from the global space industry increased 7 percent to $304.31 billion in 2012. This is a 63 percent increase from $186.64 billion in 2005. Of this amount, 26 percent, or $78.44 billion, is made up of government space budgets, which increased just 1 percent in 2012. The largest portion of the space economy is commercial satellite services, which accounts for 38 percent of global space activity or $115.97 billion. This includes telecommunications, earth observation, and positioning services.[92] China has identified four areas in which its space program brings economic benefits: 1) Creating a market for high technology; 2) The development of "spin-off" civilian technologies; 3) The use of satellite application technologies; and 4) The export of satellites and commercial launch services.

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[88] "Remarks by H.E. Ambassador WU Haitao at the Space Security Conference 2014," United Nations Conference on Disarmament, March 19, 2014, http://www.china-un.ch/eng/dbtyw/cjjk_1/cjthsm/t1140194.htm.

[89] Full text of white paper on arms control: State Council Information Office, "China's Endeavors for Arms Control, Disarmament and Non-Proliferation," www.china.org.cn/english/2005/Aug/140343.htm.

[90] "Russian Federation to the Conference on Disarmament and People's Republic of China to the Conference on Disarmament," CD/1839, accessed November 3, 2014, http://daccess-dds-ny.un.org/doc/UNDOC/GEN/G08/604/02/PDF/G0860402.pdf?OpenElement.

[91] Information Office of the State Council, China's Space Activities in 2006, October 2006, http://www.cnsa.gov.cn/n615709/n620681/n771967/79970.html.

[92] Space Foundation, *The Space Report 2013: The Authoritative Guide to Global Space Activity* (Washington, DC: Space Foundation, 2013), 5–6.

Market Creation and Spin-off Technologies

According to Chinese analysts, space has its most profound effect on high technology development, with investments in space technologies said to yield $10 in gross domestic product growth for every dollar spent.[93] Space programs can be large endeavors requiring the participation of numerous government and commercial entities and involving many different technologies, including propulsion, electronics, computers, guidance, power supply, and materials.[94] The demand created by space projects can spur advancement in computers, microelectronics, precision manufacturing, automatic control, new energy, and new materials. Chinese analysts point to the U.S. Apollo program as the best example of this, which is said to have led to advances in radar, radio-guidance, synthetic materials, computers, and biological engineering and laid a solid foundation for U.S. high-technology development and technology-based military innovation.[95]

Chinese analysts point to a similar effect in their country. China's first computer was used to develop space technology.[96] Of the 1,000 new materials developed in China, 80 percent are said to have resulted from research in space technology; and more than 2,000 space technology achievements have been reported in various sectors of the national economy and nearly 1,000 products developed by the space industry have been converted for civilian use. Finally, the work of the more than 3,000 enterprises involved in China's human spaceflight program is said to have contributed to technological progress in electronics, new materials, and automatic control.[97]

The creation of markets for high technology products is also intended to support the development of China's other strategic emerging industries through the introduction of spin off technologies—technologies originally developed for the space industry that have found a civilian application. This effort is conducted through eight industrial parks called "aerospace bases" formed through partnerships between the space industry and the governments of Beijing, Shanghai, Xi'an, Chengdu, Tianjin, Inner Mongolia, Shenzhen, and Hainan. These bases are not only designed to manufacture space products, but also to leverage the industry's capabilities in space technologies to build civilian products. In doing so, the space industry focuses on technologies and products in areas identified as strategic emerging industries by the central government. These include high-end manufacturing, alternative energy, new materials, alternative energy automobiles, and new generation information technologies.[98]

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[93] This figure appears to be taken from studies of the Apollo program, which have never been definitively proven. Zhang Shaoqiang, "我国航天产业发展的战略重点与几点思考" [Some Reflections on Our Country's Space Industry Strategic Development], 中国航天 [*Aerospace China*], 2007/4, 3.

[94] Hou Dandan, "中国航天发射服务参与国际竞争的对策研究" [Research on Countermeasure of Participation in International Competition of China Aerospace Launching Service], 导弹与航天运载技术 [*Missile and Launch Vehicle Technology*], 2000/6, 43.

[95] Feng Shuxing, "我国空间力量发展与空间安全的思考" [Reflection on Development of Space Power and Space Security] 装备学院学报 [*Journal of Academy of Equipment*], October 2012, 9.

[96] Zhang Qingwei, "发展中的中国航天" [China's Space Program in Development], 中国航天 [*Aerospace China*], 2007/8, 3.

[97] Feng, "Reflection on Development of Space Power and Space Security," 9; Zhang Shaoqiang, "我国航天产业发展的战略重点与几点思考" [Some Reflections on Our Country's Space Industry Strategic Development], 中国航天 [*Aerospace China*], 2007/4, 3.

[98] Ma Xingrui, "坚持自主创新推动中国航天事业又好又快发展" [Continue with Indigenous Innovation and Promote the Development of China's Space Enterprise], 中国航天 [*Aerospace China*], 8 (2011), 5.

Satellite Application Technologies

A second area where space can help improve the economy is in the satellite application market. Satellite application technologies refer to ancillary products designed to add value to the information provided by space technologies, such as satellite communications, remote sensing data, and satellite navigation products. Satellite communication applications include such services as satellite television and telephony. Remote sensing includes imagery of the earth in order to monitor agricultural use, environmental protection, or municipal planning. Satellite navigation products include satellite navigation receivers such as GPS receivers.

Commercial Launch Services and Satellite Exports

The third way in which space helps improve China's economy is through commercial launch services and satellite exports. China realizes that its space program must be successful in international markets if it is to become a leading space power, and the international competiveness of its space industry is viewed as an indicator of the space industry's overall strength.[99] China's struggles with developing commercial space capabilities are placed squarely on the United States and its export control laws that prohibit U.S.-manufactured satellites and satellites containing U.S. manufactured components from being launched by China. [100]

Because of this, China has focused on marketing launch services and satellites to markets in Europe and the developing world.[101] Since U.S. export control laws bar most satellites from being launched on Chinese rockets, China has decided that it must also export satellites so that it can completely break free of U.S. trade restrictions by offering Chinese-made satellites launched on Chinese rockets.[102] In doing so, China aims to capture 10 percent of the world's commercial satellite market and 15 percent of the global space launch business by 2015.[103] While the number of Chinese commercial launches is increasing, China is still some way from meeting its goal.

The results of China's commercial launch efforts are shown in Table 1. Commercial launches are defined in different ways and thus two annual commercial launch numbers are used here—one from the space consulting company Futron and the other from the U.S. Federal Aviation Administration (FAA). The number of Chinese commercial launches is further muddied by China's own calculations. As a result, this paper uses total commercial launch numbers by Futron and the FAA that takes into account two different methods of calculating the market share of Chinese commercial launches. The first measure is a more liberal definition of Chinese commercial launches provided by the China Great Wall Industry Corporation (CGWIC) that includes launches of satellites owned or operated by the Chinese government or a Chinese state-owned enterprise. This would include satellites launched for the China Satellite Communications Co. Ltd., a subsidiary of the China Aerospace Science and Technology Corporation, and the China-Brazil Earth Remote Sensing Satellite (CBERS) jointly developed by the Chinese and Brazilian governments. Another measure, called true Chinese commercial launches, is defined as the commercial launch of a satellite not owned or operated, in whole or part, by the Chinese government or a Chinese state-owned enterprise.

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99 Ibid.

100 Zhang Huiting, "中国航天发射业开拓国际市场对策分析" [Policy Analysis on Opening Up the International Market for China's Space Launch Industry], 中国航天 [*Aerospace China*], 2005/4, 7.

101 Ibid.

102 Zhang, "Policy Analysis," 8.

103 Xin Dingding, "China Seeks Bigger Share of Global Satellite Market," *China Daily*, October 21, 2010.

Table 1. China's share of the commercial launch market

Chinese Commercial Launches	Country	World Commercial Launches, Futron	PRC Share, Futron (%)	PRC Share, Futron, w/PRC owned sats (%)	World Commercial Launches, FAA	PRC Share, FAA (%)	PRC Share, FAA, w/PRC owned sats (%)	Market Share Range (%)	Market Share Range w/PRC owned sats (%)
2007									
NigComSat-1	Nigeria	20	5.0	10.0	23	4.35	8.7	4.35–5.0	8.7–10.0
ChinaSat-6B	ChinaSat, CH								
2008									
VeneSat-1	Venezuela	26	3.85	7.69	28	3.57	7.14	3.57–3.85	7.14–7.69
ChinaSat-9	ChinaSat, CH								
2009									
PALAPA-D	Indonesia	23	4.35		24	4.17		4.17–4.35	4.17–4.35
2010									
—	—	17	0	0	23	0	0	0	0
2011									
Paksat-1R	Pakistan	16	18.75	NA	18	16.67	NA	16.67–18.75	16.67–18.75
W3C	France								
NigComSat-1R	Nigeria								
2012									
Vesselsat-2	Luxembourg	19	15.79	26.32	20	15.0	25.0	15.0–15.79	25.0–26.32
VRSS-1	Venezuela								
GÖKTÜRK-2	Turkey								
APSTAR-VII	Hong Kong								
ChinaSat-12	ChinaSat, CH								
2013									
3U ISIPOD	Netherland	19	10.53	NA	23	8.7	NA	8.7–10.53	8.7–10.53
TKSAT-1	Bolivia								

According to these numbers, using the first and more liberal Chinese definition of commercial launches, China was able to meet its goal of 15 percent of the launch market for four years between 2007–2013. Using the more restrictive definition of true Chinese commercial launches, China was only able to meet its goal for two of those years.

Satellite Exports

Another area of emphasis for China's commercial space effort is satellite exports. China has built communication satellites for Nigeria, Venezuela, Pakistan, Bolivia, and a remote sensing satellite for Venezuela. It has also signed contracts for satellites with Belarus, Laos, and Sri Lanka for communication satellites and Venezuela for an additional remote sensing satellite. China's satellite exports cannot be divorced from its diplomatic agenda, however, and it is no coincidence that China's first two satellite export agreements were signed with countries with large oil reserves—Nigeria and Venezuela.

China's Satellite Exports in Detail

Nigeria

China's first satellite export was to Nigeria for the Nigeria Communications Satellite-1 (Nigcomsat-1). The contract for this satellite was signed in 2004 and launched in 2007, but failed in 2008 due to a faulty solar array. It was replaced by the Nigcomsat-1R launched in 2011. Although sources are unclear, Nigcomsat-1 cost in the range of $310 million for the building, launch, and operation of the satellite, and training of Nigerian personnel. China reportedly outbid 21 other competitors.[104]

[104] "Nigeria's N40bn Satellite Missing from Orbit," November 12, 2008, http://www.nairaland.com/194568/nigerias-n40bn-satellite-missing-orbit.

Venezuela

China has built and launched two satellites, a communication satellite in 2008 and a remote sensing in 2012 for Venezuela and in 2014 agreed to build and launch a second remote sensing satellite. The Venesat-1 "Simon Bolivar" communications satellite project was proposed by Venezuelan President Hugo Chavez in 2004 and began in 2005 with the signing of a $400 million contract. It was launched in 2008. The VRSS-1 "Francisco de Miranda" remote sensing satellite was launched in 2012 on a $144.8 million contract, which included $67.8 million for the satellite, $22 million for the launch, $16 million for the use of ground stations, $22 million for software, $2 million for a modeling system, and $7 million for training. It is equipped with a 2.5-meter resolution color imager and a 10-meter multispectral imager.[105] In July 2014, China and Venezuela signed a second contract for a remote sensing satellite in which China would build, launch, and help operate the satellite. No cost figures have been given.[106]

Pakistan

China launched Pakistan's first satellite, Pakistan-1R, on August 11, 2011. The satellite is based on the DFH-4 satellite bus with 18 Ku-band and 12 C-band transponders and a service life of 15 years.[107] The cost of the contract was not revealed by either the Pakistani or Chinese government, but a Chinese source states that Pakistan received a nearly $200 million discount.[108]

Bolivia

China has built one communication satellite for Bolivia. China launched the Tupac Katari (TKSat)-1 telecommunications satellite on December 21, 2013, for a total package cost of $302 million that included the building, launch, and operation of the satellite, and training of Bolivian personnel.[109]

Launch Services

In addition to satellite exports, launch services are also another critical area of China's commercial space effort. China has provided launch services to Indonesia, Turkey, Ecuador, Argentina, and Luxembourg and has signed contracts with Laos, Belarus, Sri Lanka, Congo, and Algeria. In 2011, CASC launched a satellite for European satellite communications provider Eutelsat. This was the first time that China had launched a foreign-made satellite for a foreign client since 1999. CASC also signed contracts for launch services with Turkey for its GK-2 satellite and with Luxembourg for two microsatellites (satellites with a mass between 10 and 100 kg). Figures on the cost of Chinese launches are scarce, but according to one BBS source the cost to launch the Palapa-D Indonesian communications satellite was $52 million.[110] If such costs are

[105] Rui C. Barbosa, "Chinese Long March 2D Launches Venezuela's VRSS-1 Satellite," September 28, 2012, http://www.nasaspaceflight.com/2012/09/chinese-long-march-2d-launches-vrss-1/; and "中国遥感卫星突破零出口" [China Breaks Through Zero Remote Sensing Satellites], September 29, 2014, http://war.163.com/12/1009/14/8DCOPFNC00014J0G.html.

[106] "中国将向委内瑞拉在轨交付一颗遥感卫星," [China Will Orbit Another Remote Sensing Satellite for Nigeria], July 22, 2014, http://news.10jqka.com.cn/20140722/c566670542.shtml.

[107] Salman Sidiqqi, "PAKSAT-1R: China Launches Pakistan's 'First' Communication Satellite, *Express Tribune*, August 12, 2011, http://tribune.com.pk/story/229797/paksat-1r-china-launches-pakistans-first-communications-satellite/.

[108] Yan Zhonghua, "中国和巴基斯坦签署通信卫星项目合作协议" [China and Pakistan Sign Cooperative Agreement for Satellite Project], 中国军网 [*China Military Net*], September 28, 2009, http://chn.chinamil.com.cn/xwpdxw/2009-09/18/content_4043287.htm.

[109] "中国为玻发射卫星造价 3 亿美元 中方担部分费用," [China Will Launch a Satellite for Bolivia Worth $300 Million, China to Provide a Portion of Funding], sina.com, December 22, 2013, http://news.sina.com.cn/c/2013-12-22/023929048296.shtml.

[110] http://webcache.googleusercontent.com/search?q=cache:WWAmXVLdrXEJ:bbs.9ifly.cn/forum.php%3Fmod%3Dviewthread%26action%3Dprintable%26tid%3D266+&cd=1&hl=en&ct=clnk&gl=us.

representative of China's launch costs then China appears to be much more competitive than Europe's Arianespace, where costs can range from $56 to 120 million.[111]

Political Benefits and Cooperative Activities

The Chinese government also uses its space program for domestic and international political gain. Space programs are described as an indicator of a country's comprehensive national power and as a measure of a country's rank in the world. The Chinese leadership believes that major powers have large space programs, and to be considered a major power one must have the trappings of a big power. This sentiment was most evident in the approval of the human spaceflight program, when many in the top leadership voiced support for the program based on its effect on prestige.[112]

The space program's effect on prestige is also directed inward. The Chinese Communist Party (CCP) is now communist in name only, and its continued legitimacy is predicated on delivering economic and nationalistic benefits in an informal social contract with its citizens: the CCP agrees to increase the standard of living and develop China into an internationally respected country, and the people agree not to rebel. By developing a robust space program and participating in high-profile activities such as human space flight and lunar exploration, the CCP can demonstrate that it is the best provider of material benefits to the Chinese people and the best organization to propel China to its rightful place in world affairs.

China conducts numerous cooperative activities with other countries and states that it holds international exchanges and cooperation "to promote inclusive space development on the basis of equality and mutual benefit, peaceful utilization and common development."[113] China pursues cooperative activities for a number of reasons. These include improving its international position, increasing its influence among less developed countries, and technology transfer. This section details China's major multilateral and bilateral space cooperation activities.

Asia Pacific Space Cooperation Organization

China's most prominent multilateral cooperative activity is the Asia Pacific Space Cooperation Organization (APSCO/亚太空间合作组织). APSCO was formally established in 2008 and is headquartered in Beijing. It is made up of nine member countries: China, Bangladesh, Indonesia, Iran, Mongolia, Pakistan, Peru, Thailand, and Turkey, and has been granted permanent status at the UN Committee on the Peaceful Uses of Outer Space. The purpose of APSCO is to promote multilateral cooperation in space science, technology, and applications between the member countries. In doing so, it conducts cooperation in six areas:

1. Space technologies and their application.
2. Earth observation, disaster management, environmental protection, satellite communications, and satellite navigation and positioning.
3. Space science research.
4. Education, training, and exchange of scientists and technology.

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[111] Amy Svitak, "Proving It," *Aviation Week & Space Technology*, March 10, 2014, 48–51; Craig Covault, "Space Probes," *Aviation Week & Space Technology*, May 5, 2008, 28–30.
[112] Deng Ningfeng, ed., 天河圆梦 [*Dream About the Milky Way Fulfilled*] (Beijing: China Astronautics Press, 2004), 41.
[113] Information Office of the State Council, China's Space Activities in 2011, December 2011, http://www.gov.cn/english/official/2011-12/29/content_2033200.htm.

5. Establishment of a central data bank for development of programs of the organization and dissemination of technical and other information relating to the programs and activities of the Organization.
6. Other cooperative programs agreed upon by the Member States.

Much of APSCO's work appears to focus on training, with nine events being held from 2009 to 2012. In addition to training, APSCO regularly holds international conferences, mainly on the application of space technologies to fields such as agriculture and earthquake monitoring. Through ASPCO, China has donated ground systems to member countries, including a data broadcasting system for its Fengyun meteorological satellites to several member countries and a receiving station for remote sensing data to Thailand.[114] China will also provide remote sensing data from its Gaofen, Ziyuan, Fengyun, and Haiyang satellites to member countries.[115]

APSCO has seven ongoing multinational R&D projects. These include the development of a data-sharing platform for remote sensing, a unified space observation network, a high-resolution earth observation satellite, a communication satellite and communication satellite applications, the promotion of satellite navigation technologies, and research on atmospheric effects on satellite communications.[116]

Brazil

The most visible of China's bilateral space activities are those conducted with Brazil, which has long-standing scientific and technological ties with China. China's first space cooperation agreement with Brazil was signed in 1984 concerning communication and remote sensing satellites, image processing, launch vehicles, and sounding rockets, but China's most prominent and first space cooperative activity with Brazil is the China-Brazil Earth Remote Sensing Satellite (CBERS).[117] In 1988, China and Brazil agreed to jointly develop two identical remote sensing satellites with China responsible for a 70 percent and Brazil a 30 percent share of the $300 million project.[118] The total included the costs of two satellites, their launchers, and launch services.[119] This agreement resulted in the development of the CBERS-1 and CBERS-2 satellites, launched in 1999 and 2003, respectively. These satellites, along with future CBER satellites, were jointly operated and controlled from Brazil's Satellite Control Center in São José dos Campos and China's Xi'an Satellite Control Center.[120]

The development of CBERS-1 and 2 was followed by an agreement in 2002 for two additional satellites, CBERS-3 and 4. These were equipped with improved payloads and were funded on a 50–50 cost share

[114] Asia-Pacific Space Cooperation Organization, "Introduction of the Organization and Its Space Cooperative Activities," http://swfound.org/media/41415/11.%20pres%20swf-cas%20space%20policies%20and%20laws%20-%20xu%20yansong%20-%20apsco%20intro.pdf; and Asia-Pacific Space Cooperation Organization, "Asia-Pacific Space Cooperation Organization (APSCO)," http://aseanregionalforum.asean.org/files/Archive/20th/ARF%20Workshop%20on%20Space%20Security,%20Hoi%20An,%206-7December2012/Annex%2019%20-%20APSCO.pdf.
[115] Wu Minghui, "中国为亚太空间合作组织成员国提供遥感卫星数据" [China Provides Remote Sensing Satellite Data to APSCO Member Countries], ifeng.com, July 6, 2013, http://news.ifeng.com/mil/2/detail_2013_07/06/27207409_0.shtml.
[116] "Program," APSCO, http://www.apsco.int/program.asp?LinkNameW1=ACAP&LinkCodeN=88.
[117] Jose Monseratt Filho, "Brazilian-Chinese Space Cooperation: An Analysis," *Space Policy*, May 1997, 157.
[118] "History," CBERS, http://www.cbers.inpe.br/ingles/satellites/history.php.
[119] Filho, "Brazilian-Chinese Space Cooperation," 158.
[120] "Control," CBERS, http://www.cbers.inpe.br/ingles/satellites/control.php.

basis.[121] CBERS-3 was launched in December 2013 but due to a launch failure did not reach orbit. CBERS-4 is scheduled to be launched at the end of 2014.

In 2004, the two countries signed another agreement for the construction and launch of CBERS-2B, which was launched in 2007 and operated until 2010.[122] This satellite was similar to CBERS-1 and 2. A CBERS-5 satellite is planned to be launched in 2017.[123]

China and Brazil shared development responsibilities for the service and payload modules for CBERS-1, 2, and 2B (see Table 2). The service module includes technologies for the operation of the satellite and is composed of the structure, thermal control, orbit and attitude control, energy supply, on-board supervision, and service telecommunications subsystems. The payload module includes the cameras, image data transmitters, recorder, and transponder for the Brazilian Environmental Data Collection System.[124]

Table 2. CBERS-1, 2, and 2B service and payload module technology development

Service Module	Structure	Brazil
	Thermal Control	China
	Attitude and Orbit Control	China
	Power	Brazil
	On Board Supervision	China
	Service Telecommunication	Brazil/China
Payload Module	CCD Camera	China
	IRMSS Camera (CBERS-1 and 2) and HRC (CBERS-2B)	China
	WFI Camera	Brazil
	Image Data Transmitter	China
	Transponder for the Brazilian Environmental Data Collection System	Brazil
	Space Environmental Monitor	China

Source: Industrial Participation CBERS-1, 2 and 2B," CBERS website, http://www.cbers.inpe.br/ingles/satellites/participation_industrial.php.

121 "CBERS 3 and 4 Launching," CBERS, http://www.cbers.inpe.br/ingles/satellites/launching_cbers3_4.php.
122 "CBERS 2B Launching," http://www.cbers.inpe.br/ingles/satellites/launching_cbers2b.php.
123 "Brazilian President Rousseff Trumpets Cooperation in Science, Space with China," Xinhuanet, July 18, 2014, http://news.xinhuanet.com/english/china/2014-07/18/c_133492063.htm.
124 "Industrial Participation CBERS-1, 2 and 2B," CBERS, http://www.cbers.inpe.br/ingles/satellites/participation_industrial.php.

Russia

China's longest cooperative space relationship is with Russia and its predecessor, the Soviet Union. This relationship began in the 1950s when the Soviet Union transferred rocket technologies, including complete rockets, to China. Their cooperation came to a halt with the breakdown of relations between the two countries in 1958. In the 1990s, the relationship was reignited as China's human spaceflight program gained momentum and the Russian space industry was in need of cash. During this time, China purchased a docking mechanism and a life support system that were reengineered for use on the Shenzhou space capsule. Russia also trained two Chinese astronauts in the mid-1990s who then served as trainers for other Chinese astronauts. More recently, China has a long-term cooperation plan with Russia that has resulted in agreements on joint space science and deep space exploration and the opening of a Russian Federal Space Agency office in Beijing and a Chinese National Space Agency (CNSA) office in Moscow. [125] As with other defense technologies, Russia's relationship with China on space technologies is not without controversy. Owing to Chinese reverse engineering, some argue that Russia has received little long-term benefit from its cooperation with China.[126]

The two countries have been discussing, and in some cases, implementing more truly cooperative activities. The most prominent cooperation to date has been the failed Mars mission, Phobos-Grunt, launched in 2012. The Chinese satellite Yinghuo-1 was paired with the Russian satellite Phobos-Grunt, which was to retrieve soil samples from the Mars moon, Phobos. China's Yinghuo-1, which was to study the space environment around Mars, was attached to the Russian satellite and was to be deployed as the spacecraft neared Mars. Due to a malfunction with the Russian satellite soon after launch, neither craft was able to complete the mission and both satellites burned up on reentry into the Earth's atmosphere.

Despite this setback, Russian Deputy Prime Minister Dmitry Rogozin has stated that his country is "ready to go forth with our Chinese friends, hand in hand" on human spaceflight and exploration of the solar system, including exploration of the moon and Mars.[127] The exact nature of the cooperation is unclear at this point and may include a joint Russian-Chinese space station to replace the International Space Station (ISS) or Russian participation in China's space station, as well as cooperation in rocket engine development.[128]

In addition, China and Russia are in discussions to build monitoring stations in each other's countries for their respective satellite navigation systems, Beidou and the Global Navigation Satellite System (GLONASS). This comes at a time when Russia has restricted the use of GPS stations on its territory.[129]

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[125] Charlotte Mathieu, "Assessing Russia's Space Cooperation With China And India: Opportunities and Challenges for Europe," *Acta Astronautica* 66, no. 3-4 (2010): 21–22; "China's Space Activities in 2006," China National Space Administration, October 2006, http://www.cnsa.gov.cn/n615709/n620681/n771967/79970.html; and "China's Space Activities in 2011," China National Space Administration, December 2011, http://www.gov.cn/english/official/2011-12/29/content_2033200.htm.

[126] "Russia, China Sign Space Exploration Agreement," *Moscow Times*, May 19, 2014, http://www.themoscowtimes.com/business/article/russia-china-sign-space-exploration-agreement/500463.html.

[127] "Russia, China Ready to Cooperate in Space, Explore Mars," *Space Travel*, July 1, 2014, http://www.space-travel.com/reports/Russia_China_Ready_to_Cooperate_in_Space_Explore_Mars_999.html.

[128] "Russia, China Sign Space Exploration Agreement."

[129] "China, Russia to Cooperate in Satellite Navigation," July 7, 2014, http://www.gpsdaily.com/reports/China_Russia_to_cooperate_in_satellite_navigation_999.html; "Russia, China Expand Cooperation on Satellite Navigation," *GPS Daily*, July 5, 2014, http://www.gpsdaily.com/reports/Russia_China_expand_cooperation_on_satellite_navigation_999.html.

Ukraine

Ukraine inherited a substantial amount of the former Soviet Union's space industry on which Ukraine bases its cooperation with China, especially those related to ballistic missile and launch vehicles. China has extensive cooperation with Ukraine under the Space Cooperation Subcommittee Mechanism of the Sino-Ukrainian Cooperation Commission,[130] with both countries seeking opportunities to expand cooperation in large-scale projects.[131] China and Ukraine signed a space cooperation plan for 2006–10 covering 29 long-term projects on the joint development of space rocketry, earthquake monitoring and remote sensing satellites, and satellites to monitor and study space weather. The two sides also discussed adding 15 new programs, including projects for the exploration of the moon and Mars, engine manufacture, welding in space, and use of solar energy.[132] In 2012, the two countries agreed to jointly work on more than 50 projects in the areas of earth observation, including a joint ionospheric satellite, Ionosat, to create an earthquake prediction system, and the development of rocket and satellite technologies, especially large launch vehicles.[133]

Europe

Europe in general and the European Space Agency (ESA) in particular are seeking opportunities for greater cooperation with China in the realm of space technologies, space exploration, and human spaceflight. This drive for greater cooperation is driven by two factors: the growing economic ties between Europe and China and reduced funding for ESA. According to Oliver Brauner of the Stockholm International Peace Research Institute,

> Beijing regularly praises the EU for being China's largest source of technology imports. According to the Chinese Ministry of Commerce, the EU accounted for 30 percent of China's overall technology imports in 2009…Gaining access to the Chinese market remains the No. 1 motivation for Europeans, with the EU Chamber of Commerce in China estimating that the Chinese government procurement market alone is worth $1 trillion…European companies want a piece of that pie.[134]

European officials insist, however, that Europe has "no intention of turning away from the Americans" and that "the cooperation with China 'complements rather than competes with' projects being undertaken with the United States."[135]

Europe and China have conducted a variety of cooperative activities since 2000. Annual ESA and CNSA workshops on space science cooperation have been held every year since 2004.[136] China and the ESA have

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130 "China's Space Activities in 2011."

131 "Ukraine, China to Expand Space Cooperation Program Until 2015 With New Large-scale Projects," *Kyiv Post*, September 12, 2013, http://www.kyivpost.com/content/business/ukraine-china-to-expand-space-cooperation-program-until-2015-with-new-large-scale-projects-329268.html.

132 "China's CPMIEC To Expand Space Cooperation With Ukraine," *Russia & CIS Military Weekly*, August 7, 2009.

133 "Yuriy Boyko, Vice Prime Minister of Ukraine for Ecology, Natural Resources, Energy and Space," *Space News*, November 25, 2013, http://www.spacenews.com/article/features/38347profile-yuriy-boyko-vice-prime-minister-of-ukraine-for-ecology-natural; "Ukraine, China to Prepare Space Cooperation in April," *China Defense Mashup*, March 22, 2012, http://www.china-defense-mashup.com/ukraine-china-to-prepare-space-cooperation-in-april.html.

134 "EU and China's Tech Rise," *Diplomat*, July 26, 2011, http://thediplomat.com/2011/07/eu-and-chinas-tech-rise/.

135 "Challenging America: Europe Seeks Space Cooperation with China," Spiegel Online International, February 2, 2012, http://www.spiegel.de/international/challenging-america-europe-seeks-space-cooperation-with-china-a-812273.html.

136 Yi Zhou, "Perspectives on Sino-U.S. Cooperation in Civil Space Programs," *Space Policy* 24 (2008): 137.

signed the “Status Quo of China-Europe Space Cooperation and the Cooperation Plan Protocol” under the mechanism of the China-Europe Joint Commission on Space Cooperation as well as the “Cooperation Agreement on the Application, Exchange and Distribution of Meteorological Satellite Data“ with the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) to promote sharing and application of meteorological satellite data.[137] Several European countries are also collaborating with China on “the Hard X-ray Modulation Telescope; developing silicon detectors for probing dark matter; and testing cross-continental quantum key distribution.”[138] European experiments will also be onboard the Shijian-10 satellite, which is to be launched in 2015.[139]

Galileo

The most high profile and contentious cooperative space activity between Europe and China was on the Galileo satellite navigation project. Europe initially sought Chinese participation in the project to enhance trade relations with China and to distance itself from the United States due to tensions arising from the U.S. invasion of Iraq.[140] China was initially invited to develop technologies for Galileo applications in the Chinese market, but this set of projects was not expanded due to concerns over China’s intentions with its Beidou satellite navigation system, the strategic nature of satellite navigation technologies, and a change in the project from a public-private partnership to a pure public venture.

Formal discussions for Chinese participation in Galileo began in 2003 and resulted in an agreement committing China to an investment of 200 million euros ($250 million).[141] Despite this investment, European technical assistance played a critical role in making these projects a success. According to one source, “Chinese officials at the Ministry of Science and Technology and the China-Europe Global Navigation Satellite System Technical Training and Co-operation Centre are adamant in recognizing that without the active involvement of European partners and European expertise/know-how and technology travelling to China, the local subcontractors would have been unable to complete projects.”[142]

Europe, however, decided not to invite additional Chinese participation in the project. After the initial invasion of Iraq, relations between the United States and Europe began to improve and Europe became more receptive to U.S. concerns over arms exports to China. Moreover, Galileo had changed from a public-private partnership to a pure public program due to the inability to get adequate private financing. As a public program, public procurement rules only allowed “non-European sources for certain components and services in case of demonstrated substantial advantages in terms of quality and costs, taking account of the strategic nature of the European global navigation satellite system programs and of the EU security and export control requirements.”[143] Additionally, Galileo officials were under the impression that Beidou would remain a regional system for military use, and when it became obvious that Beidou would be a

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[137] “China’s Space Activities in 2011.”

[138] Jane Qiu, “Head of China’s Space Science Reaches Out,” *Nature*, March 6, 2014, http://www.nature.com/news/head-of-china-s-space-science-reaches-out-1.14797.

[139] Qiu, “Head of China’s Space Science Reaches Out”; and Ni Sijie, “中国航天事业发展不平衡：空间科学待”上位” [China’s Space Sector Development is Uneven: Space Science Waits to Become Priority], http://news.ifeng.com/a/20140715/41166384_0.shtml.

[140] Nicola Casarini, *Remaking Global Order: The Evolution of Europe-China Relations and its Implications for East Asia and the United States* (New York: Oxford University Press, 2009), 130.

[141] Ibid, 102.

[142] Ibid, 105.

[143] Glen Gibbons, “Europe Readies Galileo Procurement,” *Inside GNSS*, March/April 2008, http://www.insidegnss.com/node/585.

global dual-use system Europe became concerned that Beidou would become a competitor to Galileo.[144] Security concerns were also raised when some in the European Union expressed fear that China was gaining too much access to a strategic technology.[145]

Double Star

A second prominent collaboration between China and Europe was the Double Star project conducted from 2004 to 2007 to study the Earth's magnetosphere, in particular magnetic storms that can affect space flight as well as navigation, communications, and radar systems. The agreement was signed in 2001 and was the first between CNSA and ESA. The Double Star satellites were launched in 2003 and 2004 with one in equatorial and the other in polar orbit where they studied the lower regions of the Earth's magnetosphere. ESA contributed 8 million euros to the project to refurbish and integrate European instruments, acquire data, and coordinate scientific operations.[146]

The Double Star satellites consisted of eight Chinese and eight European instruments intended to supplement Europe's Cluster II program, which was designed to measure the solar wind and its interaction with the magnetosphere.[147] The addition of Chinese satellites allowed the two missions "to observe different regions of the sky at the same time as well as to obtain tridimensional spatial and temporal readings of dynamic events in the magnetosphere."[148]

The Double Star project is described as providing "an unprecedented measurement capability of geospace" that enabled the "first coordinated six-point measurements of the Earth magnetosphere." The Double Star and Cluster II programs "drew significant attention from both the research community and public, providing many scientific discoveries including: the extent of oscillations in the tail of the magnetosphere, density holes in the solar wind, pulsed magnetic reconnection observed for several hours, and crustal cracking of a neutron star."[149]

Dragon Programs

The Dragon programs are a set of cooperative activities between ESA and the National Remote Sensing Center of China that are intended "to encourage increased exploitation of ESA space resources within China as well as stimulate increased scientific cooperation in the field of Earth Observation (EO) science and applications between China and Europe." The program is said to have become "a model for scientific and technological cooperation between China and Europe."[150]

Training is a key component of the program where "lead scientists are paired with young researchers so that know-how can be transferred to the next generation. Training seminars and advanced courses are organized routinely for PhD students, post-doctoral and research scientists from China and other Asian

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[144] Peter B. de Selding, "European Officials Poised to Remove Chinese Payloads from Galileo Sats," *Space News*, March 12, 2010, http://www.spacenews.com/article/european-officials-poised-remove-chinese-payloads-galileo-sats.
[145] Dan Levin, "Chinese Wrestle with Europe in Space; Dispute about Radio Frequency Is Latest Glitch for Galileo Satellite Project," *International Herald Tribune*, March 23, 2009.
[146] "Double Star Overview," ESA, http://www.esa.int/Our_Activities/Space_Science/Double_Star_overview2.
[147] "Double Star Instrument," ESA, http://sci.esa.int/double-star/33153-instruments/.
[148] Michael A Taverna, "Chinese, Italian Moves Highlight Growing Scientific Collaboration," *Aviation Week & Space Technology* 155, no. 18 (2001), 89.
[149] "Laurels for Cluster-Double Star Teams," *ESA*, September 29, 2010, http://www.esa.int/Our_Activities/Space_Science/Cluster/Laurels_for_Cluster-Double_Star_teams.
[150] "ESA-China Collaboration Takes Earth Observation to New Heights," *ESA*, June 29, 2012, http://www.esa.int/Our_Activities/Observing_the_Earth/ESA_China_collaboration_takes_Earth_observation_to_new_heights.

countries. Courses provide training in processing, algorithm and product development from EO data in geo-science applications."[151]

The first phase of the Dragon program was conducted from 2004 to 2008 and involved the use of ESA European Remote Sensing Satellite (ERS) and Environmental Satellite (Envisat) data for science and application development in China, including applying remote sensing data to the monitoring of flooding, forestry, agriculture, oceanography, and drought monitoring, among others, in China.[152]

The second phase of the Dragon program began in 2008 and expanded the cooperation to 25 projects using ESA and Chinese earth observation data in land, ocean and atmospheric science and applications in China. The program ended in 2012 and involved the CBERS, Haiyang, and Huanjing series of satellites, the Fengyun-3 meteorological satellite, as well as European satellites.[153]

The third phase of the Dragon program began in 2012 and will continue until 2016. Dragon 3 involves 51 projects and promotes the "exploitation of ESA and Chinese earth observation data for science and application development" to simulate scientific exchange between China and Europe.[154]

Dragoness Program

Dragoness was a project funded from 2007 to 2010 by the European Commission to assess and establish an inventory of European and Chinese capacities in marine monitoring for environment and security by capitalizing on the previous work done by the Dragon program. The end result of Dragoness was "an inventory and assessment of existing marine and coastal observing systems in both Europe and China that highlighted strengths and weaknesses, identified gaps and inconsistencies, and provided recommendations for a strategy to develop harmonized monitoring elements which met the requirements of international standards and monitoring programs."[155]

Human Spaceflight

ESA is also seeking opportunities to work with China on human spaceflight. Following discussions with Chinese human spaceflight program personnel that revealed problems with docking the Shenzhou with the Tiangong-1 space station, ESA officials discussed building a European docking mechanism for the Shenzhou space capsule and the Tiangong space station in exchange for allowing European astronauts to visit the space station. [156]

The docking mechanism is one of three working groups set up by ESA and China. The other two are crew training and the exchange of payload facilities and experiments. In 2012, a delegation from the Chinese astronaut training center spent a week at the European Astronaut Center in Germany to learn more about ESA's astronaut program. This visit was preceded by a visit by the head of the China Manned Space Agency

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151 "Dragon: 10 Years of Cooperation," *ESA*, https://dragon3.esa.int/documents/163802/523346/Dragon_cooperation_10_years.

152 See European Space Agency website on Dragon Program, https://dragon3.esa.int/.

153 "ESA-MOST Dragon 2 Cooperation Programme," *ESA*, http://dragon2.esa.int/.

154 "Dragon 3 Programme Brochure 2013," *ESA*, https://dragon3.esa.int/documents/163802/523346/Dragon_brochure_FINAL_2013.pdf/2be07b10-af1f-4839-936b-3cc3d201b4fa?version=1.0.

155 "Sixth Framework Programme Priority: Priority Title: Aeronautics and Space," *Dragoness*, November 22, 2006, http://dragoness.nersc.no/?q=system/files/Dragoness_DOW_v1.pdf.

156 "Europe May Work with China on Space Station," *Space.com*, February 26, 2013, http://www.space.com/19960-china-space-station-europe-cooperation.html.

and China's first female astronaut, Liu Yang. These trips were reciprocated by the visit of ESA astronauts and trainers to Beijing in 2013.

ESA is also "'seriously looking' at providing experiments for future Tiangong missions" as well as having European astronauts conduct Chinese experiments on the ISS, though that last possibility would have to be approved by other ISS partners, most notably the United States. Although no plans have been finalized, European astronauts are taking Chinese language courses in the event such cooperation takes place.[157]

France

China has signed a cooperation framework agreement on space and marine science and technology with France under the mechanism of the Sino-French Joint Commission on Space Cooperation, aiming at developing bilateral cooperation on astronomic satellite, ocean satellite, and other satellite programs.[158]

In March 2014, France and China agreed to work cooperatively on the Space Variable Objects Monitor (SVOM) and the China-France Oceanography Satellite (CFOSAT). According to CNES head Jean-Yves Le Gall, "France is very keen to work in space with China, whose engineers and scientists are unquestionably some of the best in the world. The boost given today to the CFOSAT and SVOM missions paves the way for closer cooperative ties likely to lead to new joint projects in the future, pursued either directly by CNES or through the European Space Agency, to which France is the main contributor."[159]

CFOSAT began in 2007 and is to be developed jointly by France's Centre National d'Etudes Spatiales (CNES) and CNSA with France investing around $200 million on the project.[160] CFOSAT will be used to study ocean surface winds and waves and will be equipped with a rotating radar built by Thales Alenia to measure both swell wave length and direction over a 70-km large swath, and a rotating scatterometer developed by China. The CFOSAT satellite bus will be built by China for an expected launch in 2018 on a three-year mission.[161]

SVOM is an astronomy mission to observe and characterize gamma-ray bursts. "France will provide the ECLAIRs burst-detection instrument and the ground alerting network." The exact sharing of responsibilities between France and China was to be decided in June 2014 with the goal to orbiting the satellite on a Chinese launcher by 2020.[162] According to a French space official, continuing revisions to the U.S. export control list and the need to consider future revisions has hindered development of SVOM. As a result, U.S.-made components on the satellite have been reduced to a minimum.[163]

In addition to this, France has also contributed a Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) system to China's Haiyang-2A ocean surveillance system launched on August 15,

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[157] Ibid.

[158] Information Office of the State Council, China's Space Activities in 2011, December 2011, http://www.gov.cn/english/official/2011-12/29/content_2033200.htm.

[159] "CNES and China National Space Administration (CNSA) Strengthen Cooperative Ties," *CNES*, March 27, 2014, http://www.cnes.fr/automne_modules_files/pPressReleases/public/r8418_81_cp038-2014_-_accord_cnsa_va.pdf.

[160] "France, China Set Sail on Joint Ocean-Surface Satellite Project," *Space News*, March 29, 2014, http://www.spacenews.com/article/civil-space/40020france-china-set-sail-on-joint-ocean-surface-satellite-project.

[161] "About CNES," Centre National d'Etudes Spatiales website, accessed September 9, 2014, http://www.cnes.fr/web/CNES-en/3773-about-cnes.php; and "CNES and China National Space Administration (CNSA) Strengthen Cooperative Ties."

[162] "CNES and China National Space Administration (CNSA) Strengthen Cooperative Ties."

[163] De Selding, "U.S. Export Rules Complicate Sino-French Cooperation."

2011.[164] The Doris system "was designed and developed by France's CNES and is used to determine the orbit of satellites equipped with Doris receivers with centimeter accuracy using a network of ground stations as reference points on Earth."[165]

France has also contracted with China to launch satellites. The French company Thales Alenia marketed an "ITAR-free" satellite, which it claimed did not contain U.S. export-controlled components. Thales Alenia has sold eight of these satellites, with five being launched on Chinese rockets. In 2013, it was determined that a U.S. supplier had mischaracterized export-controlled components and that the satellites should not have been sold to China or launched on Chinese rockets.[166]

United Kingdom

According to China's 2011 space white paper, "China and Britain have established a joint laboratory on space science and technology, jointly organized a seminar on space science and technology, and conducted exchanges on lunar exploration, earth observation, space science research and experiment, personnel training, and other areas."[167]

The most prominent example of space cooperation is the University of Surrey and Surrey Satellite Technology's (SSTL) relationship with China. In 1999, the University of Surrey entered into a 25-year joint venture agreement with Tsinghua University to form the Tsinghua-Surrey Small Satellite Company to build microsatellites. Tsinghua University owns 75 percent of the company and sought financing from the Chinese side from the China Aerospace Machinery and Electronics Corporation, the Tsinghua University Enterprise Group, and Tsinghua Tongfang Co. Ltd.[168] The company launched its first satellite, Tsinghua-1, a remote sensing satellite, in 2000.[169] In 2005, SSTL built the Beijing-1 remote sensing satellite for the Chinese government in partnership with the Beijing Landview Mapping Information Technology Co. Ltd. (BLMIT/北京宇视蓝图信息技术有限公司).[170]

In 2009, Surrey Satellite Technology was acquired by Astrium, a subsidiary of EADS, now the Airbus Group. In 2011, SSTL signed a contract with the Chinese Twenty-First Century Aerospace Technology Co. Ltd. for 110 million British pounds for three remote sensing satellites. According to one report, no Chinese personnel will be involved in the manufacture of the satellites, and the satellite will not be launched on a Chinese rocket. This is to assuage U.S. concerns over technology transfer.[171]

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164 "Doris," *CNES*, December, 2009, http://www.cnes.fr/web/CNES-en/1513-doris.php.
165 Craig Covault, "China Seeks ISS Role, Accelerates Space Program," *Aviation Week & Space Technology* 155, no. 20 (2001): 52.
166 Jim Worf, "Exclusive: U.S. Squeezes French-led Satellite Maker Over China," Reuters, February 9, 2012, http://www.reuters.com/article/2012/02/09/us-usa-france-china-satellite-idUSTRE8181F020120209; and Peter B. de Selding, "Thales Alenia Space: U.S. Suppliers at Fault in "ITAR-free" Misnomer," *Space News*, August 9, 2013, http://www.spacenews.com/article/military-space/36706thales-alenia-space-us-suppliers-at-fault-in-%E2%80%9Citar-free%E2%80%9D-misnomer.
167 Information Office of the State Council, China's Space Activities in 2011.
168 "Surrey Satellite Technology Limited," Encyclopedia.com, http://www.encyclopedia.com/doc/1G2-3479900088.html; and Wei Long, "China's First Microsat Operational," *Space Daily*, July 11, 2000, http://www.spacedaily.com/news/microsat-00k.html.
169 Wei, "China's First Microsat Operational."
170 "Deimos and Surrey Satellite Technology Contract for Spanish Imaging Mission," *Surrey*, October 10, 2006, http://www.sstl.co.uk/Press/Deimos-and-Surrey-Satellite-Technology-Contract-fo.
171 Peter B. de Selding, "Surrey to Build Three Optical Imaging Satellites for Chinese Firm," *Space News*, June 29, 2011, http://www.spacenews.com/article/surrey-build-three-optical-imaging-satellites-chinese-firm.

A second Sino-British space cooperative activity is the University of Strathclyde's partnership with the China Academy of Launch Vehicle Technology (CALT). A 2012 agreement established the International Space Mechatronic Systems Technology research laboratory with $2.3 million in funding from CALT. The laboratory will host two Chinese engineers and will conduct annual seminars to promote collaboration.[172]

Germany

Scientific exchanges between China and Germany began in the early 1980s. According to the German government's space advisor, Peter Hintze, "The Chinese have great ambitions and have such enormous means at their disposal that we can hardly keep up in areas such as manned space travel," so much so that Germany must "seek cooperation."[173]

In 1984, the Chinese Ministry of Astronautics and the Federal Ministry of Research and Technology signed the Agreement on Cooperation in Civilian Space Science and Technology. In 1988, the countries signed a contract for Deutsch Aerospace AG to provide a communications payload for the DFH-3 communications satellite. In 1993, China and Germany signed an agreement to establish a joint venture, EurasSpace. This joint venture is reported to have worked on a Sinosat Space Communications Satellite Project.[174]

China and Germany also signed a bilateral agreement on space life sciences.[175] Under this agreement, Germany supplied equipment for the Shenzhou-8 mission in 2011 to "conduct 17 biological and medical experiments in collaboration with Chinese scientists" on "immune, muscle and thyroid cells, as well as plants and euglena, under conditions of weightlessness."[176]

Venezuela

China's space cooperation with Venezuela has reportedly been the result of intense lobbying by former Venezuelan President Hugo Chavez with the resulting relationship described as a "Chavez Innovation." China and Venezuela have signed a memorandum of understanding on cooperation in space technologies and have established a technology, industry, and space sub-committee under the China-Venezuela Senior Mixed Committee.[177] China has built and launched two satellites for Venezuela. The Venesat-1 communications satellite was proposed by Chavez in 2004 and began in 2005 with the signing of a $400 million contract. The satellite was launched in 2008. The VRSS-1 remote sensing satellite was launched in 2012.[178]

China is also assisting Venezuela in building small satellites. Venezuela plans to begin manufacturing at a factory located in Borburata de Carabobo in 2014, and China is training Venezuelan engineers in the design of small satellites, which will be built with the assistance of Chinese technology.[179] In 2013, 60 Venezuelan

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[172] Lauren Reed, "University of Strathclyde and CALT Launch Joint Laboratory," *SITC Bulletin Analysis*, March 2013, http://igcc.ucsd.edu/assets/001/504437.pdf.

[173] "Germany and China Step Up Cooperation in Space," *DLR*, December 16, 2008, http://www.dlr.de/en/desktopdefault.aspx/tabid-3432/7418_read-14864/.

[174] Jiyuan Liu, "Strengthening Sino-German Space Cooperation Looking Forward to 21st Century," *Space*, http://www.space.cetin.net.cn/docs/HTM-E/002.HTM.

[175] Information Office of the State Council, "China's Space Activities in 2011."

[176] "Germany and China Step Up Cooperation in Space."

[177] Information Office of the State Council, "China's Space Activities in 2011."

[178] Rui C. Barbosa, "Chinese Long March 2D launches Venezuela's VRSS-1 satellite," *NASA Space Flight.com*, September 28, 2012, http://www.nasaspaceflight.com/2012/09/chinese-long-march-2d-launches-vrss-1/.

[179] Veronica Magan, "Venezuela: Latin America's Next Space Pioneer?" *Via Satellite*, August 23, 2013, http://www.satellitetoday.com/publications/2013/08/23/venezuela-latin-americas-next-space-pioneer-2/.

engineers were sent to China to study satellite design.[180] Venezuela is building a space base to launch these satellites with financial support from China and technical support from Belarus. According to a 2013 statement by Venezuelan President Nicolas Madura, Venezuela will launch satellites “sooner rather than later.”[181]

United States

As with its overall relationship, China’s relationship with the U.S. space program has been turbulent. Cooperative activities started small, with the two countries signing an Understanding on Cooperation in Space Technology in 1979. In 1986 China set up a ground station to receive satellite imagery from the U.S. Geological Survey’s Landsat remote sensing satellite, and in 1992 two small student experiments flew on a space shuttle mission. [182]

The most prominent cooperative activities between the two countries occurred in the 1990s when China began launching U.S.-manufactured commercial satellites. The use of Chinese launch services came about due to the phasing out of expendable rockets in favor of the space shuttle, whose launch costs promised to be cheaper. The loss of the space shuttle *Challenger* in 1986 and the subsequent grounding of the fleet for two years, and the resultant prohibition against using the shuttle for commercial launches, resulted in a backlog that could not be resolved by European launchers, leaving only Chinese launchers to fill the gap.

China launched the first U.S. manufactured commercial satellite in 1990 and launched a total of 19 U.S.-manufactured satellites between 1990 and 1999. During this time, Chinese launchers failed six times, including three times in 1995 and 1996. Investigations conducted by Hughes Space and Communications into launch failures of Hughes satellites in 1992 and 1995 and by Loral of a launch failure involving one of their satellites built for Intelsat identified the failures as resulting from a faulty fairing for the Hughes launches and from a faulty inertial measurement unit for the Loral launches. These investigations also involved their counterparts from Chinese industry, including a joint investigation by Hughes, Loral, and China’s space industry. Subsequent disclosures of these investigations led to allegations that Hughes and Loral had illegally transferred technical assistance to the Chinese that could have been used to improve the reliability of Chinese ballistic missiles.[183] In 2002, Loral reached a settlement with the U.S. government to pay a $14 million fine, but neither admitted nor denied the government’s charges as part of the settlement.[184] In 2003, Hughes Electronics Corporation and Boeing, which had acquired Hughes Space and Communications in 2000, reached a settlement with the U.S. government to pay $32 million in fines and expressed “regret for not having obtained licenses that should have been obtained” and acknowledged “the nature and seriousness of the offenses charged by the Department of State, including the harm such

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[180] “Belarus to Help Build Space Facility in Venezuela,” Fox News Latino, July 4, 2012, http://latino.foxnews.com/latino/lifestyle/2012/07/04/belarus-to-help-build-space-facility-in-venezuela/; “Venezuela Looks to Get into Space Satellite Business Thanks to Chinese,” *Before It’s News*, September 3, 2013, accessed September 4, 2014, http://beforeitsnews.com/alternative/2013/09/venezuela-looks-to-get-into-space-satellite-business-thanks-to-chinese-2754582.html.

[181] “Venezuela Looks to Get into Space Satellite Business Thanks to Chinese.”

[182] Brian Harvey, *China’s Space Program: From Conception to Manned Spaceflight* (Chichester, UK: Springer, 2004), 69, 191.

[183] For more information, see the report by the United States House of Representatives Select Committee on U.S. National Security and Military/Commercial Concerns with the People’s Republic of China (aka Cox Commission), especially chapters 5 and 6, http://www.house.gov/coxreport/ and Shirley Kan, “China: Possible Missile Technology Transfers from U.S. Satellite Export Policy: Actions and Chronology,” Congressional Research Service, September 5, 2014, http://fas.org/spp/starwars/crs/98-485.pdf.

[184] Jonathan Berr, “Loral Settles China Satellite Allegations,” Bloomberg News, January 10, 2002, http://articles.latimes.com/2002/jan/10/business/fi-loral10.

offenses could cause to the security and foreign policy interests of the United States."[185]These illegal transfers of technical know-how, coupled with the Chinese theft of U.S. nuclear weapons secrets,[186] led to a prohibition against launching U.S. satellites on Chinese launchers that remains in place to today.

After these violations, the Clinton administration became opposed to space cooperation with China and it was not until the early part of the George W. Bush administration that the United States began to reconsider space cooperation with China. By 2002, China's human spaceflight program was making progress with several unmanned test flights, and the United States began contemplating "measured and appropriate levels of space cooperation with China." In 2002, then NASA Administrator Sean O'Keefe stated that he and Deputy Secretary of State Richard Armitage had been "spending 'a lot of time' exploring whether and how to bring China into closer cooperation with the U.S. in space." O'Keefe also told a Women in Aerospace forum that NASA was "looking at cooperative arrangements, partnering arrangements, a range of different opportunities for avoiding, really, duplication of the aerospace capacity and technology that we currently have."[187]

This renewed interest in cooperation with China resulted in CNSA Administrator Sun Laiyan visiting NASA in 2004, though no substantive discussions took place.[188] This was the first time that a CNSA head had visited NASA. This visit was reciprocated in 2006 when NASA Administrator Michael Griffin and a delegation visited CNSA. This was the first time that a NASA administrator had visited CNSA,[189] and was billed as a "get acquainted session" by Griffin since the two countries up to that point had not seriously discussed space cooperation.[190] During the trip, NASA visited the Chinese Academy of Space Technology (CAST), the Chinese Academy of Sciences (CAS), and the National Satellite Meteorological Center as well as a CAST facility in Shanghai.

During a press conference covering the trip, Griffin stated that he wanted to "welcome China to the rank of space faring nations by virtue of their ability to put people into orbit entirely on their own resources. That is a milestone accomplishment and one to be proud of." But Griffin also stated that Chinese involvement in the ISS was still some way off and required much greater transparency than what the Chinese were willing to provide at that point. As Griffin stated, "with regard to cooperation on space programs generally, and human space programs in particular, that the greatest possible degree of transparency and openness is a requirement, if for no reason more important than without it we stand a chance to kill people." As if to drive home the point, Griffin cancelled a trip to China's Jiuquan Launch Center since China only offered a visit to the launch pad and not to other more informative parts of the center. Nevertheless, Griffin was encouraged by the initial discussions on cooperation in robotic space

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[185] Jeff Gerth, "Two U.S. Aerospace Companies Agree to Fines Over Helping China," *New York Times*, March 5, 2003, http://www.nytimes.com/2003/03/05/national/05CND-SPACE.html.

[186] In addition to the illegal transfer of rocket technology, a major aspect of the investigations involved the illegal transfer of nuclear weapons technology. The Cox Commission concluded that China had "stolen classified information on all of the United States' most advanced thermonuclear weapons" and that this information had helped China "fabricate and successfully test modern strategic thermonuclear weapons." See the report by the United States House of Representatives Select Committee on U.S. National Security and Military/Commercial Concerns with the People's Republic of China (aka Cox Commission), chapter 2, http://www.house.gov/coxreport/.

[187] Craig Covault, "NASA Eyes China Ties as New Shenzhou Flies," *Aviation Week & Space Technology* 156, no. 13 (2002): 27.

[188] Craig Covault, "The China Car," *Aviation Week & Space Technology* 162, no. 5 (2005): 27.

[189] Yi Zhou, "Perspectives on Sino-US Cooperation in Civil Space Programs," *Space Policy* 24 (2008): 135.

[190] "Space Diplomacy," *Aviation Week & Space Technology* 165, no. 12 (2006): 41.

exploration missions,[191] with the talks resulting in the formation of two working groups on earth and space sciences, which have had only limited contacts.[192]

During the Obama administration, the United States and China continued exploratory discussions on cooperative space activities, but achieved no real progress. During President Obama's visit to China in 2009, the countries issued a statement that "China and the United States look forward to expanding discussions on space science cooperation and starting a dialogue on human space flight and space exploration" with "reciprocal visits of the NASA Administrator and the appropriate Chinese counterpart in 2010."[193]

In 2010, NASA Administrator Charles Bolden visited China on "a very comprehensive visit to Chinese human spaceflight related facilities" that was intended for NASA to become "acquainted with relevant Chinese space officials and institutions" and to have a better "understanding of Chinese human spaceflight programs and plans, and reaching a common understanding of the importance of transparency, reciprocity, and mutual benefit as the underlying principles of any future interaction between our two nations in the area of human spaceflight."[194]

Bolden's trip to China drew criticism from members of Congress, in particular Frank Wolf (R-VA), who sat on the powerful House Appropriations Committee and who was chair of the Subcommittee on Commerce, Justice, Science, and Related Agencies which oversees NASA's budget. Wolf, now retired, a long-time critic of China who opposes space cooperation with China on human rights and security grounds, wrote in a letter to the NASA administrator that "[i]t should go without saying that NASA has no business cooperating with the Chinese regime on human spaceflight."[195] In a follow up letter, Wolf and Congressmen John Culberson (R-TX), Robert Aderholt (R-AL), and Dana Rohrabacher (R-CA), requested that NASA deliver a full briefing on the trip and a "personal assurance that at no time during your trip there were any discussions of cooperation on human space flight activities."[196] In response, Bolden wrote in a letter dated November 9, 2010, that he "appreciated the concerns raised" in their letter and that "you can be confident that my visit was introductory in nature and did not include consideration of any specific proposals for human spaceflight cooperation or new cooperation in any other areas of NASA's activities." He added that he "stood ready" to brief Congressman Wolf on the details of the trip.[197]

During the visit of Chinese President Hu Jintao to Washington in 2011, the two sides agreed on a reciprocal visit of a Chinese delegation to NASA headquarters and other NASA facilities in 2011, as a follow-up to the

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191 "NASA Administrator Michael Griffin Conference," NASA, September 27, 2006, http://www.nasa.gov/pdf/159546main_Griffin_Shanghai_China_060927.pdf.

192 James Clay Moltz, *Asia's Space Race: National Motivations, Regional Rivalries, and International Risks* (New York: Columbia University Press, 2012), 95.

193 White House, "Joint Press Statement by President Obama and President Hu of China," November 17, 2009, http://www.whitehouse.gov/the-press-office/joint-press-statement-president-obama-and-president-hu-china.

194 David Weaver, "NASA Administrator Statement on China Visit," NASA, October 25, 2010, http://www.nasa.gov/home/hqnews/2010/oct/HQ_10-270_Bolden_China.html.

195 "U.S. Lawmaker Balks at NASA Chief's China Visit," *Space.com*, October 9, 2010, http://www.space.com/9295-lawmaker-balks-nasa-chief-china-visit.html.

196 "NASA Delegation to China Sets the Stage for More Talks," *Spaceflight Now*, October 26, 2010, http://www.spaceflightnow.com/news/n1010/26boldenchina/.

197 http://wolf.house.gov/sites/wolf.house.gov/files/documents/Administrator%20Response%20to%20the%20Honorable%20Frank%20Wolf_110910.pdf

NASA administrator's visit to China in 2010, and agreed "to continue discussions on opportunities for practical future cooperation in the space arena, based on principles of transparency, reciprocity, and mutual benefit."[198] The Chinese delegation visit to NASA facilities did not take place, however. In April 2011, Congress passed a prohibition, initiated by Congressman Wolf, against NASA conducting a wide range of activities with China. The law states:

> None of the funds made available by this Act may be used for the National Aeronautics and Space Administration (NASA) or the Office of Science and Technology Policy (OSTP) to develop, design, plan, promulgate, implement, or execute a bilateral policy, program, order, or contract of any kind to participate, collaborate, or coordinate bilaterally in any way with China or any Chinese-owned company unless such activities are specifically authorized by a law enacted after the date of enactment of this Act.

The law, however, did allow NASA to engage "in activities which NASA or OSTP have certified pose no risk of resulting in the transfer of technology, data, or other information with national security or economic security implications to China or a Chinese-owned company" but that any certification "shall be submitted to the Committees on Appropriations of the House of Representatives and the Senate no later than 14 days prior to the activity in question and shall include a description of the purpose of the activity, its major participants, and its location and timing."[199]

Since the passage of the law, NASA activities with China have been curtailed, and no additional visits between NASA and CNSA have occurred in a bilateral setting. In 2013, however, Wolf accused NASA of not abiding by the notification clause when NASA hosted Chinese officials at the Committee on Earth Observation Satellites (CEOS), a multilateral body made up of 23 countries to ensure "international coordination of civil space-based earth observation programs" and promote the "exchange of data to optimize societal benefit and inform decision making for securing a prosperous and sustainable future for humankind."[200] NASA, on the other hand, argued that the restrictions and reporting requirements for Chinese participation at NASA sponsored events only applied to bilateral events and did not apply to multilateral events such as CEOS.[201] This issue came up again in 2013 when Chinese researchers were initially banned from attending a conference at NASA's Ames Research Center on the use of NASA's Kepler space telescope to search for exoplanets. The ban attracted international attention and prompted many attendees to threaten a boycott of the conference.[202] The uproar resulted in a clarification from Congressman Wolf in a letter to NASA Administrator Bolden that Chinese nationals were able to attend the conference as it was multilateral in nature.[203]

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[198] White House, "U.S.-China Joint Statement," January 19, 2011, http://www.whitehouse.gov/the-press-office/2011/01/19/us-china-joint-statement.

[199] U.S. Congress, "Consolidated and Further Continuing Appropriations Act, 2012," http://www.gpo.gov/fdsys/pkg/PLAW-112publ55/html/PLAW-112publ55.htm.

[200] "31 CEOS Members," CEOS, http://www.ceos.org/index.php?option=com_content&view=category&layout=blog&id=30&Itemid=76.

[201] "Lawmaker: NASA Broke Law with Visits by China Officials," *USA Today*, March 7, 2013, http://www.usatoday.com/story/news/politics/2013/03/07/wolf-nasa-china-kennedy-space-center/1971699/.

[202] "U.S. Scientists Boycott NASA Conference Over China Ban," *Guardian*, October 4, 2013, http://www.theguardian.com/science/2013/oct/05/us-scientists-boycott-nasa-china-ban.

[203] "Wolf Letter to NASA's Bolden Correcting Record on Restrictions Involving Chinese Nationals," Congressman Frank Wolf official website, October 8, 2013, http://wolf.house.gov/media-center/press-releases/wolf-letter-to-nasas-bolden-correcting-record-on-restrictions-involving#.U8_3nU3Qdy0.

Also in 2013, Bolden traveled to China a second time to attend the International Astronautical Congress in Beijing. Bolden made a speech at the Congress, but did not meet with Chinese space officials. He did meet, however, with Chinese Academy of Sciences President Bai Chunli. According to the *South China Morning Post*, Bolden and Bai "exchanged frank opinions on pragmatic co-operation in relevant fields in the future" and that NASA was "highly serious" about working with China, especially in earth observation.[204]

In November 2014, Bolden traveled again to China to discuss air traffic management in conjunction with the International Forum for Aviation Research. While there, he met with the head of China's State Administration for Science, Technology, and Industry for National Defense and the China National Space Administration, Xu Dazhe, and the head of China's Manned Space Agency, Wang Zhaoyao. Bolden "declined to be specific about" his talks in China, but stated that it was a "listening opportunity."[205] According to a Chinese press report, Bolden and Xu had a "frank" exchange of views on aviation and space issues and "agreed to strengthen communication and exchanges to mutually promote cooperation in the areas of aviation and space."[206] According to a news release by the China Manned Space Agency, "both parties presented with each other's latest development and follow-on planning for the manned space program, held an in-depth talk on the international manned space co-operation, exchanged opinions, and expressed the good will of strengthening the multi-lateral co-operations and communications."[207]

Other U.S.-China Cooperative Activities

The United States and China are also involved in cooperative activities that do not involve NASA. These include bilateral activities by the U.S. Geological Survey and the National Academy of Sciences and multilateral activities.

U.S. Geological Survey

In 2012 the United States and China signed a remote sensing agreement between the U.S. Geological Survey (USGS) of the Department of the Interior and Center for Earth Observation and Digital Earth of the Chinese Academy of Sciences in which the United States will provide imagery from USGS Landsat satellites. This agreement appears to continue China's use of Landsat imagery since 1986.

Landsat is a joint program by NASA and the USGS. With the launch of its first satellite in 1972, it is the longest running Earth remote sensing program. The Landsat program currently operates two satellites, Landsat-7 and 8, which image the Earth continuously and cross every point on Earth every 16 days. Landsat-7 regularly acquires 438 images per day and can image one-quarter of the Earth' surface during this 16 days. Landsat-8, on the other hand, regularly acquires 550 images per day. Together, the satellites can provide eight-day coverage.[208] The two satellites provide imagery with resolutions of 15, 30, 60, and 100 meters in the visible, infrared, and panchromatic bands. The USGS provides Landsat imagery free of charge to anyone, without restrictions.

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[204] "US and China Partner on Small-scale Space Projects," *South China Morning Post*, September 30, 2013, http://www.scmp.com/news/china/article/1321102/us-and-china-partner-small-scale-space-projects.
[205] Frank Morring, Jr., "Bolden Meets Human-Spaceflight Chief During China Visit," *Aviation Week*, December 3, 2014, http://aviationweek.com/space/bolden-meets-human-spaceflight-chief-during-china-visit.
[206] "许达哲会见美国国家航空航天局局长博尔登," [Xu Dazhe Meets with U.S. NASA Administrator Bolden], China National Space Agency, http://www.cnsa.gov.cn/n1081/n7529/n308608/656303.html.
[207] Shi Peixin, "Wang Zhaoyao Met with NASA Chief in Beijing," China Manned Space Agency, http://en.cmse.gov.cn/show.php?contentid=1469.
[208] http://landsat.usgs.gov/planned_acquisition_schedule.php

The Chinese Academy of Sciences uses imagery from the Landsat satellites for its research on environmental and land-use issues in China.[209] The use of Landsat imagery by the PLA cannot be ruled out, but due to the lower resolutions of Landsat imagery, the revisit rate of the satellites, and the availability of higher resolution from Chinese satellites, any applications may be limited to map making and observing trends in infrastructure development. For example, the U.S. military used Landsat imagery during Operation Desert Shield to create maps of the Kuwaiti theater of operations and to assist in airfield construction. Given the long deployment time before the onset of military operations during Desert Storm and the ease with which large-scale troop movements could be monitored in the desert, Landsat imagery was also used to monitor Iraqi troop deployments.[210] PLA researchers have used Landsat imagery in their research, including image fusion and map making.[211]

National Academy of Sciences

The U.S. National Academy of Sciences has created a forum for space science exchange between the National Academy of Sciences and the Chinese Academy of Sciences.[212] The first forum was held in Beijing in May 2014 to:

1. Identify and highlight the research achievements of the best and brightest young scientists currently working at the frontiers of their respective disciplines;
2. Build informal bridges between the space-science communities in China and the United States; and
3. Enhance the diffusion of insights gained from participation in the Forum to the larger space-science communities in China and the United States.[213]

Group on Earth Observations

The United States and China are members of the 90-nation Group on Earth Observations (GEO), whose mission is to "establish a comprehensive, coordinated and sustained [observation] of the Earth" in order to advance "the availability of long-term, global data and information as a basis for sound decision-making for improving human welfare; encouraging innovation and growth, [and] alleviating human suffering, including eradicating poverty; protecting the global environment; and advancing sustainable developmental [with] voluntary partnership[s]."[214] According to one source, the United States and China were the first countries to actively support establishment of the organization.[215]

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[209] See, for example, Luguang Jiang, Xiubo Yu, Huixia Yao, Yangming Zhou, "China's Wetlands Restoration Around Poyang Lake, Middle Yangtze: Evidence from Landsat TM/ETM Images," *IEEE*, 2005, 2387–89 and Hui Fengming, Cheng Xiao, Liu Yan, Zhang Yanmei, Ye Yufang, Wang Xianwei, Li Zhan, Wang Kun, Zhan Zhifei, Guo Jianhong, Huang Huabing, Li Xiuhong, Guo Ziqi, and Gong Peng, "An Improved Landsat Image Mosaic of Antarctica," *Science China* 56 (January 2013): 1–12.

[210] Robert B. Kane, "Land Remote Sensing Satellite," in Spencer C. Tucker, ed., *Persian Gulf War Encyclopedia: A Political, Social, and Military History* (Santa Barbara, CA: ABC-CLIO, 2014), 256–57.

[211] See, for example, Cong Aiyan and Lian Lian, "基于 RBF 神经网络的水深遥感研究," [Remote Sensing Image Fusion Based On Wavelet Transition], 解放军理工大学学报(自然科学版) [Journal of PLA University of Science and Technology], 1 (2013): 90–94; and Ding Jing, 利用航天遥感影像更新 1：25 万地形图数据库 [Using Space Remote Sensing Imagery for a New 1:25,000 Map Database], master's thesis, PLA University of Information Engineering, April 1, 2001.

[212] Qiu, "Head of China's Space Science Reaches Out."

[213] "Space Studies Board," National Academies website, http://sites.nationalacademies.org/SSB/SSB_086017.htm.

[214] "Geneva Convention," Group on Earth Observations, https://www.Earthobservations.org/min_declaration.php.

[215] Craig Covault, "Reopening China," *Aviation Week & Space Technology* 169, no. 9 (2008): 28–30.

CHINA'S SPACE TECHNOLOGIES

China realizes it is not alone in its drive to develop space technologies and that it still has a significant gap with the United States and other countries in advanced aerospace technology. Chinese analysts point to their country's relatively late commitment to becoming a space power as well as a lack of an ability to independently innovate.

As a result, Chinese space officials admit that they still have much more work to do to become a strong space power. According to one source, being a strong space power means having an absolute superiority in space technology that can then be expanded into other areas.[216] In order to accomplish this, one author writes that China must make progress in six broad categories of a space program's impact on technology, military and national defense, economics, management, culture, and overall effects.[217] Another source states that to be considered a strong space power China must not only be able to launch a variety of payloads into orbit, it must also be able to do so rapidly. Moreover, China must also not only have satellites of varying capabilities with long service lives, but also be able to use them effectively. Finally, China must be able to control space, described as being able to prevent its satellites from being interfered with or destroyed.[218]

Nevertheless, there is no denying that China has made tremendous progress in space technologies. Gone are the days when Chinese launchers were unreliable and China had just a few satellites in orbit. Today China has more than 100 operational satellites in orbit and has the third largest fleet of spacecraft behind the United States and Russia (See Appendix A).

Several factors have played a role in this success. First is recognition by the nation's top leadership of the importance of space to China. Chinese presidents and premiers from Jiang Zemin and Wen Jiabao to the current leadership of Xi Jinping and Li Keqiang have sought to associate themselves in public ways with the space program, in particular the human spaceflight and lunar programs. This leadership attention has translated into policy attention and ample funding of a broad range of programs.

Support for China's space program is guided by a series of goals that are to be met in five-year increments. Called "five-year plans," (FYP) these policy documents provide specific technology development goals to be met within the plan's timeframe. China is currently under the 12th FYP, which began in 2011 and will end in 2015. The 12th FYP designated the space industry as a part of the high-end manufacturing industry, one of China's seven strategic emerging industries, due to its ability to increase China's comprehensive national power and spur development in secondary industries. As a strategic emerging industry, the space program will receive preferential policy treatment and funding. Overall, the goal is to have all strategic emerging industries account for 8 percent of GDP by 2015 and 15 percent of GDP by 2020.[219]

China's five-year plans fit into a larger set of goals detailed in the 2006 Medium and Long-term Plan for Science and Technology Development (MLP). This document established a number of policies to foster

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[216] Wu Weiqiang, "浅谈航天强国评价体系研究" [A Brief Discussion on Research on the Analysis of Strong Space Power Evaluation System], 航天工业管理 [*Space Industry Management*] (March 2013): 33.
[217] Ibid., 36.
[218] "中国载人航天之父：我国离航天强国还有距离," [The Father of China of China's Space Program: Our Country is Still Far from Being a Strong Space Power], *Sina News*, June 21, 2012, http://news.sina.com.cn/c/sd/2012-06-21/163024635232.shtml.
[219] U.S.-China Business Council, *China's Strategic Emerging Industries: Policy, Implementation, Challenges, and Recommendations*, March 2013, 4.

innovation and set a number of goals for China's S&T development that are to be met in the 2006–2020 timeframe. One of the important outcomes of the MLP was the establishment of 16 mega-projects that identified 16 technology areas (13 unclassified, 3 classified) for increased funding and attention. These range from information technology to pharmaceuticals and agriculture. Space plays a prominent role in three of the megaprojects. China's space megaprojects have been unofficially dubbed the "221 Program," which refers to the two programs involving human spaceflight and lunar exploration, two programs involving earth remote sensing and Beidou satellite navigation programs, and one program involving a next generation of launch vehicles.[220]

This policy focus has also been matched by ample funding. Getting reliable data on how much China spends on its space program is difficult, but indications are that in relative terms China spends much less on space than the United States yet still manages to fund an extensive and robust program. According to one 2012 source, China invests less than 0.1 percent of its GDP on its space program. If correct, this would place China's spending on space below $8.227 billion.[221] This is in comparison to the United States, which spent $41.26 billion in 2013 on space.[222] The relatively low amount of funding is also reflected in the official budgets given for China's human spaceflight and lunar exploration programs. In 2003, Chinese officials stated that the cost of the program through Shenzhou 5 (1992–2003) was 18 billion yuan (~$2.2 billion). This included 10 billion yuan for developing the space capsule, launch vehicle, electronic and application equipment, and astronaut training. Another 8 billion yuan was spent on infrastructure, including the building of astronaut training facilities, the launch site, and the telemetry, tracking, and control (TT&C) system.[223] In 2012, a spokesperson for the China Manned Space Agency stated that the country had spent a total of 39 billion yuan ($6.35 billion) on human spaceflight, with 20 billion yuan being spent on Shenzhou flights 1–6 and 19 billion yuan being spent on Shenzhou missions 7–10.[224] The Chang'e-1 lunar orbiter, on the other hand, cost 1.0 billion–1.4 billion yuan ($130–190 million).[225]

There is apparently some concern in China on the amount of money spent on the human space program. Speaking about the human spaceflight program, Luan Enjie, former head of China's National Space Administration, admitted that "[t]here are questions about…what effect the program will have on the general economic situation. The scale of our manned program should be limited."[226]

Funding for the Beidou satellite navigation systems, however, appears to be substantial. From its initiation in 1994 to 2012, China had invested more than 16 billion yuan ($2.57 billion)[227] in Beidou and plans to

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220 Sun Laiyan, "中国航天的发展战略和重点领域" [China Space Development Strategy and Key Areas], 中国航天 [*Aerospace China*], January 2007, 7.

221 Feng Shuxing, 我国空间力量发展与空间安全的思考 [Reflection on Development of Space Power and Space Security] 装备学院学报 [*Journal of Academy of Equipment*], October 2012, 9.

222 Space Foundation, "The Space Report 2014," 4.

223 "[神舟快报] 国新版记者招待会详解神五发射" [Shenzhou News Flash] The State Council Information Office Press Conference on the Shenzhou V Launch, CCTV.com, November 4, 2003.

224 "中国载人航天预算共 390 亿元 并非一次发射 600 亿)" [The Budget for China's Human Space Flight Program is 39 Billion Yuan One Launch Does Not Cost 60 Billion Yuan], 新京报 [*Beijing News*], June 25, 2012, http://news.qq.com/a/20120625/000134.htm.

225 Bradley Perrett, Frank Morring, Jr., and Craig Covault, "Spacefarers," *Aviation Week & Space Technology*, no. 17 (2007): 26–28.

226 Craig Covault, "China Seeks ISS Role, Accelerates Space Program," *Aviation Week & Space Technology*, November 12, 2001.

227 Zhang Ke, "'北斗'今起照耀亚太区 中国版 GPS 年创产值超千亿" ['Beidou' Begins to Cover Asia China's GPS Annual Output to Exceed Billions], 低碳网 [ditan360.com], December 28, 2012.

allocate a further 40 to 50 billion yuan ($6.41–8.02 billion) from 2013 to 2020 to develop Beidou 2.[228] In addition, the country will invest 5 billion yuan ($810 million) in a Beidou industrial park.[229] These funding figures suggest Beidou is one of the most significant space projects undertaken by China. By comparison, Russia spent $694 million on its GLONASS system in 2012[230] and has budgeted more than 300 billion rubles ($10.2 billion) to further develop GLONASS and bring 30 satellites into operation by 2020. Europe has also been building the Galileo navigation system at a projected cost of $6.25 billion.[231]

Another factor contributing to China' success has been an emphasis on systems engineering, project management, and quality control. Best practices, often derived from U.S. R&D processes and developed for the human spaceflight project, appear to have been disseminated to the broader space community. An emphasis has also been placed on training and continuing education. These practices may become more fruitful and established as China's relatively young aerospace workforce gains experience.

The role of foreign technology has also played a role, although it is difficult to assess its effect due to the secretive nature of China's space program and the inability to observe most spacecraft. Nevertheless, the admission by then China Aerospace Science and Technology Corporation President Ma Xingrui in 2011 that China's space industry must move from imitative innovation to true innovation indicates that foreign technologies and designs still play an important role in China's space program.[232] In some respects this is not surprising since the acquisition of foreign technologies and know-how is a common practice for "catch-up" countries. Indeed, China's policy towards its mega-projects is inherently based on the use of foreign technologies to achieve leapfrog development.[233]

The space industry's desire for foreign technology is reflected in its cooperative activities with Europe, Russia, and Ukraine, and China's overall policy of welcoming all forms of cooperation on space activities, described earlier. In addition to the technology transfer for specific spacecraft described in the next sections, China has also been involved in illegal technology transfers that could be used for space-related applications. These include:

- The conviction of a U.S. citizen in 2013 for exporting high-grade carbon fiber to China, which has applications in the aerospace and nuclear fields.[234]

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228 "Liu Kun, "未来十年中国将投数百亿建全球北斗导航系统" [In the Coming 10 Years China Eyes Greater Market Share for its GPS Rival," 环球网 [*huanqiu.com*], December 27, 2012. http://usa.chinadaily.com.cn/business/2012-12/27/content_16062407.htm.
229 Wang Qian, "Funding Kick Starts Creative Research," *China Daily,* May 2, 2013, http://usa.chinadaily.com.cn/china/2013-05/02/content_16466336.htm.
230 "Russia to Test Second Glonass-K Satellite in 2013", *RIA Novosti,* April 17, 2012, http://en.rian.ru/science/20120417/172871888.html.
231 "Galileo Navigational System Enters Testing Stage." *Deutsche Welle,* October 13, 2012. http://www.dw.de/galileo-navigational-system-enters-testing-stage/a-16304096-1.
232 Ma Xingrui, "Continue with Indigenous Innovation and Promote the Development of China's Space Enterprise [坚持自主创新推动中国航天事业又好又快发展], *Aerospace China* [*中国航天*], 8 (2011): 6–7.
233 Ministry of Science and Technology, "State Medium and Long-term Plan for Science and Technology Development," http://www.most.gov.cn/kjgh/kjghzcq/.
234 "New York Man Sentenced in Manhattan Federal Court to Three Months in Prison for Exporting High-Grade Carbon Fiber To China," http://www.bis.doc.gov/index.php/about-bis/newsroom/press-releases/102-about-bis/newsroom/press-releases/press-releases-2013/606-new-york-man-sentenced-in-manhattan-federal-court-to-three-months-in-prison-for-exporting-high-grade-carbon-fiber-to-china.

- The conviction of a Chinese citizen in 2013 for trying to illegally export weapons-grade fiber to China.[235]
- The arrest of a U.S. citizen in 2011 on charges of illegally shipping sensitive materials to China that could be used as protective coatings on rocket nozzles.[236]
- The conviction of two Chinese nationals in 2011 for smuggling thousands of radiation-hardened computer chips to the China Aerospace Science and Technology Corporation.[237]

China's space program may also be the beneficiary of Chinese cyber espionage. In 2014, the network security firm CrowdStrike released a report detailing cyber activities against U.S. and European aerospace companies since 2007.[238] The Shanghai-based unit carrying out the attack, 61486, has been described as a unit involved in space activities and likely involved in the "intercept of satellite communications and possibly space-based signal intelligence collection."[239]

In 2014, it was reported that the German Aerospace Center was the subject of a cyber attack likely originating from China that infected all of the center's computer systems. It is unknown if or what information was compromised.[240]

Also in 2014, it was reported that Chinese hackers had stolen documents and data relating to Israel's Iron Dome missile defense system and the Arrow 3 missile. The attack first occurred in October 2011 and targeted the Israeli companies Elisra Group, Israel Aerospace Industries, and Rafael Advanced Defense Systems.[241]

In 2012, NASA Inspector General Paul Martin stated in a report that cyber attacks from Chinese IP addresses had resulted in the perpetrators gaining "full access to key Jet Propulsion Laboratory [computer] systems and sensitive user accounts."[242] According to the report,

> With full system access the intruders could: (1) modify, copy, or delete sensitive files; (2) add, modify, or delete user accounts for mission-critical JPL systems; (3) upload hacking tools to steal user credentials and compromise other NASA systems; and (4) modify

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[235] "Cyber-Sting Nets Chinese National in Attempt to Export Sensitive Defense Technology," http://www.bis.doc.gov/index.php/about-bis/newsroom/press-releases?id=538.

[236] "Manhattan U.S. Attorney Announces Arrest of Queens Resident for the Export of Military-Use Items to Taiwan and Attempting to Export Them to China," http://www.bis.doc.gov/index.php/about-bis/newsroom/archives/press-release-archives/98-about-bis/newsroom/press-releases/press-releases-2012/473-manhattan-u-s-attorney-announces-arrest-of-queens-resident-for-the-export-of-military-use-items-to-taiwan-and-attempting-to-export-them-to-china.

[237] "Chinese Nationals Sentenced 24 Months for Illegally Attempting to Export Radiation-Hardened Microchips to the PRC," http://www.justice.gov/usao/vae/news/2011/09/20110930Chinesenr.html.

[238] CrowdStrike, "Putter Panda," 2014, 5.

[239] Signals intelligence (SIGINT) is derived from electronic signals and systems, such as communications systems, radars, and weapons systems. Mark Stokes, Jenny Lin, and L.C. Russell Hsiao, "The Chinese People's Liberation Army Signals Intelligence and Cyber Reconnaissance Infrastructure," Project 2049 Institute, November 2011, 11.

[240] Swati Khandelwal, "German Aerospace Center Targeted by Self-destructing Spyware," *Hacker News*, April 14, 2014, http://thehackernews.com/2014/04/Spyware-german-aerospace-center-cyber-espionage.html.

[241] Umberto Bacchi, "Gaza: Israel's Iron Dome Blueprints Were 'Stolen by Chinese Hackers'," *International Business Times*, July 28, 2014, http://www.ibtimes.co.uk/gaza-israels-iron-dome-blueprints-were-stolen-by-chinese-hackers-1458746.

[242] Statement of Paul K. Martin, Inspector General, National Aeronautics and Space Administration, "NASA Cybersecurity: An Examination of the Agency's Information Security," February 29, 2012, 5.

system logs to conceal their actions. In other words, the attackers had full functional control over these networks.[243]

Although the extent of the damage from the Jet Propulsion Laboratory (JPL) hacking has not been revealed, JPL at the time was conducting 23 missions,[244] including missions for the Mars rovers Opportunity and Curiosity, other planetary missions to Saturn and Jupiter, the moon, earth environmental monitoring, and astronomy. Speaking broadly about compromises of NASA computer systems and the computer systems of its contractors, the NASA inspector general wrote that “some NASA systems house sensitive information which, if lost or stolen, could result in significant financial loss, adversely affect national security, or significantly impair our Nation’s competitive technological advantage” through the loss of technical and engineering data.[245] Such information could have assisted the Chinese space program in the development of its lunar rover, sensing technology such as infrared sensors and synthetic aperture radar, and the control of deep space missions.

China’s Space Projects in Detail

Human Spaceflight

China’s marquis space program is its human spaceflight program. China is just the third country to have independently launched a human into space. Overseen by the PLA’s General Armament Department, the program was officially started in September 1992 under then President Jiang Zemin and has conducted a combination of manned and unmanned launches for a total of 10 missions by the end of 2013 (Table 3). The human spaceflight program is one of China’s largest projects ever and required the services of several hundred thousand personnel and 3,000 organizations.[246] China’s human spaceflight program follows a three-step process with the goal of orbiting a 60-ton space station by 2023.

The first step in this process began in 1992 with the approval of the human spaceflight program and included development and testing of manned spaceflight technologies. China carried out its first test launch of the Shenzhou space capsule and the Long March-2F launch vehicle in 1999 and sent its first astronaut, Yang Liwei, into space in 2003 on the Shenzhou-5 capsule. It concluded in 2005 with the Shenzhou-6 mission involving multiple crew members. The second, and current, step involves extravehicular activities, space docking, and the launch of a small space laboratory. The 2008 Shenzhou-7 mission involved a spacewalk, and in 2011 the 8-ton Tiangong-1 space station was launched. Subsequent missions tested docking procedures between the Shenzhou space capsule and the space station and involved two extended habitations by three member crews, including female astronauts, to Tiangong-1. The third and final step involves the launch of a larger 60-ton space station by 2023 and a long-term human presence in space.[247]

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243 Ibid.

244 “Chinese Hackers ‘Had Full Access’ to NASA Lab that Commands 23 Spacecraft,” *Daily Mail*, March 7, 2012, http://www.dailymail.co.uk/sciencetech/article-2110506/Chinese-hackers-control-Nasa-lab-commands-23-spacecraft.html.

245 Statement of Paul K. Martin, 1.

246 Chen Ding, “专家访谈：中国航天人的差距观” [Expert Interview: The Viewpoint of Industry People on the Gaps in China’s Space Program], China National Space Administration, http://www.cnsa.gov.cn/n615708/n942529/n942833/70610.html.

247 “CMSP,” *China Manned Space Engineering*, http://en.cmse.gov.cn/list.php?catid=42.

Table 3. China's human spaceflight missions

Mission	Launch Date	Approximate Launch Interval	Flight Time	Purpose
Shenzhou-1	20 November 1999	NA	21 hours	Test
Shenzhou-2	10 January 2001	14 Months	7 days	Test
Shenzhou-3	25 March 2002	14 Months	7 days	Test
Shenzhou-4	30 December 2002	9 Months	7 days	Test
Shenzhou-5	15 October 2003	10 Months	21 hours	Manned (1 crew)
Shenzhou-6	12 October 2005	24 Months	4+ days	Manned (2 crew)
Shenzhou-7	25 September 2008	35 Months	2+ days	Manned (3 crew EVA)
Tiangong-1	29 September 2011	NA	36 months (ongoing)	Prototype space lab
Shenzhou-8	1 November 2011	37 months	17 days	Unmanned (docking)
Shenzhou-9	16 June 2012	7.5 months	13 days	Manned (3 crew docking)
Shenzhou-10	11 June 2013	12 months	15 days	Manned (3 crew docking)

Shenzhou Space Capsule

The Shenzhou spacecraft was developed by the China Academy of Space Technology.[248] The nearly 7.8-ton, 8.86-meter craft can support up to three people for seven days and is divided into three sections: an orbital module, a descent module, and a propulsion module. The Shenzhou is the largest spacecraft of its kind and is slightly larger than the Russian Soyuz space capsule.[249]

Shenzhou's orbital module has been outfitted with scientific equipment and optical imagers with a resolution of 1.6 meters, and is rumored to have electronic intelligence capabilities.[250] Shenzhou missions 1–6 had two sets of solar panels, one on the orbital module and one on the propulsion module, enabling the orbital module to remain functional for up to six months to conduct scientific experiments and earth observation.[251] The Shenzhou 7–10 missions had just one set of solar panels, however. Shenzhou-7 lost its solar panels to accommodate a spacewalk, and the solar panels on the orbital module for Shenzhou missions 8–10 were unnecessary due to the reconfiguration of the orbital module into a docking module.

[248] "Shenzhou III Unmanned Spacecraft Successfully Launched," *People's Daily*, March 25, 2002, http://english.people.com.cn/200203/25/eng20020325_92794.shtml.
[249] "Facts and Figures: China's First Manned Spaceship," *People's Daily*, October 16, 2003, http://english.people.com.cn/200310/16/eng20031016_126187.shtml.
[250] Wei Long, "New Details of Shenzhou and Its Launcher Revealed," *Space Daily*, April 1, 2002, http://www.spacedaily.com/news/china-02zf.html.
[251] Craig Covault, "China Seeks ISS Role, Accelerates Space Program," *Aviation Week & Space Technology*, November 12, 2001.

Table 4. Comparison of Shenzhou 5 space capsule and Soyuz TM

Description	Shenzhou	Soyuz TM
Length	8.86 meters	7 meters
Liftoff mass	7. 8 tons	7 tons
Descent module volume	6 cubic meters	4 cubic meters
Descent module diameter	2.5 meters	2.2 meters
Solar panels	2 pair	1 pair
Orbital module	6 month orbital capability	N/A

It is not a coincidence that the Shenzhou space capsule is similar in appearance to the Russian Soyuz (Table 4). Before designing Shenzhou, Chinese engineers looked at both the Soyuz and Apollo spacecraft designs and chose the Soyuz due to its long safety record.[252] But China has also received technological assistance from Russia. In 1995, China purchased a complete life support system, an Energiya docking module, and a Kurs rendezvous system from Russia.[253] Chinese officials assert, however, that the Shenzhou is entirely designed and constructed by China. According to Su Shuangning, the chief designer of the space capsule's astronaut systems, "All crucial technologies and equipment of our nation's manned space engineering are developed by us. Undoubtedly, we have learned and imported some advanced technology from others, but Chinese characteristics cannot be sacrificed despite this openness, and any introduction of foreign technology must be supplementary to domestic innovation."[254] Indeed, a look at the control panels in the cockpits of the Shenzhou and Soyuz demonstrate that Chinese engineers sought their own path in developing some of the spacecraft's electronic components, but examination of the parachute compartments on the two spacecraft reveal an uncanny resemblance to the Soyuz. China's use of a combination of foreign and domestic technology has culminated in a product that is said to be equivalent to Soviet 1980s or 1990s technology.[255]

Tiangong-1 Space Station

Tiangong-1 (天宫-1/Heavenly Palace) is described as an experimental space station and is often called a space laboratory. Tiangong-1 was launched on September 29, 2011. It was developed by the China Academy of Space Technology and has a mass of 8.5 tons, is 10.4 meters in length, and is 3.35 meters at its widest point. The interior of Tiangong-1 is 15 cubic meters and can house three astronauts.[256] In comparison, the International Space Station has a mass over 400 tons, is 51 meters long, with an interior

[252] Zhu Zengquan, "中国飞船- 中国载人航天工程总设计师王永志访谈录" [China's Space Capsule: An Interview with China Human Space Flight Project Chief Engineer Wang Yongzhi], *People's Daily*, October 17, 2003, http://scitech.people.com.cn/GB/1059/2138482.html.
[253] Harvey, *China's Space Program,* 147.
[254] Li Xianqing and Liu Cheng, "神舟四飞太空告诉我们 。。。" [What Shenzhou IV Tells Us about Its Space Journey], 解放军报 [*PLA Daily*], January 7, 2003, http://www.chinamil.com.cn/gb/pladaily/2003/01/07/20030107001009_todaynews.html.
[255] "神舟专家揭密载人飞船 航天员有望 2 年内升空" [Shenzhou Expert Reviews Space Capsule, Astronauts Hope to Reach Space in Two Years], china.com.cn, April 2, 2002, http://www.china.com.cn/chinese/TEC-c/126675.htm; "Reason for China's Development of Manned Spacecraft," *People's Daily*, January 16, 2003, http://english.peopledaily.com.cn/200301/16/eng20030116_110254.shtml.
[256] "天宫一号承载梦想上九霄 中国载人空间站建设大幕开启" [Tiangong-1 Bearing the Weight of the Dream Goes into the Heavens: China's Manned Space Station Begins], September 30, 2011, http://www.spacechina.com/n25/n144/n212/n309/n312/c113447/content.html.

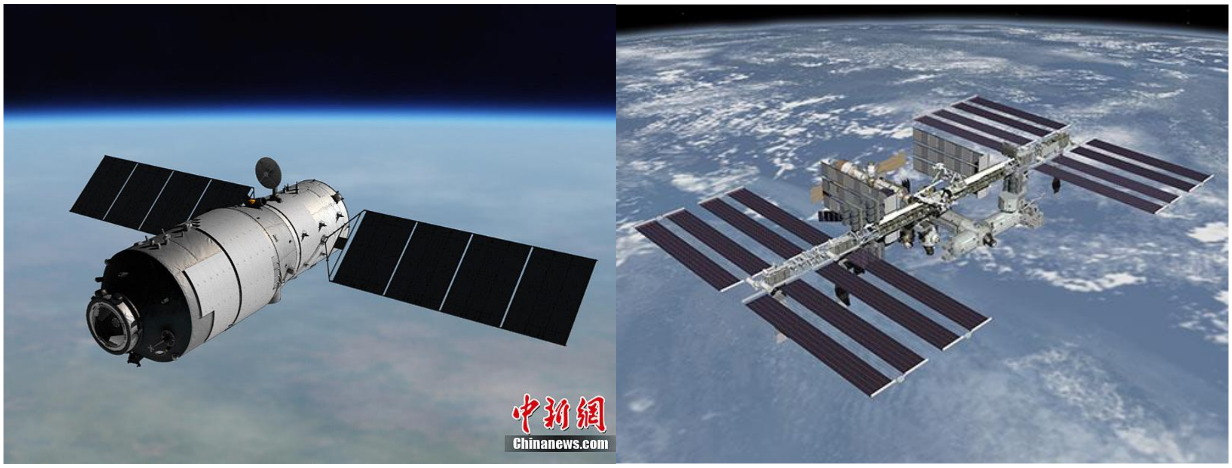

Figure 2. The Tiangong space station (left) and the International Space Station (right)

volume of 916 cubic meters and has housed up to six astronauts (see Figure 2).[257] Tiangong-1 was designed to have a service life of two years, but as of writing is still in orbit after three years. The follow-on to Tiangong-1, Tiangong-2, is to be launched in 2016.[258]

Long-term Space Station

The first of three modules for China's 60-ton space station is expected to be launched in 2018, with additional modules planned for launch in 2020 and 2022. China is still considering how best to use the space station. According to an official from the Chinese Academy of Sciences, the space station will be used to study applied physics, the origins of life, and black holes. The space station will also conduct earth observation, presumably with remote sensing equipment onboard the space station.[259]

Shenzhou Missions in Detail

Shenzhou-1

Shenzhou-1 was launched November 20, 1999 and returned to Earth 21 hours later on November 21 after orbiting the Earth 14 times.[260] The Shenzhou 1 space capsule was originally a test capsule used to test the electrical system and was not originally designed to go into space.[261] As a result, the main objectives of this first mission were to test the guidance, navigation, and control systems and reentry, separation, landing, and heat-resistant technologies.[262]

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[257] "International Space Station: By the Numbers," *Space.com*, August 03, 2010, http://www.space.com/8876-international-space-station-numbers.html; "International Space Station: Facts and Figures," NASA, accessed February 10, 15, https://www.nasa.gov/mission_pages/station/main/onthestation/facts_and_figures.html.

[258] "我国 2016 年将发射"天宫二号"空间实验室," [Our Country Will Launch Tiangong-2 Space Laboratory in 2016], 人民网, [People's Net], September 10, 2014, http://military.people.com.cn/n/2014/0910/c1011-25634041.html.

[259] Luo Wangshu, "Earlier Launch Possible for Space Station Modules," *China Daily*, July 18, 2014, http://usa.chinadaily.com.cn/china/2014-07/18/content_17831873.htm.

[260] Michael Laris, "Chinese Test Craft for Manned Orbits," *Washington Post*, November 22, 1999.

[261] Deng Ningfeng, ed., 天河圆梦 [*Dream About the Milky Way Fulfilled*] (Beijing: China Astronautics Press, 2004), 158.

[262] Zhu Zengquan, ed., 飞天梦圆：一来自中国载人航天工程的内部报告 [*The Realized Dream of Human Space Flight: Taken From the Internal Report of China's Human Space Flight Program*] (Beijing: Huayi Press, 2003), 122–24.

Shenzhou-2

Shenzhou-2 was launched January 10, 2001, and returned to Earth January 16, 2001. It was characterized as a "basic" space capsule in which many of the components used in the first Shenzhou flight had to be redesigned or reworked.[263] This includes the solar panels, which had to undergo further vibration testing.[264] Shenzhou-2 orbited the Earth 108 times, during which hundreds of orbital maneuvers were performed.[265] The main tasks for this mission were to test the reliability, compatibility, and safety of the capsule's systems and to conduct orbital maneuvers.

Shenzhou-2 is the only mission in which photos of the returned spacecraft were not released to the public. Chinese officials denied that any mishap occurred until General Armament Department head Li Jinai admitted in a 2003 *China Space News* article that "the descent did not completely reach our planned goals."[266] China has not revealed the cause of the mishap, but problems with the drogue parachute, the spacecraft's main parachute, or landing rockets could have caused a catastrophic hard landing. Shenzhou-2's orbital module stayed in orbit for 260 days after the return of the descent module.[267]

Shenzhou-3

Shenzhou-3 was launched March 25, 2002, and returned to Earth April 1.[268] The primary focus of the Shenzhou-3 mission was the testing of safety systems, including "assessing the functionality, reliability, and safety of each manned space flight system; coordination among different systems; the spacecraft environment for manned flight; the effectiveness of the improved measures that have been implemented; the escape and emergency life support systems; and the capability of the launcher's redundant control system."[269] On landing, Chinese human spaceflight program leaders declared the Shenzhou space capsule "technically suitable for astronauts."[270]

As with previous missions, the orbital module of Shenzhou-3 stayed in orbit for nearly 232 days and reentered the atmosphere on November 12, 2002, during which time ground controllers issued 2,000 commands.[271] These tests allowed ground operators to control the craft within 100 meters of its intended orbit.[272] Unlike Shenzhou-2, Shenzhou-3 carried a "simulated person" to monitor the effects of the capsule's internal environment on humans.[273]

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263 Ibid, 124.
264 Deng, *Dream About the Milky Way Fulfilled*, 236.
265 David Whitehouse, "Chinese Launch Capsule," BBC, March 25, 2002.
266 Li Jinai, "难忘的历史时刻" [An Unforgettable Historical Moment], 中国航天报 [*China Space News*], November 12, 2003, 2.
267 "Shenzhou Expert Reveals Secrets of Human Space Flight."
268 Ibid.
269 Cheng Ho, "Shenzhou-5 May Carry Out First Chinese Manned Mission," *Terra Daily*, April 9, 2002, http://www.terradaily.com/reports/Shenzhou5_May_Carry_Out_First_Chinese_Manned_Mission.html.
270 "Shenzhou III Unmanned Spacecraft Returns," *People's Daily*, April 1, 2002, http://english.people.com.cn/200203/25/eng20020325_92794.shtml.
271 "Shenzhou Expert Reveals Secrets of Human Space Flight."
272 Wei Long, "Shenzhou-3 Module Reentry Wraps Up Long-Duration Mission," *Space Daily*, November 25, 2002, http://www.spacedaily.com/news/china-02zzi.html.
273 "Exploring the Secrets of the Astronauts of the Shenzhou Spaceship: Dummy Astronauts on Board Shenzhou-3," *People's Daily*, April 6, 2002.

Shenzhou-4

Shenzhou-4 was launched December 30, 2002, and returned to Earth January 5, 2003. With the successful completion of the Shenzhou-4 mission, China stated that China's human space flight program had grown "increasingly mature, which lays a solid foundation for eventually sending up manned flights."[274] The Shenzhou-4 mission was a dress rehearsal for the Shenzhou-5 mission and included "all the systems for manned space flight, including an astronaut system and [a] life-support sub-system"[275] as well as a sleeping bag, food, medicine, fire extinguisher, hygiene articles, and other necessities.[276]

Shenzhou-5

Shenzhou-5 was launched October 15, 2003, and was China's first manned spaceflight. Shenzhou-5's mission schedule was similar to the Shenzhou-1 launch, encompassing 14 orbits.[277] Air Force Lt. Colonel Yang Liwei, selected as an astronaut in 1998, became China's first astronaut. During the flight Yang spoke with President Hu Jintao, the minister of national defense, and his family.

The capsule landed safely on October 16, 2003. Yang emerged from the capsule waving to the camera and was immediately ushered into a nearby chair. Shortly thereafter Yang was announced to be in good physical health and Chinese Premier Wen Jiabao congratulated Yang, stating "the motherland and people express thanks to you."[278] It was later revealed, however, that Yang had suffered a cut lip due to excessive g-forces during reentry and had to be cleaned up and put back in the capsule so he could emerge again for photos.[279]

Shenzhou-6

Shenzhou-6, China's second manned mission, was launched on October 12, 2005, and remained in orbit for more than four days. Shenzhou-6 was crewed by two astronauts with the purpose to gain experience in "multi-person and multi-day" flight.[280] The Shenzhou-6 space capsule contained more than 180 technical improvements, but the main mission of Shenzhou-6 was to learn how to operate in space for extended periods of time.[281] In addition to learning to live in a microgravity environment, the astronauts conducted a number of unknown scientific experiments.[282]

Shenzhou-7

Shenzhou-7 is the only Chinese mission involving an extravehicular activity (EVA). It was launched September 25, 2008, and returned on September 28, 2008 (see Figure 3). The mission was crewed by three astronauts. The Shenzhou-7 mission made a number of technological breakthroughs, including

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274 "China's Unmanned Spaceship Lands," *People's Daily*, January 6, 2003.

275 Ibid.

276 Li Heng, "Shenzhou IV Strictly Identical with Manned Spacecraft: General Director," *People's Daily*, December 31, 2002, http://china.org.cn/english/scitech/52515.htm.

277 "China's Manned Spacecraft Completes Orbit Shift," *People's Daily*, October 15, 2003, http://english.peopledaily.com.cn/200310/15/eng20031015_126092.shtml.

278 "Timeline of the Launch and Recovery of Shenzhou V," *People's Daily*, October 16, 2003, http://english.peopledaily.com.cn/200310/16/eng20031016_126192.shtml.

279 Andrew Jacobs, "In Leaked Lecture, Details of China's News Cleanups," *New York Times*, June 3, 2010.

280 "Shenzhou VI Manned Spaceship Flight," *China Manned Space Engineering*, http://en.cmse.gov.cn/list.php?catid=61.

281 "中国载人航天新起点 新跨越 新高度" [China's Human Spaceflight's New Starting Points New Advances New Heights], CCTV (Online) (中央电视台), http://www.cctv.com/news/china/20051126/100788.shtml.

282 Ibid.

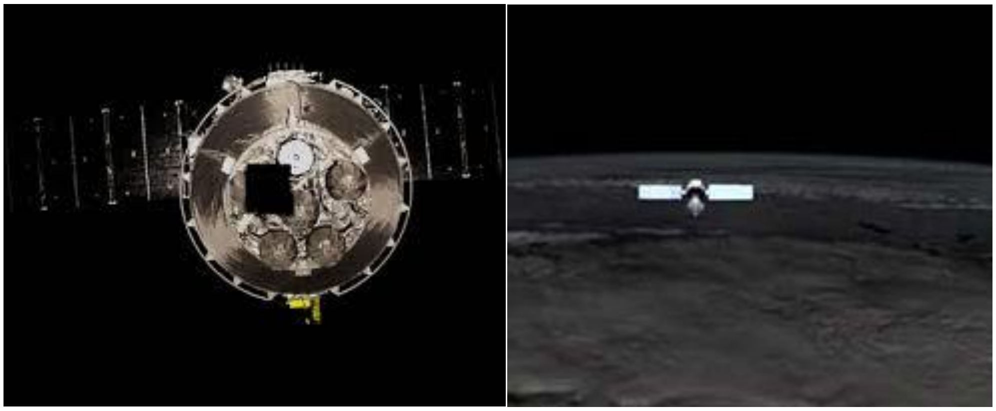

Figure 3. Two photographs of the Shenzhou-7 taken by the Banxing-1 satellite.

those for airlocks, EVA, data relay satellite, missions involving a three-person crew, and concomitant satellite technologies.[283]

On September 27, astronaut Zhai Zhigang conducted an EVA using a Chinese-made spacesuit called *feitian*. Zhai left the vehicle but was tethered to the spacecraft. A second astronaut, Liu Boming, remained in the orbital module wearing a Russian-made spacesuit. During the 20-minute spacewalk, Zhai retrieved a solid lubricant that had been attached to the outside of the orbital module to both test the spacesuit and gain experience in conducting EVAs and to test the effects of the space environment on the lubricant.[284]

In addition to the astronautic mission, the Shenzhou-7 mission also involved the release of a miniature satellite, Banxing-1 (伴星/BX-1/Companion Satellite), that flew around Shenzhou-7 at a distance of several tens of meters to several hundred meters. After the astronauts departed for Earth, BX-1 orbited Shenzhou-7 at a distance of one to two hundred kilometers. BX-1 was equipped with two cameras that took images of Shenzhou-7. The stated reason for the BX-1 was to test the orbiting of a spacecraft with the Shenzhou 7 to prepare for an eventual docking mission with a space station.[285]

The BX-1 mission was involved in some controversy when it passed within 45 kilometers of the International Space Station, leading some to conclude that the mission was also a test of a co-orbital ASAT capability[286] or that it was testing satellite inspection capabilities.[287] The proximity of the BX-1 did not

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283 "Shenzhou VII Manned Spaceship Flight," *China Manned Space Engineering*, http://en.cmse.gov.cn/list.php?catid=62.

284 "Chinese Taikonaut Greets Nation, World in First Spacewalk," Xinhuanet, September 27, 2008, http://news.xinhuanet.com/english/2008-09/27/content_10121998.htm.

285 "伴飞小卫星将"追赶"分离后的神七轨道舱" [Small Companion Satellite Will Chase After the Shenzhou 7 Orbital Capsule After Separation], Xinhuanet, September 24, 2008, http://news.xinhuanet.com/newscenter/2008-09/24/content_10104787.htm; "Shenzhou-7 Launches Small Monitoring Satellite," Xinhuanet, September 27, 2008, http://news.xinhuanet.com/english/2008-09/27/content_10123015.htm; "伴飞小卫星将给神七 '照相'" [Small Companion Satellite Will Take Photographs of Shenzhou 7], Xinhuanet, September 24, 2008, http://news.xinhuanet.com/newscenter/2008-09/24/content_10104656.htm.

286 "Closer Look: Shenzhou-7's Close Pass by the International Space Station," International Assessment and Strategy Center, October 9, 2008, http://www.strategycenter.net/research/pubID.191/pub_detail.asp.

287 "China's BX-1 Microsatellite: A Litmus Test for Space Weaponization," *Space Review*, October 20, 2008, http://www.thespacereview.com/article/1235/1.

present a hazard to the International Space Station. The Shenzhou-7 mission was also the first human spaceflight mission to use the Tianlian data relay satellite to communicate with ground control.[288]

Shenzhou-8

Shenzhou-8 was an unmanned mission launched November 1, 2011, that was intended to test docking technologies and docking procedures with the Tiangong-1 space station. The mission was completed on November 17, 2011, when Shenzhou-8 returned to Earth. Shenzhou-8 conducted two dockings. It first docked on November 3 and remained docked with Tiangong-1 for 12 days. On November 14, Shenzhou-8 was separated from Tiangong-1 and then redocked.[289]

In order to conduct the docking, the Shenzhou-8 orbital module was outfitted with a docking mechanism based on the Russian Androgynous Peripheral Attach System (APAS),[290] and a microwave radar, laser radar and a high-resolution imaging sensor to monitor the distance between the space capsule and space station.[291] According to an ESA official, the dockings experienced difficulties. Due to its relatively low mass, the Shenzhou space capsule kept bouncing off the Tiangong-1 space station, requiring the space capsule to be rammed into the space station at speeds too high to be considered safe.[292]

Shenzhou-9

Shenzhou-9 was the first manned mission to Tiangong-1 and the first mission to have a female astronaut. In total, three astronauts participated in the Shenzhou-9 mission. Shenzhou-9 was launched June 16, 2012, and returned to Earth on June 29. Its goals were to further test China's docking technology and procedures and to test the ability of Tiangong-1 to support human spaceflight.[293] Shenzhou-9 conducted two dockings with Tiangong-1. The first occurred on June 18. The second occurred on June 24 and was the first manual docking conducted by China.[294] During their stay in Tiangong-1, the astronauts conducted a number of space physiological studies and microbiological experiments.[295]

Shenzhou-10

Shenzhou-10 was the second manned mission to Tiangong-1. With this mission, the Shenzhou ended its status as an experimental spacecraft and officially became operational, indicating that major technological revisions had been completed.[296] Like Shenzhou-9, Shenzhou-10 had a crew of three, one of whom was a woman. Shenzhou-10 was launched June 11, 2013, and is China's longest human spaceflight mission,

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[288] Tianlian satellites are discussed in further detail later in the paper.
[289] "China Completes Second Space Docking Test," Xinhuanet, November 14, 2011, http://news.xinhuanet.com/english2010/china/2011-11/14/c_131246417.htm.
[290] "Europe May Work with China on Space Station," Space.com, February 26, 2013, http://www.space.com/19960-china-space-station-europe-cooperation.html.
[291] "2nd Docking of Tiangong-1 and Shenzhou-8 on Schedule," Xinhuanet, November 7, 2011, http://news.xinhuanet.com/english2010/video/2011-11/07/c_131233226.htm.
[292] "Europe May Work With China on Space Station."
[293] "Tiengong I/Shenzhou IX Manned Rendezvous and Docking Mission," China Manned Space Engineering, http://en.cmse.gov.cn/list.php?catid=206.
[294] "China's First Manual Space Docking Successful," Xinhuanet, June 24, 2012, http://news.xinhuanet.com/english/sci/2012-06/24/c_131672642.htm.
[295] "Five Space Medical Experiments Succeed Onboard Unified Tiangong 1 and Shenzhou 9," Youtube (video), June 23, 2012, https://www.youtube.com/watch?v=HV4FWYTVLsU.
[296] "China's Shenzhou-10 Mission Successful," Xinhuanet, June 26, 2013, http://news.xinhuanet.com/english/sci/2013-06/26/c_132488807.htm.

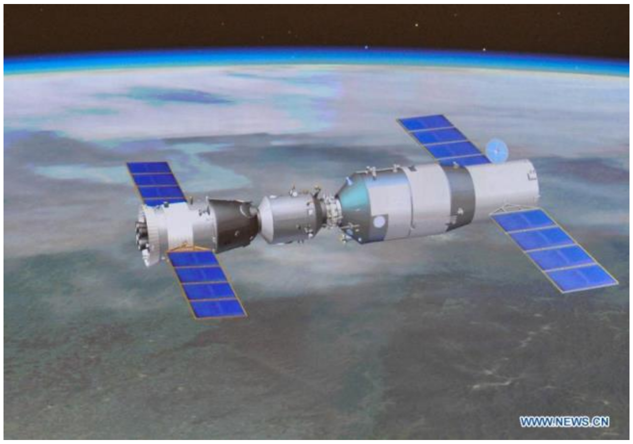

Figure 4. Shenzhou-10 (left) docked with the Tiangong-1 (right). Artist simulation.

lasting 15 days. The goal of the Shenzhou-10 mission was to further verify rendezvous and docking technology and the ability of Tiangong-1 to support human spaceflight, to conduct space physiological and space science experiments and maintenance on Tiangong-1, and test the function of Tiangong-1's systems.

Like Shenzhou-9, the Shenzhou-10 crew performed a second docking with Tiangong-1 (see Figure 4). This time the Shenzhou-10 faced in a forward-flying position while the Tiangong-1 faced in a backward-flying position. The Shenzhou space capsule was then guided around the Tiangong-1 and docked. This was the first time that the space capsule had been flown around the Tiangong space station and docked.[297]

Shenzhou-10 was the last mission to Tiangong-1.

Lunar Exploration Program

China's lunar exploration program, Chang'e, also involves three steps, which are intended to culminate in a robotic mission that will gather lunar soil samples and return them to Earth. The program is described as a "major strategic decision by the Party Central Committee, State Council, and CMC taking a broad look at our country's overall modernization and construction by grasping the world's large S&T events and promoting our country's space enterprise development, promoting our country's S&T advancement and innovation, and improving our country's CNP."[298]

The first step of the lunar exploration program was to orbit and take images of the moon. In 2007 China launched Chang'e 1 and in 2010 launched Chang'e-2 (Table 5). Chang'e-1 resulted in the first complete map of the lunar surface and was later purposefully crashed into the lunar surface to analyze lunar soil.[299] The Chang'e-2 also orbited the moon, but at a lower altitude which resulted in images with a greater resolution. After completing its lunar mission, Chang'e-2 orbited to the La Grangian point L2 to test China's ability to control deep space objects. The spacecraft then conducted a flyby of the asteroid 4179 Toutatis.

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[297] "Tiengong I/Shenzhou X Manned Spaceflight Mission."
[298] "许达哲：以'探月梦'托起'中国梦'," [Xu Dazhe: 'Lunar Exploration Dream' Upholds the 'China Dream'], http://www.sastind.gov.cn/n132/n230/n18088/c242836/content.html.
[299] "China Publishes First Full Map of the Moon Surface," SSERVI, http://sservi.nasa.gov/articles/china-publishes-first-full-map-of-the-moon-surface/.

Table 5. Chang’e launches

Spacecraft	Launch Year	Notes
Chang’e-1	2007	Lunar Orbiter
Chang’e-2	2010	Lunar Orbiter
Chang’e-3	2013	Lunar Rover Malfunctioned after landing
Chang’e-5	2014	Lunar flyby and Earth return mission

Chang’e-3 represented the second stage of China’s lunar exploration program and involved landing a robotic rover similar to the Mars rovers employed by the United States. The purpose of the Chang’e-3 was to study the lunar surface. With the successful landing of Chang’e-3 in 2013, China is just the third country to conduct a landing on the moon.

The most recent lunar exploration mission was the Chang’e-5T1. This mission involved a lunar flyby and a reentry of the Earth’s atmosphere. The Chang’e-5T1 mission has paved the way for the third phase of the lunar exploration program, the landing and return of a robot. During this phase, soil samples of the moon will be collected and returned to Earth.[300]

Consideration of a lunar exploration program began in 1991 when Chinese scientists began preliminary work under the 863 Program. In 1994, the first feasibility study was completed. In 2000, China’s first space white paper stated that China had begun preliminary research on a lunar exploration program, and in 2002 China publicly announced that it had begun a lunar exploration program. In 2004 the development program was formally started.[301]

China conducts lunar exploration for a variety of reasons. Like human spaceflight, lunar exploration is said to be able to increase China’s comprehensive national power. Prestige appears to be a main motivation of the program and China has generated positive publicity by being just one of three countries to have conducted a robotic soft landing on the moon. Science is also an important motivation, and China has conducted numerous scientific studies through its Chang’e program that have added to our knowledge of the moon. A third motivation is the development of technology, in particular the ability to control spacecraft in deep space.

A final motivation unique to China is the exploitation of the moon’s natural resources. China’s scientific exploration of the moon has centered on the composition of the lunar surface. Chinese analysis concludes that the moon contains large amounts of 14 elements that could be useful to industry, including iron, titanium, uranium, thorium, and potassium. Chinese researchers are particularly interested in helium-3. A controversial mission for the Chang’e program, helium-3 could be used to power a future nuclear fusion reactor, if one is ever invented. Chinese analysts write that 100 tons of helium-3 could power all of the Earth’s energy needs for one year and that there is 1 million to 5 million tons of helium-3 on the moon. [302]

[300] “我国月球探测工程的发展规划” [Our Country’s Lunar Exploration Project’s Development Plan], accessed September 11, 2014, http://www.cnsa.gov.cn/n1081/n7499/n314807/n330895/331346.html.
[301] “中国嫦娥工程的’大三步’和’小三步’” [China’s Chang’e Program ‘Three Large Steps’ and ‘Three Small Steps’], China News Service, December 1, 2013, http://www.chinanews.com/mil/2013/12-01/5565595.shtml.
[302] Deng Yongchun and Ouyang Ziyuan, “嫦娥一号绕月探测—中国航天迈向深空” [Chang’e-1 Lunar Exploration: China’s Space Program Marches Toward Deep Space], 航天器工程 [*Spacecraft Engineering*], November 2007, 48–50.

At an estimated value of $4 billion to 10 billion per ton,[303] Chinese analysts conclude that the revenue derived from mining helium-3 could be economically viable and could cover the costs of the infrastructure needed for such a technologically complex endeavor.

Chang'e-1 and 2

The first step of the lunar exploration program involved using the Chang'e-1 and Chang'e-2 lunar orbiters, launched in 2007 and 2010, respectively, to take images of the lunar surface. The Chang'e-1 mission resulted in the first complete map of the lunar surface[304] and was later purposefully crashed into the lunar surface to analyze the lunar soil. Chang'e-2 also orbited the moon, but at a lower altitude, which resulted in images with a one-meter resolution. After completing its lunar mission, Chang'e-2 traveled to the La Grangian point L2 to test China's ability to control deep space objects. The spacecraft then conducted a flyby of the asteroid 4179 Toutatis and imaged the asteroid.

Chang'e-1 was launched October 24, 2007, and entered lunar orbit on November 5, 2007, when it entered into an orbit 200 km above the moon. Chang'e-1's mission was to take three-dimensional images of the lunar surface, measure the depth of its regolith, and assess the composition of the lunar surface by mapping up to 14 chemical elements. The launch was originally scheduled for April 2007 but was postponed until October for unknown reasons.[305] According to chief designer Sun Jiadong, the Chang'e-1 "is much heavier than that of developed nations, even though the quality is otherwise the same and the products meet the same technical criteria."[306]

The Chang'e-1 is described as the most sophisticated satellite China had produced up until that time due to the variety of missions it needed to conduct as well as the need to conduct 10 maneuvers to reach the moon. According to Huang Jianchuan, a deputy chief designer for the program, Chang'e-1 "adopted a large amount of new technology, smart enough to find a correct path, make the right maneuvers, diagnose and repair equipment breakdowns by itself."[307]

Indeed, the TT&C system for the Chang'e missions is described as the most difficult challenge of the program since China could not have line of sight communications using control centers within its territory. In addition, the Chang'e-1 controllers had to follow a careful balancing act in which the spacecraft's sensors had to face the moon to collect data, its antennas had to face the Earth to communicate with ground control, and its solar panels had to face the sun (see Figure 5).[308]

To control the spacecraft, China built two dish antennas: a 50-meter diameter antenna near Beijing and a 40-meter diameter antenna near Kunming, Yunnan Province. The European Space Agency assisted CNSA in the tracking effort by allowing it to track a European lunar spacecraft launched in 2003.[309] In addition,

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303 Sima Hangren, "月球能源离我们有多远" [Lunar Resources Are How Far Away From Us], 中国航天 [*Aerospace China*], October 2006, 25.

304 "China Publishes First Full Map of the Moon Surface," SSERVI, http://sservi.nasa.gov/articles/china-publishes-first-full-map-of-the-moon-surface/.

305 "Chang'e-1 Satellite Launch Delayed," CRIEnglish.com, March 15, 2007, http://english.cri.cn/2906/2007/03/15/1261@205784.htm.

306 Bradley Perrett and Joseph C. Anselmo, "Steps to the Moon," *Aviation Week & Space Technology* 167, no. 18 (2007): 29–30.

307 Ibid.

308 Bradley Perrett, Frank Morring, Jr., and Craig Covault, "Spacefarers," 26–28.

309 Ibid.

Figure 5. Chang'e-1 spacecraft

ESA also provided TT&C support at its stations in Maspalomas, Canary Islands; and Kourou, French Guiana. This was the first time that a command was issued from an ESA station to a Chinese spacecraft.[310]

ESA and CNSA will also share data and scholarly exchanges on lunar exploration. According to Hermann Opgenoorth, head of ESA's Solar System Missions Division, "Participation in Chang'e-1 gives European scientists and ESA experts a welcome opportunity to maintain and pass on their expertise and to continue their scientific work. Based on the experience gained with this first mission, we intended to cooperate on the next missions in China's Chang'e line of lunar explorers."[311]

Chang'e-1 was charged with several missions. In addition to taking the first three-dimensional map of the entire moon's surface[312] and mapping the moon's resources, Chang'e-1 also assessed the thickness of the lunar soil and analyzed the space environment between the Earth and the moon.[313]

In order to conduct these missions, the Chang'e-1 was equipped with an electro-optical imager and a laser altimeter to produce three-dimensional images of the lunar surface, a spectrometer and a gamma and x-ray spectrometer to identify the composition of the lunar surface, a microwave radiometer to measure temperature variations on the lunar surface and its depth, and a high energy particle detector and solar wind detector to collect data on the space environment.[314]

The Chang'e-1 mission resulted in several scientific accomplishments. The three-dimensional images taken by the lunar orbiter resulted in a map of the entire lunar surface that was released on November

[310] "Chang'e-1 (Lunar-1 Mission of China)," eoPortal Directory, https://directory.eoportal.org/web/eoportal/satellite-missions/c-missions/chang-e-1.
[311] "Chang'E-1 New Mission to Moon Lifts Off," ESA, October 24, 2007, http://www.esa.int/Our_Activities/Space_Science/SMART-1/Chang_e-1_-_new_mission_to_Moon_lifts_off.
[312] Deng Yongchun and Ouyang Ziyuan, "嫦娥一号绕月探测—中国航天迈向深空" [Chang'e-1 Lunar Exploration: China's Space Program Marches Toward Deep Space], 航天器工程 [*Spacecraft Engineering*], November 2007, 48–50.
[313] Ibid.
[314] "Chang'e-1 (Lunar-1 Mission of China)."

12, 2008.[315] Remote imagery of the moon also provided additional information on the exact shape of the moon. Chang'e-1 also conducted the first multi-channel microwave sensing of the lunar surface allowing the measurement of thermal variance in the lunar soil and its thickness, which could assist in the location of helium-3.[316]

Chang'e-2

Chang'e-2 was launched October 1, 2010, China's national day, and entered the moon's orbit October 9, 2010. Chang'e-2 is still operating in deep space after four years of service. In July 2014, the spacecraft was 100 million km from Earth.[317] The cost of the development of Chang'e-2 was 900 million RMB.[318]

The Chang'e-2 took a more direct route to the moon than Chang'e-1, taking 112 hours or almost five days to reach the moon as opposed to the 12 days it took Chang'e-1.[319] The Chang'e-2 also flew at 100 km above the moon, half as high as the Chang'e-1, in order to take images with one-meter resolutions. The Chang'e-2 was also equipped with more precise instruments to detect lunar elements.[320] In addition, because three-dimensional mapping of the lunar surface had already been completed, Chang'e-2 was not equipped with stereoscopic imagers and instead used a high-resolution electro-optical imager.[321]

Chang'e-2 also had different mission goals from the Chang'e-1. These include making high-resolution images of the moon's poles and Rainbow Bay, the landing site of Chang'e-3. Because Chang'e-2 had fuel remaining after completing its missions, it left the moon's orbit to travel 77 days to the L2 La Grange point to test China's deep space TT&C network. China is just the third country behind the United States and Europe to have sent a satellite to L2.[322] After completing its mission at L2, in April 2012 Chang'e-2 went to image an asteroid, Toutatis, passing within two miles of the object. [323]

Chang'e-3

The Chang'e-3 mission began the second stage of China's lunar exploration program, consisting of landing a lunar rover on the surface of the moon (see Figure 6). The Chang'e-3 began development in 2008 with

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315 "嫦娥一号所拍中国首幅月球全图发布 (组图))" [Chang'e-1 in One Shot Releases China's First Full Picture of the Moon], *Sina News*, November 12, 2008, http://mil.news.sina.com.cn/s/2008-11-12/1559529860.html.

316 "China's Lunar Probe Chang'e-1 Impacts Moon," *People's Daily*, March 2, 2009, accessed September 11, 2014, http://english.peopledaily.com.cn/90001/90781/90876/6603492.html.

317 "专家：玉兔号或难修好 "嫦娥四号"或无落月计划" [Expert: Jade Rabbit or Difficult to Repair or Will 'Chang'e 4' Not Land on the Moon], People.cn, May 13, 2014, http://scitech.people.com.cn/n/2014/0513/c1007-25010766.html.

318 "嫦娥二号任务由 5 大系统构成 总投入约 9 亿元" [Chang'e-2 Mission has 5 Large Systems Total Investment About 9 Billion Yuan], *China News*, September 30, 2010, http://www.chinanews.com/gn/2010/09-30/2567259.shtml.

319 "Chang'e-2 Moon Orbiter Travels Around L2 in Outer Space," Xinhuanet, October 10, 2010, accessed September 11, 2014, http://news.xinhuanet.com/english2010/sci/2010-10/01/c_13539035.htm.

320 Ouyang Ziyuan, "嫦娥一号的初步成果" [The Initial Results of the Chang'e-2], 自然杂志 [*Chinese Journal of Nature*], June 2013, 391–93.

321 嫦娥二号与嫦娥一号的四大不同 [The Four Main Differences Between the Chang'e-2 and the Chang'e-1], 中国航天 [*Aerospace China*], October 2010, 11.

322 "Chang'e-2 Moon Orbiter Travels Around L2 in Outer Space."

323 Liu Jianun, Ren Xin, Mou Lingli, Zhang Liyan, Feng Jianqing, Wang Xiaoqian, and Li Chunlai, "嫦娥二号卫星有效载荷与科学探测"[Chang'e-2's Payload and Scientific Surveying], 生命科学仪器 [*Life Science Instruments*], January 2013, 37; Chinese Spacecraft Flies by Asteroid Toutatis," Space.com, December 17, 2012, http://www.space.com/18933-chinese-probe-asteroid-toutatis-flyby.html.

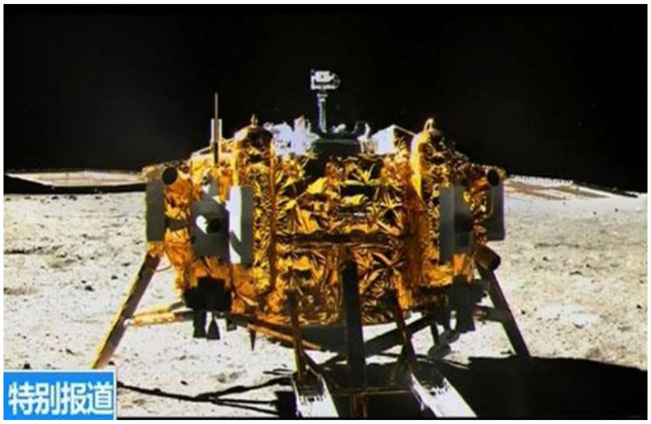

Figure 6. Chang'e-3 spacecraft on the moon.

a designed service life of three months.[324] Chang'e-3 was launched December 2, 2013, and involved landing a lunar rover, called "Yutu," or "Jade Rabbit," on the surface of the moon. Chang'e-3 landed on the moon on December 14, 2013, marking the first time that a soft landing had been conducted on the moon since the Soviet Luna 24 mission in 1976. Chang'e-3 has been called China's most complex and difficult mission due to the requirement to land a spacecraft on the moon and then separate the Jade Rabbit lunar rover from spacecraft. In doing so, both platforms had to be controlled from ground stations on Earth.[325] Perhaps as acknowledgement of the complicated nature of the mission, ESA assisted China with tracking Chang'e-3. ESA's tracking station in New Norcia, Western Australia, complemented Chinese tracking and control of the spacecraft on its descent to the lunar surface while an ESA station in Spain assisted with positioning data once the spacecraft had landed.[326]

The Chang'e-3 spacecraft is equipped with an ultraviolet telescope to observe galaxies, binary stars, active galactic nuclei, and bright stars. Viewing objects in space from the moon offers better visibility than observing them from the Earth due to interference from the Earth's atmosphere, weather, and pollution. The lander also carries a camera capable of taking images in the extreme ultraviolet band to observe the Earth's plasmasphere. The lander is also equipped with electrooptical cameras that can take still pictures and video of the rover and surrounding areas.[327]

Jade Rabbit

The Jade Rabbit is China's first lunar rover. At 140 kg, the Jade Rabbit is much smaller than the 899 kg NASA Mars rovers, Spirit and Opportunity, but uses their same six-wheel design. The Jade Rabbit underwent a competitive design competition in 2004 involving more than a dozen research institutes and

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[324] "嫦娥三号副总设计师：玉兔行进中被石块磕碰受伤" [Chang'e 3 Deputy Chief Designer: Jade Rabbit Was Injured While Moving Among Rocks], People.cn, July 20, 2014, http://scitech.people.com.cn/n/2014/0720/c1007-25304168.html; "超龄"玉兔"第八月昼再醒来 伤未好已"衰老," [Elderly Jade Rabbit Wakes Up on Eighth Lunar Day, Injury Is Good, but It Is Already Old] July 21, 2014, http://scitech.people.com.cn/n/2014/0721/c1007-25306225.html.

[325] "Chang'e-3 Deputy Chief Designer: Jade Rabbit Was Injured While Moving Among Rocks."

[326] Leonard David, "Under a China Moon: The Politics of Cooperation in Space," Space.com, December 13, 2013, accessed September 8, 2014, http://www.space.com/23965-china-moon-rover-landing-cooperation.html.

[327] "Chang'e-3: Mission Overview," Space flight 101, http://www.spaceflight101.com/change-3.html.

universities that submitted four, six, and eight-wheeled designs.[328] Jade Rabbit ended up being developed by the Shanghai Space Systems Engineering Research Institute (上海宇航系统工程研究所), a subsidiary of Shanghai Academy of Space Technology, and the Beijing Spacecraft Systems Engineering Research Institute (北京飞行器系统工程研究所).[329] Designers studied foreign designs when conducting basic research into the rover.[330]

Jade Rabbit has a payload of panoramic cameras and two spectrometers.[331] The panoramic cameras permit three-dimensional imaging while the spectrometers are used to analyze the chemistry of the lunar surface. The rover is also equipped with a ground-penetrating radar to analyze the depth of the lunar surface down to 100 meters.[332] Similar to the Mars rovers, Jade Rabbit is equipped with a robotic arm to scoop up samples of the lunar surface.

Jade Rabbit is powered by two solar panels, which were then planned to be folded in to better endure the 14-day lunar night (see Figure 7). During the long lunar night, a radioisotope heating unit made up of plutonium-238 heats the rover.

Jade Rabbit suffered a "mechanical control abnormality" after the first 14-day lunar night on January 25, 2014, and lost contact with the Earth; contact was reestablished in February 2014.[333] The problem was identified as a control circuit malfunction that prevented the rover from folding its mast and solar panels in preparation of the colder temperatures of the lunar night.[334] According to more recent reports, the rover could have been damaged by rocks that were larger than anticipated.[335] Even though the rover had mechanical problems, the mission has exceeded its designed service life of three months and at time of writing was still operational with its imagers, spectrometers, and radar in working condition, just 20 meters from the Chang'e-3 lander.[336] As a result, the mission has still been called a "complete success" by Xi Jinping, who proclaimed it to be a "new milestone" as it completed its "designated scientific and engineering tasks."[337]

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328 "China Focus: The Prequel of Jade Rabbit," Xinhuanet, June 23, 2014, http://news.xinhuanet.com/english/indepth/2014-06/23/c_133430433.htm.
329 "中国迎来探月新纪元" [China Welcomes in the New Era of Lunar Exploration], Sciencenet.cn, February 21, 2014, http://blog.sciencenet.cn/blog-85876-769553.html.
330 "China Focus: The Prequel of Jade Rabbit."
331 "Chang'e-3 Revealed—and It's Massive!" Pulispace.com, http://www.pulispace.com/en/media/news/231-change-3-revealed-and-its-massive.
332 "Chang'e-3: Mission Overview."
333 "Top Chinese Space Scientist Hopes to Send Rover 'Better than Jade Rabbit' to Mars," *South China Morning Post*, July 4, 2014, http://www.scmp.com/news/china/article/1546446/top-chinese-space-scientist-hopes-send-rover-better-jade-rabbit-explore.
334 "China Exclusive: Control Circuit Malfunction Troubles China's Yutu,"Xinhuanet, March 1, 2014, http://news.xinhuanet.com/english/china/2014-03/01/c_133152096.htm.
335 "China Exclusive: Lunar Rock Collisions Behind Yutu Damage: Designer,"Xinhuanet, July 21, 2014, http://news.xinhuanet.com/english/china/2014-07/21/c_133499472.htm.
336 "Lunar Rover Is 'Awake' but Faults Continue,"Xinhuanet, July 21, 2014, http://news.xinhuanet.com/english/china/2014-07/21/c_133498925.htm; "China Focus: Uneasy Rest Begins for China's Troubled Yutu Rover; Xinhuanet, February 23, 2014, http://news.xinhuanet.com/english/china/2014-02/23/c_133136885.htm.
337 "Lunar Rover Is 'Awake' but Faults Continue"; "习近平会见嫦娥三号任务参研参试人员代表"[Xi Jinping Sees Representatives from the Chang'e-3 Research and Testing Personnel], 中国航天 [*Aerospace China*], February 2014, 4.

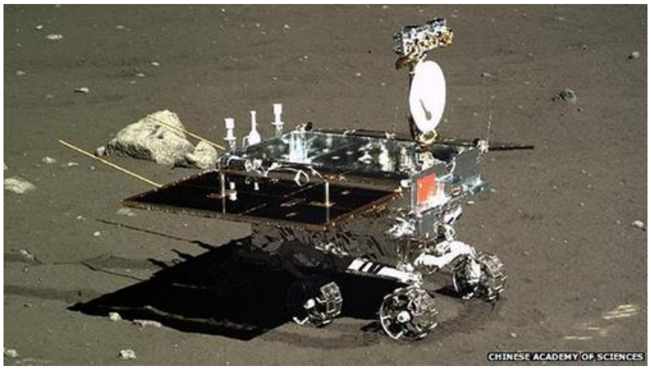

Figure 7. Jade Rabbit on the moon.

A second lunar rover mission will not follow the Chang'e-3. Similar to Chang'e-2, Chang'e-4 was a backup for Chang'e-3, but will not be launched.[338]

Chang'e-5

The Chang'e-5-T1 was launched on October 23, 2014 and was an experimental mission that conducted a lunar flyby and then returned to Earth on October 31, 2014. The mission was to test technologies and techniques to reach the moon and then conduct a reentry into the Earth's atmosphere in preparation for the Chang'e-6 mission.

Chang'e-6

The Chang'e-6 mission is planned to be launched in 2017 from China's new space launch center on Hainan Island.[339] The mission will involve landing a spacecraft on the moon, retrieving samples of the lunar soil, and then returning them to Earth. The spacecraft is designed with two modules that separate. One module will scoop the soil into a second module that will then blast off from the lunar surface and return to Earth. The soil will be scooped from a depth of up to two meters. Although no landing site has been selected, scientists are considering areas where lava flows or recent meteor impacts are present.[340]

Manned Lunar Missions

China does not have a formal plan for sending humans to the moon even though rumors existed for years that China was contemplating the endeavor.[341] In 2011, China announced that it was conducting feasibility studies for a manned mission to the moon with proposed launch dates of 2020, 2025, and 2030.[342] Parameters being studied are the number of astronauts and the duration of the mission, the launch vehicle, and the mass of the spacecraft and lunar lander.[343]

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338 "专家：玉兔号或难修好 "嫦娥四号"或无落月计划" [Expert: Jade Rabbit or Difficult to Repair or Will 'Chang'e-4' Not Land on the Moon], People.cn, May 13, 2014, http://scitech.people.com.cn/n/2014/0513/c1007-25010766.html.
339 "China Plans to Launch Chang'e-5 in 2017," Xinhuanet, December 16, 2013, http://news.xinhuanet.com/english/china/2013-12/16/c_132971252.htm.
340 "Chang'e-5, China's New Moon Mission, Is on Track for 2017 Landing," *China Topix*, Jul 29, 2014, http://www.chinatopix.com/articles/5136/20140729/china-sets-sights-2017-sample-return-lunar-mission.htm.
341 Perrett, Morring, and Covault, "Spacefarers."
342 Bradley Perrett, "Precision Innovation," *Aviation Week & Space Technology* 173, no. 1 (2011): 54.
343 "叶培建：我国载人登月的条件还没有完全具备" [Ye Peijian: Our Country Does Not Yet Have the Conditions for a Manned Moon Mission], People.cn, May 15, 2014, http://scitech.people.com.cn/n/2014/0515/c1007-25021377.html.

Although no decision has been made on whether China will send humans to the moon, many in China's space program argue for such a mission. For example, former Chief Commander and Chief Designer of Chang'e-1, Ye Peijian has stated,

> First, in order for mankind to conquer space we must first go to the moon. Americans have gone. Chinese must go and Chinese absolutely have the ability to go. Second, our country currently does not have a manned lunar mission plan, so these postings on the web that it has been cancelled is utter nonsense. Third, for a country to have a manned lunar plan depends on the country's actual strength and the overall needs of the country's development. As the country's economic capabilities develop and science and technology improve, I believe that our country sooner or later will have a manned lunar mission. The space white paper is released once every five years, the most recent one stated, "Our country has already started researching the critical technologies for manned lunar exploration." I hope that during my lifetime I can see China land people on the moon.[344]

Lunar Bases

The possibility of manned lunar missions has led some Chinese analysts to discuss the utility of lunar bases. According to an unnamed official in the Lunar Exploration Center, the ultimate goal of a manned mission to the moon would be to establish a lunar base, which would, according to a proposal by the Chinese Academy of Sciences, be established by 2050. This moon base would fulfill a variety of missions. The weaker gravity on the moon could assist in the better production of pharmaceuticals and new materials, and the moon could act as a way station for longer human spaceflight missions. The increased radiation levels on the moon could aid in the development of new strains of crops. The mining of valuable elements, such as helium-3 (described earlier in this paper), could also require a permanent manned presence.[345]

Interestingly, several analysts have written on the utility of lunar bases to conduct missile strikes against targets on Earth and in space.[346] Although the authoritativeness of these sources is unknown, according to one writer, lunar military bases "are very attractive to the military" and that "as space technologies develop and advance, lunar military bases will go from vision to reality."[347]

Despite the interest of some analysts in lunar bases, it should be remembered that China has not yet approved a manned moon program. In addition, establishing a permanent lunar base would be a technical challenge that China may decide not to initiate, based on its cost and the feasibility and value of using the moon for military and economic benefit.

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[344] "'娥之父'叶培建：嫦娥五号将首试'弹跳式返回')" [The 'Father of the Chang'e Ye Peijian: Chang'e 5 Will for the First Time Conduct a Skipping Reentry], *Guangzhou Daily*, December 25, 2013, http://news.ifeng.com/mainland/special/changesanhao/content-3/detail_2013_12/25/32449912_0.shtml.

[345] "中国预计在 2030 年前后实现载人登月建月球基地" [China Plans to Establish a Manned Lunar Base Around 2030] *China News*, December 2, 2013, http://www.chinanews.com/gn/2013/12-02/5570038.shtml. See also Deng Lianyin, Guo Jifeng, and Cui Naigang, "月球基地工程研究进展及展望" [Progress and Prospects of Engineering for Lunar Bases], 导弹与航天运载技术 [*Missile and Space Vehicle*], February 2009.

[346] "China Plans to Establish a Manned Lunar Base Around 2030"; Wu Guoxing, "月球上的军事基地" [Lunar Military Bases], 太空探索 [*Space Exploration*], 2006/10, 45.

[347]Wu Guoxing, "月球上的军事基地" [Lunar Military Bases], 太空探索 [*Space Exploration*], 2006/10, 45.

Mars Exploration Project

China is conducting preliminary research on a Mars exploration project. A full-scale model of a proposed six-wheeled lunar rover was exhibited at the 2014 Zhuhai Airshow.[348] According to Ouyang Ziyuan, who was instrumental in getting China's lunar exploration plan approved, China's plans include launching a rover to Mars in the 2020 timeframe.[349]

Earth Remote Sensing

China's Earth remote sensing megaproject is to develop satellite, airship, and aircraft systems of remote sensing and their corresponding ground system and data centers to form an all-weather, 24-hour, global earth remote sensing system by 2020 capable of monitoring the ground, atmosphere, and oceans.[350] China has a variety of remote sensing satellites, including five new series of satellites introduced since 2000: the Gaofen, Yaogan, Huanjing, Haiyang, and Tianhui satellites (Table 6). Although China has many remote sensing satellites, the first official satellite to be launched under remote sensing megaproject is the Gaofen-1, launched in 2013.[351]

Due to the increase in the number and variety of remote sensing satellites, China has greatly reduced its dependence on foreign remote sensing data. In 2009, 80 percent of the Earth imagery used in China was purchased from international providers at a cost of $19.5 million. By 2013 China purchased just 20 percent of its Earth imagery from abroad and is expected to reduce this to 10 percent in 2014.[352]

Gaofen Satellites

The Gaofen (GF) series of satellites was approved in 2011 and is the first satellite launched as part of the Earth remote sensing mega-project of the 2006–2020 Medium and Long-term Plan for Science and Technology Development. The satellite was developed by the China Spacesat Company (航天东方红卫星有限公司). The first Gaofen satellite was launched April 26, 2013, and is equipped with a two-meter resolution CCD camera, an eight-meter resolution multi-spectrum imager, and a 16-meter resolution wide-field multi-spectrum imager. The Gaofen-1 uses the CAST2000 satellite bus and has a planned service life of 5 to 8 years.[353] The satellite is said to have been developed according to the requirements of the Ministry of Land and Resources, the Ministry of Agriculture, and the Ministry of Environmental Protection.[354]

Gaofen-2 was launched in August 2014 and uses the CS-L3000A bus and features an electro-optical imager with a one-meter resolution and a four-meter resolution multi-spectrum imager.

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348 Zhao Lei, "China Looks Towards Mars as Rover Model Debuts," *China Daily*, November 18, 2014, http://www.chinadaily.com.cn/china/2014-11/18/content_18931565.htm.

349 "Mars: China's Next Goal?," *China Daily*, September 25, 2014, http://www.chinadaily.com.cn/china/2014-09/25/content_18662327.htm.

350 "高分频率对地观测系统" [High Resolution Ground Monitoring System], State Administration of Science, Technology and Industry for National Defense, PRC, September 30, 2013, http://www.sastind.gov.cn/n132/c43594/content.html.

351 "聚焦高分一号卫星的创新与突破" [Focusing on Gaofen-1's Innovations and Breakthroughs], CNSA, April 27, 2013, http://www.cnsa.gov.cn/n1081/n7634/n516721/n516736/528906.html.

352 Peter B. de Selding, "China Quickly Weaning Itself off Earth Observation Data Bought from Abroad," *Space News*, September 12, 2014, http://www.spacenews.com/article/civil-space/41848world-satellite-business-week-china-quickly-weaning-itself-off-Earth.

353 "高分一号卫星地面系统介绍" [An Introduction to the Gaofen-1 Ground System], China Center for Resources Satellite Data and Application, http://www.cresda.com/n16/n1145/n189058/index.html.

354 "高分一号卫星应用纪实：破空间时间分辨率冲突" [Gaofen-1 Satellite Application Account: Breaking Through the Differentiation of Space and Time], *Chinese Science News*, February 13, 2014, http://mil.huanqiu.com/china/2014-02/4828166.html.

Table 6. Chinese Earth remote sensing satellites

Satellite	Year Launched	Sensor Type	Resolution (meters)	Active
Gaofen-1	2013	EO	2.0	Y
		Multispectral	8.0	
Gaofen-2	2014	EO	1.0	Y
		Multispectral	4.0	
Yaogan-1	2006	Possible SAR payload/Broke up in orbit in 2010.	1.5	N
Yaogan-2	2007	Possible EO payload	1.0	N
Yaogan-3	2007	Possible SAR payload	1.5	N
Yaogan-4	2008	Possible EO payload	1.0	N
Yaogan-5	2008	Possible EO payload	1.0	N
Yaogan-6	2009	Possible SAR payload	1.5	N
Yaogan-7	2009	Possible EO payload	1.0	N
Yaogan-10	2010	Possible SAR payload	1.5	Y
Yaogan-11	2010	Possible EO payload	1.0	Y
Yaogan-12	2011	Possible EO payload	1.0	Y
Yaogan-13	2011	Possible SAR payload	1.5	Y
Yaogan-14	2012	Possible EO payload	1.0	Y
Yaogan-15	2012	Possible SAR payload	1.5	Y
Yaogan-16A, B, C	2012	Possible ELINT payload	NA	Y
Yaogan-17A, B, C	2013	Possible ELINT payload	NA	Y
Yaogan-18	2013	Possible SAR payload	Unknown	Y
Yaogan-19	2013	Possible SAR payload	Unknown	Y
Yaogan-20A, B, C	2014	Possible ELINT payload	NA	Y
Yaogan-21	2014	Possible EO payload	Unknown	Y
Yaogan-22	2014	Possible EO payload	Unknown	Y
Yaogan-23	2014	Possible SAR payload	Unknown	Y
Yaogan-24	2014	Possible EO payload	Unknown	Y
Haiyang-1A	2002	EO	250	N
		Color Scanner	1,100	
Haiyang-1B	2007	EO	250	N
		Color Scanner	3,000	
Haiyang-2	2011	Microwave Imager	NA	Y
Huanjing-1A	2008	EO	30	N
		Hyperspectral	100	
Huanjing-1B	2008	EO	30	N
		Hyperspectral	100	
Huanjing-1C	2012	SAR	20	Y
Tianhui-1A	2010	3-D Survey Camera	5.0	Y
		Multispectral	10	
		Panchromatic	2.0	
Tianhui-2A	2012	3-D Survey Camera	5.0	Y
		Multispectral	10	
		Panchromatic	2.0	
Ziyuan-1-02C	2011	EO	2.36	Y
		Panchromatic	5.0	
		Panchromatic	10	
Ziyuan-03-01	2013	EO	2.1	Y
		EO	3.5	
		Multispectral	6.0	
Fengyun-2D	2006	Meteorological	Multiple	N
Fengyun-2E	2008	Meteorological	Multiple	N
Fengyun-2F	2012	Meteorological	Multiple	Y
Fengyun-3A	2010	Meteorological	Multiple	Y
Fengyun-3B	2012	Meteorological	Multiple	N
Fengyun-3C	2013	Meteorological	Multiple	Y

Gaofen-1 incorporates several design innovations. These include the integration of sensor, data distribution, and control technologies and the ability to use both sensors at the same time. The two-meter resolution electro-optical imager is an improved version of the imager used on the Ziyuan-2C remote sensing satellite, and the eight-meter resolution multi-spectral imager is based on the 30-meter multispectral imager on the HaiyangY-1A/B satellites. The Gaofen-1 is the first satellite to use two gyroscopes for three-axis stabilization. In addition, its increased service life is due to a battery that is 28 percent more efficient than that used on previous satellites.[355]

According to a presentation given by a CNSA official, the Gaofen-1 "has been used in land resource investigation, mineral resource management, atmospheric and water environment quality monitoring, and natural disaster emergency response and monitoring," and its imagery has been used by "tens of national ministries and agencies, local governments, research institutions, universities, enterprises and organizations in China."[356]

The Gaofen series will be made up of either five or seven satellites. Gaofen-3 will also use the CS-L3000A bus with an eight-year service life. Unlike Gaofen-1 and 2, it will have a synthetic aperture radar (SAR) payload with one-meter accuracy and may launch in 2015. Gaofen-4 is also scheduled to be launched in 2015 into a geosynchronous orbit. It will be outfitted with a staring camera with a 50-meter resolution. Gaofen-5 will use the SAST5000B satellite bus and will be equipped with six types of sensors: a visible and short-wave infra hyper-spectral camera, a spectral imager, a greenhouse gas detector, an atmospheric environment infrared detector at very high spectral resolution, a differential absorption spectrometer for atmospheric trace gas, and a multi-angle polarization detector. It is also designed to have an eight-year service life and will be launched in 2016. Gaofen-6 will have the same characteristics as Gaofen-1.[357] According to one source, the Gaofen-7 satellite will be a stereoscopic satellite similar to the Ziyuan-3.[358]

Yaogan Satellites

Yaogan (遥感/Remote Sensing) is a series of remote sensing satellites first launched in 2006. Up to August 2014 China had launched 26 Yaogan satellites. Official Chinese press describe the satellites as being used to conduct "scientific experiments, carry out land surveys, monitor crop yields and aid in preventing and reducing natural disasters,"[359] but the secretive nature of the program suggests that these satellites are primarily intended for military use. The satellites are rumored to be a mixture of electro-optical, synthetic aperture radar, and electronic intelligence satellites. They are reported to have a resolution of one meter for the electro-optical variant and 1.5 meters for the SAR variant.[360]

In March 2010, November 2012, and August 2014 China launched three Yaogan satellites on one launcher to form constellations suspected of being electronic intelligence satellites (Yaogan-9A, 9B, 9C/Yaogan-16A,

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355 Bai Zhaoguang, "高分一号卫星的技术特点" [The Technical Characteristics of the Gaofen-1], 中国航天 [*China Aerospace*], August 2013, 7–8.

356 "Construction and Development of China High Resolution Earth Observation System," presentation, Coordination Group for Meteorological Satellites, CNSA, May 22, 2014.

357 "高分一号的落后与特色" [Gaofen-1 Deficiencies and Characteristics], *Defense Review*, http://news.qq.com/zt2013/GF1/; "Construction and Development of China High Resolution Earth Observation System."

358 Li Xia, "自主创新开启我国航天摄影测量新纪元：'资源三号卫星测绘关键技术'成果展示" [Independent Innovation: A New Era Begins for Our Country's Imaging and Monitoring: Ziyuan-3 Critical Surveying Technology], 科技成果管理与研究 [*Management and Research on Scientific & Technical Achievements*], February 2013, 67.

359 "China Launches Remote-Sensing Satellite," Xinhuanet, August 9, 2014, http://news.xinhuanet.com/english/china/2014-08/09/c_133544286.htm.

360 "Yaogan," Dragon in Space, accessed June 30, 2012, http://www.dragoninspace.com/earth-observation/yaogan.aspx.

16B, 16C/Yaogan-20A, 20B, 20C, respectively) due to the similarity of the constellation and its orbit to the U.S. Naval Ocean Surveillance System (NOSS) used for electronic intelligence. [361]

On February 4, 2010, Yaogan-1 broke up in orbit. Due to the slow speed of the debris (22 meters per second versus hundreds of meters per second in an ASAT test), it is suspected that the satellite suffered an internal explosion, such as that from a battery.[362] According to NASA, the satellite broke up into seven pieces traveling at moderate speeds, with two of them at least two meters long.[363]

Haiyang Satellites

Haiyang satellites are China's ocean monitoring satellites, funded by the Chinese State Oceanic Administration.[364] They were a goal of China's Ninth Five-Year Plan (1996–2000). The Haiyang is planned to consist of three series of satellites. The Haiyang-1 (HY-1) series are color remote sensing satellites that use infrared remote sensing technology to monitor ocean pollution and topography in shallow waters. The Haiyang-2 (HY-2) series is a dynamic environment satellite that uses microwave remote sensing technology to monitor ocean wind fields and ocean surface temperatures. The Haiyang-3 (HY-3) series will be an ocean surveillance satellite that will have the combined features of the previous two series as well as SAR.[365] To date, three Haiyang satellites have been launched: two Haiyang-1 series satellites and one Haiyang-2 satellite.

China plans to launch eight Haiyang satellites before 2020. This will include four satellites to observe the color of the sea, two to observe ocean currents, and two maritime radar satellites. Although Haiyang satellites are ostensibly used to monitor the ocean environment, a Chinese official has stated that the satellites can be used to monitor the disputed Senkaku/Diaoyu islands and Scarborough Shoal/Huangyan Island.[366]

Haiyang-1

The first HY-1 satellite, HY-1A, was launched May 15, 2002, and cost 200 million yuan (~$24.2 million) to manufacture.[367] The satellite has a mass of 360 kilograms[368] and has a 10-band color scanner with a 1,100-meter resolution. It has a two frequency infrared sensors, eight visible light sensors, and an imager with a 250-meter resolution.[369] The satellite observed the characteristics of seawater, including chlorophyll

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361 "China Returns to Action with Yaogan Weixing-20 Mission," NASA Spaceflight, August 9, 2014, http://www.nasaspaceflight.com/2014/08/china-returns-yaogan-weixing-20-mission/.

362 "Yaogan-1 Erupts," *Arms Control Wonk*, February 11, 2010, http://forden.armscontrolwonk.com/archive/2625/yaogan-1-erupts.

363 "Orbital Debris Success Story: A Decade in the Making," *Orbital Debris Quarterly News* 14, no. 2 (2010), http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv14i2.pdf.

364 "China's Surge Continues with HaiYang-2A Launch via Long March 4B," NASA Spaceflight, August 15, 2011, http://www.nasaspaceflight.com/2011/08/chinas-surge-haiyang-21a-launch-long-march-4b/.

365 "China Plans to Launch 3rd Ocean Survey Satellite in 2010," *Beijing Review*, February 18, 2009, http://www.bjreview.com.cn/science/txt/2009-02/18/content_179265.htm; "中国的海洋卫星" [China's Ocean Satellites], 中国航天 [*Aerospace China*], April 2009, 10–11.

366 "Nation to Upgrade Maritime Satellite Network By 2020," *China Daily*, September 6, 2012, http://usa.chinadaily.com.cn/china/2012-09/06/content_15737032.htm.

367 "Oceanic Satellites to Form a Network to Monitor Sea," *People's Daily* [online], June 7, 2002, http://english.peopledaily.com.cn/200206/07/eng20020607_97331.shtml.

368 "China's First Independently Developed Marine Satellite," *People's Daily* [online], May 15, 2002, http://english.peopledaily.com.cn/200205/15/eng20020515_95726.shtml.

369 Zuo Saichun, "追踪我国第一颗海洋卫星" [Following the Trail of Our Country's First Ocean Satellite], 中国航天报 [*China Space News*] [online], May 15, 2002.

density, color of the ocean, sea surface temperature, suspended sand content, yellow materials, and marine pollution.[370]

The HY-1A is based on the CAST 968 platform and had a designed service life of two years. It is said to have many innovative characteristics for Chinese satellites, including redundancy, an optimized payload, mechanical cooling, and a rotating solar panel to maximize exposure to the sun. It has been used to develop maps of the Yellow, Yangtze, and Pearl rivers focusing on the mouths of the rivers, and to monitor vegetation distribution around these rivers, detail the changes in the coastline and the sediment in rivers, as well as to forecast sea ice in the Bohai Sea and gather data on the North and South Poles. It has also detected red tide and oil spills. The use of the satellite by fishery departments is said to have increased fishing harvests and profits.[371]

The HY-1B was launched April 11, 2007. It is based on the HY-1A, but is said to have had an improved ocean color scanner and coastal imaging device. The remote sensing view of the ocean color scanner had its width increased from 1,600 km to 3,000 km and its return rate has been reduced from three days to one. The coastal imaging device has improved spectrum resolution so it can more clearly see things like red tide, and its storage capacity has increased from 80 MB to 2 GB. The amount of propellant has been increased as well, in part to accommodate an increased mass of 75 kg. The service life was also increased from two to three years with a more reliable structure and increased protection from external impact. The HY-1B also provided three times the data with lower power consumption.[372]

Haiyang-2

The HY-2 was launched August 15, 2011, and was designed to monitor and detect the dynamic ocean environment and to conduct all-weather 24-hour integrated monitoring of the sea surface wind field, sea surface height, wave field, oceanic gravity field, oceanic currents, and sea surface temperature. The HY-2 is equipped with a radar altimeter, microwave diverging meter, and microwave radiation meter, which are all new technologies for China and are said to have achieved an advanced level by international standards. It had a design life of three years. The HY-2 satellite platform is based on the Ziyuan-1 satellite platform using mature technology. The satellite is equipped with GPS, DORIS, and satellite laser ranging. By using all three in combination with ground tracking, the satellite can achieve millimeter-level accuracy on orbit. The satellite was used to conduct China's first test of a satellite-ground laser communication data transmission. The satellite can transfer data at 504 Mbps, which is said to be at international levels.

Huanjing Satellites

China's Huanjing (环境/HJ), or "environment," satellites are designed for environmental and disaster forecasting and monitoring. In 2003, the Chinese government approved the development of an environment and disaster small satellite constellation to forecast and monitor pollution, ecosystem destruction, and natural disasters. They are to be used by the Ministry of Civil Affairs and the Ministry of Environmental Protection.[373] The project is divided into two phases. The first phase is a constellation of three satellites made up of two optical satellites and a SAR satellite. This constellation was to have been

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370 "Oceanic Satellites to Form a Network to Monitor Sea," *People's Daily* [online], June 7, 2002, http://english.peopledaily.com.cn/200206/07/eng20020607_97331.shtml.

371 "China's Ocean Satellites," 10.

372 Ibid.

373 "环境与灾害监测预报小卫星" [Environmental and Disaster Monitoring and Forecasting Small Satellite], Ministry of Industry and Information Technology of the People's Republic of China, April 3, 2009, http://www.miit.gov.cn/n11293472/n11293877/n12221440/n12221472/12227839.html.

established by 2010, but was not completed until 2012. The second phase of development will involve the launch of four optical satellites and four SAR satellites.[374]

Three Huanjing satellites have been launched since 2008. The first two satellites, HJ-1A and HJ-1B, were launched September 6, 2008. Both were manufactured by the China Spacesat Company (航天东方红卫星有限公司) and use the CAST 968 satellite bus with a designed service life of three years.[375] The HJ-1A was equipped with an electro-optical imager with a 30-meter resolution and a 700-km swath, and a hyperspectral imager with a 100-meter resolution and a 50-km swath. The HJ-1B was also equipped with an electro-optical imager with a 30-meter resolution and an infrared multispectral imager with a 150-meter resolution and a 700-km swath.

A third Huanjing satellite, HJ-1C, was launched November 16, 2012, and is equipped with a synthetic aperture radar with a resolution of 20 meters and a swath of 100 meters.[376] The HJ-1C is reported to be the first Chinese satellite equipped with SAR. It also has a service life of three years and uses the CAST2000 satellite bus.[377]

Tianhui

The Tianhui (天绘) series are stereoscopic satellites that can provide three-dimensional images. Two Tianhui satellites, manufactured by China Spacesat, were launched in 2010 and 2012. A third Tianhui will be launched in 2015 so that there are at least two of the satellites in operation at any one time.

The satellites are based on the CAST2000 satellite bus and have a service life of 3 to 5 years. They are equipped with a three-dimensional survey camera with a resolution of five meters, a multispectral imager with a resolution of 10 meters, and a two-meter panchromatic imager.[378] They also are equipped with a GPS device for accurate orbital positioning.[379]

The Tianhui satellites are said to have had a significant impact on China's surveying enterprise and were described in 2012 as China's most complex and most technologically diverse satellites.[380] They are also the first satellite using completely indigenously derived technologies and manufacturing to not only achieve stereoscopic images, but also the best imagery resolution at that time. In addition to indigenously

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[374] Wang Qiao, Wu Chuanqing, and Li Qing, "Environment Satellite 1 and Its Application in Environmental Monitoring," *Journal of Remote Sensing* 1 (2010): 104.

[375] "China Launches Natural Disaster Monitoring Satellites," Xinhuanet, September 6, 2008, http://news.xinhuanet.com/english/2008-09/06/content_9806611.htm.

[376] "HJ-1A/1B," CRESDA, http://www.cresda.com/n16/n92006/n92066/n98627/index.html.

[377] "环境卫星 (一)" [Huanjing Satellite (Part 1)], 360Doc, http://www.360doc.com/content/11/0722/17/2506309_135239891.shtml; "CAST 2000 平台卫星研制中环境工程的应用研究" [Applied Research on the CAST2000 Satellite Bus for the Huanjing Satellite Project], Docin, http://www.docin.com/p-788342801.html.

[378] Wang Rong, Li Shengli, and Deng Wei, "天回一号卫星及应用" [Tianhui-1 and Its Uses], 卫星应用 [*Satellite Applications*], June 2014, 21.

[379] Xu Zhenyao, Yang Junfeng, Li Hui, and Li Jing, "天回一号立体测绘卫星概览"[Overview of the Tianhui-1 Stereoscopic Survey Satellite], 国际太空 [*Space International*], May 2013, 41.

[380] "走近我国首颗传输型立体测绘卫星天绘一号" [Taking a Look at Our Country's First Stereoscopic Satellite Tianhui-1], Xinhuanet, December 26, 2012, http://news.xinhuanet.com/tech/2012-12/26/c_124151354.htm.

developed satellite payloads, the data ground receivers, control, and production are said to completely rely on Chinese technologies and manufacturing.[381]

Interestingly, the Tianhui is one of the few satellites that China admits has been used for military purposes. According to a 2012 article, the satellites have been used during the "Peace Mission" (和平使命) military exercises, counter-terror operations in Xinjiang, and air defense for Beijing.[382]

Ziyuan Satellites

China's Ziyuan satellites (ZY/资源/Resources) are based on the CBERS series of satellites built jointly with Brazil. The Ziyuan-1 2C, launched December 22, 2011, was manufactured by the China Academy of Space Technology and has a service life of three years.[383] The ZY-1 2C is equipped with a high-resolution camera with a resolution of 2.36 meters and a panchromatic multi-spectral camera with a resolution of five meters and 10 meters.[384]

There is relatively little information on the Ziyuan-2 series of satellites. A total of three ZY-2 satellites were launched between 2000 and 2004 to form a three-satellite constellation.[385] They are reported to have a three-meter resolution electro-optical imager.[386] The satellites are said to have an unstated "long" service life due to improved solar panels.[387]

The ZY-3 was launched January 9, 2012. It was manufactured by the China Academy of Space Technology with a service life of five years.[388] The primary customer for the satellite is stated to be the National Administration of Surveying, Mapping, and Geoinformation (国家测绘地理信息局).[389] The satellite is equipped with three cameras with a resolution of 2.1 meters and 3.5 meters that when used together can provide stereoscopic images. The satellite also has a multispectral camera with a resolution of six meters. The ZY-3 is reported to be the first Chinese remote sensing satellite that can provide imagery comparable to international standards.[390] The satellite is also equipped with GPS for accurate positioning.[391]

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381 "中国首颗传输型立体测绘卫星天绘一号组网运行" [China's Stereoscopic Tianhui-1 Network Operating], GMW.cn, December 27, 2012, http://mil.gmw.cn/2012-12/27/content_6162317.htm.

382 "走近我国首颗传输型立体测绘卫星天绘一号" [Taking a Look at Our Country's First Stereoscopic Satellite Tianhui-1], Xinhuanet, December 26, 2012, http://news.xinhuanet.com/tech/2012-12/26/c_124151354.htm.

383 "中国成功发射资源一号 02C 卫星" [China Successfully Launches Ziyuan-1 02C], 航天器工程 [*Spacecraft Engineering*], 2012/1, 30.

384 "资源一号 02C 卫星" [Ziyuan-1 02C Satellite], http://www.cresda.com/n16/n1130/n175275/175577.html.

385 Tian Zhaoyun, "中国资源二号 03 星升空 长征火箭 40 次发射成功" [China Ziyuan 2 03 Satellite Launched Into Space for 40th Successful Launch of Long March Rocket], 人民网[*People's Net*], http://www.people.com.cn/GB/shizheng/1026/2969850.html

386 "江苏省委书记听取南京地理与湖泊所成果汇报（图）" [Jiangsu Provincial Committee Chair Listens to the Nanjing Geography and Lakes Activities Report], http://web.archive.org/web/20050429135623/http://www.cas.ac.cn/html/Dir/2003/06/09/4945.htm.

387 "中国的资源探测卫星（上）" [China's Resource Monitoring Satellites (Part 1)], 中国航天 [*Aerospace China*], 2008/12, 15.

388 "我国成功发射'资源'三号卫星" [Our Country Successfully Launches Ziyuan-3], 航天工业管理 [*Aerospace Industry Management*], 2012/1, 42.

389 Yu Shaojie, "我国首颗高分辨率光学立体测绘卫星：资源三号交付使用" [Our Country's First High Resolution Stereoscopic Satellite: Ziyuan-3 Delivered], 中国航天 [*Aerospace China*], 2012/8, 13.

390 Xin Dingding, "New Remote-Sensing Satellite on the Job," *China Daily*, July 31, 2012, http://usa.chinadaily.com.cn/business/2012-07/31/content_15634589.htm.

391 Cao Haiyi, Liu Xigang, Li Shaohui, Zhang Xinwei, "'资源三号'卫星遥感技术" [ZY-3 Satellite Remote Sensing Technology], 航天返回与遥感 [*Spacecraft Recovery & Remote Sensing*], 2012/6, 12.

Fengyun Meteorological Satellites

China is the third country behind the United States and the Soviet Union to have independently launched meteorological satellites. China began researching meteorological satellites in the late 1970s and launched its first satellite, Fengyun-1A (FY-1A/风云) in 1988. China has since launched 12 satellites in total. As of 2013, seven were still functioning.[392]

Fengyun-1

The Fengyun-1 is China's first generation of meteorological satellites. A total of four FY-1 satellites were launched between 1988 and 2002 to provide visible and infrared radiometry measurement for weather forecasting and environmental monitoring. These polar orbiting satellites had service lives of two to three years, though one source states that they exceeded five years.[393] For example, the FY-1C was launched in 1999 with a service life of two years, but as of 2005 was still operational. The FY-1A/B carried five channel electro-optical and infrared imagers with a resolution of 1,100 meters.[394]

Fengyun-2

From 1997 to 2008 China launched six Fengyun-2 satellites into geostationary orbits. The Fengyun-2 satellites monitor weather conditions through optical and infrared imagers for day and night observation. They are said to be at the same level as the first generation of U.S., European, and Japanese meteorological satellites and are comparable to the U.S. GOES-1M meteorological satellite.[395]

The first two FY-2 satellites were experimental and were equipped with a three-channel visible and infrared scanning radiometer (VISR). The last two satellites, FY-2C/D were said to feature improved sensors and have better reliability than the FY-2A/B and are equipped with a five channel VISR. The FY-2A was China's first geostationary meteorological satellite. The FY-2D/E is said to have improved performance over the other FY-2 satellites, including an increased battery life,[396] a wide coverage area, the ability to make more frequent observations, and the capability to take stereoscopic images of clouds.

Fengyun-3

The Fengyun-3 is China's second generation of meteorological satellites and is planned to be in use until 2021. It was built by the Shanghai Academy of Space Technology.[397] It is also China's most recent meteorological satellite series and features improved vertical temperature and humidity sounding, ozone detection, and microwave, visible, and infrared imaging.[398] The FY-3 was planned to be comparable to the U.S. National Polar-orbiting Operational Environmental Satellite System satellite. A total of eight FY-3 are to be launched. The FY-3 are equipped with many more sensors than the FY-1 or FY-2. These include a visible and infrared radiometer, an infrared atmospheric sounder, a microwave temperature sounder, a microwave humidity sounder, a medium-resolution spectral imager, a solar backscatter ultraviolet sounder, a total ozone unit microwave radiation imager, a solar irradiation monitor, an Earth radiation

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392 "风云三号卫星太原升空" [Fengyun-3 Launches from Taiyuan], 中国航天 [*Aerospace China*], 2013/10, 22.

393 Li Qing, "中国气象卫星技术成就与展望（上）" [The Technological Accomplishments and Future of China's Meteorological Satellites (Part 1)], 中国航天 [*Aerospace China*], 2008/6, 8.

394 http://www.nsmc.cma.gov.cn/NewSite/NSMC_EN/Channels/100182.html.

395 Li, "The Technological Accomplishments and Future of China's Meteorological Satellites (Part 1)," 11–12.

396 "FY-2 Program," National Satellite Meteorological Center, http://www.nsmc.cma.gov.cn/NewSite/NSMC_EN/Channels/100096.html.

397 "风云三号卫星太原升空" [Fengyun-3 Launches from Taiyuan], 中国航天 [*Aerospace China*], 2013/10, 22.

398 "Overview of Fengyun Meteorological Satellite Programs," National Satellite Meteorological Center, http://www.nsmc.cma.gov.cn/NSMC_EN/Channels/100090.html.

monitor, and a space environment monitor. The FY-3A/B were planned to have limited sounding capabilities that were to be improved in subsequent satellites. [399]

FY-3 are equipped with a 10-channel electro-optical imager, a 26-channel infrared imager, and a microwave radiation imager. At least some of these imagers have a resolution of 250 meters. The FY-3 is China's first meteorological satellite to be able to conduct three-dimensional, quantitative, and 24-hour monitoring. They have the most sensors of any of China's meteorological satellites, with eight different types to monitor vegetation, ice and snow pack, sand storms, the marine environment, strong storms, soil temperature, ozone levels, and solar radiation, and measure humidity and temperature at altitudes below 20 km.[400] Future FY-3 models will be equipped with sensors to monitor atmospheric composition for greenhouse gases.[401]

China is researching a FY-4 satellite that will be similar to the U.S. GOES-R satellite.[402] The Fengyun-4 will feature three-axis stabilization, improved optical and microwave imagers, a lightning detector, and extreme ultraviolet and x-ray solar observation.403 The satellite was proposed to have a fast scanning capability that can image an area in less than 7.5 minutes or in critical situations in less than one minute. It was also proposed that the FY-4 would be divided into an electro-optical satellite series and a SAR satellite series with the first two being experimental satellites with a service life of five years.[404] The first FY-4 is planned to be launched in 2015 with subsequent satellites in 2017 and 2019.405

China Brazil Earth Remote Sensing Satellite

The China Brazil Earth Remote Sensing Satellite (CBERS) is a series of remote sensing satellites jointly developed by China and Brazil. To date, a total of four satellites have been launched, divided between CBERS-01 and 02 and CBERS-03 (Table 7).

CBERS-01 and 02

The CBERS-01 and 02 were launched in 1999 and 2003, respectively, and were identical spacecraft. Each was equipped with three imagers. The first was a wide field imager (WFI) with a ground swath of 890 km

Table 7. CBERS launches

Satellite	Launch Year	Notes
CBERS-01	1999	NA
CBERS-02	2003	NA
CBERS-02B	2007	NA
CBERS-03	2013	Launch failure

[399] Peng Zhang, "Present and Future Chinese Meteorological Satellite Mission for Atmospheric Remote Sensing," presentation given at Europe-China Dragon Program conference; and Yang Jun, "Progress on CMA's Meteorological Satellites," presentation given to the World Meteorological Organization, April 12–16, 2011, http://earth.esa.int/dragon/Opening-L1-ZhangP.pdf.
[400] Li, "The Technological Accomplishments and Future of China's Meteorological Satellites (Part 1)," 10.
[401] "Overview of Fengyun Meteorological Satellite Programs," National Satellite Meteorological Center, http://www.nsmc.cma.gov.cn/NSMC_EN/Channels/100090.html.
[402] "风云三号卫星太原升空" [Fengyun-3 Launches from Taiyuan], 中国航天 [*Aerospace China*], 2013/10, 22.
[403] "FY-4 Program," National Satellite Meteorological Center, http://www.nsmc.cma.gov.cn/NewSite/NSMC_EN/Channels/100099.html.
[404] Peng, "Present and Future Chinese Meteorological Satellite Mission for Atmospheric Remote Sensing"; Yang "Progress on CMA's Meteorological Satellites."
[405] "Overview of Fengyun Meteorological Satellite Programs."

with a spatial resolution of 260 m. The second was a high-resolution charge-coupled device (CCD) imager that provided images with a ground swath of 113 km and 20-meter spatial resolution. The third was an infrared multispectral scanner (IRMSS) that operated in four spectral bands in the thermal infrared spectral region. It imaged a 120-km swath with a resolution of 80 meters.

CBERS-02B

The CBERS-02B was launched in 2007 and was nearly identical to the CBERS-01 and 02. Instead of the IRMSS it was equipped with a high resolution camera capable of producing images with a swath of 27 km and a 2.7-meter spatial resolution,[406] a new on-board recording system, and an advanced positioning system that used GPS and a star sensor.[407]

CBERS-03 and 04

CBERS-03 was launched in 2013 but did not reach orbit due to a launch failure. CBERS-04 was launched in December 2014. These satellites have four cameras with improved geometrical and radiometric performance and include a PanMux camera, a multispectral camera, an infrared scanning medium resolution scanner, and a wide-field imaging camera.[408]

The Chinese built PanMux camera (PANMUX) produces stereoscopic images with a swath width of 60 km and a 2-meter spatial resolution. The multispectral camera (MUXCAM) is built by Brazil and produces images with a 120-km swath and a 20-meter resolution.

The infrared medium resolution scanner (IRSCAM) is built by China and is an upgrade of the Infrared Multispectral Scanner (IRMSS) carried by the CBERS-1 and 2 satellites. It can produce images with a 120 km swath and a spatial resolution of 40 meters.

The wide field imaging camera (WFICAM) built by Brazil is an upgrade of the wide field imager (WFI) of the CBERS-1, 2, and 2B satellites. It can produce images with a swath width of 866 km and a spatial resolution of 64 meters.[409]

Satellite Navigation

Beidou is China's satellite navigation system and is intended to reduce China's reliance on the U.S. Global Positioning System (GPS). Similar to the human spaceflight, lunar exploration, and earth remote sensing programs, Beidou is one of China's 16 mega-projects under the Medium and Long-term Plan for Science and Technology Development. China is spending significant sums on Beidou and plans to spend between $6 billion to $8 billion on the development of Beidou technologies to 2020. Like GPS, Beidou is fundamentally a military-run program with civilian applications. Beidou's architecture, however, differs substantially from GPS in terms of technology, number of satellites, and performance.

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[406] "CBERS-1, 2 and 2B Cameras," Brazil National Institute for Space Research, http://www.cbers.inpe.br/ingles/satellites/cameras_cbers1_2_2b.php.
[407] "CBERS-2B Launching," Brazil National Institute for Space Research, http://www.cbers.inpe.br/ingles/satellites/launching_cbers2b.php.
[408] "CBERS 3 and 4 Launching," Brazil National Institute for Space Research, http://www.cbers.inpe.br/ingles/satellites/launching_cbers3_4.php.
[409] "CBERS 3 and 4 Cameras," Brazil National Institute for Space Research, http://www.cbers.inpe.br/ingles/satellites/cameras_cbers3_4.php.

Table 8. Beidou launches

Spacecraft	Launch Year	Comments
Beidou-1A	2000	NA
Beidou-1B	2000	NA
Beidou-1C	2003	NA
Beidou-1D	2007	NA
Beidou-2 Compass-M1	2007	Test satellite/Atomic clock malfunction
Beidou-2 Compass-G2	2009	Drifting
Beidou-2 Compass-G1	2010	GEO
Beidou-2 Compass-G3	2010	GEO
Beidou-2 Compass-IGSO1	2010	Inclined GEO
Beidou-2 Compass-G4	2010	GEO
Beidou-2 Compass-IGSO2	2010	Inclined GEO
Beidou-2 Compass-IGSO3	2011	Inclined GEO
Beidou-2 Compass-IGSO4	2011	Inclined GEO
Beidou-2 Compass-IGSO5	2011	Inclined GEO
Beidou-2 Compass-G5	2012	GEO
Beidou-2 Compass-M3	2012	MEO
Beidou-2 Compass-M4	2012	MEO
Beidou-2 Compass-M5	2012	MEO
Beidou-2 Compass-M6	2012	MEO
Beidou-2 Compass-G6	2012	GEO

Like other programs, China's Beidou navigation satellite program has followed a three-step development plan.[410] This plan has produced two generations of the system (Table 8). In Step 1, the program launched an experimental regional system, Beidou-1, in 2000 that became operational in 2003. Beidou-1 uses an active system called radio determination satellite service (RDSS). This system comprised two satellites in geostationary orbit, a backup satellite, at least one ground station, and customer receiver/transmitters that communicated with each other. These receivers both pick up the satellite signal and send a signal back to the satellites, which then forward it to the ground station. The ground station then calculates the position of the receiver and communicates this data to the receiver. Beidou-1 could achieve accuracies of up to 20 meters. It also supports a short message service for messages of up to 120 characters.

[410] Li Chengzhi, "The Chinese GNSS: System Development and Policy Analysis," *Space Policy* 29 (2013): 9–19.

In Step 2, development of the more advanced Beidou-2 system was initiated in 2007 and began operating on a regional basis in 2012. Beidou currently provides regional coverage with 16 satellites using the same active system used by Beidou-1. This system uses an open code that provides accuracies of 10 meters or better, depending on the location, and a restricted military service that could provide better accuracies. GPS, on the other hand, uses as few as 24 satellites to provide positioning accuracies of just several meters. Chinese officials, however, claim that with the optimized positioning of Beidou satellites over China and the construction of thousands of differential ground stations, Beidou's accuracy will be boosted to one meter and possibly even centimeters. This is in comparison to a GPS accuracy of three to five meters in China. Currently, maritime users can receive accuracies of three centimeters, and with the introduction of a recently developed Beidou receiver chip, other users can receive accuracies of 2.5 meters.[411]

In Step 3, Beidou-2 will expand to provide a global service by 2020, with 35 satellites using a passive system similar to the one used by GPS. Like its predecessor, Beidou-2 also provides a short message service that allows communication between Beidou receivers.

Military Use

As Beidou's capabilities improve, the PLA can be expected to replace its GPS receivers with Beidou. In a 2011 article, a PLA officer assigned to a border unit in Xinjiang identified Beidou, along with helicopters, as the most important technology used by his outfit while acknowledging that for times when truly precise location and positioning data were required they used GPS.[412] In 2009, the CMC designated Beidou as the timing standard for the PLA and according to a 2013 news report, Beidou is now used in the majority of units at the regiment level and above.[413]

China used Beidou in a 2011 cross-border operation into Laos to capture the drug lord Naw Kham, who was accused of ordering the deaths of multiple Chinese fishermen.[414] In addition, the use of Beidou was described as one of the three bright spots of the "Mission Action-2013" exercise along with early warning aircraft and airborne command and control aircraft.[415] Information on the use of Beidou in weapon systems such as in missiles or bombs is scant, but it should be expected that Beidou is being incorporated into these munitions. A 2013 article stated that the PLA Navy had for the first time used an unmanned surface vehicle guided by Beidou.[416] The Changjian-10 long-range cruise missile and DF-11 ballistic missile are also rumored to be guided by Beidou.[417] To incorporate security and accuracy, these weapons could be outfitted with a receiver that accepts both the GPS and Beidou signals.

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[411] Tu Yun, "BeiDou Has Better Accuracy than GPS in Some Regions: Experts," CRIENLISH.com, September 4, 2014, http://english.cri.cn/12394/2014/09/04/3521s843043.htm.

[412] Meng Jia and Liu Yanping, "探秘中国北斗导航卫星: 最高机密到民用历时 20 年" [Exploring China's Beidou Navigation Satellite System: Top Secret to Civilian-Use Period Lasts 20 Years], 中国新闻周刊 [*China News Weekly*], June 20, 2011, http://news.xinhuanet.com/tech/2011-06/20/c_121557752.htm.

[413] "北斗副总师：没先进定位手段曾是心中说不出的痛" [Beidou Deputy Chief Designer: Not Having Advanced Positioning Methods Was an Unspeakable Suffering], http://youth.chinamil.com.cn/qnht/2013-11/11/content_5640840.htm.

[414] Li Yun, Wu Xu, and Gao Chongquan, "总参卫星导航定位总站致力北斗导航事业记事," [An Account of the GSD Satellite Navigation and Positioning Main Station Devoting Itself to Beidou], 新华 [Xinhua], Nov. 9, 2013.

[415] "南京军区"使命行动 2013"演习开展海陆军投送" [Nanjing Military Region 'Mission Action-2013' Exercise Opens with Naval Ground Force Delivery], 人民网 [*People's Net*], http://js.people.com.cn/html/2013/09/27/258563.html.

[416] "海军无人靶船首用北斗定位" [Naval Unmanned Surface Vehicle for the First Time Uses Beidou Positioning], http://youth.chinamil.com.cn/qnht/2013-11/11/content_5640878.htm.

[417] "长剑-10 导弹配合北斗系统可毁万吨巡洋舰" [Missile Incorporates Beidou System and Can Destroy a 10,000-ton Cruiser], http://money.163.com/13/1022/08/9BPE68CR00254TI5.html; and "汉和称中国东风 11 导弹已配北斗系统打击精度超高"

Commercialization

Due to its early adoption, superior performance, and free availability, GPS has a 95 percent market share in China. Viewing the adoption of Beidou as a national security imperative, China wants to capture 70–80 percent of the market by 2020. To achieve this goal, China has implemented a number of measures to encourage or force the adoption of Beidou technologies. These include requiring the installation of Beidou receivers on 80 percent of all buses and trucks in nine provinces and requiring new heavy trucks and semi-trucks to have factory-installed Beidou receivers.[418]

Communication Satellites

China uses a combination of foreign and domestically made communication satellites. The China Satellite Communications Company (Chinasat), a subsidiary of the China Aerospace Science and Technology Corporation, operates 13 satellites under the Chinasat and Apstar series (Table 9). Several communication satellites are not claimed by Chinasat and are suspected of being operated by the military. These include the Chinasat-1A, 2A, 20, 20A, 22, and 22A.

Chinese communication satellites use the DFH-3 and DFH-4 satellite buses. Both the DFH-3 and DFH-4 are three axis stabilized as opposed to the DFH-2, which was spin stabilized. A total of five DFH-3 have been launched since 1994. The first DFH-3 to become operational was launched in 1997.

The DFH-4 satellite bus replaced the DFH-3 and is described as having more power, a larger payload capacity, and an extended service life. A total of eight DFH-4 communication satellites have been launched since 2006, but this satellite series has experienced many technical problems. The solar panels of the first DFH-4, Sinosat-2, failed to open, resulting in the loss of the satellite.[419] The Nigerian communications satellite Nigcomsat-1, launched in 2007, also experienced problems with its solar panels and was lost.[420] Chinasat-6A, launched in 2010, suffered a leak in its propulsion system that reduced its service life from 15 to 10 years.[421]

China's main spacecraft builder, the China Academy of Space Technology, is developing a larger version of its DFH-4 bus with a launch mass of 5.5 tons as well as the DFH-5 which "is still in its initial development phase." The DFH-5 bus will "meet the demand for new-generation large [geostationary] communications satellites and Earth-observation satellites." According to *Aviation Week and Space Technology*, "In late 2010, DFH-5 was due to go into service in 2016 or 2017, but no firm target is given now."[422]

Tianlian

The Tianlian (天链/Skylink) satellites are a series of data rely satellites similar to the U.S. Tracking and Data Relay Satellite (TDRS). The satellites are built by the China Academy of Space Technology and are

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[Kanwa States China DF-11 Missile Incorporates Beidou System for High Precision Strikes], http://mil.news.sina.com.cn/2013-10-19/1153745174.html.

418 "China Promotes Beidou Tech on Transport Vehicles", *China Daily,* January 14, 2013, http://www.chinadaily.com.cn/china/2013-01/14/content_16115994.htm.

419 "Failed Sinosat-2 May Be Pushed Out of Orbit," *China Daily*, November 29, 2006, http://www.chinadaily.com.cn/china/2006-11/29/content_746362.htm.

420 "Chinese Space Failure," *Aviation Week and Space Technology* 169, no. 19 (2008): 22.

421 Peter B. de Selding, "New Chinese Satellite Suffers Life-Shortening Leak," *Space News*, September 13, 2010, http://www.space.com/9110-chinese-satellite-suffers-life-shortening-leak.html.

422 Bradley Perrett, "Long Pole," *Aviation Week & Space Technology,* March 25, 2013, 30.

Table 9. DFH communication satellites

No.	Satellite	Launch Year	Comments
1	DFH Satellite	1984	Experimental
2	DFH	1984	Experimental
3	DFH	1986	Experimental
4	DFH	1988	NA
5	DFH	1988	NA
6	DFH	1990	NA
7	DFH	1991	NA
8	DFH	1994	NA
9	ChinaSat 6	1997	NA
10	ChinaSat 20	2003	NA
11	ChinaSat 22A	2006	NA
12	SinoSat-2	2006	Malfunction
13	NigComSat-1	2007	Malfunction
14	SinoSat-3	2007	NA
15	VeneSat-1	2008	NA
16	SinoSat-6	2010	Propellant leakage
17	PakSat-1R	2011	NA
18	NigcomSat-1R	2011	NA
19	ChinaSat-11	2013	NA
20	TKSAT-1	2013	NA

Source: "Communication Satellites," China Great Wall Industry Corporation, accessed September 2, 2014, http://www.cgwic.com/In-OrbitDelivery/CommunicationsSatellite/DFHList.html.

based on the DFH-3 satellite bus, with a service life of six years.[423] Similar to the U.S. system, the satellites were developed to relay data and communications between China's manned spacecraft and ground control. The first Tianlian satellite was launched in 2008, with two more satellites launched in 2011 and 2012 (Table 10). With three satellites strategically positioned at 120-degree intervals around the Earth, these satellites eliminated the communication blackout periods experienced by early Shenzhou missions.

Table 10. Tianlian launches

Spacecraft	Launch Year	Notes
Tianlian-1-01	2008	NA
Tianlian-1-02	2011	NA
Tianlian-1-03	2012	NA

423 "天链一号星和第四颗北斗导航试验卫星交付使用" [Tianlian-1 and the Fourth Beidou Navigation Satellite Handed Over for Use], 中国航天 [*Aerospace China*], 2009/1, 15.

Although primarily developed to serve China's human spaceflight program, these satellites have additional applications. They can be used to transmit remote sensing data from satellites not in line of sight of China's receiving stations. A remote sensing satellite at an altitude of 600 km, such as China's Yaogan series, can communicate with ground stations at a range of around 2,800 km. Beyond this range they must retain their data until they come in range of a ground station.[424] With the use of data relay satellites operating in GEO above ISR satellites, an ISR satellite can transmit its data to a data relay satellite, which will then transmit the data to a ground station. In this way, time-sensitive data and communications can be immediately downloaded to a ground station for processing. They can also be used to assist with data transmission from launch vehicles to ground stations and can transfer data between aircraft, space tracking ships, and other craft.[425]

Other Satellites

Kuaizhou

The Kuaizhou (Quick Vessel/快舟) satellites are small remote sensing satellites with a mass of no more than 400 kg. Kuaizhou-1 was launched on September 25, 2013 on the Kuaizhou rocket. The second Kuaizhou was launched on November 21, 2014. Both satellites were developed by the Harbin Institute of Technology (哈尔滨工业大学), the first satellite at a cost of 790 million yuan (~$128 million).[426]

Fengniao

The Fengniao (Humming Bird or Hummersat/蜂鸟) satellites were two microsatellites (satellites with a mass between 10 and 100 kg) launched November 18, 2012, with the HJ-1C satellite. According to a research article on the proposed mission, China Spacesat Co. built the two satellites as technology demonstrators for a new type of microsatellite bus based on the CAST968 and CAST2000 satellite buses. The larger of the two satellites, Fengniao-1,, according to two reports, had a mass of either 130 kg or 60 kg, and its counterpart, Fengniao-1A, has a mass of 30 kg. The two satellites were used to test formation flying, perhaps to study its ability to form a constellation of minisatellites. In addition, the larger Fengniao was equipped with a remote sensing payload of an unspecified nature.[427]

Xinyan-1

The Xinyan-1 (XY-1/新技术试验卫星/新验-1) is a microsatellite launched with the HJ-1C satellite November 19, 2012. The XY-1 was independently developed by the China Academy of Space Technology and was equipped with sensors to monitor the space environment to improve future spacecraft reliability.[428]

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[424] Roger Cliff, Chad J. R. Ohlandt, and David Yang, *Ready for Takeoff China's Advancing Aerospace Industry*, (Santa Monica, CA: RAND, 2001), 95.

[425] Wang Jiasheng, "填补我国航天技术空白的终端卫星系统" [Relay Satellite System Fills a Gap in Our Country's Space Technologies], 国际太空 [*Space International*], 2013/6, 25

[426] Guo Xuan, "消息称解放军或再添太空装备可迅速摧毁敌卫星" [Sources Say the PLA Can Add Space Equipment or Destroy Enemy Satellites], http://mil.news.sina.com.cn/2013-10-11/0959743810.html.

[427] Zhang Xiaomin, Xie Bin, Dai Shoulun, Zhang Weiwen, Hu Gefeng, and Lan Ding, "First Micro-Satellite and New Enhanced Small Satellite Series in DFH Satellite Co. Ltd.," *Acta Astronautica,* June-August 2007; and Xie Bin, Luo Ying, Zhang Xiaomin, Lan Ding, Dai Shoulun and Zhang Weiwen, "Hummersat-1: A New Space Mission with Microsatellite and Nanosatellite for Twin-satellite Formation Flying Test, proceedings of the International Astronautical Federation, 58th International Astronautical Congress, 2007, http://www.lw20.com/201206148925519.html.

[428] http://www.shenkong.net/News/1209/WGJJFSXJSSYWX1H27093307.htm.

Zhejiang University Pico Satellite

The Zhejiang University Pico Satellite-1 (ZDPS-1/浙江大学皮卫星) was launched May 25, 2007, along with the Yaogan-2 satellite. ZDPS-1 was developed by the Zhejiang University Microsatellite Center as part of the GAD's 11th Five-Year Plan's basic research into picosatellites (satellites with a mass of no more than 1 kg). The satellite did not appear to carry a payload and appears to be a technology demonstration of the satellite itself.[429]

Chuangxin

Chuangxin (Innovation/创新) satellites cover the Chuangxin-1 series and the Chuangxin-3. The Chuangxin-1 is a series of satellites built by the Chinese Academy of Sciences and launched between 2003 and 2011. These microsatellites have a mass of 88 kg and appear to have been experimental satellites for communications and are described as the first small Chinese satellite to integrate the satellite with command and control, and ground applications. This involved the development of the satellite, ground control and application equipment, and low cost mobile satellite communication terminals.[430] The Chuangxin-3 mission appears similar to Chuangxin-1, but involved the transmission of data rather than communications.[431]

Shijian Satellites

China's Shijian (Practice/实践) satellites test new technologies. Even though China has launched 25 Shijian satellites, Chinese press accounts provide little information on their missions. The Shijian-16, for example, is described as conducting "space science and research."[432] Sources do reveal the functions of at least some of the Shijian satellites. Shijian-1 was China's second satellite and was a platform to test satellite technologies. Shijian-2, 4, and 5 launched in 1981, 1994, and 1999, respectively, took measurements of the space environment. Shijian-2 actually consisted of three satellites (Shijian-2A, B, and C) launched on the same rocket.[433] Shijian-5 may have been used to test the first CAST 968 satellite bus.[434] Shijian-8 was the world's first satellite devoted to crop breeding. Seeds were placed in the satellite and then exposed to the higher radiation levels of space in the hopes that genetic mutations may occur.[435] The seeds were then removed from the satellite after it returned to Earth and grown. The Shijian-9A satellite, launched in 2012, is a remote sensing satellite with a multi-spectral imager that took part in the search for Malaysian Airlines flight 370.[436]

A total of six Shijian-11 satellites have been launched. It is speculated that these satellites are early warning satellites designed to detect the heat signatures of ballistic missiles. Early warning satellites have been identified by some Chinese press accounts as a necessary component of a future missile defense

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[429] http://microsat.zju.edu.cn/redir.php?catalog_id=2341.

[430] Jiang Mianheng, "创新一号卫星研制实践及微小卫星发展趋势" [Chuangxin-1 Research and Development and the Development Trend of Microsatellites], 中国科学院 [*Chinese Academy of Sciences*], 2003/18, 420–21.

[431] 创新三号、试验七号有效载荷数据传输分系统在轨开机工作正常 [Chuangxin-3, Shiyan-7 Payload Data Subsystem Operating Normally in Orbit], http://www.cssar.ac.cn/xwzx/kydt/201308/t20130820_3915839.html

[432] "China Launches Experimental Satellite Shijian-16," Xinhuanet.com, October 25, 2013, http://news.xinhuanet.com/english/photo/2013-10/25/c_132830192.htm.

[433] Harvey, *China's Space Program*, 61.

[434] Wu Bing, "当代中国航天器的发展" [Contemporary Chinese Spacecraft Development], 现代军事 [*ConMilLit*], 2009/7, 18.

[435] Ibid., 16.

[436] "实践九号 A 星多光谱相机首次在美国中部开机成像," [Shijian 9A Multi-spectral Imagers Take Images of the American Midwest for the First Time], October 21, 2012, http://news.ifeng.com/mil/bigpicture/detail_2012_10/21/18411852_0.shtml?_from_ralated#p=1.

system and could indicate a change in China's nuclear posture (see Conclusion). In 2014, the Shijian-11 program received a first class national defense science and technology award suggesting that it was a significant leap in technology.[437]

Launch Vehicles

Chinese launch vehicles have a history of unreliability that has harmed China's efforts to become a major player in the commercial launch market. Since 2000, however, the reliability of Chinese launchers has improved dramatically and has reached international standards. China currently operates four different types of Long March launch vehicles that can launch a variety of payloads to low earth, medium earth, and high Earth orbits. The Long March series of launch vehicles are derived from China's Dongfeng ballistic missiles. The first Long March, a Long March-1, flew on April 24, 1970, and deposited China's first satellite into orbit. Since then China has conducted more than 190 launches.

Following a series of launch failures in the mid-1990s, China's Long March launchers are now generally as reliable as their counterparts in the United States, Europe, and Russia. The Long March booster reached a 95 percent success rate based on more than 190 launches, a figure equivalent to international standards. The success rates of the Long March family vary widely depending on launcher, however. The LM-2C continues to be a solid workhorse with just one failure in 41 launches. The LM-3, on the other hand, has just a 77 percent success rate. As a result, while the success rate of the Long March family as a whole is at international levels, certain launchers are still far from reaching these standards (Table 11). Because of this, the Great Wall Industry Corporation, the commercial representative for the China Aerospace Science and Technology Corporation, does not market the LM-2E and LM-3 to international customers.

China is now launching more rockets and satellites than at any other time in its history (Table 12). China launched just one satellite in 2001 but in 2013 conducted 14 launches and launched 17 spacecraft. In 2010 and 2011, China first equaled and then surpassed the number of U.S. launches. In 2010, China and the United States both conducted 15 launches, and in 2011 China conducted 19 launches compared to 18 by the United States. Based on the 12-year period 2001–2013, China's Long March launch vehicles successfully completed 125 of 128 launches for a 98 percent success rate, a rate comparable with international competitors. China's goal is to launch 100 rockets during the 12th Five-year Plan (2011–2015).[438]

From 2011–2013 China launched 52 rockets; this means it will have to conduct nearly as many launches during the last two years of the 12th FYP as it did during its first three years if it is to meet its 100-launch goal (Table 13).

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437 "遥感卫星九号和实践十一号卫星喜获国防科技进步一等奖," [Yaogan 9 and Shijian 11 Satellites Win the First Class National Defense Science and Technology Advancement Award], China Spacesat Co., Ltd, http://www.spacesat.com.cn/templates/content/index.aspx?nodeid=9&page=ContentPage&contentid=694.

438 "China Aims to Launch 100 Satellites by 2015," *China Daily*, March 10, 2012, http://usa.chinadaily.com.cn/china/2012-03/10/content_14806055.htm.

Table 11. Long March family success rates

Vehicle	Launches	Successes	Failures	Success Rate
LM-1	2	2	0	100%
LM-2	1	0	1	0%
LM-2C	41	40	1	98%
LM-2D	20	20	0	100%
LM-2E	7	5	2	71%
LM-2F	11	11	0	100%
LM-3	13	10	3	77%
LM-3A	23	23	0	100%
LM-3B	26	24	2	92%
LM-3C	10	10	0	100%
LM-4A	2	2	0	100%
LM-4B	20	19	1	95%
LM-4C	13	13	0	100%
TOTAL	**189**	**179**	**10**	**95%**

Table 12. International launches

	2013	2012	2011	2010	2009	2008	2007	2006
China	14	19	19	15	6	11	10	6
United States	18	13	18	15	24	15	20	17
Russia	32	29	35	31	29	26	26	25
Europe	5	8	5	6	7	6	6	5

Table 13. Chinese launches, 2001–2013

Year	Satellites	Spacecraft	Total	Launches	Failures
2001	0	1	1	1	0
2002	3	2	5	5	0
2003	6	1	7	6	0
2004	10	0	10	8	0
2005	4	1	5	5	0
2006	7	0	7	6	0
2007	10	0	10	10	0
2008	13	1	14	11	0
2009	6	0	6	7	1
2010	16	0	16	15	0
2011	19	2	21	19	1
2012	25	1	26	15	0
2013	16	1	17	14	1
Totals	**135**	**9**	**145**	**125**	**3**

Current Chinese Long March Launch Vehicles

Long March 2
The first Long March 2 was launched in 1975 and has been a steady workhorse for China's launch industry ever since. It had constituted 79 of 188 Chinese launches by the end of 2013. The Long March 2 series has three variants: the LM-2C, D, and F/G. The LM-2C and D are used for satellite launches and can launch payloads up to 3,850 kg into low Earth orbit (LEO), 1,900 kg into sun synchronous orbit (SSO) or 1,250 kg into geosynchronous transfer orbit (GTO), depending on the variant.[439]

The LM-2F is dedicated to the China's human spaceflight program. It is 58.3 meters long and comes with a dedicated payload faring that houses the Shenzhou space capsule. Because it can deliver up to eight metric tons into LEO, the LM-2F differs significantly from the other variants. Unlike the LM-2C and D, the LM-2F has four 2.25-meter diameter strap-on boosters that can each generate 740 kN of thrust to enable it to launch heavier payloads.[440]

The LM-2F also differs significantly from other LM-2 variants in that as a human-rated launcher it features enhanced reliability and survivability. The components of the LM-2F were subjected to increased quality control procedures and standardization for the 55,000 electrical components that incorporated 55 new technologies. In addition, an escape system on top of the payload faring is designed to propel the space capsule away from a failed launch. With improved manufacturing processes and escape systems, the LM-2F is intended to achieve a 97 percent launch success rate and a 99.7 percent survivability rating.[441]

The LM-2G is similar to the LM-2F, but features a modified payload faring to fit the Tiangong-1 space station.

Long March 3
The Long March 3 is a three-stage rocket based on the LM-2 and is mainly used to launch communication satellites into GEO. By the end of 2013, the LM-3 made up 72 of 188 Chinese launches. The first two stages of the rocket are 3.35 meters in diameter with the third stage three meters in diameter. The LM-3A is mainly used for launching satellites into GTO and is capable of lifting 2,600 kg into that orbit. The LM-3B is capable of launching 5,100 kg into orbit while an "E" version of the launcher can lift 5,500 kg into GTO. The LM-3C is similar to the LM-3B, but with just two strap-on boosters and a reduced payload capacity of 3,800 kg into GTO[442].

Long March 4
The Long March 4 is three-stage launch vehicle with a core diameter of 3.35 meters. The LM-4 is the least used Chinese launcher and by the end of 2013 constituted only 35 of China's 188 launches. The launcher was originally developed as a backup to the Long March 3 to launch communication satellites into SSO,

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[439] "LM-2D," China Great Wall Industry Corporation, http://www.cgwic.com/LaunchServices/LaunchVehicle/LM2D.html; "LM-2C," China Great Wall Industry Corporation, http://www.cgwic.com/LaunchServices/LaunchVehicle/LM2C.html.
[440] "Long March 2F Launch Vehicle," http://www.spaceflight101.com/long-march-2f.html.
[441] See Kevin Pollpeter, "Organization as Innovation: Instilling a Quality Management System in China's Human Spaceflight Program," in Tai Ming Cheung, ed., *Forging China's Military Might: A New Framework for Assessing Innovation*, (Baltimore, MD: Johns Hopkins University Press, 2014), 213–40.
[442] "LM-3A," China Great Wall Industry Corporation, http://www.cgwic.com/LaunchServices/LaunchVehicle/LM3A.html; "LM-3B," China Great Wall Industry Corporation, http://www.cgwic.com/LaunchServices/LaunchVehicle/LM3B.html; "LM-3C," China Great Wall Industry Corporation, http://www.cgwic.com/LaunchServices/LaunchVehicle/LM3C.html.

but has since been used to launch remote sensing and meteorological satellites into LEO.[443] The LM-4A has a length of 41.9 meters and the LM-4B is slightly longer at 45.58 meters. The LM-4A can lift 1,500 kg into SSO and the LM-4B can lift 2,200 kg into SSO.[444]

See Table 14 for summary of specifications for the Long March launchers.

New Generation of Launch Vehicles

Despite the improved performance of China's current launch vehicles, China is developing a new generation that will be capable of launching China's large space station and larger satellites. This new generation of launch vehicles would also presumably play a central role in any manned lunar exploration program. Reflecting the importance of these new launchers, former China Aerospace Science and Technology Corporation President Ma Xingrui told a delegation of U.S. space engineers and scientists: "I remind government leaders that engines are the heart of space launch technology, and that is where money must be invested."[445]

The new rockets are designed to meet China's launch needs for the next 30–50 years and offer increased reliability and adaptability and will be powered by "nonpoisonous" and "nonpolluting" engines that will provide more thrust than the current generation of launch vehicles.[446] The new generation of rockets will be divided into light, medium, and heavy-lift versions that will be able to send 1 to 25 metric ton payloads into LEO and 1 to 14 metric ton payloads into GEO.[447] This presents a significant increase in payload capacity. China's current heaviest launch vehicle, the LM-2F, can lift eight metric tons into low Earth orbit.

This new generation of Long March vehicles has been designated the Long March 5, 6, and 7. The Long March 5 will be used to launch the heaviest payloads into orbit, such as China's planned large space station. The Long March 7 will be a medium-lift rocket that will be used to ferry supplies to the space station. The Long March 6 is a light launch vehicle intended to launch payloads of up to one metric ton into orbit. In addition to these liquid fuel rockets, China is also developing the Long March 11, Kuaizhou, and Feitian solid-fuel rockets. These rockets are designed to launch lighter payloads on short notice. The Kuaizhou was first launched in September 2013.

China is also researching rockets even larger than the LM-5. China is conducting preliminary research on a super-heavy-lift launcher with an eight-meter core diameter rocket, the Long March 9, capable of lifting 100 tons into orbit into low Earth orbit.[448] The LM-9 will be submitted for approval during the current five-year plan and could be used to send large payloads to the moon, such as a manned lunar lander.[449]

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[443] "LM-4," China Great Wall Industry Corporation, http://www.cgwic.com/LaunchServices/LaunchVehicle/LM4.html.
[444] "长征四号运载火箭 (组图)" [The Long March 4 Launch Vehicle], sina.com.cn, September 30, 2005, http://news.sina.com.cn/c/2005-09-30/16147910699.shtml.
[445] Bradley Perrett, "Thrust for the Moon," *Aviation Week & Space Technology* March 12, 2012, 32.
[446] Zhang Feng, "中国的长征五号运载火箭" [China's Long March 5 Launch Vehicle], 卫星应用 [*Satellite Application*], 2012/5, 29.
[447] Sun Zifa, "中国未来 5 年实现"长征"五号六号七号火箭首飞" [In 5 Years China Will Realize the First Flights of the 'Long March' 5, 6, and 7], sohu.com, http://news.sohu.com/20130301/n367552968.shtml.
[448] Xin Dingding, "Jumbo Rocket Design Poses Challenges," *China Daily*, http://usa.chinadaily.com.cn/china/2013-03/04/content_16272148.htm.
[449] Bradley Perret, "Chinese Super-Heavy Launcher Designs Exceed Saturn V," *Aviation Week & Space Technology*, September 30, 2013, http://www.aviationweek.com/Article.aspx?id=/article-xml/AW_09_30_2013_p22-620995.xml

Table 14. Selected Long March launcher data

LM-2C				
Stage	1st Stage	2nd Stage	Upper Stage	
Stage diameter	3.35	3.35		
Propellant	UDMH/N_2O_4			
Overall length(m)	42			
	LM-2C	LEO	3850(200km/63°)	
		SSO	1400(600km)	
	LM-2C/SM	GTO	1250(28°)	
	LM-2C/SMA	SSO	1900(600km)	
LM-2D				
		2nd Stage		
Stage	1st Stage	Main Engine	Vernier Engine	
Diameter (m)	3.35	3.35		
Propellant	N_2O_4/UDMH			
Overall length	41.056			
SSO payload capability (kg)	1300			
LM-3A				
Stage	1st Stage	2nd Stage	3rd Stage	
Stage diameter (m)	3.35	3.35	3.00	
Propellant	N_2O_4/UDMH		LOX/LH2	
Overall length (m)	52.52			
GTO launch capability (kg)	2600			
LM-3B				
Stage	Booster	1st Stage	2nd Stage	3rd Stage
Stage diameter (m)	2.25	3.35	3.35	3.00
Propellant	N_2O_4/UDMH			LOX/LH2
Overall length (m)	54.838/56.326*			
GTO Launch capacity (kg)	5100/5500*			
LM-3C				
Stage	Booster	1st Stage	2nd Stage	3rd Stage
Stage diameter (m)	2.25	3.35	3.35	3.00
Propellant	N_2O_4/UDMH			LOX/LH2
Overall length (m)	54.838(56.638)			
GTO launch capacity (kg)	3800			
LM-4B				
Stage	Booster	1st Stage	2nd Stage	3rd Stage
Stage diameter (m)		3.35	3.35	2.9
Propellant	N2O4/UDMH			
Overall length (m)	45.80			
LEO launch capacity (kg)	2800 (GTO: 1500)			
LM-4C				
Stage	Booster	1st Stage	2nd Stage	3rd Stage
Stage diameter (m)		3.35	3.35	2.9
Propellant	N2O4/UDMH			
Overall length (m)	39.98			
GTO launch capacity (kg)	1500			

*LM-3B/E launch vehicle.

The planned maiden launches of these new rockets have changed. A 2002 *Aviation Week and Space Technology* article stated that the first new rocket would launch in 2008 to coincide with the Beijing Olympics.[450] In 2006, CNSA Vice Administrator Luo Ge stated that the launch of the Long March 5 would occur by 2011, but this date has been repeatedly pushed back and is now scheduled for 2015.[451] The Long March 6 was originally scheduled to be launch in 2013, but that launch has not yet occurred. The Long March 7 is planned to be first launched in 2014, but has not yet occurred at time of writing.[452] The Long March 11, on the other hand, is planned to be launched by 2016.[453]

These new launch vehicles are expected "to improve rocket reliability to 0.98 for unmanned missions and 0.99 for manned flights, compared with 0.91 for the existing model line." They are also planned to reduce launch costs by 20 percent to 30 percent and have reduced launch preparation times of less than 15 days.[454] Despite the promise of increased reliability and reduced costs, China is expected to continue using its current generation of Long March launchers for 10 to 20 more years until the new rockets become fully mature.[455]

A focus of the new generation of launch vehicles is the development of new engine technology with staged combustion technology to increase payload. The focus of the effort has been on the YF-100 engines for the Long March 5, based on the Russian RD-120 engine, capable of generating 120 tons of thrust. The Long March 6 and 7 will also use staged combustion in their second stages. According to *Aviation Week and Space Technology*, a staged combustion cycle "has limited meaning for China's military capabilities since it is used on liquid-fueled engines," but the

> practical result should be a greater payload to orbit for a launcher of a given size. The improved performance will probably be essential for China's next generation of launchers to be competitive as the technology becomes increasingly common in the future…and underscores the country's ability to catch up with advanced foreign aerospace technology.[456]

With the use of just one engine using staged combustion cycle, Chinese rockets should be able to achieve a 5–10 percent increase in payload. With the use of two they could achieve a 10–15 percent increase in payload.[457]

Another important feature of the new engine technology for the next generation of liquid-fueled launch vehicles is the use of so-called non-polluting fuel consisting of liquid hydrogen, liquid oxygen, and liquid oxygen kerosene engines instead of hydrazine-fueled engines. Hydrazine is easier to ignite than kerosene,

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[450] Michael A. Taverna, "Giant Leap," *Aviation Week & Space Technology*, October 6, 2003, 46.
[451] Bradley Perret, "China's Long March 5 Will Not Launch Until 2015," *Aviation Week & Space Technology,* March 25, 2013, http://www.aviationweek.com/Article.aspx?id=/article-xml/AW_03_25_2013_p30-561101.xml.
[452] "2014 Maiden Launch for Long March-7 Rocket," *China Daily*, http://www.chinadaily.com.cn/china/2013-03/01/content_16267164.htm
[453] Bradley Perret, "China's Long March 5 Will Not Launch Until 2015," *Aviation Week & Space Technology,* March 25, 2013, http://www.aviationweek.com/Article.aspx?id=/article-xml/AW_03_25_2013_p30-561101.xml.
[454] Michael A. Taverna, "Giant Leap," *Aviation Week & Space Technology*, October 6, 2003, 46.
[455] Xin Dingding, "Jumbo Rocket Design Poses Challenges," *China Daily*, http://usa.chinadaily.com.cn/china/2013-03/04/content_16272148.htm.
[456] Bradley Perrett, Frank Morring Jr., Amy Svitak, and Jay Menon, "Out of the Bottle," *Aviation Week & Space Technology*, September 16, 2013, 50.
[457] Bradley Perrett, "Next Stage," *Aviation Week & Space Technology*, January 10, 2011, 35.

but it is also toxic and can create hazards during fueling and in the event of catastrophic failure when parts of a rocket separate from the launcher and return to Earth. In March 2011, for example, a part from a Long March 3 fell in Guizhou Province and was surrounded by a yellow cloud.[458]

Kerosene, on the other hand, packs more energy, but requires liquid oxygen that must be cryogenically stored. Developing the means to cryogenically store the liquid has been one of the major efforts of the new-generation launch vehicle and one in which China has sought outside assistance. China is working with a Russian design bureau on the new engines,[459] and in 2009 a native of China and naturalized U.S. citizen, Shu Quan-sheng, was convicted of illegally exporting rocket engine cryogenic technology to China.[460]

China's New Long March Launchers in Detail

Long March 5

The Long March 5 is the largest rocket under development by China. It is comparable to the U.S. Delta IV[461] and will have the ability to launch 25 metric tons into LEO and 14 metric tons into GTO. Research and development of the Long March 5 was begun in 2000. The LM-5 will stand 60 meters tall and is based on a core vehicle with a diameter of five meters as compared to the 3.35 diameter of the current largest Long March launchers. The rocket is the first Chinese rocket to be completely designed digitally, which is said to have improved its quality and reduced development times.[462]

The LM-5 is the most technically challenging of the new rockets, due to the large diameter core engines divided into two stages housing 50-ton LOX/LH2 engines.[463] The LM-5 will come in six configurations to carry a variety of payloads with the use of either 2.25-meter or 3.35-meter boosters attached to the sides of the core engines.[464]

The rocket is essential to carrying out China's future human space flight and potential manned lunar missions and is being developed specifically to launch China's large space station. It is also expected to launch China's next generation of remote sensing and communication satellites, which are expected to be larger than the current generations. Difficulties in manufacturing the LM-5 core structure, however, have led to continuing delays, and is believed to be the reason why plans to complete China's large space station have been delayed from 2020 to 2023.[465]

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[458] Zhang Feng, "中国的长征五号运载火箭" [China's Long March 5 Launch Vehicle], 卫星应用 [*Satellite Application*], 2012/5, 29.

[459] Michael A. Taverna, "Giant Leap," *Aviation Week & Space Technology*, October 6, 2003, 46.

[460] "Virginia Physicist Sentenced to 51 Months in Prison for Illegally Exporting Space Launch Data to China and Offering Bribes to Chinese Officials," FBI, http://www.fbi.gov/norfolk/press-releases/2009/nf040709.htm.

[461] "In Orbit," *Aviation Week & Space Technology,* September 14, 2009, 18.

[462] Zhang, "China's Long March 5 Launch Vehicle," 31.

[463] Li and Cheng, "The New Generation of Launch Vehicles and Its Applying to China's Lunar Exploration Program"; Tangming Cheng, Xiaojun Wang, and Dong Li, "The New Generation Launch Vehicles of Long-March Family," paper presented at the 54th International Astronautical Congress of the International Astronautical Federation, the International Academy of Astronautics, and the International Institute of Space Law, September 29–3 October 3, 2003, Bremen, Germany, 4, http://arc.aiaa.org/doi/pdf/10.2514/6.IAC-03-V.1.04.

[464] Li and Cheng, "The New Generation of Launch Vehicles and Its Applying to China's Lunar Exploration Program."

[465] Xin Dingding, "Jumbo Rocket Design Poses Challenges," *China Daily*, http://usa.chinadaily.com.cn/china/2013-03/04/content_16272148.htm.

Long March 6

The Long March 6 is a light-lift rocket capable of launching one metric ton into LEO. The LM-6 is made up of a 2.25-meter core with a 120-ton engine based on the strap-on boosters of the LM-5 and a second stage powered by a 15-ton engine.[466] The LM-6 was approved in 2009 and is being developed by the Shanghai Academy of Space Technology and is said to use many new technologies that have never been used before in China.[467]

Long March 7

The Long March 7 is a medium-lift rocket capable of launching 13.5 metric tons to LEO and 5.5 metric tons into SSO. Its first launch is expected around 2016. The LM-7 will be two stages made up of two 3.35-meter core engines and 2.25-meter strap-on boosters.[468] The LM-7 will eventually replace the LM-2F in transporting personnel and supplies to China's space station.

Long March 11

The Long March 11 program, officially started in 2012, will be China's largest solid-fueled rocket.[469] It is reportedly based on the DF-31A ballistic missile and is expected to make its first launch by the end of 2015.[470] As a solid-fueled rocket, the LM-11 is positioned to provide China an ability to launch satellites into orbit on shorter notice than its liquid-fueled cousins. Chinese press accounts tout its ability to respond quickly to natural disasters and "sudden instances," which probably includes natural disasters and military conflict.[471]

Kuaizhou

Kuaizhou (快舟) is a small, solid-fueled rocket first launched September 25, 2013 that involved launching the Kuaizhou-1 small satellite into orbit. Developed by the China Aerospace Science & Industry Corporation (CASIC) and similar to the LM-11, Kuaizhou is also intended to give China a rapid response launch capability. A second launch of the Kuaizhou rocket and the Kuaizhou-2 satellite occurred November 21, 2014.[472] The program was formally begun in 2009 and is said to have involved many new concepts and technologies for China, including grid fins.[473] The Kuaizhou can launch satellites from a mobile launcher and is reported to be based on the three-stage DF-21-derived KT-1 solid-fueled rocket, which experienced

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466 Li and Cheng, "The New Generation of Launch Vehicles and Its Applying to China's Lunar Exploration Program"; Cheng, Wang, and Li, "The New Generation Launch Vehicles of Long-March Family."

467 Yin Linfa, "我国火箭家族天壤新成员长征六号研制启动" [Research and Development of the Long March 6, a New Member of the Rocket Family, Started], 中国航天 [*Aerospace China*], 2009/9, 9.

468中国 2016 年左右发射长征七号与天舟货船[China Around 2016 Will Launch the Long March 7 and Supply Vessel for the Tianggong and Shenzhou], 新华[Xinhua], http://news.xinhuanet.com/tech/2014-03/02/c_119565025.htm; Fan Ruixiang and Rong Yi, "我国新一代中型运载火箭的发展展望" [The Development and Prospects of Our Country's New Generation Medium Lift Launch Vehicle], 载人航天 [*Manned Spaceflight*], 2013/1, 2; Li and Cheng, "The New Generation of Launch Vehicles and Its Applying to China's Lunar Exploration Program"; Cheng, Wang, and Li, "The New Generation Launch Vehicles of Long-March Family."

469 "China's First Solid-fuel Rocket to Debut Before 2016," *China Daily*, http://www.chinadaily.com.cn/china/2013-03/02/content_16269380.htm.

470 "长征 11 号快速机动小型固体运载火箭通过国家立项" [Long March 11 Rapid and Mobile Small Solid Fueled Rocket is Approved by the Government], http://www.shenkong.net/News/1209/CZ11HKSJDXXGTYZHJTGGJLX07070110.htm.

471 Ren Qinqin, "长征 11 号十二五首飞 中国首枚固体运载火箭" [Long March 11 Will Launch During the 12th FYP China's First Solid Fueled Rocket], March 2, 2013, 21cn.com, http://mil.21cn.com/gn/a/2013/0302/13/20515412.shtml.

472 "我国成功发射"快舟二号"卫星," [Our Country Successfully Launches Kuaizhou-2 Satellite], 新华社 [Xinhua], November 21, 2014.

473快舟固体运载火箭总设计师 [Kuaizhou Solid Fueled Rocket Chief Designer], http://liuqiankktt.blog.163.com/blog/static/12126421120144248303922 3/.

one, if not two, launch failures in 2002 and 2003 and was reportedly not approved for further development. The Kuaizhou is said to have a 1.7 meter diameter booster instead of the 1.4-meter diameter booster of the KT-1. The Kuaizhou is also said to be related to the KT-409, which ultimately was developed into the Dongneng-1 (动能-1/DN-1) direct-ascent kill vehicle used in China's 2007 ASAT test. Kuaizhou was designated one of the top ten news stories of China's national defense industry in 2013.[474]

Feitian

Feitian (飞天) is a small, solid-fuel rocket developed by the China Aerospace Science and Industry Corporation. The existence of the Feitian was first made public at the 2014 Zhuhai Airshow and it is not known to have been launched. The three-stage Feitian is very similar to the Kuaizhou rocket and can launch 300 kg into orbit with just four hours of preparation. As such, Feitian is also advertised as providing operationally responsive space capabilities. Due to its similarity to the Kuaizhou, Chinese press reports have speculated that it is a commercial version of the Kuaizhou meant for export.[475]

Counterspace Technologies

China has a broad-based development program for counterspace technology that consists of jammers, direct-ascent kinetic-kill vehicles, directed-energy weapons, and co-orbital spacecraft.[476] China's development of counterspace weapons appears to be aimed at developing an all-around capability to threaten satellites with a variety of weapons at all orbits (Table 15).

Table 15. Chinese ASAT tests and tests with counterspace implications

Year	Technology
2006	Chinese laser paints U.S. satellite, though intent of action is unknown
2007	China destroys aging FY-1C meteorological satellite with direct-ascent kinetic-kill vehicle
2007	Unattributed hacking attack against Landsat-7 satellite command and control center resulted in 12 or more minutes of interruption
2008	Unattributed hacking attack against Landsat-7 satellite command and control center resulted in 12 or more minutes of interruption
2008	Unattributed hacking attack against Terra EOS satellite command and control center resulted in two or more minutes of interruption
2008	Unattributed hacking attack against Terra EOS satellite command and control center resulted in nine or more minutes of interruption
2010	China conducts mid-course ballistic missile defense test
2010	Two Shijian satellites involved in close proximity operation, causing slight change in one satellite's orbit
2013	China conducts mid-course ballistic missile defense test
2013	Three satellites involved in close proximity operation to test space debris removal and robotic arm technologies
2013	China conducts "high altitude science" mission with rocket reaching GEO
2014	China conducts mid-course ballistic missile defense test

[474] Ibid.

[475] "观察者网珠海航展前线：飞天一号火箭引发关注 4 小时即可"飞天"" [Guancha Net on the Frontlines of the Zhuhai Airshow: Feitian-1 Triggers Attention That it Can Launch in Four Hours], http://m.guancha.cn/military-affairs/2014_11_12_285792.

[476] Office of the U.S. Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China* (2012), 9.

The most prominent demonstration of China's counterspace technologies was the 2007 destruction of a defunct FY-1C meteorological satellite 800 kilometers above the Earth's surface with a direct-ascentkinetic-kill vehicle. The U.S. government was the first to announce the January 11 test and did so on January 18 after consulting with the Chinese Foreign Ministry, which appeared to be ignorant of the matter. It was not until January 23—five days after the U.S. announcement—that China admitted to the test, stating that it "was not targeted against any country and does not pose a threat to any country."[477]

The seeming ignorance of the Chinese Foreign Ministry and the five-day wait between the U.S. announcement and the Chinese statement admitting the test raised serious questions about civil-military relations in China and the message, if any, that was intended by the test. According to one interlocutor, the test was briefed at the highest levels of the Chinese government, but its potential ramifications, including space debris, were not covered. According to one analysis based on numerous interviews with Chinese interlocutors, the test was actually a missile defense test that was carried out against a satellite because it was an easier object to target than a speeding warhead. The test, according to their interlocutors, was "carefully vetted" before being presented to the ultimate, but unidentified, decision-makers.[478] According to former Secretary of Defense Robert Gates, the U.S. Defense Department would assess that the test "had been conducted by the PLA without the knowledge of the civilian leadership in Beijing."[479]

This test was widely condemned as being seemingly contrary to China's stance against the weaponization of space. More importantly, the test created more than 3,400 pieces of debris, the majority of which are still in orbit and traveling as fast as 17,500 mph. According to NASA, more than 50 percent of this debris could still be in orbit 20 years later.[480]

Due to the increasing amount of debris in LEO, space debris is becoming an increasing hazard to spacecraft. The International Space Station has been forced to change orbit to avoid debris created by the 2007 ASAT test,[481] and in 2013 a small Russian satellite was destroyed after space debris generated from the 2007 test rammed into it.[482] China's space program has also been affected by space debris. China states that debris comes close to Chinese spacecraft at least twice per week.[483]

Interestingly, Chinese officials do not admit responsibility for the debris caused by the 2007 ASAT test. A 2014 statement by the head of the China National Observatory only mentions the 2009 collision between a Russian Cosmos satellite and an Iridium communications satellite and the 2013 destruction of the small Russian satellite, but does not assign responsibility.[484] Chinese researchers also follow a similar tack and

[477] Edward Cody, "China Confirms Firing Missile to Destroy Satellite," *Washington Post*, January 24, 2007, http://www.washingtonpost.com/wp-dyn/content/article/2007/01/23/AR2007012300114.html.
[478] Gregory Kulacki and Jeffrey Lewis, "Understanding China's ASAT Test," Union of Concerned Scientists, http://www.ucsusa.org/nuclear_weapons_and_global_security/solutions/us-china-cooperation/understanding-chinas-asat.html.
[479] Robert Gates, *Duty: Memoirs of a Secretary at War* (New York: Knopf, 2014).
[480] "Fengyun-1C Debris Cloud Remains Hazardous," *Orbital Debris Quarterly News*, January 2014, 3–4.
[481] Tariq Malik, "Space Station Dodges Debris from Destroyed Chinese Satellite," Space.com, http://www.space.com/14398-space-station-dodges-chinese-space-junk.html.
[482] Leonard David, "Russian Satellite Hit by Debris from Chinese Anti-Satellite Test," Space.com, http://www.space.com/20138-russian-satellite-chinese-space-junk.html.
[483] "我国应对空间碎片威胁成果丰硕" [Our Country's Substantial Achievements in Countering the Threat of Space Debris], http://jmjhs.miit.gov.cn/n11293472/n11295193/n11312030/16000759.html.
[484] Ibid.

only identify the 2009 collision as the major source of space debris and neglect to mention the 2007 ASAT test.[485]

Since the 2007 ASAT test, China appears to have become more serious about mitigating the threat of space debris, although one analyst writes that China's research on space debris is still comparatively weak.[486] China has been a member of the Inter-Agency Space Debris Coordination Committee (IADC) since 1995. During the group's 32nd annual meeting in Beijing in May 2014, an official from the Chinese Foreign Ministry stated, "Human exploration and use of outer space during the past decades have resulted in a large amount of debris. The increase of debris poses a serious threat to space activities, space assets, and the space environment. This issue can only be resolved through the joint efforts of all spacefaring countries…China requires its domestic institutions to conduct space activities in accordance with the work plan of the IADC and urges the Chinese space agency and enterprises to abide by its own guidelines on mitigation of space waste."[487]

According to Xu Dazhe, head of CNSA, "China has allocated a considerable amount of resources in research and development for the detection, protection, and mitigation of space debris," and has established an initial surveillance and early warning system that was "beginning to provide technical support to our manned space exploration and satellite operation." CNSA has also implemented a space debris plan, established a space debris coordination and expert group, established a space debris high-speed-collision testing center, and established the Chinese Academy of Sciences Space Target and Debris Monitoring Research Center (中国科学院空间目标与碎片观测研究中心).[488] China has also redesigned its launch vehicles to minimize the creation of debris during launch and orbiting of satellites[489] and has retired satellites to higher orbits so that they do not interfere with operational satellites.[490]

In 2005 China published the "PRC Space Sector Standards—Space Debris Mitigation Requirements" (中国人民共和国航天行业标准--空间碎片减缓要求) and in 2009 published the "Space Debris Mitigation Guide" (空间碎片减缓指南). In 2009, China also published the "Provisional Management Methods for Space Debris Mitigation and Protection" (空间碎片减缓与防护暂行管理办法),[491] which were the first Chinese regulations governing debris mitigation measures for the R&D of Chinese spacecraft. The "Management Methods" may have been written in response to the 2007 ASAT test, as drafts of the

[485] See, for example, Ying Luju, "太空垃圾挑战人类" [Space Debris and the Challenge to Humans], 近日科技 [*Today Science and Technology*] 2 (2009): 52; and Lin Laixing, "空间碎片现状与清理" [Status and Removal of Space Debris], 航天器工程 [*Spacecraft Engineering*] 6 (2012): 3.
[486] Ping Guodong, "关于完善我国空间碎片减控立法的思考和建议" [Some Reflections and Suggestions on Improving Our Country's Space Debris Mitigation Laws], 中国航天 [*Aerospace China*], 2014/2, 32.
[487] Zhao Lei, "China Aids in Cutting Down Space Debris," *China Daily*, May 13, 2014, http://www.chinadaily.com.cn/china/2014-05/13/content_17503107.htm.
[488] "多国航天机构在京研讨应对太空垃圾" [Many Space Organizations from Around the World Meet in Beijing to Discuss Space Debris], http://tech.ifeng.com/discovery/astronomy/detail_2014_05/13/36294721_0.shtml/ ; Wang Haiping and Ma Weihong, "我国有了"太空垃圾"观测中心" [Our Country has a 'Space Debris" Monitoring Center], 人民网 [*People's Net*], March 10, 2005, http://scitech.people.com.cn/GB/25892/3232749.html; and
[489] "China Aids in Cutting Down Space Debris," http://www.china.org.cn/china/2014-05/13/content_32369026.htm.
[490] "China's Space Activities in 2011," Information Office of the State Council, December 2011, http://www.gov.cn/english/official/2011-12/29/content_2033200.htm.
[491] "中国代表在联合国外空委法律小组委员会第 52 届会上关于"空间碎片"议题的发言," [China Delegation at the 52nd Meeting of the UN Committee on Space Law Delivers Speech on 'Space Debris'], http://www.chinesemission-vienna.at/chn/hplywk/t1034115.htm; and Zhao Lei, "China Aids in Cutting Down Space Debris," *China Daily*, May 13, 2014, http://www.chinadaily.com.cn/china/2014-05/13/content_17503107.htm.

regulations were discussed by the Space Debris Research Office (空间碎片研究专项办公室) and the Space Debris Research Expert Group (空间碎片研究专家组) in November 2007 and March 2008.[492] The regulations assigned the State Administration for Science, Technology, and National Defense (SASTIND) responsibility for space debris mitigation efforts for civilian-use satellites and launch vehicles and for cooperation with IADC. They also stipulated that manufacturers of spacecraft and launch vehicles must sign the "Provisional Methods for the Management of Civil space Launch Permit" (民用航天发射项目许可证管理暂行办法), which acknowledges that spacecraft and launch vehicles have been built to mitigate space debris.[493]

Despite these documents, CNSA has not posted a space debris mitigation policy or information on its website nor are there any postings on the IADC website, even though the mitigation policies of the U.S. government, NASA, ESA, and France are posted.[494]

China is also conducting research on space debris mitigation technologies. The Shanghai Astronomical Observatory established a preliminary laser ranging system for space debris in 2006. The tests used a Chinese 40W laser with a range of 900 km, and 1,200 km using a 10W U.S. laser. The tests demonstrated that China could establish the range of an object in space with a precision of 50–70 cm.[495] China has also developed a space debris protection design system, developed many types of high-speed launch devices to simulate debris impacts, and developed new structures and materials to protect against space debris.[496] China has also been conducting research on the use of robotic arms to remove space debris. To date, Chinese press reports have stated this research has involved modeling and simulation and will move to actual testing in the future. The testing of robotic arm technologies also has counterspace implications and was the focus of a 2013 test involving satellites in orbit (discussed in more detail later).[497]

China's sensitivity to the creation of space debris appears to be reflected in its subsequent ASAT-related tests. In 2010, 2013, and 2014, China conducted mid-course tests of a missile defense system that are believed to be de facto ASAT tests. The technologies associated with midcourse missile defense technologies are so similar to direct-ascent kinetic-kill ASAT technologies that they provide an inherent counterspace capability. But because interceptions during the midcourse phase take place at such low altitudes, any debris produced by the interception quickly returns to Earth. The utility of midcourse missile defense technologies for counterspace operations was demonstrated in 2008 when the United States used an SM-3 missile interceptor to destroy an errant satellite.[498]

Some Chinese commentators assess that China's missile defense technologies have dramatically improved, or even achieved, their initial operational capability. Second Artillery Engineering Institute professor Song Zhongping stated that the success of the 2013 missile defense test meant "that China has

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[492] Ping Guodong, "关于完善我国空间碎片减控立法的思考和建议" [Some Reflections and Suggestions on Improving Our Country's Space Debris Mitigation Laws], 中国航天 [*Aerospace China*], 2014/2, 30.
[493] Ibid., 31.
[494] 'References," http://www.iadc-online.org/index.cgi?item=documents.
[495] Zhang Zhongping, Yang Fumin, Zhang Haifeng Zhang, Wu Zhibo, Chen Juping, Li Pu, and Meng Wendong, "The Use of Laser Ranging to Measure Space Debris," *Research in Astronomy and Astrophysics* 12, no. 2 (2012): 212–18.
[496] "Our Country's Substantial Achievements in Countering the Threat of Space Debris."
[497] "中国进军太空垃圾清理 验证机械手捕捉碎片" [China Advances Towards Space Debris Mitigation Testing Robotic Arm Technology to Remove Debris], http://war.163.com/14/0906/12/A5F6DIB200014OMD.html.
[498] Taken from Kevin Pollpeter, "China's Second Ballistic Missile Defense Test: A Search for Strategic Stability," *SITC News Bulletin*, February 2013, http://igcc.ucsd.edu/assets/001/504391.pdf.

already successfully resolved the issues of upper atmosphere target identification and tracking and terminal guidance issues and that its mid-course missile defense technology is at the forefront of world technology."[499] At the same time, Chinese commentators noted that China had conducted just two tests and was still far behind the United States. Many more issues need to be addressed, including improving the system's accuracy and reaction time, its resistance to electromagnetic jamming, and its ability to intercept multiple warheads. Moreover, for a mid-course interceptor system to be truly effective, it needs to be supported by a capable C4ISR system, especially a space-based early warning system.[500]

After China's July 2014 test, the U.S. State Department called on China to "refrain from destabilizing actions—such as the continued development and testing of destructive anti-satellite systems—that threaten the long term security and sustainability of the outer space environment, on which all nations depend." China, however, has denied the counterspace implications of the test, stating that "to associate it with an anti-satellite test is entirely groundless."[501]

In addition to missile defense tests, China conducted a "high altitude science mission" in 2013 using a sounding rocket. According to the Chinese Academy of Sciences, the rocket reached an altitude of more than 10,000 kilometers and released a barium cloud to study the dynamic characteristics of the Earth's magnetosphere.[502] This claim appeared to be contradicted by a U.S. government assessment that the rocket "appeared to be on a ballistic trajectory nearly to geosynchronous Earth orbit (GEO)," which could refer to a distance of 30,000 kilometers.[503] If so, the test would represent an expansion of China's ASAT capabilities. The 2007 ASAT destroyed a satellite at an altitude of 800 kilometers, demonstrating the ability to threaten satellites, such as remote sensing satellites, in LEO. The May 2013 high-altitude science mission would allow China to threaten satellites such as GPS and communication satellites in medium and high Earth orbits.

There is little information in Chinese sources on the interceptor technology used to conduct these tests. The missile used to conduct the initial 2007 ASAT test, the SC-19,[504] also reportedly called the Dongneng-1 (动能-1/DN-1), is, according to one blog posting, based on the Kaituozhe-1 (KT-1/开拓者一号/Pioneer), a solid-fueled launch vehicle that was never deployed.[505] The SC-19 was developed by the China

499 "中国反导战力快速突破 海基拦截系统也开始起步" [China Makes Breakthrough in Missile Defense Combat Effectiveness Sea-based Interception System Also Begun], January 31, 2013, http://news.ifeng.com/mil/4/detail_2013_01/31/21820257_0.shtml.

500 Pollpeter, "China's Second Ballistic Missile Defense Test: A Search for Strategic Stability."

501 Mike Gruss, "U.S. State Department: China Tested Anti-Satellite Weapon," Space News, July 28, 2014, http://www.spacenews.com/article/military-space/41413us-state-department-china-tested-anti-satellite-weapon.

502 "中国再次高空科学探测试验：高度更高数据更多" [China Again Conducts a High Altitude Science Mission: Higher Altitude and More Data], 中国新闻网 [*China News*], May 14, 2013, http://www.chinanews.com/gn/2013/05-14/4817925.shtml.

503 Brian Weeden, "Through a Glass, Darkly: Chinese, American, and Russian Anti-Satellite Testing in Space," *Space Review*, March 17, 2014, http://www.thespacereview.com/article/2473/1.

504 "Senator Clinton Questions Vice Admiral John M. McConnell, USN (Ret), Director of National Intelligence and Lieutenant General Michael Maples, USA, the Director of the Defense Intelligence Agency at a Senate Armed Services Committee Hearing on Worldwide Threats," http://web.archive.org/web/20070330225204/http://www.senate.gov/~clinton/news/statements/details.cfm?id=269792.

505 快舟固体运载火箭总设计师 [Kuaizhou Solid Fueled Rocket Chief Designer], http://liuqiankktt.blog.163.com/blog/static/12126421120144248303922 3/.

Aerospace Solid Propellant Launch Vehicle company (ASLV) of CASIC and is based on the road-mobile DF-21 medium-range ballistic missile.[506]

A larger version of the KT-1, the KT-2, based on the road-mobile DF-31 ballistic missile, was also reported to be under development. The KT-2 may have been used in China's 2013 high altitude science mission. This missile has also been called the Kunpeng-7 (鲲鹏七号/Roc), though one source states that this was the name of the mission rather than the rocket.[507]

China is also developing directed-energy weapons such as lasers, high-powered microwave, and particle beam weapons for ASAT missions.[508] The Defense Department concluded in 2006 that China had "at least one…ground-based laser designed to damage or blind imaging satellites."[509] Lasers at higher power levels can permanently damage satellites and at lower power levels can temporarily blind the imagers of a remote sensing satellite. Lasers can be based on the ground, on aircraft, on ships, or in space. In 2006 it was reported that China had fired a laser at a U.S. satellite. According to U.S. officials, the intent of the lasing is unknown and did not damage the satellite, suggesting that China could have been determining the range of the satellite rather than trying to interfere with its function.[510]

China is also researching radio frequency (RF) weapons that could be used against satellites. Radio frequency weapons using high power microwaves can be ground-based, space-based, or employed on missiles to temporarily or permanently disable electronic components through either overheating or short circuiting. RF weapons are thus useful in achieving a wide spectrum of effects against satellites in all orbits.[511] RF weapons employed on satellites may be detected since the satellite would need to be close to the target satellite for the weapon to be effective. A satellite armed with an RF weapon on a crossing orbit with the target satellite, however, may not be recognized as a threat. RF weapons launched on rockets could detonate near the target satellites and thus may not be detected. Because RF weapons affect the electronics of satellites, evaluating the success of an attack may be difficult since no debris would be produced.[512]

China may also have been involved in computer hacks against satellite computer systems. In October 2007 and July 2008, a computer attack against the command and control system of Landsat-7, a remote sensing satellite operated by the USGS and NASA, resulted in 12 or more minutes of interference on each occasion. The attacks did not result in the perpetrator achieving the ability to take command of the satellite. In June and October 2008, the command and control system for the Terra EOS (Earth Observation System) was

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[506] Richard Fisher, "China's Direct Ascent ASAT," International Assessment and Strategy Center, http://www.strategycenter.net/research/pubID.142/pub_detail.asp.

[507]快舟固体运载火箭总设计师 [Kuaizhou Solid Fueled Rocket Chief Designer], http://liuqiankktt.blog.163.com/blog/static/121264211201442483039223/.

[508] Office of the U.S. Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China* (2012), 9.

[509] Office of the U.S. Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China* (2006), 35.

[510] Elaine M. Grossman, "Top Commander: Chinese Interference with U.S. Satellites Uncertain," *World Politics Review,* October 18, 2006.

[511] Office of the U.S. Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China* (2006), 34; and Office of Technology Assessment, *Anti-Satellite Weapons, Countermeasures, and Arms Control*, September 1985, 66–67.

[512] David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security: A Reference Manual* (Cambridge, MA: American Academy of Arts and Sciences, 2005), 133.

hacked into, resulting in two or more minutes and nine or more minutes of interference, respectively. In both cases, the perpetrator had the ability to command the satellite, but refrained from doing so.[513] China has denied responsibility for the attacks.[514]

China has also acquired foreign and indigenous jammers that give it "the capability to jam common satellite communications bands and GPS receivers."[515] GPS, in particular, can be easily jammed due to the attenuation of the signal over the 12,500-mile distance between the satellites and Earth.[516] As a result, even low-power jammers can achieve effects over long distances. According to the Defense Science Board, "modest (few watt) jammers can deny acquisition [of the GPS signal]" at ranges up to hundreds of kilometers.[517]

China's 2008 defense white paper mentions all services, except the PLA Navy, as having electronic warfare units that could be used to jam satellite communications and GPS signals. Ground force electronic warfare units are subordinate to the General Staff Department's Fourth Department and are maintained at the military region level. The PLA Air Force and Second Artillery also maintain their own electronic warfare units while PLA Navy electronic warfare capabilities are resident on individual ships. Although China's GPS jamming strategy is unknown, given the relatively small size and long range of GPS jammers, it could consist of a series of vehicle-mounted jammers that are spaced at intervals within the theater of operations to provide overlapping GPS jamming zones.

Space-based jamming is less of a threat since jamming is conducted against receivers and not transmitters. As a result, GPS satellites would not be the targets of GPS jamming, although satellites that use GPS to aid in orbital positioning could be.

In addition, China could detonate a nuclear weapon in space to destroy satellites through both the blast and the electromagnetic pulse generated by the explosion. The use of a nuclear weapon in space, however, would also affect China's satellites, as well as those of third parties.[518]

According to the U.S. Defense Department, China has also "conducted increasingly complex close proximity operations between satellites."[519] The ability to conduct these operations has been aided by the development of a TT&C system to support China's human spaceflight and lunar exploration programs that enables China to better control with precision its own satellites as well as to monitor the satellites of potential adversaries.

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[513] U.S.-China Economic and Security Review Commission, *2011 Report to Congress of the U.S.-China Security and Economic Review Commission,* November 2011, 216.
[514] Sui-lee Wei, "China Denies It Is Behind Hacking of U.S. Satellites," Reuters, October 31, 2011, http://www.reuters.com/article/2011/10/31/us-china-us-hacking-idUSTRE79U1YI20111031?feedType=RSS&feedName=scienceNews&utm_source=dlvr.it&utm_medium=twitter&dlvrit=309301.
[515] Office of the U.S. Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China* (2011), 37.
[516] Congressional Budget Office, "The Global Positioning System for Military Users: Current Modernization Plans and Alternatives," October 2011, 4.
[517] Defense Science Board, "Report of the Defense Science Board Task Force on Tactical Air Warfare," November 1993, 12.
[518] Office of the U.S. Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China* (2011), 37.
[519] Office of the U.S. Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China* (2012), 9.

In addition to the BX-1 test discussed earlier, China has conducted other close proximity operations. In August 2010 it was reported that after conducting a series of maneuvers the Shijian-12 (SJ-12) satellite had most likely bumped into the Shijian 6F (SJ-6F), causing it to drift slightly from its original orbit. The maneuvering could have been practice for docking the Shenzhou space capsule with the Tiangong-1 space station, but Chinese silence on the true intention of the test fueled concern that it was a cover for testing ASAT capabilities.[520]

In addition to these tests, in August 2013 China conducted a test of robotic arm technologies involving the Chuangxin-3, Shiyan-7, and Shijian-15 satellites where one of the satellites acted as a target satellite and another satellite, most likely equipped with a robotic arm, grappled the target satellite. As with the August 2010 test involving the SJ-12 and SJ-6F, the test could have been for a legitimate peaceful purpose: the testing of robotic arm technologies that will be used on future Chinese space stations. As with the August 2010 tests, however, the dual-use nature and silence by the Chinese on the matter have only fueled speculation that China was also testing counterspace technologies.[521]

ORGANIZATION

Similar to the United States, China's space enterprise is made up of a numerous organizations spanning the military, government, and defense industry. Like the United States, China does not appear to have a peacetime executive agent for space. The military, through the General Armament Department (GAD), oversees the R&D of all spacecraft and operates China's launch centers and satellite control centers. Although the GAD oversees spacecraft R&D, it also appears that civilian stakeholders, such as the China National Meteorological Administration and the State Oceanographic Administration, provide requirements during the R&D process for satellites in their respective areas of responsibilities and operate their own spacecraft. In fact, one justification given for the development of multiple types of remote sensing satellites is to have primarily civilian-use satellites available for civilian end-users to have access to remote sensing data without going through more complicated military channels.[522]

Unlike the United States, however, China's space enterprise is inherently dual-use. In the United States, for example, civilian meteorological satellites are operated by the National Oceanic and Atmospheric Agency, while the military has its own Defense Meteorological Satellite Program satellites.[523] Chinese weather satellites, on the other hand, serve both civilian and military purposes. As a result, in the event of military conflict, it is probable that the military will take direct command over all space assets regardless of their peacetime affiliation.

Two large space industry conglomerates, the China Aerospace Science and Technology Corporation and the China Aerospace Science and Industry Corporation, conduct Chinese spacecraft R&D. Similar to the operation of spacecraft, both military and civilian stakeholders can also participate in R&D for satellites in their respective areas of responsibility. The work of the space industry is overseen by the military through the GAD and by the government through SASTIND.

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[520] Brian Weeden, "Dancing in the Dark: The Orbital Rendezvous of SJ-12 and SJ-06F," *Space Review*, August 30, 2010, http://www.thespacereview.com/article/1689/1.
[521] See Kevin Pollpeter, "China's Space Robotic Arm Programs," *SITC News Analysis,* October 2013, http://igcc.ucsd.edu/assets/001/505021.pdf.
[522] "高分一号的落后与特色" [Gaofen-1 Deficiencies and Characteristics], *Defense Review*, http://news.qq.com/zt2013/GF1.
[523] The Defense Meteorological Satellite Program is run by a joint military-NOAA team.

Creation of an Executive Agent for Space and a Military Space Force

The multiplicity of organizations responsible for different aspects of China's space program have led some in China to conclude that China's space enterprise is too dispersed among a number of different organizations and that effective coordination is not possible without centralized command. Ye Peijian, chief designer of China's first moon probe, and Qi Faren, former chief designer of the Shenzhou space capsule, stated at the 2009 session of the National Committee of the Chinese People's Political Consultative Conference that China's space bureaucracy is made up of too many disparate pieces that cannot be coordinated well, and advocated for an executive agent for space. Ye asserts that the country's response to the earthquake in 2008 would have been better had it had an integrated approach to the organization of space.[524]

The Chinese Academy of Sciences has also recognized the need for an executive agent for space, at least on the civil side. In its *Vision 2020: The Emerging Trends in Science and Technology and Strategic Option of China*, the Academy writes

> For example, the essence of human spaceflight and deep space survey programs is the human exploration of space, with the goal of scientific discovery and scientific research, thereby motivating technological development. The managing organs executing these two programs, however, are not the same ministry, and these two organs do not have the function of developing science. This then has unavoidably made it so that these two programs have an intense emphasis on the project mission and technological breakthrough.
>
> In the area of space applications, China has launched a large quantity of application satellites, but because of separation between ministries, there is a lack of unified planning and coordination, data sharing rates are extremely low, and the phenomenon of redundant acquisition of the same or similar data is commonplace, creating low-level redundancy.[525]

The Academy then provides a series of recommendations that include

- Restoring the leadership of a special committee in the central government for space policy and planning
- Establishing a national space ministry
- Breaking down the barriers dividing ministries that have satellites
- Commercializing launch and satellite research and development to lower costs, improve quality, and promote the transfer of space technologies to other sectors[526]

The inevitably of conflict in space has also led many Chinese military analysts to propose establishing an independent military space force to combine the various functions of China's space program into one

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[524] "Scientists: China Should Integrate Space Resources to Improve Emergency Response," People's Daily Online, March 4, 2009, http://english.people.com.cn/90001/90781/90876/6605410.html.

[525] Gregory Kulacki, "Strategic Options for Chinese Space Science and Technology: A Translation and Analysis of the 2013 Report from the Chinese Academy of Sciences, Union of Concerned Scientists," November 2013, 15.

[526] Ibid.

organization.[527] The most vociferous organization arguing for control of China's military space program is the PLA Air Force (PLAAF). Institutionally, the Air Force follows a strategy of "integrated air and space, simultaneous offensive and defensive operations" (空天一体, 攻防兼备）that suggests that the service is at least rhetorically committed to the space mission. PLAAF researchers, however, are less circumspect in their belief that the PLAAF should lead the PLA's space efforts. Supporters of an "integrated air and space force" argue that although air and space are different mediums, the integration of force enhancement capabilities with air power and the eventual deployment of manned space planes will technologically merge the two mediums into one seamless medium. Consequently, future wars will see combat between manned space plane "fighter craft" and intercontinental bombing missions conducted through space.[528]

PLAAF analysts also write that air power is critical to the success of any operation and that the air force is inextricably linked to the use of space-based information.[529] Moreover, PLAAF officers describe their service as the most technical of all of the services and the most suitable choice for leading a space force.[530] A final argument made by PLAAF analysts is that every other military in the world places the responsibility for the command of space forces with its air force. As one author writes, "as of today, no country, from the large such as the United States and Russia to the small such as Israel, puts the country's space force under a service other than the air force, let alone under the establishment of the rocket forces."[531] Unstated by PLAAF researchers, but perhaps also relevant, is the service's responsibility for missile defense, which would give the PLAAF responsibility for a de facto ASAT capability.

The PLAAF is not the only service that may have a role in China's space enterprise, however. The use of road-mobile direct-ascent assets and the PLA's push to develop an operationally responsive space capability using road-mobile launchers to quickly launch satellites into orbit suggests that the Second Artillery, China's strategic rocket force, may also have a claim to the space mission. The Second Artillery's responsibility for the launching ballistic missiles would also seem to be more suitable experience on which to base an argument for leading a space force than the PLAAF's space plane argument, which is at yet unproven, and in the case of manned space planes, operationally questionable.

How this may conclude is unclear. In September 2014, the Japanese paper *Yomiuri Shimbun* reported that China had established a space force as an independent service,[532] but there is no additional evidence supporting this claim. Considering that the establishment of an independent space force may signal a more militaristic intent towards space, China may choose not to form a space force. It may instead spread the space mission across various organizations where the GAD maintains responsibility for the launch and operation of satellites, the Air Force assumes responsibility for space planes and missile defense, and the Second Artillery assumes responsibility for direct ascent road-mobile ASATs. But even this scenario is uncertain.

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527 Li Xin, Lei Xu, and Li Jun, 未来航天部队 C4ISR 系统建设初探 ["Preliminary Analysis of Future Space Unit C4ISR System Construction"], *飞航导弹* [*Winged Missile Journal*], March 2006, 41; and Yang Zhiqiang and Zhang Dongliang, 空间力量与联合作战体系["Space Power and Joint Operations System"], *飞航导弹* [*Winged Missile Journal*], July 2008, 32.
528 Li Guangchang, Cheng Jian, and Zheng Lianqing, 空天一体信息作战 [*Integrated Aerospace Information Operations*], (Beijing: Military Sciences Press, 2004), 9, 18; Zhu Hui, ed., 战略空军论 [*Strategic Air Force*] (Beijing: Blue Sky Press, 2009), 43.
529 Zhu Hui, ed., *Strategic Air Force* [战略空军论] (Beijing: Blue Sky Press, 2009), 48.
530 Chen Ling and Chen Peng, "Interview with Major General Lu Gang, Head of the PLAAF Informatization Specialists Advisory Committee and Director of the PLAAF Equipment Research Institute," *AirForce News*, April 19, 2007, 2.
531 Zhu, *Strategic Air Force*, 48.
532 Zachary Keck, "China's Military Creates New Space Force," *Diplomat,* September 10, 2014, http://thediplomat.com/2014/09/chinas-military-creates-new-space-force/.

Space Organizations in Detail

Military Organizations

General Staff Department (总参某部/GSD)
The General Staff Department acts as the headquarters for the PLA and is responsible for the military's day-to-day operations, planning, training, and mobilization. The GSD's role in China's space enterprise is to provide operational tasking for China's remote sensing, meteorological, and communication satellites, although the inner workings of the GSD are not well understood. It most likely provides requirements to the General Armament Department, which maintains operational control over China's satellites. The GSD is also a consumer of space products and in this role receives, processes, and analyzes space-derived information.

The GSD accomplishes this through several organizations. The collection of imagery intelligence is conducted by the GSD's Second Department, responsible for intelligence. This is most likely conducted through the Department's Technology Reconnaissance Bureau. Meteorological data is most likely requested by the GSD's First Department, which is responsible for operations. Satellite communications, on the other hand, is the responsibility of the Informatization Department (总参信息化部).[533]

The GSD is most involved in satellite navigation. Its Surveying, Mapping, and Navigation Bureau (总参测绘导航局) was responsible for the development of the Beidou satellite navigation system[534] and most likely runs the China Satellite Navigation System Management Office (中国卫星导航系统管理办), a joint organization responsible for the development, promotion, and industrialization of the Beidou system and its applications.[535]

General Armament Department (总装备部/GAD)
The General Armament Department was formed in April 1998 and is responsible for the PLA's weapons and equipment research, development, acquisition, and maintenance. It determines, formulates, supervises, and implements the policies, laws, and regulations regarding weapons and equipment for the entire military. In conducting these tasks, the GAD operates China's test, evaluation, and training bases.[536]

The GAD is responsible for the R&D of nearly China's entire space program, including all satellite and launch vehicle R&D, with the exception of China's lunar exploration program, which is managed by SASTIND. In addition, the GAD, under the auspices of the China Manned Space Agency, manages China's human spaceflight program.

The GAD also runs China's four launch centers at Jiuquan, Xichang, Taiyuan, and Wenchang, its control centers at Xi'an and Beijing, and a network of TT&C stations based in China and around the world as well as three operational tracking ships (Figure 8).

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533 Mark A. Stokes and Ian Easton, "The Chinese People's Liberation Army General Staff Department: Evolving Organization and Missions," in Kevin Pollpeter and Kenneth W. Allen, *The PLA as Organization: Reference Volume 2.0* (Washington, DC: Defense Group Inc., forthcoming), 119–42.
534 Meng and Liu, "Exploring China's Beidou Navigation Satellite System."
535 China Satellite Navigation Office, "Report on the Development of the BeiDou Satellite Navigation System (Version 2.2)," December 2013, 1.
536 Fu Quanyou, ed., *The Chinese Military Encyclopedia: Supplemental* [*中国军事百科全书: 增补*] (Beijing: Military Science Press, 2002), 658.

Figure 8. China's space launch centers

Jiuquan Satellite Launch Center (中国酒泉卫星发射中心)
The Jiuquan Satellite Launch Center is China's oldest and largest, and conducts launches of spacecraft into low, medium, and high Earth orbits. Although the launch center is named after the city of Jiuquan in Gansu Province, it is actually located 210 kilometers from Jiuquan in Inner Mongolia. It is the only launch center that conducts human space flight launches.[537]

The launch center is composed of a northern launch pad and a southern launch pad. The northern launch pad launches LM-2C and 2D rockets while the southern launch pad launches LM-2E and 2F rockets. In addition to the launch pads, the launch center has a command and control center, a rocket fuel storage area, a tracking station, a satellite and launch vehicle assembly station, a solid fuel rocket assembly station, and other support facilities.[538]

Taiyuan Satellite Launch Center (中国太原卫星发射中心)
The Taiyuan Satellite Launch Center is located near Taiyuan, Shanxi Province. Construction of the Taiyuan Satellite Launch Center began in 1967. The launch center conducts launches of satellites into sun synchronous and low Earth orbits, including meteorological, remote sensing, and communications satellites. The center consists of a launch site, a command and control center, and a technology testing area. The launch site consists of a single launch pad.[539]

Xichang Satellite Launch Center (中国西昌卫星发射中心)
The Xichang Satellite Launch Center is located 60 kilometers north of Xichang, Sichuan Province. Construction on the launch center began in 1970. This center launches satellites into geosynchronous orbits, including communication, broadcast, and meteorological satellites. The launch center is composed

[537]解放军总装备部:中国军工系统核心 ["PLA General Armament Department: China Defense Industry System Core"], www.360doc.com/content/11/1214/11/5575132_172141966.shtml; and http://www.cgwic.com/LaunchServices/LaunchSite/JSLC.html.
[538] Zhang, *China Military Encyclopedia (Second Edition): Introduction to Military Equipment*, 434–36.
[539] Ibid., 438–39.

of a headquarters department, a launch site, a communication station, a command and control center, a technology testing station, and three tracking stations. The technology testing station has a launch vehicle testing facility, a satellite assembly and testing facility, and a rocket engine assembly, testing, and flaw detection facility.[540]

Wenchang Satellite Launch Center (文昌卫星发射中心)

The Wenchang Satellite Launch Center on Hainan Island was approved in 2007 by the Central Military Commission. As of September 2014, the center was still under construction, but possessed all of the facilities for launch.[541] The launch center's closer proximity to the equator than China's three other launch centers can increase launch payloads by 10–15 percent and satellite life by 2–3 years, a factor important for developing the commercial launch market. Launches will also be directed over the ocean, which will permit debris from launches to land safely out to sea.

China Manned Space Agency (中国载人航天工程办公室/CMSA)

The China Manned Space Agency is responsible for planning, technology development, engineering, facilities, outlays, international cooperation, and promotion of the human spaceflight program. CMSA manages the human spaceflight program through the entire process of technology development, astronaut training, and operations.[542]

Government Organizations

State Administration for Science, Technology, and Industry for National Defense (国家国防科技工业局/SASTIND)

The State Administration for Science, Technology, and Industry for National Defense is a regulatory and policy-making body that oversees the work and personnel management of the defense industry. SASTIND was created in 2008 out of the former Commission on Science, Technology, and Industry for National Defense (COSTIND). Whereas COSTIND was a ministry-level organization, SASTIND was placed under the Ministry of Industry and Information Technology and is thus of lower bureaucratic rank than COSTIND. Although the China National Space Agency is often called "China's NASA", it appears that SASTIND oversees the work of the space industry. SASTIND also appears to manage China's lunar exploration program.

China National Space Agency (中国航天局/CNSA)

The China National Space Agency oversees the work of the space industry by providing policy, guidance, and regulations as well as promoting efforts to capitalize on the dual-use nature of space products. The SASTIND director is also the director of CNSA. In addition to its policy and regulatory role, CNSA is responsible for promoting international collaboration on civilian space programs and technologies.

The National Remote Sensing Center of China (中国遥感中心/NRSCC)

The National Remote Sensing Center of China acts as a nationwide coordinating body for organizations involved in remote sensing and Earth observation.[543] Its intended aim is to develop China's innovation capacity and foster strategic industries in the areas of remote sensing, geographic information systems,

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[540] Ibid., 436–38.

[541] "杨利伟：海南发射场已基本完工 具备发射条件," [Yang Liwei: Hainan Launch Site is Basically Completed Possesses Conditions for Launch], 人民网 [*People's Net*], September 10, 2014, http://scitech.people.com.cn/n/2014/0910/c1007-25637052.html.

[542] http://www.cmse.gov.cn/AboutUs/list.php?catid=9\.

[543] "Functions," National Remote Sensing Center of China, 2012, http://www.nrscc.gov.cn/nrscc/en/functions/.

and navigation and positioning.[544] NRSCC was established as an independent organization reporting to the Ministry of Science and Technology (MOST) in 2006, having begun in 1981 within the State Science and Technology Commission.[545]

NRSCC's primary roles include providing recommendations to MOST regarding China's overall remote sensing development strategy; supplying information to the General Office of the State Council regarding natural disasters and other agricultural, ecological, and environmental developments; and implementing remote sensing and space information technology projects.[546] It is centrally involved in international cooperation efforts as well, responsible for coordinating the implementation of the China-Europe Cooperation Project on Galileo; participating in formulating national standards, norms, and regulations in the fields of Earth observation and navigation technology; organizing multilateral and bilateral international cooperation and personnel exchange activities; hosting the China Secretariat of the Committee on Earth Observation Satellites and Group on Earth Observations and acting as China's national focal point for the United Nations Regional Space Applications Program for Sustainable Development in Asia and the Pacific; and liaising with remote sensing institutes in China to provide technical training and consultancy services.[547] The center has additionally played a role in software testing and evaluation and coordinated efforts aimed at producing indigenous GIS software, remote sensing imaging processing software, and GNSS applications software copyrights.[548]

Center for Resources Satellite Data and Application (中国资源卫星应用中心/CRESDA)

China's Center for Resources Satellite Data and Application, described as a "scientific research and operational management institution", is subordinate to both the National Development and Reform Commission (NDRC) and SASTIND, but defense conglomerate China Aerospace Science and Technology Corporation (CASC) is responsible for the administrative management of its research efforts.[549] "Its tasks include developing strategies, plans, and budgets for remote sensing satellite development, providing program design, engineering supervision, technical coordination, and operational management functions for the development of remote sensing satellite applications, setting quality and technical standards for these applications, and organizing research and development efforts for applications, technologies, and approaches relating to remote sensing data.[550] It also provides key recommendations to NDRC and data end-users, submitting development proposals based on user community demands and internal research results and suggesting applications in the fields of resource, environment, and disaster monitoring.[551] Surprisingly, CRESDA is not located within the network of satellite-related institutions coordinated by the NRSCC.

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544 Ibid.
545 "Introduction and Main Functions" [简介及主要职能], National Remote Sensing Center of China, 2011, http://www.nrscc.gov.cn/nrscc/zxgk/jjjzyzn/.
546 "Functions."
547 Ibid.
548 "Software Evaluation Expert Committee [软件测评专家委员会]", National Remote Sensing Center of China, 2011, http://www.nrscc.gov.cn/nrscc/zjdw/zjwyh/.
549 "Center Introduction" [中心介绍], China Centre for Resources Satellite Data and Application, 2001, http://www.cresda.com/n16/n1085/n1220/index.html;
"CRESDA Introduction," China Centre for Resources Satellite Data and Application, 2012, http://www.cresda.com/n16/n92006/n92162/n98541/index.html.
550 Ibid.
551 Ibid.

The center has operated six satellites: CBERS-01 and -02, -02B, operated jointly with a facility in Brazil and Huanjing-1A, 1B, and 1C.[552] It has developed data processing systems on the ground to complement these,[553] yielding applications in areas such as resource investigation, environmental protection, and disaster monitoring.[554]

National Satellite Meteorological Satellite Center (国家卫星气象中心)
China's National Satellite Meteorological Satellite Center reports to the China Meteorological Administration. The center is responsible for the operation and management of China's Fengyun meteorological satellites and the processing and dissemination of meteorological satellite imagery and data.

Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences (中国科学院遥感与数字地球研究所)
The Institute of Remote Sensing and Digital Earth (RADI) was created in 2012, merging the Institute of Remote Sensing Applications and the Center for Earth Observation and Digital Earth.[555] RADI is now said to be China's largest research institute in this field, working to promote the development of cutting-edge scientific research.[556] Its stated objectives are threefold: to explore leading technologies in earth observation, geospatial information science, and remote sensing data acquisition and distribution; to construct and operate major earth observation infrastructures, in particular a "spaceborne-airborne-ground system" for data acquisition; and to enhance capacity for worldwide environmental and natural resources observation through the creation of a digital earth science platform.[557]

RADI's primary subordinate organizations, which conduct its research work, include the State Key Laboratory of Remote Sensing Science, the Center for Applied Technologies of Earth Observation, the National Engineering Center for Geoinformatics, the CAS Laboratory of Digital Earth Sciences, the China Remote Sensing Satellite Ground Station, and the CAS Center for Airborne Remote Sensing.[558] It also houses other centers and laboratories involved in space technology, engineering technology, and land satellite data.[559]

Satellite Surveying and Mapping Application Center (国家测绘地理信息局卫星测绘应用中心/SASMAC)
China's Satellite Surveying and Mapping Application Center, subordinate to the State Bureau of Surveying and Mapping of China, which in turn reports to the Ministry of Land and Resources of the State Council,

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552 "CBERS-01/02," China Centre for Resources Satellite Data and Application, 2012, http://www.cresda.com/n16/n92006/n92066/n98575/index.html.
553 "CBERS-02B Data Processing System," China Centre for Resources Satellite Data and Application, 2012, http://www.cresda.com/n16/n92006/n92096/n98716/index.html.
554 "Resource Investigation," China Centre for Resources Satellite Data and Application, 2012, http://www.cresda.com/n16/n92006/n92123/n98829/index.html.
555 "Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences," Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, 2013, http://english.ceode.cas.cn/.
556 "Director Speech" [所长致辞], Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, 2014, http://www.radi.cas.cn/skjs/szzc/.
557 "Brief Introduction," Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, 2013, http://english.radi.cas.cn/ARADI/Vision/; "Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences"; "Message from the Director", Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, 2013, http://english.radi.cas.cn/ARADI/DM/.
558 "Introduction," Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, 2013, http://english.radi.cas.cn/Research/Introduction/.
559 Ibid.

was established in 2009 to conduct planning functions for satellite applications development in the specific areas of surveying and mapping.[560] SASMAC also comprises the Department of Satellite Surveying and Mapping within the NRSCC, which coordinates a wide network of satellite-related institutions throughout China.[561] In addition to planning functions, SASMAC is responsible for the establishment, management, and maintenance of the applications system in this field, as well as data processing and related scientific research.[562] It is primarily engaged in constructing the satellite application system for the Ziyuan-3.[563] The Ministry of Land and Resources, rather than SASMAC, operates the satellite,[564] the only one with which the center is reported to be affiliated.[565]

SASMAC has a total of 58 staff members including those from affiliated government institutions, 14 of whom have doctorates.[566] Ultimately the center aims to become a "national processing and service center" and "world-class research and application service institution" in the domain of satellite surveying and mapping.[567]

China's National Satellite Ocean Application Service (中国卫星海洋应用中心/NSOAS)

The National Satellite Ocean Application Service receives, processes, and utilizes data generated by China's ocean monitoring satellites. NSOAS responsibilities include developing ocean remote sensing applications, building and operating ground receiving stations, organizing technical standards and user training, managing databases and producing information products, initiating commercialization and technological research opportunities, fostering international cooperation and academic exchange, and annually compiling the "China Ocean Satellite Application Report."[568] To this end, it has constructed an ocean remote sensing infrastructure, including three ground receiving stations in Beijing, Sanya, and Mudanjiang, a data processing and applications center in Beijing, and a laboratory for ocean remote sensing applications, also in Beijing.[569]

NSOAS is located within two chains of command. It was created in 2000 as an independent organization under the jurisdiction of the State Oceanic Administration (SOA), replacing a former SOA department created in 1996.[570] SOA is subordinate to the Ministry of Land and Resources, which in turn reports to the State Council.[571] NSOAS also, however, comprises the Department of Ocean Remote Sensing under the NRSCC,[572] an organization reporting to the State Council's Ministry of Science and Technology that

560 "Department of Satellite Surveying and Mapping," National Remote Sensing Center of China, 2012, http://www.nrscc.gov.cn/nrscc/en/departments/201205/t20120508_30924.html
561 Ibid.
562 Ibid.
563 Ibid.
564 "ZY-3A," EOPortal, 2014, https://directory.eoportal.org/web/eoportal/satellite-missions/v-w-x-y-z/zy-3a.
565 "Department of Satellite Surveying and Mapping."
566 Ibid.
567 Ibid.
568 "Main Responsibilities," National Satellite Ocean Application Service, 2012, http://www.nsoas.gov.cn/NSOAS_En/responsibilities.html;"National Satellite Ocean Application Service Introduction [国家卫星海洋应用中心介绍]", National Satellite Ocean Application Service, 2007, http://nsoas.gov.cn/zx/channel/default.asp.
569 "Department of Ocean Remote Sensing," National Remote Sensing Center of China, 2012, http://www.nrscc.gov.cn/nrscc/en/departments/201205/t20120508_30907.html.
570 "About NSOAS," National Satellite Ocean Application Service, 2012, http://www.nsoas.gov.cn/NSOAS_En/index.html.
571 "State Oceanic Administration," Central People's Government of the People's Republic of China, December 29, 2009, http://english.gov.cn/2005-10/01/content_73182.htm.
572 "Department of Ocean Remote Sensing."

provides strategic planning and support in the field of Earth observation and navigation technology and also coordinates actors in this field nationwide.[573]

NSOAS has been active in international collaboration, notably participating in the search for Malaysian Airlines Flight 370 in March 2014,[574] and won China's leading Maritime Science and Technology Award in 2013 for a research project involving a remote sensing survey of China's "island and coastal zone."[575] The primary end users of the satellite data NSOAS generates are said to be marine administration agencies, environmental protection agencies, and departments for marine rights protection and law enforcement,[576] the latter likely including the China Coast Guard and China Marine Surveillance organizations, also located within SOA.

Defense Industrial Organizations

China Aerospace Science and Technology Corporation (中国航天科技集团/CASC)

The China Aerospace Science and Technology Corporation was established in 1998, but traces its roots back to 1956. It is China's sole entity performing development, production, and launch testing of launch vehicles, manned spacecraft, space station, deep space exploration spacecraft, and strategic missiles, and is also heavily engaged in satellites and tactical missiles. Additionally, it puts significant investment into applications for space technology into other products, such as satellite applications, IT, new energy and new material products, auto parts, and space biology products. In services, it focuses on satellite and ground operations, international space commerce, aerospace financial investment, and software and information services. It is China's only domestic service provider for broadcast communication satellite operations.[577]

CASC is composed of eight large research and production academies, 14 specialized firms, and nine listed firms. Its development and production bases are located in Beijing, Shanghai, Xi'an, Chengdu, Tianjin, Inner Mongolia, Shenzhen, and Hainan. It is also home to 11 defense S&T key laboratories, one national engineering laboratory, and five national engineering research centers. As of 2011, it employed 159,400 individuals.[578]

China Academy of Launch Vehicle Technology (中国运载火箭技术研究院/CALT)

Established November 16, 1957, the China Academy of Launch Vehicle Technology, or CASC First Academy, is China's largest base for missile and rocket research, design, prototyping, testing and production. Its research and production activities center on aerospace engineering and aerospace technology applications, including overall system design, space flight, control automation, ground launch control, and total test assembly.[579] It is the lead developer of the LM-1D, LM-1F, LM-2, LM-2C, LM-2E, LM-2F, LM-3,

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573 "Functions."

574 "National Satellite Ocean Application Service Emergency Monitoring Loses Contact with Malaysia Airlines Passenger Plane" [国家卫星海洋应用中心紧急监测马航客机失联海域], National Satellite Ocean Application Service, March 11, 2014, http://www.nsoas.gov.cn/new/channel/detail.asp?Content_id=430.

575 "National Island and Coastal Region Remote Sensing Survey Research Project Wins 2013 Annual Marine Science and Technology Award" [我国海岛与海岸带遥感调查研究项目获得 2013 年度海洋科学技术奖一等奖], National Satellite Ocean Application Service, May 26, 2014, http://www.nsoas.gov.cn/new/channel/detail.asp?Content_id=439.

576 "Department of Ocean Remote Sensing."

577 "中国航天科技集团公司：公司简介" [China Aerospace Science and Technology Corporation: Company Introduction], http://www.spacechina.com/n25/n142/n152/n164/index.html.

578 Ibid.

579 "中国运载火箭技术研究院：本院概况" [China Academy of Launch Vehicle Technology (CALT): Academy Introduction], http://www.calt.com/GuanYuWoMen.

LM-3A, LM-3B, LM-3C, LM-3F, and LM-5 Long March rockets.[580] While not mentioned on its website, CALT also produces the Dong Feng DF-1 and DF-2 short-range ballistic missiles, the DF-3 medium-range ballistic missile, the DF-4 intermediate-range ballistic missile, and the DF-5 intercontinental ballistic missile.[581] The latest number of employees reported on its website is 29,900.[582]

Academy of Aerospace Solid Propulsion Technology (航天动力技术研究院)

The Academy of Aerospace Solid Propulsion Technology, or CASC Fourth Academy, was established July 1, 1962 and is China's largest institute working on solid rocket motors. Headquartered in Xi'an, it is comprised of five research institutes, three production facilities, and five subsidiary companies. It is also host to the State Key Laboratory on Work Process for Solid Rocket Motors. It has over 10,000 employees.[583]

China Academy of Space Technology (中国空间技术研究院/CAST)

The China Academy of Space Technology, also known as the Fifth Academy, was established February 20, 1968 and is China's premier institute for satellite and spacecraft development. It engages in space technology development, spacecraft development, and the facilitation of foreign exchanges and cooperation in space technology. Additionally, it participates in the formation of national space technology development plans. It has been involved in prominent Chinese space projects, beginning with the development of China's first artificial satellite Dongfanghong I (DFH-1). More recently, it has developed the Shenzhou series of manned spacecraft, China's lunar orbiter, and the Tiangong-1 space laboratory. In addition to these large projects, it designs many other satellite types, including communications/broadcasting satellites, retrievable satellites, Earth resources satellites, meteorological satellites, scientific/technological experiment satellites, navigation and positioning satellites, and remote sensing satellites. It employs over 10,000 individuals.[584]

Academy of Aerospace Propulsion Technology (航天推进技术研究院)

The Academy of Aerospace Propulsion Technology, or Sixth Academy, was established in 1965 and is headquartered in Xi'an. As China's primary liquid rocket engine development center, it reportedly is the only center in China that integrates research, design, production, and testing of primary power systems, orbit attitude control power systems and spacecraft propulsion systems for rockets. It oversees 12 subsidiary companies with approximately 18,000 employees. It has been involved in China's first long-range rocket, the DFH satellite series, the Shenzhou manned space project, and the lunar exploration project. Notably, it has developed all the liquid rocket engines for the Long March rocket family.[585]

Sichuan Academy of Aerospace Technology (四川航天技术研究院)

The Sichuan Academy of Aerospace Technology, also known as the Seventh Academy, is headquartered in Chengdu and has approximately 15,000 employees. Its primary products include multiple launch rocket systems, including the WS-1, WS-1B, WS-1E, and WS-2. The academy also performs work on integrated

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580 China Academy of Launch Vehicle Technology webpage, English version, http://www.calt.com/english/ps/?pageIndex=1; "China Academy of Launch Vehicle Technology: CALT, 1st Academy," GlobalSecurity.org, http://www.globalsecurity.org/wmd/world/china/calt.htm.

581 "China Academy of Launch Vehicle Technology: CALT, 1st Academy."

582 "China Academy of Launch Vehicle Technology (CALT): Academy Introduction."

583 "航天动力技术研究院：研究院简介" [Academy of Aerospace Solid Propulsion Technology (AASPT): Academy Introduction], http://www.sunvalor-casc.com/guanyu.aspx.

584 中国空间技术研究院 [China Academy of Space Technology], http://www.cast.cn/Castcn/.

585 "航天推进技术研究院" [Academy of Aerospace Propulsion Technology], http://www.aalpt.com/www/index.asp.

manufacturing, precision machining and electronic control equipment, turbojet engines, and control guidance equipment.[586]

Shanghai Academy of Spaceflight Technology (上海航天技术研究院)
The Shanghai Academy of Spaceflight Technology, also known as the Eighth Academy, was established in 1961 and has approximately 22,000 employees. It is a major developer of missile systems, rocket systems, and satellites, and a major contributor to the manned space program and lunar exploration program.[587] It produces the LM-2D and LM-4 launch vehicles.[588]

China Academy of Aerospace Electronics Technology (中国航天电子技术研究院)
The China Academy of Aerospace Electronics Technology, also referred to as the CASC Ninth Academy or the China Academy of Space Electronics Technology, produces electronics for the missile and space industry. It is headquartered in Beijing.[589]

China Academy of Aerospace Aerodynamics (中国航天空气动力技术研究院)
The China Academy of Aerospace Aerodynamics, or CASC Tenth Academy, was established in 1956 and employs about 1,400 individuals. It performs research on aircraft aerodynamics. Its primary product is the "Cleve Hawk" Series UAV system.[590]

China Aerospace Science & Industry Corp. (中国航天科工集团公司/CASIC)
The China Aerospace Science & Industry Corporation is the second major industrial enterprise engaged in space-related R&D and production. Established in 1956 as the Fifth Academy of the Ministry of Defense, CASIC now has five academies, two scientific research and production bases, six publicly-listed companies, and over 570 enterprises and institutes, with more than 137,000 employees.

As the largest missile weapon designer and manufacturer in China, CASIC is engaged in development, research and manufacturing of air defense missile systems, cruise missile systems, solid rockets, and space products. CASIC has successively developed dozens of advanced missile weapons, including the Hongqi series and DF series. CASIC is building a space-ground integrated security and support system in manned spaceflight, lunar exploration, and other major national projects.

CASIC Academy of Information Technology (CASIC First Academy)
Established in 2002 and restructured in 2009, CASIC's First Academy is focused on research and development of information systems and the production of related equipment.[591] It is also engaged in the R&D of satellite navigation and communication. One of its subordinate companies, Xi'an Aerospace Huaxun Technology Corp., Ltd, is the pioneer in China's GPS/Beidou navigation core chip technology with

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586 "四川航天技术研究院" [Sichuan Academy of Aerospace Technology], http://scaat.spacechina.com.
587 "上海航天技术研究院" [Shanghai Academy of Spaceflight Technology], http://www.spacechina.com/n25/n150/n284/n298/c123114/content.html.
588 "LM-2D," 中国长城工业集团有限公司 [China Great Wall Industry Corporation], http://www.cgwic.com/LaunchServices/LaunchVehicle/LM2D.html; Gu Song-an and Gong Jun, "LM-4 and LM-2D Launch Vehicles," *Proceedings of the Euro-Asia Space Week on Cooperation in Space: 'Where East & West Finally Meet'*, February 1999, http://adsabs.harvard.edu/full/1999ESASP.430..499S.
589 Evan S. Medeiros et al., *A New Direction for China's Defense Industry* (Santa Monica, CA: RAND, 2005), 57.
590 China Academy of Aerospace Aerodynamics webpage, English version, http://www.caaa-spacechina.com/Enhangtian/channels/70.html.
591 "中国航天科工信息技术研究院 (中国航天科工一院) 简介" [Overview of CASIC Academy of Information Technology (CASIC First Academy)], 中国航天科工一院网站 [CASIC First Academy website], February 25, 2014, http://www.xxjs.casic.cn/n382287/n382288/index.html.

the fourth-generation Beidou navigation chip launched in 2014.[592] As a major player in the national emergency satellite communication network, the academy has constructed communication sites for five major domestic satellites and more than 600 remote sites.[593] One institute under CASIC's First Academy specializes in space-based and missile-borne electronic countermeasure research and development.[594]

CASIC Academy of Defense Technology (CASIC Second Academy)

CASIC's Second Academy is the principal institute for kinetic-kill counterspace systems, and is China's largest producer of air defense missile systems.[595] Established in 1957, it has developed early-generation missile control systems and China's first solid fueled strategic missiles. The academy consists of a design department, eight specialized research institutes, a simulation center, a factory, and one public listed enterprise. With a growing emphasis on integrated air and space defense, it is engaged in research and development of overall weapon systems, radar, simulation technology, and ground equipment.[596] The Second Academy's most prominent defense products include the Hongqi-series anti-aircraft missiles system, including the missile, radar, and associated ground equipment.[597]

CASIC Academy of Cruise Missile Technology (CASIC Third Academy)

CASIC's Third Academy, established in 1961, is China's premier entity engaged in design, development, and production of aerodynamic technology. Its products include cruise missiles (Hong Niao series), anti-ship missiles (Ying Ji series),[598] propulsion systems, and associated launchers.[599] The academy has one design department, 10 research institutes, two factories and seven subordinate companies.[600] Centered upon the "Hai Ying" series UAV, it intends to develop an unmanned combat surveillance system.[601] The 31st research institute under the Third Academy is engaged in R&D on ramjet (scramjet) technology, including an air-breathing supersonic combustion engine that is in support of a national hypersonic cruise vehicle program.[602] Today, it appears that the Third Academy has a near monopoly on the Chinese cruise missile market.[603]

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592 "高性能第四代北斗导航芯片 定位精确度达到 2.5 米" [The Fourth Generation Beidou High-performance Chip Positioning Accuracy Reaches 2.5 Meter], 科技讯 [*Kejixun*], August 15, 2014, http://www.kejixun.com/article/201408/65448.html.

593 Yang Shu, "中国航天科工信息技术研究院信息化产品开发的经验和展望" [Experience and Outlook of Information Product Development of CASIC Academy of Information Technology], 电子设计应用 [*Electronic Design & Application World for Design and Application Engineers*], 2010, Z1.

594 Mark A. Stokes and Dean Cheng, "China's Evolving Space Capabilities: Implications for U.S. Interests," report prepared for the U.S.-China Economic and Security Review Commission, April 26, 2012, 21.

595 Ibid.

596 "二院简介" [Overview of Second Academy], 中国航天科工二院网站 [CASIC Second Academy website], June 15, 2011, http://www.fyjs.casic.cn/n355672/n355673/index.html.

597 "中国航天二院二部成立 50 年引领中国防空导弹研发" [50th Anniversary of CASIC Second Academy Second Department: Leading R&D of China's Air Defense Missile], 中国新闻网 [Chinanews.com], October 18, 2008, http://www.chinanews.com/gn/news/2008/10-18/1416679.shtml.

598 "俄媒评中国鹰击 12 导弹：配冲压发动机速度极快" [Russian Media Comments on China Yingji-12 Missile: High Speed with Ramjet], 新浪 [Sina.com], January 21, 2014, http://mil.news.sina.com.cn/2014-01-21/1024761079.html.

599 Stokes and Cheng, "China's Evolving Space Capabilities," 21.

600 "航天科技：中国航天科工飞航技术研究院关于公司详式权益变动报告" [Detailed Report on Change of Equity of CASIC Academy of Cruise Missile Technology], 金融界 [JRJ.com], September 19, 2009, http://stock.jrj.com.cn/share,disc,2009-09-19,000901,00000000000001yjll.shtml.

601 Duan Danfeng, "中国航天科工推出海鹰无人机品牌" [CASIC Launched Haiying UVA Brand], 人民网 [People.cn], November 13, 2012, http://scitech.people.com.cn/n/2012/1113/c1007-19569150.html.

602 Liu Yidan, "中国航天科工三院三十一所：为飞航导弹铸"心" [31st Research Institute of CASIC Third Academy: Build 'Heart' for Cruise Missile], 人民日报 [*People's Daily*], November 24, 2012, http://www.qstheory.cn/kj/kjcx/201211/t20121124_196070.htm.

603 Stokes and Cheng, "China's Evolving Space Capabilities," 21.

CASIC Academy of Launch Technology & China Sanjiang Aerospace Group (CASIC Fourth Academy)
CASIC's Fourth Academy was established in late 2011 and is a consolidated entity from the original CASIC Fourth Academy, which is also known as CASIC Academy of Vehicle Technology, and the original CASIC Ninth Academy, also known as the 066 Base. This merger and reorganization is CASIC's major effort to develop a world-class research institute on solid-fueled technology.

As a majority of previous subordinate entities remain, the new academy has 31 member units with around 20,000 employees.[604] The priority of the new Fourth Academy is likely to remain the development and production of missile weapon systems and solid fueled rockets.[605] Both the original Fourth Academy and the Ninth Academy had been engaged in the design, development, and manufacturing of the DF series ballistic missiles.[606]

CASIC Academy of Propulsion Technology (CASIC Sixth Academy)
Located in Inner Mongolia, the CASIC Sixth Academy is China's first development, production, and test base of large-scale solid rocket motors.[607] Formally a subsidiary of the CASC Fourth Academy, key landmark achievements of the Sixth Academy were the LM-1 third stage solid rocket motor and the EPKM perigee orbit solid rocket motor.[608] The Academy also manages smaller diameter motors, including kick motors designed to boost communications satellites to geosynchronous orbit.[609] Beside rocket engines, its self-developed F-12 high-strength organic fibers have been widely used in both military and civilian areas.

IMPLICATIONS FOR THE UNITED STATES

China is a nation on a quest for wealth and power. No longer guided by Maoist proletarian ideology, it now sees science and technology as a major factor in its rise as a world power as it seeks increased influence and independence. China's pursuit of space power is a reflection of this emphasis on science and technology and its grand strategy to, in the words of David Lampton, "regain the nation's former status as a great power that controls its own fate."[610]

China's goal is to become a space power on par with the United States and to foster a space industry that is the equal of those in the United States, Europe, and Russia. China takes a comprehensive, long-term approach to its space program that emphasizes the accrual of the military, economic, and political benefits space can provide. By placing much of its space program in a 15-year development program and providing adequate funding, the Chinese government provides a stable environment in which its space program can prosper. Even longer-range studies, such as the feasibility studies currently being conducted for manned

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604 Wang Min, "中航科工重组旗下固体火箭资源 打造国际一流固体运载技术研究院' [CASIC Restructure Its Solid Rocket Resources to Build a World-Class Research Institute on Solid Vehicle Technology], 人民网 [People.cn], December 31, 2011, http://finance.people.com.cn/BIG5/70846/16777381.html.
605 "四院简介" [Overview of the Fourth Academy], 中国航天科工四院网站 [CASIC Fourth Academy website], July 13, 2011, http://www.yzjs.casic.cn/n382323/n382324/c423755/content.html.
606 Stokes and Cheng, "China's Evolving Space Capabilities," 21, 22.
607 http://www.dljs.casic.cn/n1605869/n1605883/index.html
608 "塞外铸神剑 赤诚捍和平" [Casting the Great Excalibur to Defend Peace], 中国共产党新闻网 [CPC.people.com], July 15, 2012, http://cpc.people.com.cn/n/2012/0715/c87228-18519272.html.
609 Stokes and Cheng, "China's Evolving Space Capabilities," 22.
610 Lampton, *The Three Faces of Chinese Power*, 25.

lunar missions and analysts' writings on mining the moon, may spur the Chinese government to think even bigger when it comes to space.

National Security Implications

China's space program has made the most progress in addressing its national security needs. According to former Secretary of Defense Chuck Hagel, the United States is "entering an era where American dominance on the seas, in the skies, and in space…can no longer be taken for granted….And while the United States continues to maintain a decisive military and technological edge over any potential adversary, our continued superiority is not a given."[611] China's improving space capabilities has negative-sum consequences for U.S. military security and require the United States to prepare to confront an adversary possessing space and counterspace technologies.

Chinese analysts assess that space-based information will become a deciding factor in future wars, that space will be a dominant battlefield, and that in order to achieve victory on Earth, one must first seize the initiative in space. This will require China to achieve space supremacy, defined as the ability to freely use space and to deny the use of space to adversaries. Moreover, the assessment that space is the dominant battlefield has led PLA analysts to conclude that war in space is inevitable. In making this assessment, Chinese writings are reminiscent of U.S. writings on space during the 1950s and 1960s. This includes a universal belief that space is the strategic high ground, and a prominent role for manned military space missions, including the use of manned military space planes, space stations, and lunar bases.

Whether it is the acquisition of intelligence or navigation information from space-based platforms to enable long-range strikes or the use of offensive space control measures against U.S. satellites, space plays a prominent role in China's efforts to establish an effective A2/AD capability. The denial of critical space-based C4ISR capabilities integrated with cyber and kinetic attacks against non-space based C4ISR nodes could greatly complicate the ability of the U.S. military to flow forces to the region and to conduct operations effectively. This strategy gains more salience when pitted against the U.S. concept of air-sea battle, which emphasizes standoff weaponry enabled by information technologies to penetrate and defeat A2/AD systems.[612]

Although the PLA is not expected to be able to conduct large-scale operations far from its coast prior to 2020,[613] space-based remote sensing capabilities will become more important due to China's lack of airborne ISR assets that can cover the long distances to targets in the western Pacific and South China Sea. According to a 2011 study, China can image a target near Taiwan 35 times per day.[614] The PLA could also use this capability to identify both land- and sea-based targets across Asia and to provide intelligence for PLA aviation and missile forces to adjust fire, restrike targets, or verify a target's destruction. With the use of space-based ISR capabilities in combination with the 1,500-kilometer range DF-21D anti-ship ballistic missile and the 2,000+ kilometer range DH-10, China "could engage surface ships while keeping its own navy out of range of the adversary's surface ships. These attacks could also force the U.S. Navy to operate

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611 Lolita C. Baldor, "Hagel: U.S. Needs to Maintain Military Superiority," ABC News, September 3, 2014, http://abcnews.go.com/Politics/wireStory/hagel-us-maintain-military-superiority-25232419.
612 David Fulghum, "Navy Aviation in the Crosshairs," *Aviation Week*, April 9, 2012, 49.
613 Office of the U.S. Secretary of Defense, *Annual Report to Congress* (2010), 27.
614 Eric Hagt and Matthew Durnin, "Space, China's Tactical Frontier," *Journal of Strategic Studies* 34, no. 5 (2011): 741.

beyond the optimal limits of its carrier-based aircraft, shortening the amount of time that these aircraft could stay on station."[615]

The PLA's space-based ISR capabilities will be assisted by its network of Tianlian data relay satellites. As discussed earlier, China's constellation of data relay satellites allows the PLA to receive communications and data from other satellites regardless of their position relative to the Earth's surface. With the use of the Tianlian constellation, remote sensing satellites beyond the range of China's land-based satellite data receiving stations can still transmit this data back to stations in China, providing near real-time transmittal of ISR data. Such near real-time capabilities could greatly assist in providing timely battlefield intelligence, including the position of ships, the movements of which would be tracked for the targeting of anti-ship cruise and ballistic missiles.

The Tianlian constellation, however, is not absolutely necessary for China's military to receive timely space-based ISR intelligence, since the Chinese Academy of Sciences operates three satellite remote sensing data stations in Kashgar, Xinjiang; Beijing; and Sanya, Hainan (see Figure 9). Together, these three stations can receive data from satellites covering the entirety of China's territory, including Taiwan and areas in the South China and East China Seas where China has territorial disputes. The Sanya station, in particular, covers all three disputed areas whereas the Beijing station can cover Taiwan and the disputed Senkaku/Diaoyu Islands. Data received by any one of these stations can then be transmitted to other organizations, such as leadership or intelligence organizations in Beijing. In addition, the timely transmittal of data may not be critically affected if one of these stations were inoperable. For example, in the event of the loss of the Sanya station, a satellite on a northbound track would be in range of the Beijing station within five minutes of passing over Hainan Island. Satellites passing over the South China Sea on a southbound track would not be in range of the Kashgar station until 90 minutes later, however.[616]

As a result, the Tianlian provides four main benefits to the PLA in terms of delivering timely space-based ISR intelligence: 1) the timely transmittal of data from areas beyond the range of China's ground-based receiving stations; 2) the timely transmittal of data directly to leadership or PLA intelligence organizations located in Beijing; 3) redundancy in China's ISR transmittal capabilities in the event other stations are inoperable; and 4) greater download times for ISR data that may not be possible given a narrow download window to ground stations.

China's improving satellite navigation and positioning system will also make China's military operations more secure. Although the Beidou system only provides ten-meter accuracy, it provides the PLA with the autonomy that it could not obtain from using a foreign satellite-navigation system. Such autonomy would immunize China against U.S. efforts to deny GPS to China and would allow the PLA to jam GPS while continuing to use its own Beidou system for navigation and to guide precision munitions.

Additionally, China appears to be developing operationally responsive space capabilities that will allow it to replace depleted or destroyed satellites quickly. Its development of the Kuaizhou, Feitian-1, and Long March-11 solid-fueled rockets provide China with the capability to launch relatively small satellites rapidly if other satellites destroyed or degraded. Although not as capable as larger satellites, these smaller

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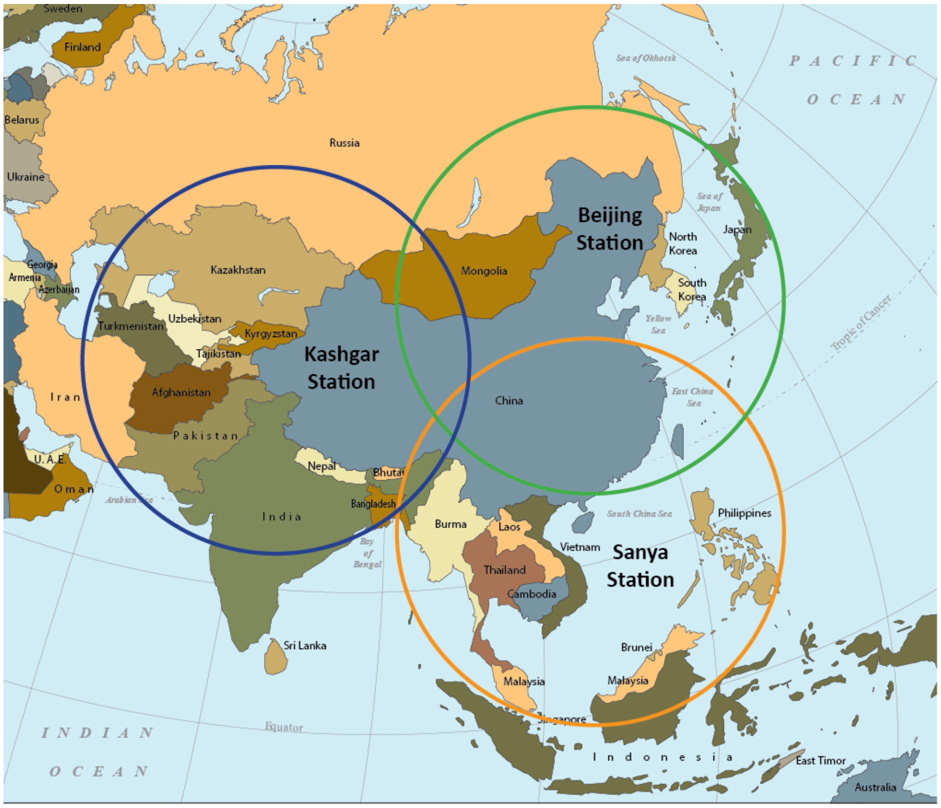
[615] Kevin Pollpeter, "Controlling the Information Domain: Space, Cyber, and Electronic Warfare," in Ashley J. Tellis and Travis Tanner, *Strategic Asia 2012–2013: China's Military Challenge*, (Seattle and Washington, DC: National Bureau of Asian Research, 2012), 185.
[616] Jonathan McDowell, email interview, November 9, 2014.



Source: "中国遥感卫星地面站"[China's Remote Sensing Satellite Ground Stations], 遥感与数字地球研究所 [Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences].

Figure 9. Range of Chinese satellite remote sensing stations

satellites would be "good enough" to meet the needs of the Chinese warfighter. Moreover, the ability to launch these rockets from road-mobile launchers will also provide the Chinese military with the capability to replenish or augment its satellite architecture when its launch centers have been damaged or destroyed and would be less susceptible to U.S. prompt global strike capabilities.

China's growing counterspace capabilities will also present a threat to the U.S. military. The loss of critical sensor and communications capabilities could imperil the military's ability to operate effectively in the western Pacific or, at the very least, to win victories with minimal casualties. China's directed-energy, kinetic-kill vehicle, co-orbital satellite, and cyber capabilities threaten satellites across the spectrum in terms of type and orbit, and their effectiveness will be aided by China's growing tracking and control capabilities. Moreover, due to the inherent dual-use nature of most space technologies, technologies developed for legitimate peaceful use can have military applications. China's debris mitigation technology program is just one example. Laser ranging techniques to determine the altitude of space debris can also determine the altitude of an adversary's satellites for better targeting. Similarly, China's space robotic arm technology cannot only be used to remove debris, but could also be used against an adversary's satellite. These activities are supported by China's improving network of satellite tracking and control stations. These stations—21 in China, one each in Pakistan, Namibia, Kenya, Australia, and Chile, and one in the works in Argentina—will enhance China's ability to control its spacecraft from around the globe and facilitate the tracking and targeting of adversary spacecraft.

Table 16. U.S. satellites by class and orbit

	Orbit				
Satellite class	**LEO**	**MEO**	**GEO**	**Elliptical**	**Total**
Commercial	95	0	112	3	210
Military	62	32	51	7	152
Government	103	0	13	4	120
Civil	19	0	1	0	20
Total	**279**	**32**	**177**	**14**	**502**

As China's space program grows in capability and its counterspace technologies improve, a larger number of U.S. satellites may be susceptible to Chinese counterspace threats. According to the Union of Concerned Scientist Satellite Database, there are 1,167 satellites in orbit around Earth (see Appendix B). Of these, more than half (605) are in LEO and more than one-third are in GEO. Of these 1,167 satellites, just under half (502) belong to the United States. Of these 502, 152 are military, 210 are commercial, 120 government, and 20 civil satellites (Table 16).

The majority of U.S. satellites are in LEO and are the most susceptible to Chinese counterspace platforms. These include direct-ascent kinetic-kill vehicles, ground-based directed energy weapons, and co-orbital satellites. The majority of satellites in LEO are communication satellites operated by Iridium and Orbcom. Both are contractors to the U.S. government and military. The majority of U.S. military satellites in LEO are ISR satellites.

All 32 U.S. satellites in MEO belong to the U.S. military's Global Positioning System. These satellites would be susceptible to larger direct-ascent kinetic-kill vehicles, such as the sounding rocket launched by China in May 2013, and to co-orbital satellites. Ground-based directed-energy weapons would be less effective against these satellites, unless extremely high powered.

The majority of satellites in GEO are communications satellites, including 35 military communication satellites. The U.S. military also operates six early warning satellites and five electronic intelligence satellites in GEO.

The effects of a Chinese attack on U.S. satellites need not be as catastrophic as is sometimes reported, however. According to an analysis conducted by Geoffrey Forden of the Massachusetts Institute of Technology on the operational effects of direct-ascent ASAT attacks against U.S. satellites, China would have to limit its attacks to the U.S. satellites above China. In conducting these attacks, China would need 36 mobile launchers and its fixed launch centers. Assuming that the United States absorbs the first blow and all strikes are successful, by focusing exclusively on GPS satellites, China could deny GPS to U.S. forces for as little as a few hours until the constellation was repositioned or has many as eight hours per day, depending on the number of satellites destroyed. Similarly, an attack solely against communication satellites would degrade, but not eliminate, the U.S. ability to communicate through satellites if civilian satellites are used. The effect on the U.S. space-based ISR system could be more problematic, however. Additionally, Forden concludes that for an attack solely against satellites in LEO,

> China could destroy a total of nine such satellites before the US responds in the specific case examined here. This includes two out of the three functioning Keyhole high resolution photo-reconnaissance satellites, one of the three Lacrosse signals intelligence

> satellites in orbit, and six of the 15 NOSS satellites that the Navy uses to locate enemy ships at sea. This represents billions of dollars lost and, more important, a large fraction of the US space assets in low Earth orbit that could have been used in the subsequent conflict.[617]

Chinese counterspace developments since the publication of his analysis could lead to a revision of the impact of Chinese ASAT attacks on the U.S. military, however. First, it is uncertain if China would limit the number of road-mobile launchers to 36, especially if the Second Artillery is given the direct ascent ASAT mission. The Second Artillery has more than 300 road-mobile launchers for its conventional and nuclear road- mobile missiles, and it would not be unthinkable that China could easily expand an inventory of road-mobile ASAT launchers beyond the 36 envisioned by Forden.[618] Forden's analysis also does not take into account Chinese lasers or the prepositioning of co-orbital ASATs in space. Forden's analysis also assumes that China would have to launch direct-ascent ASATs at targets beyond LEO from its four fixed launch centers. The rocket used for China's 2013 high-altitude science mission, however, may have reached GEO and was most likely derived from the road-mobile DF-31 ballistic missile that does not require a fixed launch site.[619]

Forden also concludes that "the United States could effectively stop China's attack simply by changing the remaining satellites' orbital speeds."[620] But research by Brian Weeden at the Secure World Foundation calls into question the effectiveness of changing the orbits of targeted satellites. Weeden argues that changing the orbit of satellite to an incoming attack is virtually impossible given the speed of missiles and directed energy weapons and the relatively long period of time needed to send commands to a satellite. The United States, on the other hand, could preemptively change the orbit of its satellites, but the net effect would still be beneficial to China. Although the United States could avoid damage to its satellites by placing them out of range of China's ASAT weapons, they would also be out of range of the areas that need coverage. Moreover, all satellites in sun synchronous orbit, such as remote sensing satellites with electro-optical imagers, fly over the entire surface of the Earth due to the nature of their orbits and would sooner or later have to fly over Chinese territory in range of ASAT weapons.[621]

In addition, Forden's analysis neither takes into account Chinese warfighting doctrine, with its emphasis on seizing the initiative at the beginning of a conflict, nor Chinese military writings on space, with their emphasis on conducting strong strikes at the beginning of a conflict. As a result, the effects of a well-coordinated, simultaneous, and multi-pronged attack against U.S. remote sensing, communication, and GPS satellites using multiple counterspace methods could, through the denial of access to strategic areas or the disabling or destruction of satellites, result in serious gaps in U.S. C4ISR capabilities, especially considering the U.S. military's dependence on space. Moreover, China's military strategy does not necessarily call for the PLA to achieve space supremacy for the entirety of a conflict. Instead, the PLA could work to achieve space supremacy in a specific location or for a certain period of time, which would allow it to conduct a critical strike against U.S. forces. Gaps in intelligence, precision navigation, and communications described in the analysis, though limited, could thus have decisive effects.

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[617] Noah Shachtman, "How China Loses the Coming Space War," *Wired*, January 10, 2008, http://www.wired.com/2008/01/inside-the-chin/.
[618] National Air and Space Intelligence Center, *Ballistic and Cruise Missile Threat*, 2013, 13–21.
[619] Weeden, "Through a Glass, Darkly: Chinese, American, and Russian Anti-Satellite Testing in Space."
[620] Shachtman, "How China Loses the Coming Space War."
[621] Brian Weeden, "How China 'Wins' a Space War," *China Security* 4 (2008): 137–50.

As a result, over the long term, a dynamic may exist in which, in their pursuit of offensive capabilities designed to suppress each other's information systems, both the United States and China must also increase their reliance on them. While China is now pursuing an asymmetrical advantage over the United States, over the long-term both sides are actually responding symmetrically to the threat posed by the other. Indeed, Chinese efforts to develop A2/AD space capabilities to keep the U.S. military at bay, and the possibility that the U.S. military would try "to get to left of the kill chain" to defeat those capabilities, suggests that a potentially unstable situation may occur where it is advantageous for both sides to strike first in order to negate the precision firepower of the other. Certainly China's extensive counterspace programs, coupled with U.S. plans to gain advantages in space control technologies[622] and to "accelerate initiatives to counter adversary space capabilities including adversary ISR and space-enabled precision strike,"[623] suggest that outcome is now more probable.

The targeting of early warning satellites that detect ballistic missile launches, such as the U.S. Space-based Infrared System (SBIRS) or a Chinese space-based early warning system that detects missile launches may be further destabilizing. The degradation of either side's early warning satellites in the support of conventional strikes could lead to concern that the strikes are a prelude to a nuclear strike. This is especially concerning considering the prominent role that conventionally armed ballistic missiles play in Chinese operations and the role that U.S. early warning satellites would play in defending against them. Moreover, the deployment of a space-based ballistic missile early warning system may also signal a change in China's nuclear doctrine from "no first use" to "launch on warning." China's current nuclear forces doctrine relies on retaliating only after a nuclear first strike from an opponent. A launch on warning system would make China's nuclear force more survivable since China would have warning that an attack is imminent, but would also present the possibility for false warnings, which could be catastrophically destabilizing during a conventional conflict.

The military implications of China's space program do not just have implications for the United States. Countries around China's periphery, especially those in territorial disputes with China, will face a PLA that is more capable, in part, because China is deriving benefit from the use of space. A space-enabled U.S. military has handily defeated lesser powers; and it is this capability that the PLA seeks with its development of space power. A Chinese military made strong, in part, by the use of space would also increase the costs of war to a potential adversary to such an extent that it may decide that it is not in its interest to fight China. This could potentially challenge U.S. influence in Asia, as countries decide whether to balance against or bandwagon with a rising China.

Economic Implications

China's rise as a space power also appears to have potential negative sum economic consequences for the United States, although it appears to have had less of an immediate effect. For example, China's entrance into the commercial satellite sector so far has had little effect on established satellite manufacturers. The satellites sold to Nigeria, Venezuela, Pakistan, Bolivia, and Laos were part of a competitive package that included launch services, training for local operators, and low-cost loans through its export-import bank. Indeed, China's approach to satellite exports has been to target countries unable to afford satellites from more established, higher-priced satellite manufacturers. In this way, China's satellite manufacturing is following a business plan similar to that used by Chinese information technology giant Huawei, which first entered into lower-priced, but underserved, markets to gain

[622] U.S. Department of Defense, *Quadrennial Defense Review 2014*, 20.
[623] Ibid., 37.

experience and build up its technology before moving into the higher-end markets of Europe and the United States. Moreover, some of China's commercial launches have been for Chinese state-owned enterprises that may have no choice but launch their satellites on Chinese rockets. As a result, China has had only a minor effect on the international launch market since many of its customers would not have been able to afford non-Chinese satellites.

If China is successful in breaking back into the commercial launch for high-end satellites, it could portend trouble for more established commercial launch providers serving a relatively small market in terms of number of launches. The Russian government is the clear leader in the commercial launch sector and regularly captures more than 50 percent of the market. The European company Arianespace makes a strong presence by regularly capturing more than 20 percent of the market. China has been able to break back into the market by offering prices well below these two competitors. According to former Arianespace chairman Jean-Yves Le Gall speaking in 2009, "China offers prices which do not reflect economic reality,"[624] and are "probably about three-quarters the cost."[625] Until recently, the United States was priced out of the commercial launch market with launch costs 10 to 20 percent higher than their competitors.[626] In recent years, however, U.S. launch providers, led by SpaceX, have made a comeback and have captured up to 26 percent of the market. In fact, officials from China's space industry have stated that they cannot beat the SpaceX price of $54 million per launch,[627] while SpaceX's vice president for government affairs has stated that his company views China as the main competition.[628]

The economic consequences of China's rise as a space power could also impact the market for space-related technologies and services, such as those for positioning, navigation and timing, and remote sensing. For example, the designation of China's Beidou satellite navigation system as "national infrastructure" and preferential policies designed to decrease the market share of products and services based on GPS indicate a preference for Chinese companies in China's GNSS market. Although China is not marketing space remote sensing products, the entrance into this weak market as its remote sensing satellites become more capable could disrupt the market.

The ability of China's space program to jump-start technology development is also in question. Although the Apollo program is regarded as having provided a market for certain technologies in their infancy, such as semiconductors, it is not apparent that these market conditions exist today in China. The manufacture of solar panels by China's space industry, for example, comes at a time when that market is experiencing a global glut and a dramatic downturn in prices. It is possible that other types of technology may benefit from the expertise of China's space industry, but these as of yet do not appear to be internationally competitive.

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[624] "China to Build, Launch Satellite for Laos," AFP, September 26, 2009, http://www.spacedaily.com/reports/China_to_build_launch_satellite_for_Laos_999.html.
[625] Doug Young, "China Trades Goods, Influence for Satellite Launches," Reuters, November, 9 2009, http://www.reuters.com/article/2009/11/09/arianespace-idCNHKG21345620091109.
[626] Peter B. de Selding, "Satellite Firms Tap Warner in Bid for Wider Access to Launchers," *Space News*, September 16, 2009, http://www.spacenews.com/article/satellite-firms-tap-warner-bid-wider-access-launchers.
[627] Frank Morring, Jr., "China Great Wall Confounded by SpaceX Prices," *Aviation Week & Space Technology*, April 15, 2011, http://aviationweek.com/awin/china-great-wall-confounded-spacex-prices.
[628] Mike Wall, "China Looms as Main Launch Competition, SpaceX Says," Space.com, October 15, 2013, http://www.space.com/23207-spacex-commercial-launch-competition-china.html.

Diplomatic Implications

Whereas space can contribute to the hard power accumulation of military and economic capabilities, it can also work to increase China's soft power. According to Joseph Nye, "soft power is more than just persuasion or the ability to move people by argument, though that is an important part of it. It is also the ability to attract, and attraction often leads to acquiescence."[629] Although measuring the effects of soft power is difficult, Nye writes that it rests "on the ability to shape the preferences of others."[630]

China's burgeoning space program is used as one of the many barometers of its rise as a military, economic, and political power. It reinforces the image that China is a dynamic country capable of doing things well and also a country with which relations can be beneficial. This could make China more attractive, especially to developing countries without strong democratic traditions.

China's strategy thus appears to be a combination of seeking cooperative activities with the main space powers while at the same time seeking leadership opportunities with lesser space powers through such activities as its leadership of APSCO and its agreements to build Beidou stations in several countries in Asia. These activities reinforce the image that China can interact with the major space powers as equals while also creating an "alternative universe" where China can lead space activities free from the interference of the other major space powers. ASPCO, for example, does not grant other countries observer status.[631]

Moreover, as China becomes more capable in space, it will become a more attractive partner for Europe, Russia, and smaller space powers. These activities may increase multipolarity by presenting another avenue for countries to participate in space in addition to—or without—the United States. This is especially true in the area of human spaceflight where the lack of an independent capability to launch humans into space by the United States has made China an attractive new partner for collaboration. Although Europe states that its collaborative activities with China do not mean a diminution of its activities with the United States, reduced budgets for space programs and the orbiting of China's larger space station at the same time that the International Space Station will be nearing the end of its service life may result in increasing influence for China in space.

These additional opportunities for collaboration could not only assist China's space program in becoming more competitive, they could also assist Europe's space industry in becoming less dependent on the United States for space technology. As China's space program continues to improve, countries without the security concerns of the United States will increasingly look upon space as another venue for interacting with China. China cooperates with many countries in space and looks to Europe in particular for access to technology and expertise denied by the United States. It maintains important cooperative activities with Russia and Ukraine and has cooperative relationships with the European Space Agency and the countries of the European Union. Spurred on by U.S. export control laws, European cooperation with China could improve China's space technology while at the same time making Europe more technologically independent of U.S. industry. Although the "ITAR-free" satellites sold to China were eventually determined to be anything but, the possibility of further collaboration cannot rule out such satellites being developed in the future.

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629 Joseph Nye, *Soft Power: The Means to Success in World Politics* (New York: PublicAffairs, 2004), 6.
630 Ibid., 5.
631 Clay Moltz, interview via email, November 19, 2014.

The importance of China's space diplomacy should not be overstated, however. Relations in space do not drive relations on Earth. International cooperation on space activities usually follows progress in the overall relationship and is more of an indicator of the state of a relationship than a critical component. Although China's increasing space power does play a role in advancing its diplomatic interests, there is no evidence that it has directly produced tangible political benefits in other areas besides space.[632] As its space power increases this may change. China, for example, could have more of a say in international technical organizations such as the International Telecommunications Union over rules governing satellites and satellite frequency issues, but as yet this is unrealized.

Conclusion

Even if U.S. space power continues to improve in absolute terms, China's rapid advance in space technologies will result in relative gains that challenge the U.S. position in space. The real question concerning U.S. competiveness may not be whether Chinese satellites and launchers are the equal of their U.S. competitors, but whether their products provide sufficient value. A Chinese industry that can offer moderately priced but sufficiently capable products may be able to compete effectively in the market. Similarly, a Chinese space program that can provide a good enough solution to deter or raise the costs of military intervention for an adversary may be all that is necessary.

If the current trajectory of China's space program continues, by 2030 the China will have a new line of advanced launch vehicles, a robust, space-based C4ISR network made up of imagery satellites with resolutions well below one meter, and more capable electronic intelligence communication satellites linked together by data-relay satellites, in addition to a global satellite-navigation system that may gradually approach current GPS standards. At this point, China could also likely have made operational a number of advanced counterspace capabilities, including kinetic-kill, directed-energy, and co-orbital ASAT capabilities as well as some form of missile defense system. In addition, China's more capable satellites and launch vehicles could not only compete with U.S., European, and Russian industry but also provide new avenues for cooperation. This could be especially true if China were to conduct manned lunar missions.

Although China is probably truthful when it says that it is not in a space race, such statements mask the true intent of its space program: to become militarily, diplomatically, commercially, and economically as competitive as the United States is in space. Despite Chinese statements that it is not in a space race, China's space program has generated concern both in the United States and in Asia. As Clay Moltz of the Naval Postgraduate School writes, "There is a space race going on in Asia, but its outcome—peaceful competition or military confrontation—is still uncertain." He concludes that although "there are still reasonable prospects for avoiding negative outcomes in space…Asia is at risk of moving backward, motivated by historical mistrust and animosities and hindered by poor communications on security matters."[633] As a result, China's progress in space technologies, whether in relative or absolute terms, has implications for the United States and its neighbors. As China's space program increases in capability, it can be expected to wield this power in ways that, according to Bonnie Glaser, not only "persuade its neighbors that there is more to gain from accommodating Chinese interests" but also "deter countries from pursuing policies that inflict damage on Chinese interests."[634]

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[632] Clay Moltz, interview via email, November 19, 2014.
[633] James Clay Moltz, *Asia's Space Race: National Motivations, Regional Rivalries, and International Risks* (New York: Columbia University Press, 2012), 191.
[634] Bonnie S. Glaser, "China's Grand Strategy in Asia."

Nevertheless, although China's space program may pose challenges for the United States and its space power neighbors, it may also present opportunities for scientific collaboration on the Earth's environment and outer space. In addition, it may make human spaceflight safer by providing additional capabilities to rescue stranded or imperiled astronauts through the use of common docking apparatus.

Moreover, what is unwritten in Chinese analyses is that as China becomes more invested in space capabilities it takes on the same vulnerabilities as the United States. Although China would not have the same asymmetries as the United States in a conflict in the Western Pacific, the goal of having a global, 24-hour, all-weather remote sensing capability and spending nearly $1 billion per year until 2020 to establish a global satellite navigation system and associated technologies indicates that China is devoting significant effort and resources to establish a system that is similar in architecture to that of the U.S. military's space program. With this trajectory, China will have as much to lose as it has to gain from the management or mismanagement of the outer space global commons. It is in this vein that some sort of strategic accommodation that ameliorates the worst effects of competition could be achieved.

APPENDIX A
CHINESE OPERATIONAL SATELLITES IN ORBIT

Satellite	Launch Date	Operator/Owner	Purpose	Class of Orbit	Planned Service Life (years)
CIVIL					
BeijinGalaxy-1 (Beijing 1 [Tsinghua], Tsinghau-2, China DMC+4)	10/27/05	Beijing Landview Mapping Information Technology Co. Ltd (BLMIT)	Earth Observation	LEO	UNK
Tian Xun-1 (TX-1)	11/9/11	Nanjing University of Aeronautics an d Astronautics	Technology Development	LEO	UNK
XW-1 (Hope Oscar 68, HO-68, Xi Wang 1, Hope-1, CAS-1)	12/15/09	DFH Satellite/AMSAT-China	Communications	LEO	UNK
Zheda Pixing 1B (ZP-1B, Zhejiang University-1B)	9/22/10	Zhejiang University	Scientific Research	LEO	UNK
Zheda Pixing 1C (ZP-1C, Zhejiang University-1B)	9/22/10	Zhejiang University	Scientific Research	LEO	UNK
COMMERCIAL					
Apstar 1	7/21/94	APT Satellite Holdings Ltd.	Communications	GEO	9
Apstar 1A	7/3/96	APT Satellite Holdings Ltd.	Communications	GEO	10
Apstar 6	4/12/05	APT Satellite Holdings Ltd.	Communications	GEO	15
Apstar 7	3/31/12	APT Satellite Holdings Ltd.	Communications	GEO	15
AsiaSat 3S (Asiasat 3SA)	3/21/99	Asia Satellite Telecommunications Co. Ltd. (SES [Société Européenne des Satellites (SES)])	Communications	GEO	15
AsiaSat 4	4/12/03	Asia Satellite Telecommunications Co. Ltd. (SES [Société Européenne des Satellites (SES)])	Communications	GEO	15
AsiaSat 5	8/11/09	Asia Satellite Telecommunications Co. Ltd. (SES [Société Européenne des Satellites (SES)])	Communications	GEO	15
AsiaSat 7	11/25/11	Asia Satellite Telecommunications Co. Ltd. (SES [Société Européenne des Satellites (SES)])	Communications	GEO	15
Sinosat-6 (Chinasat-6A, XN-6)	9/4/10	China Direct Broadcast Satellite co.	Communications	GEO	15 (10 due to leak)
ABS-2i (MBSat, Mobile Broadcasting Satellite, Han Byul)	3/13/04	Asia Broadcasting Satellite	Communications	GEO	UNK
COMMERCIAL/GOVERNMENT					
ChinaSat 6B (Zhong Xing 6B)	7/6/07	China Satellite Communication Corp. (China Satcom)	Communications	GEO	15
GOVERNMENT					
Chuangxin 1-1 (Innovation 1-1, Chuang Xin 1, CZ-1-1)	10/21/03	Chinese Academy of Sciences	Communications	LEO	UNK
Chuangxin 1-2 (Innovation 1-2)	11/5/08	Chinese Academy of Sciences	Earth Observation	LEO	UNK
Chuangxin 1-3 (Innovation 1-3)	11/20/11	Chinese Academy of Sciences	Earth Observation	LEO	UNK
Chuangxin-3	7/19/13	Chinese Academy of Sciences	Technology Development	LEO	UNK
Fengniao 1 (Hummingbird 1)	11/20/12	Chinese Academy of Space Technology (CAST)	Technology Development	LEO	2
Fengniao 1A (Hummingbird 1A)	11/20/12	Chinese Academy of Space Technology (CAST)	Technology Development	LEO	UNK
Fengyun 2D (FY-2D)	12/8/06	China Meteorological Administration	Earth Science	GEO	3
Fengyun 2E (FY-2E)	12/23/08	China Meteorological Administration	Earth Science	GEO	3
Fengyun 2F (FY-2F)	1/12/12	China Meteorological Administration	Earth Science	GEO	3
Fengyun 3A (FY-3A)	5/27/08	China Meteorological Administration	Earth Science	LEO	3
Fengyun 3B (FY-3B)	11/4/10	China Meteorological Administration	Earth Science	LEO	3

Satellite	Launch Date	Operator/Owner	Purpose	Class of Orbit	Planned Service Life (years)
GOVERNMENT (CONT.)					
Fengyun 3C (FY-3C)	9/23/13	China Meteorological Administration	Earth Science	LEO	5
Gaofen 1	4/26/13	Shanghai Academy of Spaceflight Technology (SAST)	Remote Sensing	LEO	5 to 8
Haiyang 1B (HY 1B, Ocean 1B)	4/11/07	State Oceanic Administration (SOA)	Meteorology	LEO	3
Haiyang 2A (HY 2A)	8/15/11	State Oceanic Administration (SOA)	Meteorology	LEO	3
HJ-1A (Huan Jing 1A)	9/5/08	National Remote Sensing Center (NRSCC)	Remote Sensing	LEO	3
HJ-1B (Huan Jing 1B)	9/5/08	National Remote Sensing Center (NRSCC)	Remote Sensing	LEO	3
HJ-1C (Huan Jing 1C)	11/18/12	National Committee for Disaster Reduction and State Environmental Protection	Remote Sensing	LEO	3
Kuaizhou-1 (KZ-1)	9/25/13	National Academy of Sciences	Remote Sensing	LEO	UNK
Shijian 11-01 (SJ-11-01)	11/12/09	Chinese Academy of Space Technology (CAST)	Space Physics	LEO	UNK
Shijian 11-02 (SJ-11-02)	7/29/11	Chinese Academy of Space Technology (CAST)	Technology Development	LEO	UNK
Shijian 11-03 (SJ-11-03)	7/6/11	Chinese Academy of Space Technology (CAST)	Technology Development	LEO	UNK
Shijian 11-05 (SJ-11-05)	7/15/13	Chinese Academy of Space Technology (CAST)	Technology Development	LEO	UNK
Shijian 12 (SJ-12)	6/15/10	Chinese Academy of Space Technology (CAST)	Technology Development	LEO	UNK
Shijian 15 (SJ-15)	7/19/13	Chinese Academy of Space Technology (CAST)	Technology Development	LEO	UNK
Shijian 16 (SJ-16)	10/25/13	Chinese Academy of Space Technology (CAST)	Technology Development	LEO	UNK
Shijian 6A (SJ-6A, Dong Fang Hong 60)	9/8/04	Chinese Academy of Space Technology (CAST)	Space Physics	LEO	UNK
Shijian 6B (SJ-6B)	9/8/04	Chinese Academy of Space Technology (CAST)	Space Physics	LEO	UNK
Shijian 6C (SJ-6-02A)	10/23/06	Chinese Academy of Space Technology (CAST)	Space Physics	LEO	UNK
Shijian 6D (SJ-6-02B)	10/23/06	Chinese Academy of Space Technology (CAST)	Space Physics	LEO	UNK
Shijian 6E (SJ6-03A, SJ-6E)	10/25/08	Chinese Academy of Space Technology (CAST)	Space Physics	LEO	UNK
Shijian 6F (SJ6-03B, SJ-6F)	10/25/08	Chinese Academy of Space Technology (CAST)	Space Physics	LEO	UNK
Shijian 6G (SJ6-04A)	10/6/10	Chinese Academy of Space Technology (CAST)	Reconnaissance	LEO	UNK
Shijian 6H (SJ6_04B)	10/6/10	Chinese Academy of Space Technology (CAST)	Reconnaissance	LEO	UNK
Shijian 7 (SJ7, Dong Fang Hong 65)	7/5/05	Chinese Academy of Space Technology (CAST)	Space Physics	LEO	UNK
Shijian 9A (SJ 9A)	10/14/12	Chinese Academy of Space Technology (CAST)	Technology Development	LEO	UNK
Shijian 9B (SJ 9B)	10/14/12	Chinese Academy of Space Technology (CAST)	Technology Development	LEO	UNK
Shiyan 1 (SY 1, Tansuo 1, Experimental Satellite 1)	4/18/04	Chinese Academy of Space Technology (CAST)	Remote Sensing	LEO	UNK
Shiyan 3 (SY3, Experimental Satellite 3)	11/5/08	Chinese Academy of Space Technology (CAST)	Remote Sensing/Research	LEO	2
Shiyan 4 (SY4, Experimental Satellite 4)	11/20/11	Chinese Academy of Space Technology (CAST)	Remote Sensing/Research	LEO	UNK
Shiyan 5 (SY5, Experimental Satellite 5)	11/25/13	Chinese Academy of Space Technology (CAST)	Remote Sensing/Research	LEO	UNK
Tiangong-1 (TG-1)	9/29/11	Beijing Aerospace Flight Control Center	Technology Development	LEO	2

Satellite	Launch Date	Operator/Owner	Purpose	Class of Orbit	Planned Service Life (years)
GOVERNMENT (CONT.)					
Tianhui 1-01	8/24/10	China Aerospace Science and Technology Corporation (CASTC)	Earth Observation	LEO	3 to 5
Tianhui 1-02	5/6/12	China Aerospace Science and Technology Corporation (CASTC)	Earth Observation	LEO	3 to 5
TianLian 1 (TL-1-01, CTDRS)	4/25/08	Chinese Academy of Space Technology (CAST)	Communications	GEO	6
TianLian 2 (TL-1-02, CTDRS)	7/11/11	Chinese Academy of Space Technology (CAST)	Communications	GEO	6
TianLian 3 (TL-1-03, CTDRS)	7/25/12	Chinese Academy of Space Technology (CAST)	Communications	GEO	6
Tiantuo 1	5/10/12	National University of Defense Technology	Technology Development	LEO	UNK
Xinyan 1 (XY-1)	11/18/12	DFH Satellite	Technology Development	LEO	UNK
Yaogan 4 (Remote Sensing Satellite 4)	12/1/08	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 5 (Remote Sensing Satellite 5, JB 5-C, Jian Bing 5-C)	12/15/08	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 6 (Remote Sensing Satellite 6, Jian Bing 7-A)	4/22/09	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 7 (Remote Sensing Satellite 7)	12/9/09	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 8 (Remote Sensing Satellite 8)	12/15/09	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 9A (Remote Sensing Satellite 9A)	3/5/10	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 9B (Remote Sensing Satellite 9B)	3/5/10	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 9C (Remote Sensing Satellite 9C)	3/5/10	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Zhongxing 10 (XZ-10, Chinasat 10)	6/20/11	China Satellite Communication Corp. (China Satcom)	Communications	GEO	15
Zhongxing 11 (Chinasat 11)	5/1/13	China Satellite Communication Corp. (China Satcom)	Communications	GEO	15
Zhongxing 12 (Chinasat 12, ZX-12)	11/27/12	China Satellite Communication Corp. (China Satcom)	Communications	GEO	15
Zhongxing 9 (Chinasat 9, Chinastar 9)	6/9/08	China Satellite Communication Corp. (China Satcom)	Communications	GEO	15
Ziyuan 1-02C	12/22/11	China Centre for Resources Satellite Data and Application (CRESDA)	Earth Observation	LEO	3
Ziyuan 3 (ZY-3)	1/9/12	China Centre for Resources Satellite Data and Application (CRESDA)	Earth Observation	LEO	5
MILITARY					
Compass G-1 (Beidou G1)	1/16/10	Chinese Defense Ministry	Navigation/Global Positioning	GEO	8
Compass G-10 (Beidou ISGO-5)	12/1/11	Chinese Defense Ministry	Navigation/Global Positioning	GEO	8
Compass G-11 (Beidou G5)	2/24/12	Chinese Defense Ministry	Navigation/Global Positioning	GEO	8
Compass G-3 (Beidou G3)	6/2/10	Chinese Defense Ministry	Navigation/Global Positioning	GEO	8
Compass G-4 (Beidou G4)	10/31/10	Chinese Defense Ministry	Navigation/Global Positioning	GEO	8
Compass G-5 (Beidou IGSO-1)	7/31/10	Chinese Defense Ministry	Navigation/Global Positioning	GEO	8
Compass G-6 (Beidou 2-16)	10/25/12	Chinese Defense Ministry	Navigation/Global Positioning	GEO	8
Compass G-7 (Beidou IGSO-2)	12/17/10	Chinese Defense Ministry	Navigation/Global Positioning	GEO	8
Compass G-8 (Beidou IGSO-3)	4/9/11	Chinese Defense Ministry	Navigation/Global Positioning	GEO	8
Compass G-9 (Beidou ISGO-4)	7/26/11	Chinese Defense Ministry	Navigation/Global Positioning	GEO	8
Compass M1 (Beidou M1)	4/14/07	Chinese Defense Ministry	Navigation/Global Positioning	MEO	8

Satellite	Launch Date	Operator/Owner	Purpose	Class of Orbit	Planned Service Life (years)
MILITARY (CONT.)					
Compass M3 (Beidou 2-12)	4/28/12	Chinese Defense Ministry	Navigation/Global Positioning	MEO	8
Compass M4 (Beidou 2-13)	4/28/12	Chinese Defense Ministry	Navigation/Global Positioning	MEO	8
Compass M5 (Beidou 2-14)	9/18/12	Chinese Defense Ministry	Navigation/Global Positioning	MEO	8
Compass M6 (Beidou 2-15)	9/18/12	Chinese Defense Ministry	Navigation/Global Positioning	MEO	8
Shiyan 7 (SY7, Experimental Satellite 7)	7/19/13	Chinese Academy of Space Technology (CAST)	Technology Development	LEO	UNK
Yaogan 10 (Remote Sensing Satellite 10)	8/9/10	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 11 (Remote Sensing Satellite 11)	9/22/10	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 12 (Remote Sensing Satellite 12)	11/9/11	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 13 (Remote Sensing Satellite 13)	11/29/11	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 14 (Remote Sensing Satellite 14)	5/10/12	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 15 (Remote Sensing Satellite 15)	5/29/12	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 16A (Remote Sensing Satellite 16A, Yaogan Weixing 16)	11/25/12	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 16B (Remote Sensing Satellite 16B)	11/25/12	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 16C (Remote Sensing Satellite 16C)	11/25/12	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 17A (Remote Sensing Satellite 17A, Yaogan Weixing 17)	9/1/13	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 17B (Remote Sensing Satellite 17B)	9/1/13	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 17C (Remote Sensing Satellite 17C)	9/1/13	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 18 (Remote Sensing Satellite 18)	10/29/13	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 19 (Remote Sensing Satellite 19)	11/20/13	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 2 (Remote Sensing Satellite 2, Jian Bing 5-2, JB 5-2)	5/25/07	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Yaogan 3 (Remote Sensing Satellite 3, Jian Bing 5-3, JB 5-3)	11/11/07	People's Liberation Army (C41)	Remote Sensing	LEO	UNK
Zhangguo Ziyuan 2B (ZY-2B, JB-3B)	10/27/02	Chinese Academy of Space Technology	Remote Sensing	LEO	2
Zhangguo Ziyuan 2C (ZY-2C, JB-3C)	11/4/04	Chinese Academy of Space Technology	Reconnaissance	LEO	UNK
Zhongxing 1A (Chinasat 1A, Fenghuo 2)	9/18/11	People's Liberation Army (C41)	Communications	GEO	UNK
Zhongxing 20A	11/24/10	People's Liberation Army (C41)	Communications	GEO	8
Zhongxing 22A (Chinastar 22A)	9/12/06	China Satellite Communication Corp. (China Satcom)	Communications	GEO	8
MILITARY/GOVERNMENT					
Zhongxing 2A (Chinasat 2A)	5/26/12	People's Liberation Army (C41)	Communications	GEO	3

Source: Data from Union of Concerned Scientists database, updated January 31, 2014, http://www.ucsusa.org/nuclear_weapons_and_global_security/solutions/space-weapons/ucs-satellite-database.html#.VHUDZU3Qe74.

APPENDIX B
U.S. OPERATIONAL SATELLITES IN ORBIT

Satellite	Launch Date	Owner	Purpose	Orbit
CIVIL				
GOES 3 (Geostationary Operational Environmental Satellite, GOES-C)	6/16/1978	University of Miami, Rosenstiel School of Marine and Atmospheric Science (RSMAS) (loaned by NOAA)	Communications	GEO
Amsat-Oscar 7 (AO-7)	11/15/1974	Amsat-NA	Amateur Radio	LEO
CAPE-2 (Cajun Advanced Picosatellite Experiment)	11/19/2013	University of Louisiana at Lafayette	Technology Development	LEO
CINEMA-1 (Cubesat for Ion, Neutral, Electron, Magnetic fields)	9/13/2012	University of California-Berkeley/Imperial College-London	Space Science	LEO
CINEMA-2 (Cubesat for Ion, Neutral, Electron, Magnetic fields)	11/21/2013	University of California-Berkeley/Imperial College-London	Space Science	LEO
CINEMA-3 (Cubesat for Ion, Neutral, Electron, Magnetic fields)	11/21/2013	University of California-Berkeley/Imperial College-London	Space Science	LEO
CUNYSat-1 (City University of New York Satellite-1)	12/6/2013	City University of New York	Technology Development	LEO
CUSat-1 (Cornell University Satellite 1)	9/29/2013	Space Systems Design Studio, Cornell University	Technology Development	LEO
Eagle 2 ($50Sat)	11/21/2013	Morehead State University	Technology Development	LEO
FAST 1 (Sara Lilly and Emma, USA 222)	11/20/2010	University of Texas - Austin	Technology Development	LEO
Ho'oponopono-2 (H2)	11/19/2013	University of Hawaii	Radar Calibration	LEO
KySat-2	11/19/2013	Kentucky Space	Technology Development	LEO
M-Cubed/E1P-U2 (Michigan Multipurpose Minisat; Explorer 1 Prime - Unit 2 - HRBE [William A. Hiscock Radiation Belt Explorer])	10/28/2011	University of Michigan/Montana University	Technology Development	LEO
MCubed-2 (Michigan Multipurpose Minisatellite 2)	12/6/2013	University of Michigan Exploratory Lab	Technology Development	LEO
Vermont Lunar Cubesat	11/19/2013	Vermont Technical College/University of Vermont	Technology Development	LEO
CIVIL/GOVERNMENT				
DANDE (Drag and Atmospheric Neutral Density Explorer)	9/29/2013	University of Colorado, Boulder	Technology Development	LEO
Firebird-A (Focused Investigations of Relativistic Electron Burst, Intensity, Range, and Dynamics)	12/6/2013	Firebird Consortium (Montana State Univ., Univ. of New Hampshire, Aerospace Corp., Los Alamos National Laboratory)	Space Science	LEO
Firebird-B (Focused Investigations of Relativistic Electron Burst, Intensity, Range, and Dynamics)	12/6/2013	Firebird Consortium (Montana State Univ., Univ. of New Hampshire, Aerospace Corp., Los Alamos National Laboratory)	Space Science	LEO
O/OREOS (Organism/Organic Exposure to Orbital Stresses, USA 219)	11/20/2010	NASA-Ames Research Center/Stanford University	Scientific Research	LEO

Satellite	Launch Date	Owner	Purpose	Orbit
CIVIL/MILITARY				
Falconsat-3	3/9/2007	US Air Force Academy	Technology Development	LEO
COMMERCIAL				
Intelsat 5 (Arabsat 2C, Panamsat-5, PAS-5)	8/28/1997	Intelsat, Ltd.	Communications	GEO
Sirius 1 (SD Radio 1)	6/30/2000	Sirius Satellite Radio	Communications	Elliptical
Sirius 2 (SD Radio 2)	9/5/2000	Sirius Satellite Radio	Communications	Elliptical
Sirius 3 (SD Radio 3)	11/30/2000	Sirius Satellite Radio	Communications	Elliptical
Galaxy-13 (Horizons 1, Galaxy 13L)	10/1/2003	PanAmSat (Intelsat, Ltd.)/Sky Perfect JSAT Corp.	Communications	GEO
Horizons 2	12/21/2007	Horizons 2 Satellite, LLC (Intelsat, Sky Perfect JSAT Corporation)	Communications	GEO
MSAT 1	4/20/1996	Mobile Satellite Ventures	Communications	GEO
MSAT 2 (AMSC-1, ACTel-1)	4/7/1995	Mobile Satellite Ventures	Communications	GEO
Afristar	10/28/1998	1Worldspace	Communications	GEO
AMC-1 (Americom 1, GE-1)	9/8/1996	SES (Société Européenne des Satellites (SES))	Communications	GEO
AMC-10 (Americom-10, GE 10)	2/5/2004	SES (Société Européenne des Satellites (SES))	Communications	GEO
AMC-11 (Americom-11, GE 11)	5/19/2004	SES (Société Européenne des Satellites (SES))	Communications	GEO
AMC-15 (Americom-15)	10/14/2004	SES (Société Européenne des Satellites (SES))	Communications	GEO
AMC-16 (Americom-16)	12/17/2004	SES (Société Européenne des Satellites (SES))	Communications	GEO
AMC-18 (Americom 18)	12/8/2006	SES (Société Européenne des Satellites (SES))	Communications	GEO
AMC-2 (Americom 2, GE-2)	1/30/1997	SES (Société Européenne des Satellites (SES))	Communications	GEO
AMC-21 (Americom 21)	8/14/2008	SES (Société Européenne des Satellites (SES))	Communications	GEO
AMC-3 (Americom 3, GE-3)	9/4/1997	SES (Société Européenne des Satellites (SES))	Communications	GEO
AMC-4 (Americom-4, GE-4)	11/13/1999	SES (Société Européenne des Satellites (SES))	Communications	GEO
AMC-5 (Americom-5, GE-5)	10/28/1998	SES (Société Européenne des Satellites (SES))	Communications	GEO
AMC-6 (Americom-6, GE-6)	10/22/2000	SES (Société Européenne des Satellites (SES))	Communications	GEO
AMC-7 (Americom-7, GE-7)	9/14/2000	SES (Société Européenne des Satellites (SES))	Communications	GEO
AMC-8 (Americom-8, GE-8, Aurora 3)	12/19/2000	SES (Société Européenne des Satellites (SES))	Communications	GEO
AMC-9 (Americom 9, GE-12)	6/7/2003	SES (Société Européenne des Satellites (SES))	Communications	GEO
AsiaStar	3/21/2000	1Worldspace	Communications	GEO
DirecTV-10	7/7/2007	DirecTV, Inc.	Communications	GEO
DirecTV-11	3/19/2008	DirecTV, Inc.	Communications	GEO
DirecTV-12	12/29/2009	DirecTV, Inc.	Communications	GEO
DirecTV-4S	11/27/2001	DirecTV, Inc.	Communications	GEO
DirecTV-5 (Tempo 1)	5/7/2002	DirecTV, Inc.	Communications	GEO
DirecTV-7S	5/4/2004	DirecTV, Inc.	Communications	GEO
DirecTV-8	5/22/2005	DirecTV, Inc.	Communications	GEO
DirecTV-9S	10/13/2006	DirecTV, Inc.	Communications	GEO
Echostar 10	2/15/2006	Echostar Technologies, LLC	Communications	GEO

Satellite	Launch Date	Owner	Purpose	Orbit
COMMERCIAL (CONT.)				
Echostar 11	7/16/2008	Echostar Technologies, LLC	Communications	GEO
Echostar 12 (Rainbow-1)	7/17/2003	Echostar Technologies, LLC	Communications	GEO
Echostar 14	3/20/2010	Echostar Technologies, LLC	Communications	GEO
Echostar 15	7/10/2010	Echostar Technologies, LLC	Communications	GEO
Echostar 16	11/20/2012	Echostar Technologies, LLC	Communications	GEO
Echostar 17	7/5/2012	Echostar Technologies, LLC	Communications	GEO
Echostar 3	10/5/1997	Echostar Technologies, LLC	Communications	GEO
Echostar 6	7/14/2000	Echostar Technologies, LLC	Communications	GEO
Echostar 7	2/21/2002	Echostar Technologies, LLC	Communications	GEO
Echostar 8	8/21/2002	Echostar Technologies, LLC	Communications	GEO
Echostar 9/Galaxy 23 (G-23, Intelsat 1A-13, Telstar 13)	8/8/2003	Echostar Technologies, LLC/Intelsat	Communications	GEO
Echostar G1 (ICO G1, DBSD G1)	4/14/2008	Dish Network	Communications	GEO
Galaxy-11	1/21/1999	PanAmSat (Intelsat, Ltd.)	Communications	GEO
Galaxy-12	4/9/2003	PanAmSat (Intelsat, Ltd.)	Communications	GEO
Galaxy-14	8/13/2005	PanAmSat (Intelsat, Ltd.)	Communications	GEO
Galaxy-15	10/13/2005	PanAmSat (Intelsat, Ltd.)	Communications	GEO
Galaxy-16	6/18/2006	PanAmSat (Intelsat, Ltd.)	Communications	GEO
Galaxy-17	5/4/2007	Intelsat, Ltd.	Communications	GEO
Galaxy-18	5/21/2008	Intelsat, Ltd.	Communications	GEO
Galaxy-19	9/24/2008	Intelsat, Ltd.	Communications	GEO
Galaxy-25 (G-25, Intelsat 1A-5, Telstar 5)	5/24/1997	Intelsat, Ltd.	Communications	GEO
Galaxy-26 (G-26, Intelsat 1A-6, Telstar 6)	2/15/1999	Intelsat, Ltd.	Communications	GEO
Galaxy-27 (G-27, Intelsat IA-7, Telstar 7)	9/25/1999	Intelsat, Ltd.	Communications	GEO
Galaxy-28 (G-28, Intelsat IA-8, Telstar 8)	6/23/2005	Intelsat, Ltd.	Communications	GEO
Galaxy-3C	6/15/2002	PanAmSat (Intelsat, Ltd.)	Communications	GEO
Intelsat 10 (PAS-10)	5/14/2001	PanAmSat (Intelsat, Ltd.)	Communications	GEO
Intelsat 10-02 (Thor 4)	6/16/2004	Intelsat, Ltd.	Communications	GEO
Intelsat 11 (PAS 11)	10/5/2007	PanAmSat (Intelsat, Ltd.)	Communications	GEO
Intelsat 14 (IS-14)	11/23/2009	Intelsat, Ltd.	Communications	GEO
Intelsat 15 (IS-15, JCSat 85)	11/30/2009	Intelsat, Ltd./Sky Perfect JSAT Corp.	Communications	GEO
Intelsat 16 (IS-16)	2/12/2010	Intelsat, Ltd.	Communications	GEO
Intelsat 17 (IS-17)	11/26/2010	Intelsat, Ltd.	Communications	GEO
Intelsat 18 (IS-18)	10/5/2011	Intelsat, Ltd.	Communications	GEO
Intelsat 19 (IS-19)	6/1/2012	Intelsat, Ltd.	Communications	GEO
Intelsat 1R (IS-1R, PAS-1R, PanAmSat 1R)	11/15/2000	PanAmSat (Intelsat, Ltd.)	Communications	GEO
Intelsat 20 (IS-20)	8/2/2012	Intelsat, Ltd.	Communications	GEO
Intelsat 21 (IS-21)	8/19/2012	Intelsat, Ltd.	Communications	GEO
Intelsat 22	3/25/2012	Intelsat, Ltd.	Communications	GEO
Intelsat 23	10/14/2012	Intelsat, Ltd.	Communications	GEO
Intelsat 25 (IS-25, Protostar 1, Chinasat 8)	7/7/2008	Intelsat, Ltd.	Communications	GEO
Intelsat 26 (JCSat R, JCSAT-4, Japan Communications Satellite 4)	2/16/1997	Intelsat, Ltd.	Communications	GEO
Intelsat 603 (Intelsat 6 F-3, IS-603)	3/14/1990	Intelsat, Ltd./New Skies Satellites N.V. [SES] (shared capacity)	Communications	GEO
Intelsat 7 (IS-7, PAS-7)	9/16/1998	PanAmSat (Intelsat, Ltd.)	Communications	GEO

Satellite	Launch Date	Owner	Purpose	Orbit
COMMERCIAL (CONT.)				
Intelsat 701	10/22/1993	Intelsat, Ltd.	Communications	GEO
Intelsat 702	6/17/1994	Intelsat, Ltd.	Communications	GEO
Intelsat 706	5/17/1995	Intelsat, Ltd.	Communications	GEO
Intelsat 8 (IS-8, PAS-8)	11/4/1998	PanAmSat (Intelsat, Ltd.)	Communications	GEO
Intelsat 805	6/18/1998	Intelsat, Ltd.	Communications	GEO
Intelsat 9 (IS-9, PAS-9)	7/28/2000	PanAmSat (Intelsat, Ltd.)	Communications	GEO
Intelsat 901	6/9/2001	Intelsat, Ltd.	Communications	GEO
Intelsat 902	8/30/2001	Intelsat, Ltd.	Communications	GEO
Intelsat 903	3/30/2002	Intelsat, Ltd.	Communications	GEO
Intelsat 904	2/23/2002	Intelsat, Ltd.	Communications	GEO
Intelsat 905	6/5/2002	Intelsat, Ltd.	Communications	GEO
Intelsat 906	9/6/2002	Intelsat, Ltd.	Communications	GEO
Intelsat 907	2/15/2003	Intelsat, Ltd.	Communications	GEO
Intelsat APR-2 (INSAT 2E)	4/3/1999	Intelsat, Ltd.	Communications	GEO
Intelsat New Dawn	4/22/2011	Intelsat, Ltd.	Communications	GEO
QuetzSat-1	9/29/2011	SES World Skies (SES [Société Européenne des Satellites (SES)]) -- total capacity leased to subsidiary of EchoStar Corp.	Communications	GEO
SES-1 (AMC-4R)	4/24/2010	SES World Skies (SES [Société Européenne des Satellites (SES)])	Communications	GEO
SES-2	9/21/2011	SES World Skies (SES [Société Européenne des Satellites (SES)])	Communications	GEO
SES-3	7/15/2011	SES World Skies (SES [Société Européenne des Satellites (SES)])	Communications	GEO
SES-4	2/14/2012	SES World Skies (SES [Société Européenne des Satellites (SES)])	Communications	GEO
SES-5 (Sirius 5, Astra 4B)	7/9/2012	SES World Skies (SES [Société Européenne des Satellites (SES)])	Communications	GEO
SES-6	6/3/2013	SES World Skies (SES [Société Européenne des Satellites (SES)])	Communications	GEO
SES-7 (Protostar 2, Indostar 2)	5/16/2009	SES World Skies (SES [Société Européenne des Satellites (SES)])	Communications	GEO
SES-8	12/3/2013	SES World Skies (SES [Société Européenne des Satellites (SES)])	Communications	GEO
Sirius FM-5	6/30/2009	Sirius XM Radio, Inc.	Communications	GEO
Sirius FM-6	10/25/2013	Sirius XM Radio, Inc.	Communications	GEO
Sirius XM-5	10/14/2010	Sirius XM Radio, Inc.	Communications	GEO
SkyTerra 1	11/14/2010	LightSquared	Communications	GEO
Spaceway 3	8/14/2007	Hughes Network Systems	Communications	GEO
Spaceway F1	4/26/2005	DirecTV, Inc.	Communications	GEO
Spaceway F2	11/16/2005	DirecTV, Inc.	Communications	GEO
TerraStar 1	7/1/2009	TerraStar Corporation	Communications	GEO
ViaSat-1	10/19/2011	ViaSat, Inc.	Communications	GEO

Satellite	Launch Date	Owner	Purpose	Orbit
COMMERCIAL (CONT.)				
WildBlue 1	12/8/2006	WildBlue Communications	Communications	GEO
XM Radio 3 (Rhythm)	3/1/2005	XM Satellite Radio USA	Communications	GEO
XM Radio 4 (Blues)	10/30/2006	XM Satellite Radio USA	Communications	GEO
XM Rock (XM 2)	3/18/2001	XM Satellite Radio USA	Communications	GEO
XM Roll (XM 1)	5/8/2001	XM Satellite Radio USA	Communications	GEO
AprizeSat 3	7/29/2009	Aprize Satellite/Latin Trade Satellite	Communications/ Maritime Tracking	LEO
AprizeSat 4	7/29/2009	Aprize Satellite/Latin Trade Satellite	Communications/ Maritime Tracking	LEO
AprizeSat 5	8/17/2011	Aprize Satellite/Latin Trade Satellite	Communications /Maritime Tracking	LEO
AprizeSat 6	8/17/2011	Aprize Satellite/Latin Trade Satellite	Communications/ Maritime Tracking	LEO
AprizeSat 7	11/21/2013	Aprize Satellite/Latin Trade Satellite	Communications/ Maritime Tracking	LEO
AprizeSat 8	11/21/2013	Aprize Satellite/Latin Trade Satellite	Communications/ Maritime Tracking	LEO
Aerocube 4.5A	9/13/2012	Aerospace Corporation	Technology Development	LEO
Aerocube 4.5B	9/13/2012	Aerospace Corporation	Technology Development	LEO
Aerocube 5A	12/6/2013	Aerospace Corporation	Technology Development	LEO
Aerocube 5B	12/6/2013	Aerospace Corporation	Technology Development	LEO
Ardusat-1	11/19/2013	NanoSatisfi Inc.	Technology Development	LEO
Dove-2	4/19/2013	Planet Labs, Inc.	Technology Development	LEO
Dove-3	11/21/2013	Planet Labs, Inc.	Technology Development	LEO
Dove-4	11/21/2013	Planet Labs, Inc.	Technology Development	LEO
Genesis-1	7/12/2006	Bigelow Aerospace	Technology Development	LEO
Genesis-2	6/28/2007	Bigelow Aerospace	Technology Development	LEO
Globalstar M004 (Globalstar 4)	2/14/1998	Globalstar	Communications	LEO
Globalstar M006 (Globalstar 6)	4/24/1998	Globalstar	Communications	LEO
Globalstar M023 (Globalstar 9)	2/9/1999	Globalstar	Communications	LEO
Globalstar M025 (Globalstar 21)	6/10/1999	Globalstar	Communications	LEO
Globalstar M027 (Globalstar 34)	8/17/1999	Globalstar	Communications	LEO
Globalstar M028 (Globalstar 30)	7/25/1999	Globalstar	Communications	LEO
Globalstar M029 (Globalstar 47)	11/22/1999	Globalstar	Communications	LEO
Globalstar M031 (Globalstar 44)	10/18/1999	Globalstar	Communications	LEO
Globalstar M037 (Globalstar 16)	3/15/1999	Globalstar	Communications	LEO
Globalstar M039 (Globalstar 45)	11/22/1999	Globalstar	Communications	LEO
Globalstar M040 (Globalstar 10)	2/9/1999	Globalstar	Communications	LEO
Globalstar M047 (Globalstar 23)	6/10/1999	Globalstar	Communications	LEO
Globalstar M056 (Globalstar 43)	10/18/1999	Globalstar	Communications	LEO
Globalstar M059 (Globalstar 42)	10/18/1999	Globalstar	Communications	LEO
Globalstar M063 (Globalstar 49)	2/8/2000	Globalstar	Communications	LEO
Globalstar M065 (Globalstar 65)	5/29/2007	Globalstar	Communications	LEO
Globalstar M066 (Globalstar 66)	10/20/2007	Globalstar	Communications	LEO
Globalstar M067 (Globalstar 67)	10/20/2007	Globalstar	Communications	LEO
Globalstar M068 (Globalstar 68)	10/20/2007	Globalstar	Communications	LEO
Globalstar M069 (Globalstar 69)	5/29/2007	Globalstar	Communications	LEO
Globalstar M070 (Globalstar 70)	10/20/2007	Globalstar	Communications	LEO
Globalstar M071 (Globalstar 71)	5/29/2007	Globalstar	Communications	LEO

Satellite	Launch Date	Owner	Purpose	Orbit
COMMERCIAL (CONT.)				
Globalstar M072 (Globalstar 72)	5/29/2007	Globalstar	Communications	LEO
Globalstar M073 (Globalstar 73, Globalstar 2-6)	10/19/2010	Globalstar	Communications	LEO
Globalstar M074 (Globalstar 74, Globalstar 2-2)	10/19/2010	Globalstar	Communications	LEO
Globalstar M075 (Globalstar 75, Globalstar 2-5)	10/19/2010	Globalstar	Communications	LEO
Globalstar M076 (Globalstar 76, Globalstar 2-3)	10/19/2010	Globalstar	Communications	LEO
Globalstar M077 (Globalstar 77, Globalstar 2-4)	10/19/2010	Globalstar	Communications	LEO
Globalstar M078 (Globalstar 95, Globalstar 2-23)	2/6/2013	Globalstar	Communications	LEO
Globalstar M079 (Globalstar 79, Globalstar 2-1)	10/19/2010	Globalstar	Communications	LEO
Globalstar M080 (Globalstar 80, Globalstar 2-14)	12/28/2011	Globalstar	Communications	LEO
Globalstar M081 (Globalstar 81, Globalstar 2-11)	7/13/2011	Globalstar	Communications	LEO
Globalstar M082 (Globalstar 82, Globalstar 2-15)	12/28/2011	Globalstar	Communications	LEO
Globalstar M083 (Globalstar 83, Globalstar 2-7)	7/13/2011	Globalstar	Communications	LEO
Globalstar M084 (Globalstar 84, Globalstar 2-13)	12/28/2011	Globalstar	Communications	LEO
Globalstar M085 (Globalstar 85, Globalstar 2-10)	7/13/2011	Globalstar	Communications	LEO
Globalstar M086 (Globalstar 86, Globalstar 2-18)	12/28/2011	Globalstar	Communications	LEO
Globalstar M088 (Globalstar 88, Globalstar 2-8)	7/13/2011	Globalstar	Communications	LEO
Globalstar M089 (Globalstar 89, Globalstar 2-12)	7/13/2011	Globalstar	Communications	LEO
Globalstar M090 (Globalstar 90, Globalstar 2-17)	12/28/2011	Globalstar	Communications	LEO
Globalstar M091 (Globalstar 91, Globalstar 2-9)	7/13/2011	Globalstar	Communications	LEO
Globalstar M092 (Globalstar 92, Globalstar 2-16)	12/28/2011	Globalstar	Communications	LEO
Globalstar M093 (Globalstar 87, Globalstar 2-20)	2/6/2013	Globalstar	Communications	LEO
Globalstar M094 (Globalstar 93, Globalstar 2-21)	2/6/2013	Globalstar	Communications	LEO
Globalstar M095 (Globalstar 96, Globalstar 2-24)	2/6/2013	Globalstar	Communications	LEO
Globalstar M096 (Globalstar 94, Globalstar 2-22)	2/6/2013	Globalstar	Communications	LEO
Globalstar M097 (Globalstar 78, Globalstar 2-19)	2/6/2013	Globalstar	Communications	LEO
Ikonos-2	9/24/1999	GeoEye	Remote Sensing	LEO
ORBCOMM FM-10 (ORBCOMM A2)	12/23/1997	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-11 (ORBCOMM A3)	12/23/1997	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-12 (ORBCOMM A4)	12/23/1997	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-13 (ORBCOMM B1)	8/2/1998	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-14 (ORBCOMM B2)	8/2/1998	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-15 (ORBCOMM B3)	8/2/1998	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-16 (ORBCOMM B4)	8/2/1998	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-18 (ORBCOMM B6)	8/2/1998	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-19 (ORBCOMM B7)	8/2/1998	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-20 (ORBCOMM B8)	8/2/1998	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-22 (ORBCOMM C2)	9/23/1998	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-23 (ORBCOMM C3)	9/23/1998	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-25 (ORBCOMM C5)	9/23/1998	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-27 (ORBCOMM C7)	9/23/1998	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-30 (ORBCOMM D2)	12/4/1999	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-31 (ORBCOMM D3)	12/4/1999	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-32 (ORBCOMM D4)	12/4/1999	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-34 (ORBCOMM D6)	12/4/1999	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-35 (ORBCOMM D7)	12/4/1999	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-36 (ORBCOMM D8)	12/4/1999	ORBCOMM Inc.	Communications	LEO

Satellite	Launch Date	Owner	Purpose	Orbit
COMMERCIAL (CONT.)				
ORBCOMM FM-4 (ORBCOM G2)	2/10/1998	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-5 (ORBCOMM A6)	12/23/1997	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-6 (ORBCOMM A7)	12/23/1997	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-7 (ORBCOMM A8)	12/23/1997	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-8 (ORBCOMM A1)	12/23/1997	ORBCOMM Inc.	Communications	LEO
ORBCOMM FM-9 (ORBCOMM A5)	12/23/1997	ORBCOMM Inc.	Communications	LEO
Quickbird 2	10/18/2001	DigitalGlobe Corporation	Earth Observation	LEO
SkySat-1	11/21/2013	Skybox Imaging	Remote Sensing	LEO
Vesselsat-1	10/12/2011	ORBCOMM Inc.	Communications/ Maritime Tracking	LEO
Vesselsat-2	1/9/2012	ORBCOMM Inc.	Communications/ Maritime Tracking	LEO
COMMERCIAL/GOVERNMENT				
GeoEye-1 (Orbview 5)	9/6/2008	GeoEye	Remote Sensing	LEO
GOVERNMENT				
Chandra X-Ray Observatory (CXO)	7/23/1999	NASA Goddard Space Flight Center	Astrophysics	Elliptical
Interstellar Boundary EXplorer (IBEX)	10/19/2008	NASA/Goddard Space Flight Center	Space Physics	Elliptical
Van Allen Probe A (RBSP-A, Radiation Belt Storm Probes)	8/30/2012	NASA/Johns Hopkins University Applied Physics Laboratory	Earth Science	Elliptical
Van Allen Probe B (RBSP-B, Radiation Belt Storm Probes)	8/30/2012	NASA/Johns Hopkins University Applied Physics Laboratory	Earth Science	Elliptical
GOES 13 (Geostationary Operational Environmental Satellite, GOES-N)	5/24/2006	NOAA (National Oceanographic and Atmospheric Administration)	Earth Science/ Meteorology	GEO
GOES 14 (Geostationary Operational Environmental Satellite, GOES-O)	6/27/2009	NOAA (National Oceanographic and Atmospheric Administration)	Earth Science/ Meteorology	GEO
GOES 15 (Geostationary Operational Ennvironmental Satellite, GOES-P)	3/4/2010	NOAA (National Oceanographic and Atmospheric Administration)	Earth Science/ Meteorology	GEO
SDO (Solar Dynamics Observatory)	2/11/2010	National Aeronautics and Space Administration (NASA)	Space Science	GEO
TDRS-10 (Tracking and Data Relay Satellite, TDRS-J)	12/4/2002	National Aeronautics and Space Administration (NASA)	Communications	GEO
TDRS-11 (Tracking and Data Relay Satellite, TDRS K)	1/31/2013	National Aeronautics and Space Administration (NASA)/Goddard Space Flight Center	Communications	GEO
TDRS-12 (Tracking and Data Relay Satellite, TDRS L)	1/23/2014	National Aeronautics and Space Administration (NASA)	Communications	GEO
TDRS-3 (Tracking and Data Relay Satellite, TDRS-C)	9/29/1988	National Aeronautics and Space Administration (NASA)	Communications	GEO
TDRS-7 (Tracking and Data Relay Satellite, TDRS-G)	7/13/1995	National Aeronautics and Space Administration (NASA)	Communications	GEO

Satellite	Launch Date	Owner	Purpose	Orbit
GOVERNMENT (CONT.)				
TDRS-8 (Tracking and Data Relay Satellite, TDRS-H)	6/30/2000	National Aeronautics and Space Administration (NASA)	Communications	GEO
TDRS-9 (Tracking and Data Relay Satellite, TDRS-I)	3/8/2002	National Aeronautics and Space Administration (NASA)	Communications	GEO
EOS-PM Aqua (Advanced Microwave Scanning Radiometer for EOS, EOS PM-1)	5/4/2002	NASA - Earth Science Enterprise/Japan Meteorological Agency/Brazilian Space Agency	Earth Observation	LEO
Global Change Observation Mission - 1 Water (GCOM-1, Shikuzu)	5/17/2012	Japan Aerospace Exploration Agency (JAXA)	Earth Science	LEO
Jason 2	6/20/2008	NASA/Centre National d'Etudes Spatiales (CNES)/NOAA/EUMETSAT	Earth Science	LEO
EOS-AM Terra	12/18/1999	Earth Sciences Enterprise (NASA)	Earth Science	LEO
AcrimSat (Active Cavity Radiometer Irradiance Monitor)	12/21/1999	NASA Goddard Space Flight Center, Jet Propulsion Laboratory	Solar Physics	LEO
Aeneas	9/13/2012	Department of Homeland Security	Technology Development	LEO
AIM (Aeronomy of Ice in Mesosphere)	4/25/2007	Center for Atmospheric Sciences, Hampton University/NASA	Earth Science	LEO
CFESat (Cibola Flight Experiment Satellite)	3/9/2007	Los Alamos National Labs (LANL)	Technology Development	LEO
EO-1 (Earth Observing 1)	11/21/2000	NASA Earth Science Office	Earth Observation/ Research	LEO
EOS-CHEM Aura	7/15/2004	Goddard Space Flight Center/EOS Data and Operations System	Remote Sensing	LEO
Fermi Gamma-Ray Space Telescope (formerly GLAST)	6/11/2008	NASA/GSFC	Astrophysics	LEO
FORTÉ (Fast On-orbit Recording of Transient Events)	8/29/1997	Los Alamos National Labs/DOE	Earth Observation	LEO
IPEX (Intelligent Payload Experiment, CalPoly 8)	12/6/2013	NASA/Goddard Space Flight Center	Technology Development	LEO
IRIS (Interface Region Imaging Spectrometer)	6/28/2013	National Aeronautics and Space Administration (NASA)	Space Science	LEO
Landsat 7	4/15/1999	NASA/US Geological Survey	Earth Science	LEO
Landsat 8	2/11/2013	NASA/US Geological Survey	Earth Science	LEO
NOAA-15 (NOAA-K)	5/13/1998	National Oceanographic and Atmospheric Administration (NOAA) (part of international program)	Earth Science/ Meteorology	LEO
NOAA-16 (NOAA-L)	9/21/2000	National Oceanographic and Atmospheric Administration (NOAA) (part of international program)	Earth Science/ Meteorology	LEO
NOAA-18 (NOAA-N, COSPAS-SARSAT)	5/20/2005	National Oceanographic and Atmospheric Administration (NOAA) (part of international program)	Meteorology	LEO
NOAA-19 (NOAA-N Prime, COSPAS-SARSAT)	2/6/2009	National Oceanographic and Atmospheric Administration (NOAA) (part of international program)	Meteorology	LEO

Satellite	Launch Date	Owner	Purpose	Orbit
GOVERNMENT (CONT.)				
NPP (National Polar-orbiting Operational Environmental Satellite System [NPOESS])	10/28/2011	National Oceanographic and Atmospheric Administration (NOAA)/NASA	Meteorology	LEO
NuSTAR (Nuclear Spectroscopic Telescope Array)	6/13/2012	National Aeronautics and Space Administration (NASA)	Space Science	LEO
PCSat (Prototype Communications SATellite, Navy-Oscar 44, NO-44)	9/30/2001	US Naval Academy	Technology Development/ Communications	LEO
Phonesat 2.4	11/19/2013	National Aeronautics and Space Administration (NASA)	Technology Development	LEO
NPS-SCAT (Naval Post-graduate School - Solar Cell Array Tester)	11/19/2013	Naval Post-Graduate School	Technology Development	LEO
GOVERNMENT/CIVIL				
Swift	11/20/2004	Goddard Space Flight Center/Penn State University	Astrophysics	LEO
Cloudsat	4/28/2006	NASA/Colorado State University	Earth Science	LEO
Firefly	11/19/2013	NASA/Sienna College/Univ. of Maryland	Earth Science	LEO
HESSI (RHESSI, Reuven Ramaty High Energy Solar Spectroscopic Imager)	2/5/2002	Space Sciences Laboratory, UC Berkeley/NASA	Astrophysics	LEO
SORCE (SOlar Radiation and Climate Experiment)	1/25/2003	NASA Earth Science Office/Laboratory for Atmospheric and Space Physics, Univ. of Colorado	Astrophysics	LEO
TIMED (Thermosphere • Ionosphere • Mesosphere • Energetics and Dynamics)	12/7/2001	NASA/Applied Physics Laboratory, Johns Hopkins	Astrophysics	LEO
GOVERNMENT/COMMERCIAL				
TDRS-5 (Tracking and Data Relay Satellite, TDRS-E)	8/2/1991	SES Americom (SES [Société Européenne des Satellites (SES)])	Communications	GEO
TDRS-6 (Tracking and Data Relay Satellite, TDRS-F)	1/13/1993	NASA/SES Americom (SES [Société Européenne des Satellites (SES)])	Communications	GEO
Iridium 10 (Iridium SV010)	6/18/1997	Iridium Satellite LLC	Communications	LEO
Iridium 11A (Iridium SVO88)	12/19/1998	Iridium Satellite LLC	Communications	LEO
Iridium 12 (Iridium SV012)	6/18/1997	Iridium Satellite LLC	Communications	LEO
Iridium 13 (Iridium SV013)	6/18/1997	Iridium Satellite LLC	Communications	LEO
Iridium 14A (Iridium SV092)	6/11/1999	Iridium Satellite LLC	Communications	LEO
Iridium 15 (Iridium SV015)	7/9/1997	Iridium Satellite LLC	Communications	LEO
Iridium 18 (Iridium SV018)	7/9/1997	Iridium Satellite LLC	Communications	LEO
Iridium 19 (Iridium SV019)	9/27/1997	Iridium Satellite LLC	Communications	LEO
Iridium 20A (Iridium SV089)	12/19/1998	Iridium Satellite LLC	Communications	LEO
Iridium 21A (Iridium SVO93)	6/11/1999	Iridium Satellite LLC	Communications	LEO
Iridium 22 (Iridium SV022)	8/21/1997	Iridium Satellite LLC	Communications	LEO
Iridium 23 (Iridium SV023)	8/21/1997	Iridium Satellite LLC	Communications	LEO
Iridium 25 (Iridium SV025)	8/21/1997	Iridium Satellite LLC	Communications	LEO
Iridium 29 (Iridium SV029)	9/14/1997	Iridium Satellite LLC	Communications	LEO
Iridium 3 (Iridium SV078)	8/19/1998	Iridium Satellite LLC	Communications	LEO
Iridium 30 (Iridium SV030)	9/14/1997	Iridium Satellite LLC	Communications	LEO
Iridium 31 (Iridium SVO31)	9/14/1997	Iridium Satellite LLC	Communications	LEO
Iridium 32 (Iridium SV032)	9/14/1997	Iridium Satellite LLC	Communications	LEO

Satellite	Launch Date	Owner	Purpose	Orbit
GOVERNMENT/COMMERCIAL (CONT.)				
Iridium 34 (Iridium SV034)	9/27/1997	Iridium Satellite LLC	Communications	LEO
Iridium 35 (Iridium SV035)	9/27/1997	Iridium Satellite LLC	Communications	LEO
Iridium 37 (Iridium SV037)	9/27/1997	Iridium Satellite LLC	Communications	LEO
Iridium 39 (Iridium SV039)	11/9/1997	Iridium Satellite LLC	Communications	LEO
Iridium 40 (Iridium SV040)	11/9/1997	Iridium Satellite LLC	Communications	LEO
Iridium 41 (Iridium SV041)	11/9/1997	Iridium Satellite LLC	Communications	LEO
Iridium 42 (Iridium SV042)	12/8/1997	Iridium Satellite LLC	Communications	LEO
Iridium 43 (Iridium SV043)	11/9/1997	Iridium Satellite LLC	Communications	LEO
Iridium 45 (Iridium SV045)	12/20/1997	Iridium Satellite LLC	Communications	LEO
Iridium 47 (Iridium SV047)	12/20/1997	Iridium Satellite LLC	Communications	LEO
Iridium 49 (Iridium SV049)	12/20/1997	Iridium Satellite LLC	Communications	LEO
Iridium 5 (Iridium SV005)	5/5/1997	Iridium Satellite LLC	Communications	LEO
Iridium 50 (Iridium SV050)	2/18/1998	Iridium Satellite LLC	Communications	LEO
Iridium 51 (Iridium SV 051)	3/25/1998	Iridium Satellite LLC	Communications	LEO
Iridium 52 (Iridium SV052)	2/18/1998	Iridium Satellite LLC	Communications	LEO
Iridium 53 (Iridium SV053)	2/18/1998	Iridium Satellite LLC	Communications	LEO
Iridium 54 (Iridium SV054)	2/18/1998	Iridium Satellite LLC	Communications	LEO
Iridium 55 (Iridium SV055)	3/30/1998	Iridium Satellite LLC	Communications	LEO
Iridium 56 (Iridium SV056)	2/18/1998	Iridium Satellite LLC	Communications	LEO
Iridium 57 (Iridium SV057)	3/30/1998	Iridium Satellite LLC	Communications	LEO
Iridium 58 (Iridium SV058)	3/30/1998	Iridium Satellite LLC	Communications	LEO
Iridium 59 (Iridium SV059)	3/30/1998	Iridium Satellite LLC	Communications	LEO
Iridium 6 (Iridium SV006)	5/6/1997	Iridium Satellite LLC	Communications	LEO
Iridium 60 (Iridium SV060)	3/30/1998	Iridium Satellite LLC	Communications	LEO
Iridium 61 (Iridium SV061)	3/25/1998	Iridium Satellite LLC	Communications	LEO
Iridium 62 (Iridium SV062)	4/7/1998	Iridium Satellite LLC	Communications	LEO
Iridium 63 (Iridium SV063)	4/7/1998	Iridium Satellite LLC	Communications	LEO
Iridium 64 (Iridium SV064)	4/7/1998	Iridium Satellite LLC	Communications	LEO
Iridium 65 (Iridium SV065)	4/7/1998	Iridium Satellite LLC	Communications	LEO
Iridium 66 (Iridium SV066)	4/7/1998	Iridium Satellite LLC	Communications	LEO
Iridium 67 (Iridium SV067)	4/7/1998	Iridium Satellite LLC	Communications	LEO
Iridium 68 (Iridium SV068)	4/7/1998	Iridium Satellite LLC	Communications	LEO
Iridium 7 (Iridium SV007)	5/5/1997	Iridium Satellite LLC	Communications	LEO
Iridium 70 (Iridium SV070)	5/17/1998	Iridium Satellite LLC	Communications	LEO
Iridium 72 (Iridium SV072)	5/17/1998	Iridium Satellite LLC	Communications	LEO
Iridium 74 (Iridium SV074)	5/17/1998	Iridium Satellite LLC	Communications	LEO
Iridium 75 (Iridium SV075)	5/17/1998	Iridium Satellite LLC	Communications	LEO
Iridium 76 (Iridium SV076)	8/19/1998	Iridium Satellite LLC	Communications	LEO
Iridium 77 (Iridium SV077)	9/8/1998	Iridium Satellite LLC	Communications	LEO
Iridium 8 (Iridium SV008)	5/5/1997	Iridium Satellite LLC	Communications	LEO
Iridium 80 (Iridium SV080)	9/8/1998	Iridium Satellite LLC	Communications	LEO
Iridium 81 (Iridium SV081)	9/8/1998	Iridium Satellite LLC	Communications	LEO
Iridium 82 (Iridium SV082)	9/8/1998	Iridium Satellite LLC	Communications	LEO
Iridium 83 (Iridium SV083)	11/6/1998	Iridium Satellite LLC	Communications	LEO
Iridium 84 (Iridium SV084)	11/6/1998	Iridium Satellite LLC	Communications	LEO
Iridium 86 (Iridium SV086)	11/6/1998	Iridium Satellite LLC	Communications	LEO

Satellite	Launch Date	Owner	Purpose	Orbit
GOVERNMENT/COMMERCIAL (CONT.)				
Iridium 90 (Iridium SV090)	2/11/2002	Iridium Satellite LLC	Communications	LEO
Iridium 91 (Iridium SV091)	2/11/2002	Iridium Satellite LLC	Communications	LEO
Iridium 94 (Iridium SV094)	2/11/2002	Iridium Satellite LLC	Communications	LEO
Iridium 95 (Iridium SV095)	2/11/2002	Iridium Satellite LLC	Communications	LEO
Iridium 96 (Iridium SV096)	2/11/2002	Iridium Satellite LLC	Communications	LEO
Iridium 97 (Iridium SV097)	6/20/2002	Iridium Satellite LLC	Communications	LEO
Iridium 98 (Iridium SV098)	6/20/2002	Iridium Satellite LLC	Communications	LEO
GOVERNMENT/MILITARY				
MTI (Multispectral Thermal Imager)	3/12/2000	US Department of Energy/Office of Nonproliferation and National Security	Technology Development	LEO
MILITARY				
Improved Trumpet 4 (NROL-22, National Reconnaissance Office Launch-22, SBIRS HEO-1, Twins 1, USA 184)	6/28/2006	National Reconnaissance Office (NRO)	Electronic Surveillance	Elliptical
Improved Trumpet 5 (NROL-28, National Reconnaissance Office Launch-28, SBIRS HEO-2, Twins 2, USA 200)	3/13/2008	National Reconnaissance Office (NRO)	Electronic Surveillance	Elliptical
SDS III-4 (Satellite Data System) (NRO L-1, Nemesis, USA 179)	8/31/2004	National Reconnaissance Office (NRO)/US Air Force	Communications	Elliptical
SDS III-5 (Satellite Data System) (NRO L-24, Scorpius, USA 198)	12/10/2007	National Reconnaissance Office (NRO)/US Air Force	Communications	Elliptical
SLDCOM-3 (Satellite Launch Dispenser Communications System) (USA 119)	5/12/1996	National Reconnaissance Office (NRO)	Communications	Elliptical
TacSat 4	9/27/2011	Naval Research Laboratory	Technology Development	Elliptical
Trumpet 3 (NROL-4, National Reconnaissance Office Launch-4, USA 136)	11/8/1997	National Reconnaissance Office (NRO)/USAF	Electronic Surveillance	Elliptical
Leasat 5 (Syncom IV-5, Leased Satellite F5)	1/9/1990	US DoD/Royal Australian Navy/Panamsat (owner)	Communications	GEO
Advanced Orion 2 (NROL 6, USA 139)	5/9/1998	National Reconnaissance Office (NRO)	Electronic Surveillance	GEO
Advanced Orion 3 (NROL 19, USA 171)	9/9/2003	National Reconnaissance Office (NRO)	Electronic Surveillance	GEO
Advanced Orion 4 (NRO L-26, USA 202)	1/18/2009	National Reconnaissance Office (NRO)	Electronic Surveillance	GEO
Advanced Orion 5 (NRO L-32, USA 223)	11/21/2010	National Reconnaissance Office (NRO)	Electronic Surveillance	GEO
Advanced Orion 6 (NRO L-15, USA 237)	6/29/2012	National Reconnaissance Office (NRO)	Electronic Surveillance	GEO
AEHF-1 (Advanced Extremely High Frequency satellite-1, USA 214)	8/14/2010	US Air Force	Communications	GEO
AEHF-2 (Advanced Extremely High Frequency satellite-2, USA 235)	5/3/2012	US Air Force	Communications	GEO
AEHF-3 (Advanced Extremely High Frequency satellite-3, USA 246)	9/18/2013	US Air Force	Communications	GEO
DSCS III-A3 (USA 167, DSCS III-A3) (Defense Satellite Communications System)	3/11/2003	US Air Force	Communications	GEO
DSCS III-B6 (USA 170, DSCS III B-6) (Defense Satellite Communications System)	8/29/2003	US Air Force	Communications	GEO
DSCS III-F10 (USA 135, DSCS III B-13) (Defense Satellite Communications System)	10/24/1997	US Air Force	Communications	GEO
DSCS III-F11 (USA 148, DSCS III B-8) (Defense Satellite Communications System)	1/1/2000	US Air Force	Communications	GEO
DSCS III-F12 (USA 153, DSCS III B-11) (Defense Satellite Communications System)	10/20/2000	US Air Force	Communications	GEO
DSCS III-F6 (USA 82, DSCS III B-12) (Defense Satellite Communications System)	7/2/1992	US Air Force	Communications	GEO
DSCS III-F8 (USA 97, DSCS III B-10) (Defense Satellite Communications System)	11/28/1993	US Air Force	Communications	GEO

Satellite	Launch Date	Owner	Purpose	Orbit
MILITARY (CONT.)				
DSCS III-F9 (USA 113, DSCS III B-7) (Defense Satellite Communications System)	7/31/1995	US Air Force	Communications	GEO
DSP 18 (USA 130) (Defense Support Program)	2/23/1997	Air Force	Early Warning	GEO
DSP 20 (USA 149) (Defense Support Program)	5/18/2000	Air Force	Early Warning	GEO
DSP 21 (USA 159) (Defense Support Program)	8/6/2001	Air Force	Early Warning	GEO
DSP 22 (USA 176) (Defense Support Program)	2/14/2004	Air Force	Early Warning	GEO
FLTSATCOM-8 (USA 46)	9/25/1989	US Navy	Communications	GEO
Mercury 1 (Advanced Vortex 1, USA 105)	8/27/1994	National Reconnaissance Office (NRO)/USAF	Surveillance	GEO
Mercury 2 (Advanced Vortex 2, USA 118)	4/24/1996	National Reconnaissance Office (NRO)/USAF	Surveillance	GEO
Milstar DFS-1 (USA 99, Milstar 1-F1) (Military Strategic and Tactical Relay)	2/7/1994	US Air Force	Communications	GEO
Milstar DFS-2 (USA 115, Milstar 1-F2) (Military Strategic and Tactical Relay)	11/6/1995	US Air Force	Communications	GEO
Milstar DFS-4 (USA 157, Milstar 2-F2) (Military Strategic and Tactical Relay)	2/27/2001	US Air Force	Communications	GEO
Milstar DFS-5 (USA 164, Milstar 2-F3) (Military Strategic and Tactical Relay)	1/16/2002	US Air Force	Communications	GEO
Milstar DFS-6 (USA 169) (Military Strategic and Tactical Relay)	4/8/2003	US Air Force	Communications	GEO
MUOS-1 (Mobile User Objective System 1)	2/24/2012	DoD/US Navy	Communications	GEO
MUOS-2 (Mobile User Objective System 2)	7/19/2013	DoD/US Navy	Communications	GEO
PAN-1 (Palladium at Night, P360, USA 207)	9/8/2009	Unknown US agency	Communications	GEO
SBIRS GEO 1 (Space Based Infrared System Geosynchronous 1, USA 230)	5/7/2011	US Air Force	Early Warning	GEO
SBIRS GEO 2 (Space Based Infrared System Geosynchronous 2, USA 241)	3/19/2013	US Air Force	Early Warning	GEO
SDS III-2 (Satellite Data System) (NRO L-10, Great Bear, USA 155)	12/6/2000	National Reconnaissance Office (NRO)	Electronic Surveillance	GEO
SDS III-3 (Satellite Data System) (NRO L-12, Aquila-1, USA 162)	10/10/2001	National Reconnaissance Office (NRO)/US Air Force	Communications	GEO
SDS III-6 (Satellite Data System) NRO L-27, Gryphon, USA 227)	3/2/2011	National Reconnaissance Office (NRO)/US Air Force	Communications	GEO
SDS III-7 (Satellite Data System) NRO L-38, Drake, USA 236)	6/20/2012	National Reconnaissance Office (NRO)/US Air Force	Electronic Surveillance	GEO
UFO-10 (USA 146, UHF F/O F10) “UHF Follow-On”	11/24/1999	US Navy	Communications	GEO
UFO-11 (USA 174) “UHF Follow-On”	12/18/2003	US Navy	Communications	GEO
UFO-2 (USA 95) “UHF Follow-On”	9/3/1993	US Navy	Communications	GEO
UFO-4 (USA 108, UFO F4 EHF) “UHF Follow-On”	1/29/1995	US Navy	Communications	GEO
UFO-6 (USA 114, UFO F6 EHF) “UHF Follow-On”	10/22/1995	US Navy	Communications	GEO
UFO-7 (USA 127, F7 EHF) “UHF Follow-On”	7/25/1996	US Navy	Communications	GEO
UFO-8 (USA 138, UHF F/O F8) “UHF Follow-On”	3/16/1998	US Navy	Communications	GEO
Wideband Global Satcom 1 (WGS-1, USA 195)	10/11/2007	Military Satellite Communications - US Air Force	Communications	GEO
Wideband Global Satcom 2 (WGS-2, USA 204)	4/4/2009	Military Satellite Communications - US Air Force	Communications	GEO
Wideband Global Satcom 3 (WGS-3, USA 211)	12/6/2009	Military Satellite Communications - US Air Force	Communications	GEO
Wideband Global Satcom 4 (WGS-4, USA 233)	1/20/2012	Military Satellite Communications - US Air Force	Communications	GEO

Satellite	Launch Date	Owner	Purpose	Orbit
MILITARY (CONT.)				
Wideband Global Satcom 5 (WGS-5, USA 243)	5/25/2013	Military Satellite Communications - US Air Force	Communications	GEO
Wideband Global Satcom 6 (WGS-6, USA 244)	8/8/2013	Military Satellite Communications - US Air Force	Communications	GEO
ALiCE (AFIT LEO iMESA CNT E)	12/6/2013	US Air Force Institute of Technology	Technology Development	LEO
C/NOFS (Communication/Navigation Outage Forecasting System)	4/16/2008	US Air Force	Technology Development	LEO
Coriolis (Windsat)	1/6/2003	US Air Force/ US Navy/NASA	Earth and Space Science	LEO
DMSP 5D-2 F13 (Defense Meteorological Satellites Program, USA 109)	3/24/1995	DoD/NOAA	Earth Science/Meteorology	LEO
DMSP 5D-2 F14 (Defense Meteorological Satellites Program, USA 131)	4/4/1997	DoD/NOAA	Earth Science/Meteorology	LEO
DMSP 5D-3 F15 (Defense Meteorological Satellites Program, USA 147)	12/12/1999	DoD/NOAA	Earth Science/Meteorology	LEO
DMSP 5D-3 F16 (Defense Meteorological Satellites Program, USA 172)	10/18/2003	DoD/NOAA	Earth Science/Meteorology	LEO
DMSP 5D-3 F17 (Defense Meteorological Satellites Program, USA 191)	11/4/2006	DoD/NOAA	Earth Science/Meteorology	LEO
DMSP 5D-3 F18 (Defense Meteorological Satellites Program, USA 210)	10/18/2009	DoD/NOAA	Earth Science/Meteorology	LEO
FIA Radar 1 (Future Imagery Architecture (FIA) Radar 1, NROL-41, USA 215, Topaz)	9/21/2010	National Reconnaissance Office (NRO)	Reconnaissance	LEO
FIA Radar 2 (Future Imagery Architecture (FIA) Radar 2, NROL-25, USA 234, Topaz)	4/3/2012	National Reconnaissance Office (NRO)	Reconnaissance	LEO
FIA Radar 3 (Future Imagery Architecture (FIA) Radar 3, NROL-39 , USA 247, Topaz)	12/6/2013	National Reconnaissance Office (NRO)	Reconnaissance	LEO
Keyhole 3 (Advanced KH-11, KH-12-4, Advanced Keyhole, Misty-2, EIS-1, 8X Enhanced Imaging System, USA 144)	5/22/1999	National Reconnaissance Office (NRO)	Reconnaissance	LEO
Keyhole 4 (Advanced KH-11, Advanced Keyhole, Improved Crystal, EIS-2, 8X Enhanced Imaging System, NROL 14, USA 161)	10/5/2001	National Reconnaissance Office (NRO)	Reconnaissance	LEO
Keyhole 5 (Advanced KH-11, KH-12-5, Improved Crystal, EIS-3, USA 186)	10/19/2005	National Reconnaissance Office (NRO)	Reconnaissance	LEO
Keyhole 6 (NRO L49, Advanced KH-11, KH-12-6, Improved Crystal, USA 224)	1/20/2011	National Reconnaissance Office (NRO)	Reconnaissance	LEO
Keyhole 7 (NRO L65, Advanced KH-11, Improved Crystal, USA 245)	8/28/2013	National Reconnaissance Office (NRO)	Reconnaissance	LEO
Lacrosse/Onyx 3 (Lacrosse-3, USA 133)	10/24/1997	National Reconnaissance Office (NRO)	Surveillance	LEO
Lacrosse/Onyx 4 (Lacrosse-4, USA 152)	8/17/2000	National Reconnaissance Office (NRO)	Surveillance	LEO
Lacrosse/Onyx 5 (Lacrosse-5, NROL 16, USA 182)	4/30/2005	National Reconnaissance Office (NRO)	Surveillance	LEO
NFIRE (Near Field InfraRed Experiment)	4/24/2007	Missile Defense Agency	Technology Development	LEO
ORS - Tech 1	11/19/2013	US Army	Technology Development	LEO
ORS - Tech 2	11/19/2013	US Army	Technology Development	LEO
ORS-1 (Operationally Responsive Space One, USA 231)	6/30/2011	U.S. Air Force/ DoD	Reconnaissance	LEO
ORSES (ORS Enabler Satellite)	11/19/2013	US Army	Technology Development	LEO
Prometheus 1A	11/19/2013	Los Alamos National Laboratory	Technology Development	LEO
Prometheus 1B	11/19/2013	Los Alamos National Laboratory	Technology Development	LEO
Prometheus 2A	11/19/2013	Los Alamos National Laboratory	Technology Development	LEO
Prometheus 2B	11/19/2013	Los Alamos National Laboratory	Technology Development	LEO

Satellite	Launch Date	Owner	Purpose	Orbit
MILITARY (CONT.)				
Prometheus 3A	11/19/2013	Los Alamos National Laboratory	Technology Development	LEO
Prometheus 3B	11/19/2013	Los Alamos National Laboratory	Technology Development	LEO
Prometheus 4A	11/19/2013	Los Alamos National Laboratory	Technology Development	LEO
Prometheus 4B	11/19/2013	Los Alamos National Laboratory	Technology Development	LEO
Rapid Pathfinder Program (NROL-66, USA 225)	2/6/2011	National Reconnaissance Office (NRO)	Technology Development	LEO
SBSS-1 (Space Based Space Surveillance Satellite, SBSS Block 10 SV1, USA 216)	9/26/2010	Strategic Space Command/Space Surveillance Network	Reconnaissance	LEO
SB-WASS 3-1 (Space Based Wide Area Surveillance System) (NOSS 3-1, NOSS C1-1, USA 160)	9/8/2001	National Reconnaissance Office/US Navy	Electronic Surveillance/Ocean	LEO
SB-WASS 3-1 (Space Based Wide Area Surveillance System) (NOSS 3-1,USA 160, NOSS C1-2)	9/8/2001	National Reconnaissance Office/US Navy	Electronic Surveillance/Ocean	LEO
SB-WASS 3-2 (Space Based Wide Area Surveillance System) (NOSS 3-2, USA 173, NOSS C2-1)	12/2/2003	National Reconnaissance Office/US Navy	Electronic Surveillance/Ocean	LEO
SB-WASS 3-2 (Space Based Wide Area Surveillance System) (NOSS 3-2, USA 173, NOSS C2-2)	12/2/2003	National Reconnaissance Office/US Navy	Electronic Surveillance/Ocean	LEO
SB-WASS 3-3 (Space Based Wide Area Surveillance System) (NOSS 3-3, USA 181, NRO L23)	2/3/2005	National Reconnaissance Office/US Navy	Electronic Surveillance/Ocean	LEO
SB-WASS 3-3 (Space Based Wide Area Surveillance System) (NOSS 3-3, USA 181, NRO L28)	2/3/2005	National Reconnaissance Office/US Navy	Electronic Surveillance/Ocean	LEO
SB-WASS 3-4 (Space Based Wide Area Surveillance System) NOSS 3-4, USA 194, NRO L30)	6/15/2007	National Reconnaissance Office/US Navy	Electronic Surveillance/Ocean	LEO
SB-WASS 3-4 (Space Based Wide Area Surveillance System) NOSS 3-4, USA 194, NRO L30)	6/15/2007	National Reconnaissance Office/US Navy	Electronic Surveillance/Ocean	LEO
SB-WASS 3-5 (Space Based Wide Area Surveillance System) NOSS 3-5, USA 229, NRO L34)	4/15/2011	National Reconnaissance Office/US Navy	Electronic Surveillance/Ocean	LEO
SB-WASS 3-5 (Space Based Wide Area Surveillance System) NOSS 3-5, USA 229, NRO L34)	4/15/2011	National Reconnaissance Office/US Navy	Electronic Surveillance/Ocean	LEO
SB-WASS 3-6 (Space Based Wide Area Surveillance System) NOSS 3-6, USA 238, NRO L36)	9/13/2012	National Reconnaissance Office/US Navy	Electronic Surveillance/Ocean	LEO
SB-WASS 3-6 (Space Based Wide Area Surveillance System) NOSS 3-6, USA 238, NRO L36)	9/13/2012	National Reconnaissance Office/US Navy	Electronic Surveillance/Ocean	LEO
SMDC-ONE 1.1 (Techsat)	9/13/2012	U.S.Army Space and Missile Defense Command	Technology Development	LEO
SMDC-ONE 1.2 (ORSES [Operationally Responsive Space Enabler Satellite])	9/13/2012	U.S. Army Space and Missile Defense Command	Technology Development	LEO
SMDC-ONE 2.3	12/6/2013	U.S. Army Space and Missile Defense Command	Technology Development	LEO
SMDC-ONE 2.4	12/6/2013	U.S. Army Space and Missile Defense Command	Technology Development	LEO
SNaP-3-1 (Space and Missile Defense Command NanoSat Program)	12/6/2013	U.S. Southern Command	Communications	LEO
STARE-B (Horus [Space-Based Telescopes for Actionable Refinement of Ephemeris])	11/19/2013	National Reconaissance Office	Remote Sensing	LEO
STPSat-2 (USA 217)	11/20/2010	USAF Space Test Program	Technology Development	LEO
STPSat-3 (Space Test Program Satellite-3)	11/19/2013	US Air Force	Technology Development	LEO
STSS ATRR (Space Tracking and Surveillance System Advanced Technology Risk Reduction Satellite, USA 205)	5/5/2009	Missile Defense Agency (MDA)	Technology Development	LEO
STSS Demo-1 (Space Tracking and Surveillance System Demonstrator)	9/25/2009	Missile Defense Agency (MDA)	Technology Development	LEO
STSS Demo-2 (Space Tracking and Surveillance System Demonstrator)	9/25/2009	Missile Defense Agency (MDA)	Technology Development	LEO
TacSat 6		Operational Responsive Space (ORS) Office	Technology Development	LEO
X37-B OTV-1 (USA 240)	12/11/2012	US Air Force	Technology Development	LEO

Satellite	Launch Date	Owner	Purpose	Orbit
MILITARY/COMMERCIAL				
Worldview 1	9/18/2007	DigitalGlobe Corporation	Earth Observation	LEO
Worldview 2	10/8/2009	DigitalGlobe Corporation	Earth Observation	LEO
Navstar GPS II-10 (Navstar SVN 23, PRN 32, USA 66)	11/26/1990	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS II-14 (Navstar SVN 26, PRN 26, USA 83)	7/7/1992	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS II-21 (Navstar SVN 39, PRN 09, USA 92)	6/26/1993	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS II-23 (Navstar SVN 34, PRN 04, USA 96)	10/26/1993	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS II-24 (Navstar SVN 36, PRN 06, USA 100)	3/10/1994	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS II-25 (Navstar SVN 33, PRN 03, USA 117)	3/28/1996	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS II-26 (Navstar SVN 40, PRN 10, USA 126)	7/16/1996	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS II-28 (Navstar SVN 38, PRN 08, USA 135)	11/6/1997	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS II-35 (Navstar SVN 35, PRN 30, USA 94)	8/30/1993	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIF-1 (Navstar SVN 62, PRN 25, USA 213)	5/28/2010	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIF-2 (Navstar SVN 63, PRN 01, USA 232)	7/16/2011	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIF-3 (Navstar SVN 65, USA 239)	10/4/2012	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIF-4 (Navstar SVN 66, USA 242)	5/15/2013	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIR-10 (Navstar SVN 47, PRN 22, USA 175)	12/21/2003	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIR-11 (Navstar SVN 59, PRN 19, USA 177)	3/20/2004	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIR-12 (Navstar SVN 60, PRN 23, USA 178)	6/23/2004	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIR-13 (Navstar SVN 61, PRN 02, USA 180)	11/6/2004	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIR-2 (Navstar SVN 43, PRN 13, USA 132)	7/23/1997	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIR-3 (Navstar SVN 46, PRN 11, USA 145)	10/7/1999	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIR-4 (Navstar SVN 51, PRN 20, USA 150)	5/11/2000	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIR-5 (Navstar SVN 44, PRN 28, USA 151)	7/16/2000	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIR-6 (Navstar SVN 41, PRN 14, USA 154)	11/10/2000	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIR-7 (Navstar SVN 54, PRN 18, USA 156)	1/30/2001	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIR-8 (Navstar SVN 56, PRN 16, USA 166)	1/29/2003	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIR-9 (Navstar SVN 45, PRN 21, USA 168)	3/31/2003	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIR-M-1 (Navstar SVN 53, PRN 17, USA 183)	9/26/2005	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIR-M-2 (Navstar SVN 52, PRN 31, USA 190)	9/25/2006	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIR-M-3 (Navstar SVN 58, PRN 12, USA 192)	11/17/2006	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIR-M-4 (Navstar SVN 55, PRN 15, USA 196)	10/17/2007	DoD/US Air Force	Navigation/Global Positioning	MEO

Satellite	Launch Date	Owner	Purpose	Orbit
MILITARY/COMMERCIAL (CONT.)				
Navstar GPS IIR-M-5 (Navstar SVN 57, PRN 29, USA 199)	12/20/2007	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIR-M-6 (Navstar SVN 48, PRN 07, USA 201)	3/15/2008	DoD/US Air Force	Navigation/Global Positioning	MEO
Navstar GPS IIR-M-8 (Navstar SVN 50, PRN 05, USA 206)	8/17/2009	DoD/US Air Force	Navigation/Global Positioning	MEO

Source: Data from Union of Concerned Scientists database, updated January 31, 2014, http://www.ucsusa.org/nuclear_weapons_and_global_security/solutions/space-weapons/ucs-satellite-database.html#.VHUDZU3Qe74.