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MICROSATELLITES

A BELLWETHER OF CHINESE AEROSPACE PROGRESS?

ANDREW S. ERICKSON

Central to China's rise in space—no less important than its becoming the third nation to test an anti-satellite weapon (on January 11, 2007) and the third to orbit an astronaut (on October 15, 2003)—is its rapid development of microsatellites. Microsatellites (weighing 10 to 100 kg, or far less than the average satellite) are believed by both Western and Chinese analysts to represent the key to improving space capabilities by lowering the cost of establishing a robust presence in space with built-in redundancy to ensure system continuity. They do so by enabling mass production and modularization, and through their flexible use in multisatellite constellations for applications such as communications. For these reasons, microsatellites will be the focus of this chapter. To be sure, microsatellites cannot be separated entirely from their larger counterparts in function and significance. This chapter will consider small satellites (those weighing up to 500 kg) and their microsatellite "cousins" (which weigh less than 100 kg). The development of small-satellite technologies played a role in the cultivation of microsatellites somewhat later. Satellites weighing more than 500 kg, such as the 2,200 kg Beidou navigation satellites, are beyond the scope of this study.

China's increasingly sophisticated microsatellites are a vital element of Beijing's overall aerospace development, but to what end? Small/microsatellite production offers Beijing three major benefits: support for national development, lucrative and geostrategically relevant foreign sales, and potential military space control applications. The first two benefits have provided a major motivation for Chinese microsatellite development thus far, and may well be the most important current benefit. In foreign sales, for example, Chinese satellites (albeit of larger ones, thus far), components, and

Table 14.1 Chinese Satellite Categories

Type	Weight Range	Chinese Name	Pronunciation
large satellite	>=500 kg	大卫星	dàwèixīng
small satellite	<500 kg	小卫星	xiǎowèixīng
minisatellite	10–200 kg	微小卫星	wéixiǎowèixīng
microsatellite	10–100 kg	微型卫星	wéixíngwèixīng
nano-satellite	<110 kg	纳卫星	nàwèixīng
pico-satellite	<1 kg	皮卫星	píwèixīng
femto-satellite	<0.1 kg	飞卫星	fēiwèixīng
LightSat	DARPA blanket designation for small satellites	轻卫星	qīngwèixīng

launch and training services have performed relatively well by giving developing nations otherwise unaffordable access to space.

China today has only a fraction of the overall space capability of the United States, has major gaps in coverage in every satellite application, and relies to a considerable extent on technology acquired through nonmilitary programs with foreign companies and governments. But China is combining this new knowledge with increasingly robust indigenous capabilities to produce potent advances of its own. China's satellite developers are experimenting with a new workplace culture that emphasizes modern management, standardization, quality control (including ISO 9000 management initiatives), and an emerging capacity for mass production—part of a larger trend in China's dual-use military-technological projects. For a complete categorization of Chinese satellite designations, see Table 14.1.[1] Note that there is some overlap between these categories, and they are used somewhat differently in different publications.[2]

History: A National Development Imperative

Long before the concept of microsatellites was considered to be a key development trend in either the West or China, satellite development writ large was considered critical to furthering China's national interests. In January 1958, Qian Xuesen, the father of China's space program, initiated Project 581[3] to build China's first satellite when, with other scientists, he drafted a satellite development program and designated a working group.[4] Following the Soviet launch of Sputnik III in 1958, Project 581 became a top national priority. "We too should produce man-made satellites," Mao declared to his fellow leaders on May 17, 1958.[5] Premier Zhou Enlai later added, "We should try our best to develop our own meteorological satellites."[6]

On April 29, 1965, China's Defense Science and Technical Commission submitted the "Plan for the Development of China's Artificial Satellites," which called for launching China's first satellite in 1970–1971.[7] On August 10, 1965, Zhou Enlai formally approved the plan, which directed "that the satellite should be visible from the ground and that its signals should be heard all over the world."[8] In May 1966, Qian and his scientific colleagues solidified the plans for China's first satellite launch, agreeing on a name (Dong Fang Hong [East is Red]-1 [DFH-1]), a launcher (CZ-1), and a deadline (the end of 1970).[9] DFH-1's successful launch on April 24, 1970, from China's Jiuquan launch facility made China only the fifth country to launch a satellite.[10] DFH-1's mission was political: its sole function was to broadcast the Chinese national song, "The East Is Red."[11]

Satellite development has been a consistent priority for China since the 1960s. During the past three decades, the country's satellite development and testing have gradually increased in volume and sophistication. China developed and launched the DFH series of large satellites, the Shijian (SJ), or "Practice," series of small satellites, and Da Qi-1 and 2, a pair of atmospheric research balloons.[12] SJ-1 through SJ-4 performed a wide variety of scientific experiments. Some Western experts have speculated that SJ-2 and Da Qi (DQ)-1 and DQ-2 also performed electronic intelligence (ELINT) missions.[13] They are listed in Chinese sources as having "succeeded" as "technological probes" and as "scientific survey balloons, used to research the upper atmosphere."[14]

Initially produced to demonstrate China's national capacity and promote key technological advances, satellites were determined to have vital military significance as well as great potential to support national development. Satellites are regarded as key to China's strategy of efficient investment, a strategy grounded in the notion that a nation can leapfrog traditional stages of technological development.[15] Over the past three decades, satellites have provided China with tremendous benefits in land survey, crop monitoring, forestry, hydrology, geology and petroleum exploration, archaeology and cultural preservation, meteorological observation, natural disaster response and mitigation, oceanography, space environmental exploration, communications and broadcasting, and scientific and technical experiments.[16] These functions are regarded as vital for national modernization given China's vast, largely mountainous territory; complex terrain; and imbalanced economic development.[17]

By the end of the Cold War, China, according to one Chinese analyst, had "become one of the few countries in the world with an ability to launch all categories of satellites with her own launching vehicle; control and manage satellites with her own TT&C [tracking, telemetry, and control] communications network, with services for launching and TT&C of foreign satellites starting to be provided."[18] Chinese analysts believed their nation's technologies of satellite telemetry and recovery and their ability to launch geostationary satellites have been on a par with the most advanced countries in the world.[19] Beijing also became more involved in international satellite conferences and cooperation by the end of the Cold War. Development had progressed steadily and appeared to be gaining momentum.

For most of the Cold War, the United States, the USSR, and other leading space powers sought to build ever larger and more sophisticated satellites. Because of technological and manufacturing limitations, the Soviet Union produced a greater volume of satellites with simpler construction and shorter mission lives than their U.S. counterparts. Here China may have benefited from its relative limitations. Resource constraints meant that most of China's satellites were of relatively low mass and complexity, though there was a slowly emerging group of high-performance or mission-specific satellites. A national focus on developing the civilian economy meant that many of China's satellites were dual-use and multifunctional in nature. Though few people on either side of the Pacific realized it at the time, the stage was being set for China to align itself with a powerful technological trend.

Chinese development of small and microsatellites began with the 863 Program/National Defense Basic Science Research Program, which Beijing launched in 1986. Microsatellites therefore represent the next frontier of People's Republic of China (PRC) aerospace development, one that is receiving increasing priority. According to one PRC analyst, "Developing our country's small satellite technology, [which is] leading our country's remote sensing spaceflight enterprise, has risen to [the level of] an important impetus."[20] While China has been prioritizing its satellite programs since the 1960s, the country experienced limited success until quite recently. In the 1990s, however, with significant increases in technology access and funding, progress accelerated markedly (as it did in other technological development sectors).

Development work with foreign partners has been central to this progress. Nearly every PRC satellite in recent years has benefited significantly from foreign technology (for example, from the United Kingdom, the European Space Agency, and Brazil). PRC advances in microsatellites would have been limited without these contributions. While this international development assistance is a trend in the satellite industry overall, it appears also to represent an important aspect of China's technology development strategy. This suggests that, for the foreseeable future, China's satellite development will exhibit significant foreign influence. But China has been careful to diversify its development partners, and there is no chance of a repeat of the Sino-Soviet split, in which rapid withdrawal of Soviet advisers in 1960 severely limited Chinese aerospace development for years. Moreover, China is cultivating a new generation of extremely talented engineers who are learning from foreign partnerships while developing their own capabilities. The indigenous development and production capabilities that China has already accrued should not be underestimated.

This early history offers yet another example of China's capacity to achieve its national military-technological goals through an all-out effort (as with nuclear weapons and ballistic missiles, albeit on a smaller scale). But now a potent combination of world-class technological competence and commercial dynamism is propelling microsatellite development in ways that China's government could not achieve alone. Today rapid advancement and significant breakthroughs are possible in the field of microsatellite development for two main reasons: the programs are no longer solely reliant on government prioritization, and there is now consistent access to high-level personnel, funding, and technology. Other sectors may well benefit from similar dynamics, but the minimal regulation and unique aspects of satellites suggests that this will continue to be a leading sector.[21]

Chinese Development and Production Facilities

A wide variety of facilities support Chinese satellite development efforts. Beijing Satellite Manufacturing Factory (BSMF), subordinate to China Aerospace Science and Technology Corporation (CAST) since February 27, 1968, is a state-owned enterprise. Formerly the Chinese Academy of Sciences' Beijing Scientific Instrument Factory, BSMF has been involved in the assembly, integration, and testing of a wide variety of satellites since before 1970. Today it has an assembly workshop, five professional laboratories, seven small producing workshops, and the Beijing Xingda Technology Development Company (which develops commercial products). Another supporting facility, CAST, has developed several models of small satellites; the Chinese Academy of Sciences (CAS) has conducted research on payloads for small and nanosatellites; the Shanghai Space Administration has developed small satellite propulsion systems; and the Harbin Institute of Technology has established a small satellite research center and is running some small satellite projects related to the 863 program. Finally, microsatellites such as Shijian 5 and Haiyang 1 have been tested at the CM series magnetic test facility.[22]

The most sophisticated and cost-effective microsatellite development seems to be taking place at China's foremost research universities and major satellite production companies. These appear to be organizationally lean, employ young technical talents, and operate on quasi-market principles. This recipe for success, applied unevenly elsewhere in China's defense/science and technology industry, is bearing significant fruit. China has also received considerable technological assistance (and potential managerial and organizational influence) from many foreign entities, most prominently Surrey

Satellite Technology Limited (SSTL), a leading U.K.-based supplier of small satellites.[23]

Tsinghua University ("China's MIT") has clearly been recognized as a core PRC microsatellite development center.[24] Tsinghua's role is hardly coincidental. As one Chinese writer observes, microsatellites rely on "machinery, mechanics, electronic information, optics, heat energy, material, [and] control, [and] can drive multi-disciplinary synthesis development, making it a perfect domain for colleges and universities to enter."[25] On September 16, 1998, Tsinghua established the Aerospace Technology Research Center/ Tsinghua Space Research Center (TSRC) to pursue (in part) microsatellite development, and, as of 2003, the center already had "a 300 square meter super-clean room with ten thousand–level cleanliness, a 1200 square meter research and test base," a number of laboratories, and fifty graduate students.[26]

In June 2000, Tsinghua University Enterprise Group joined China Aerospace Science and Industry Corporation (CASIC) and Tsinghua Tongfang Limited Company to fund and jointly establish Aerospace Tsinghua Satellite Technology Company, Ltd. In September 2001, China Yintai Investment Company became the fourth shareholder by providing venture capital.[27] Aerospace Tsinghua is among China's first satellite development and manufacturing companies to establish itself in accordance with modern industrial practices. It shares many features with typical Western businesses, including accounting and logistics management, research and development flowsheets, and an ethos of standardized management; countless documents outline everything from purchasing to quality control to technical specifications; and the firm passed its ISO 9000 review in 2003. As a result of these efforts, the firm claims that "there has not been any quality problem during any satellite launch process of the company."[28]

Also reminiscent of best practices in the West, Aerospace Tsinghua employees are carefully selected and mentored. Their average age in 2004 was under thirty-one. Employees can choose a department in which to work, based on their personal interests and aspirations, and they are given promotions with reasonable frequency if they perform well. Based on its core principles of market orientation, economies of scale, and integrating market demand with technological development, Aerospace Tsinghua has reportedly "developed small satellites and related products on the basis of international and domestic market needs."[29]

Founded by CAST and its parent company, CASC, in August 2001, Aerospace Dongfanghong Satellite Company, Ltd. (DFH Satellite Company) is China's foremost satellite manufacturer. The firm is engaged in the research and design of small satellites and microsatellites, and the system design and production R&D of satellite application projects. DFH Satellite Company works closely with China Space Technology Research Institute and the Fifth Academy. In 2003, General Manager Li Zuhong, a leader of the small satellite development group and formerly vice president of the Fifth Academy, reported that the company had more than 120 personnel, 80 percent of whom held postsecondary degrees. According to *China Aerospace News*, DFH Satellite Company has implemented innovative corporate management methods.[30] If true in practice, this human resource approach indicates both unusual personnel efficiency for China (a breakthrough also reported in the Shenzhou piloted spaceflight program) and high project priority. Such horizontal coordination represents a potent model that might be gradually introduced throughout China's defense-industrial sector. In a key example of the commercial aspect of Chinese satellite development, DFH Satellite Company is also said to have established a joint venture with a Japanese high technology enterprise based in China, and intends to "gradually seize [a portion of] the small satellite market."[31]

In late 2004, DFH Satellite Company completed construction of the China National Engineering Research Center on Small Satellites and Applications in northwest Beijing.[32] Billed as the world's largest small satellite facility, the center has the capacity to build six to eight microsatellites per year. Given the current trajectory of China's satellite construction, this target seems to be readily attainable. According to *People's Daily*, the center "will strengthen the cooperation with foreign and Chinese institutions, [thereby] promoting the industrialization of microsatellites."[33]

Microsatellite Projects

This section surveys some of the latest microsatellites that China has developed. (Appendix 14.1 contains a complete list with technical details of all Chinese small satellite projects.) Chuangxin-1 (CX-1), or "Innovation," was successfully launched aboard a Long March 4 rocket from Taiyuan on October 21, 2003. During the first fifty-five days of its orbit, it successfully endured "two solar gales and . . . securely resisted twenty-three single-particle motions."[34] China's first modern microsatellite with a weight of less than 100 kg is also its first low-orbit digital communications satellite. It stores and rebroadcasts data through two-way communication with ground terminals in Shanghai, Beijing, Xinjiang, and Hainan. The results of various experiments "showed that the entire system operated well and met the requirements to enter the user trial phase."[35] The microsatellite was produced by the CAS, which initiated its development in 1999 as part of its Knowledge Innovation Project. The satellite's objective consists of electronic memory, transmission, and communications experiments. The payload has electronic memory, processing, and transmission (store and forward) functions.[36] It has been credited with achieving "breakthrough progress in low-orbit communications technology, monitoring, and control; design of shared communications channels for communications businesses; satellite in-orbit forecasts; satellite self-management and operation; and miniaturized satellite communications terminals."[37] CX-1 was launched with the second China-Brazil Earth Resources Satellite (CBERS 2).[38]

Naxing-1 was launched with SY-1. At 25 kg, Naxing-1, or "Nano-satellite," made China the fourth country (after Russia, the United States, and the United Kingdom) to launch a satellite approaching nano-satellite designation (10 kg or less). Hailed as an important breakthrough by the Chinese press, it enabled China to enter the international arena of small satellite research. NX-1 was produced by Tsinghua University and its subsidiary, Aerospace Tsinghua Satellite Company, and was designed to conduct high-technology experiments. NX-1's "primary missions" included using a CMOS camera to conduct image formation experiments. Other experiments involved miniature inertia survey, orbit maintenance and change, software upload procedures, and partial primary devices. As this technology matures, it will be used in applications such as optical image formation and environmental and meteorological observation. NX-1's designers claim that it is not only the smallest three-axis satellite in the world, but that it is also "China's first satellite having software uploading capabilities."[39]

On September 27, 2008, China launched, monitored, and controlled a satellite from a spacecraft for the first time.[40] The Shenzhou 7 spacecraft spring-launched the Banxing ("Companion") microsatellite (also called BX-1). The Shanghai Institute of Technical Physics, working under the CAS, developed and delivered BX-1 in less than three years.[41] Reportedly related to predecessor Chuangxin 1 (launched in 2003), the 0.4 m, cube-shaped satellite has a payload of less than 10 kg, and includes systems to support three missions: the in-orbit release experiment; photography of the Shenzhou 7; and a subsequent change of orbit to "chase" the orbit module. After being launched, the BX-1 flew around the Shenzhou 7 and photographed it with CCD cameras before moving 100 to 200 km away under control of a ground tracking station. This ground tracking station "measure[ed] the relative distance between the companion satellite and the orbit module." After the astronauts returned to Earth on September 28, the researchers at the ground flight control center were able to direct the small companion satellite to "chase" the orbit module, catch up to it, and enter into an elliptical orbit around it.

Zhu Zhencai, BX-1's chief designer and a researcher at the Shanghai Microsatellite Engineering Center, stated that "the working life that was originally expected is three months at the least. Therefore, we need to perform some more technical experiments, including Earth observation and further or long-term evaluation of the orbit."[42] Future experiments aside, the BX-1 performed admirably in its first journey, surpassing overall mission requirements (for example, making upward of twenty revolutions around the orbit module, when just three revolutions would have qualified as a "success"), and a Chinese news report concluded, "The success of [BX-1] lays a foundation for in-orbit troubleshooting and support for large spacecraft. The functions and applications of spacecraft can be extended and broadened and . . . will also provide useful experience for the rendezvous and docking of spacecraft in the future."[43]

China's Small Satellite Buses: Indicators of Mass Production Ability

In a development that mirrors Western efforts to reduce costs and enhance reliability, satellite buses or standardized platforms will constitute the backbone of China's future microsatellite efforts. China is developing at least five variants of three major small satellite buses: CAST968A, B, and C; CAST2000; and CASTMINI (for true microsatellites). By analyzing the performance parameters of China's small satellite buses, future researchers may discern for which combination of capabilities and missions China's new generation of microsatellites have been optimized. In turn, this will provide insights into China's true space interests and intentions.

CAST968. DFH Satellite Company has developed CAST968, China's first small satellite bus.[44] Already applied to several satellites, its operating performance has reportedly been extremely stable and reliable.[45] According to CAST, the bus "has strong expandability suitable for various payloads" and can be configured for "different kinds of missions from [low and medium Earth] orbits, as well as single satellite, multisatellite, and piggyback launch missions."[46] These missions include Earth and ocean observation, space science, communications, engineering tests, reconnaissance, and surveillance. CAST968's payload mass is roughly 30 to 60 percent of the platform mass. It is designed with a network-based system to manage and control multiple missions and resources simultaneously, and is able to support a variety of attitude control modes. In accordance with international standards, it employs a USB measurement and control system. CAST968 is powered by a combination of solar and battery power. Its primary thermal system is passive, while its secondary system is active. DFH Satellite Company provides technical support and states that CAST968 will be used successfully with a variety of new satellites. The CAST968 bus is divided into three variants—A, B, and C—each more advanced than the last. The CAST968A bus was the first created by CAST, in August 1996. The mission of the CAST968 bus program was to use mature technology and equipment, integrated systems, and computer software to create a platform that could support technological development and advanced experiments. Progress in these areas was important:

decision makers wanted to raise performance requirements and avoid catastrophic system failure. The successful deployment of the SJ-5 small satellite's payload in 1999 determined that the CAST968A bus had satisfied performance targets and user requirements.

The CAST968B bus was created to satisfy Chinese customer demands and to achieve true interchangeability, seriation, and "combinationalization."[47] These concepts, which are also gaining popularity in other areas of China's defense sector, are critical to the dual-use approach to modern defense-industry development in China. CAST968B was developed primarily to support HY-1, and, accordingly, CAST968B's propulsion system was enlarged to satisfy HY-1's payload work requirements. This enabled HY-1 to achieve orbit change and maintenance capability. Attitude control precision was increased, as were solar cell area, "segment transfer efficiency," and platform output power.[48] CAST968B abandoned its predecessor's driven-type solar array in favor of a more advanced version capable of automatically tracking the sun.[49] The GPS location system and satellite orbit self-stabilization capability were also augmented.

Analysis of Chinese and foreign markets for small satellites, and ongoing demonstration work concerning various kinds of small satellite bus requirements, determined that CAST968A and B could still not meet comprehensively high performance payload application demands. For instance, Earth observation satellites need to carry such diverse payloads as high-spectrum and high-resolution cameras, synthetic aperture radar (SAR), and microwave/optical remote sensing equipment. For this reason, the CAST team decided once again to revamp their product to meet the demands of current end-users; CAST968C was developed with the goal of meeting all types of high-resolution, high-performance, and multiuse payload requirements. China apparently plans to use this bus in future advanced satellites. HJ-1A and 1B, the initial members of China's first satellite constellation, all reportedly use the CAST968 bus.

CAST2000. DFH Satellite Company has already started to develop the CAST2000 bus to achieve small satellite volume production capability.[50] According to the China National Aerospace Information Center (CNAIC), CAST2000 was used in the SY-2 small satellite launched on November 18, 2004; if this is true, SY-2 would be the first satellite to use the recently developed CAST2000 bus. The bus enabled SY-1 to demonstrate cutting-edge technology, including high accuracy control, integrated management, highly effective power sourcing, multipurpose structural technology, enhanced attitude and control precision, standardization, network capabilities, high-speed information exchange, new power sources, and new control-system technology.

The CAST2000 bus reportedly delivers improvements in antimagnetic, vibration, and radiation protection; system expansion ability; and multimission adaptability. In another indication of commercial motivations being behind much of China's microsatellite development, CNAIC emphasizes that CAST2000 is world-class, meets international standards, uses commercial data-storage components extensively, and is intended for eventual export. As indicated earlier in this study, the buses represent a breakthrough in technological development under the aegis of a completely new management model for China's strategic technological industry. Organizationally, DFH Satellite Company is divided between the CAST968 and CAST2000 satellite buses, with separate but parallel chains of command.[51]

Conclusion

While I have found that Chinese publications often use florid expressions and exaggerate capabilities by emphasizing relatively minor achievements out of context and overlooking deficiencies, the overall scale and form of China's microsatellite developments suggest a significant increase in satellite capabilities. This should surprise no one: China's microsatellite development and production appear to be part of a broader pattern of defense-industry development that serves both commercial and military purposes. China has demonstrated key successes, albeit with substantial foreign assistance. In doing so, Beijing is demonstrating the value of a development paradigm that differs significantly from that of the United States. Many Chinese microsatellites appear to be dual-use in capability, whereas U.S. satellites are more strictly segregated (the U.S. military's extensive use of commercial satellite imagery being a significant exception). Whereas China encourages technology transfer from Europe, Israel, Brazil, and Russia to its benefit, America has alienated even some of its closest allies, and forfeited key sales opportunities, with its unyielding approach to export controls. A great beneficiary of these transfers is the European Space Agency, which is in high demand as a partner around the world, and particularly in China. By prohibiting the use of U.S. components in foreign satellites not cleared through the stringent International Traffic in Arms (ITAR) process, Washington gives Europe and China powerful incentives to develop their own. This raises the distinct possibility, at some point in the future, of Europe (and perhaps even, someday, China) setting international standards to its advantage.

Those who maintain that the U.S. political system precludes a more effective dual-use approach and that national security concerns make export controls nonnegotiable should nevertheless consider a third area, over which the United States wields undisputed control—its own satellite development approach. While U.S. satellites are unquestionably more sophisticated than their Chinese counterparts (and are likely to remain so for some time to come), the U.S. tendency to create ever larger and more expensive satellites surely has drawbacks. With the proliferation of space debris and anti-satellite weapons, it is unwise to concentrate so much economic and strategic value in a single location with little possibility of timely replacement. For at least some space applications, the use of some configuration of small/microsatellites (with replacements perhaps cycled through more frequently, even in nonemergency situations) could have significant benefits. In addition to the obvious security and potential cost savings, this approach could help satellites fall less far behind technologically during long in-orbit lives, and even reach orbit with a better technology freshness-to-cost ratio thanks to more extensive use of commercial off-the-shelf (COTS) technologies.

Now is the time to act, before mounting concerns about threats to satellites trigger a major increase in expensive and cumbersome countermeasures that offer only marginal security benefits. Perhaps best of all, the resulting standardization, increase in development tempo, commercial interrelation, and ability to take risks could make the U.S. satellite industry far more competitive and versatile technologically. This process holds inherent challenges, with corresponding improvements in launchers being an important component. But in an era in which the U.S. government may not be able to afford a purpose-built designer solution to every space application, it may be the only truly sustainable way forward. China's microsatellite program has taken many lessons from U.S. programs; it would be the height of conceit and folly for Washington to imagine that it has nothing to learn from Beijing.

NOTES

The views expressed in this essay are those of the author alone and do not represent the policy or estimates of the U.S. Navy or any other element of the U.S. government. The author thanks Lyle Goldstein, Joan Johnson-Freese, William Martel, Anthony Mastalir, Oriana Mastro, and Kathleen Walsh for their incisive comments.

1 It is worth noting that while both Western and Chinese sources categorize satellites by weight, they often use terms in an overlapping fashion and even interchangeably. Unless otherwise specified, this study will use the term "microsatellite" as a collective term meaning any satellite weighing less than 100 kg. Because satellites are categorized by weight, some of China's earliest and least sophisticated satellites are still considered to be "microsatellites." PRC satellites are often given multiple names, and sometimes renamed, which has led to inconsistency in Western reports. This study will use designations currently used by U.S. government analysts and attempt to resolve ambiguity wherever possible.

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3 This program has also been referred to as Project 651. See Stephen J. Isakowitz et al., *International Reference Guide to Space Launch Systems*, 4th ed. (Reston, Va.: American Institute of Aeronautics and Astronautics, 2004), 261.

4 Iris Chang, *The Thread of the Silkworm* (New York: Basic Books, 1995), 225.

5 Yu Yongbo et al., *China Today: Defense Science and Technology* (Beijing: National Defense Industry Press, 1993), 1:30; "DFH-1," accessed March 27, 2011, http://www.globalsecurity.org/space/world/china/dfh-1.htm.

6 Fang Zongyi, Xu Jianmin, and Guo Lujun, "The Development of China's Meteorological Satellite and Satellite Meteorology," in *Space Science in China*, ed. Hu Wenrui (Amsterdam: Gordon and Breach Science Publishers, 1997), 239.

7 See, for example, Tu Shancheng, "Space Technology in China: An Overview," in Hu, *Space Science*, 15; also see Chang, *Silkworm*, 226.

8 Isakowitz et al., *International Reference Guide*, 261.

9 The Chinese designations are 东方红一号 and 长征一号, respectively. CZ-1 was developed from the DF-4 missile. Ibid.

10 Yu Yongbo et al., *China Today*, 1:98; Roger Cliff, *The Military Potential of China's Commercial Technology* (Arlington, Va.: RAND, 2001), 28. Previous nations were the Soviet Union, the United States, France, and Japan.

11 Shi Jianzhong, "The Song 'East Is Red' Was Transmitted from Space: Recording the Process of Developing 'Dong Fang Hong' 1's Shortwave Transmitter" (original in Chinese), *Aerospace Industry Management* 5 (2005): 12–13.

12 For further information on DQ-1A and DQ-1B, see Hu Wenrui, "Space Science in China: Progress and Prospects," in Hu, *Space Science*, 5.

13 "SJ-2," accessed March 27, 2011, http://www.globalsecurity.org/space/world/china/sj-2.htm; "DQ-1," accessed March 27, 2011, http://www.globalsecurity.org/space/world/china/dq-1.htm.

14 Gu Songfen et al., eds., *The History of World Space Science Development* (original in Chinese) (Zhengzhou: Henan Science and Technology Press, 2000), 272; Editorial Committee, *The Soaring Journey of Chinese Spaceflight* (original in Chinese) (Beijing: China Literature and History Press, 1999), 418.

15 Min Guirong, "Review of Chinese Space Programs," in *Devotion to Spaceflight in the Benefit of Humanity: The Collected Works of Academician Min Guirong* (original in Chinese) (Beijing: China Aerospace Publishing House, 2003), 189.

16 See, for example, Guo Huadong, ed., *Radar Remote Sensing Applications in China* (New York: Taylor & Francis, 1999); Min Guirong, "Spin-off from Space Technology in China," paper presented to the forty-third Congress of the International Astronautical Federation, IAF-92–0180, essay in Min, *Devotion*, 253.

17 Zhuang Yaoli and Wang Hualong, "Modern Microsatellite Communication," *Modern Communication* (February 2002).

18 Yu Yongbo et al., *China Today*, 1:176.

19 Ibid., 2:889.

20 Li Zhizhong, Wang Yongzhang, and Xu Shaoyu, "Microsatellites' Earth Observation and Application Prospects," *Territory, Natural Resources, and Remote Sensing* (April 2004).

21 Unlike Chinese aircraft, for instance, satellites do not have passenger safety requirements and can be usefully tested at any stage of development or sophistication.

22 See, for example, Chiang Yuen-p'ing, "The ROC's Countermeasures to the PRC's Satellite Development" (original in Chinese), *Navy Studies Monthly* (April 2005), OSC# CPP20070402312004; and Huang Bencheng and Ma Youli, eds., *Spacecraft Space Environment Test Technology* (original in Chinese) (Beijing: National Defense Industry Press, 2002), 235.

23 For more information, see Surrey Space Technology Limited's website, accessed March 27, 2011, http://www.sstl.co.uk/.

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26 Gong Ke, Vice President, Tsinghua University, "Bring Cooperation into Bloom, Stride Forward with Development—Spaceflight Science and Technology at Tsinghua" (original in Chinese), in *China Spaceflight Moves into the World: Commemorating the Tenth Anniversary of the Founding of China National Space Administration*, ed. Luo Ge (Beijing: China Space Navigation Press, 2003), 257.

27 Xia Guohong, You Zheng, Meng Bo, and Xin Peihua, "An Attempt by China's Spaceflight Enterprise System to Blaze New Trails—Aerospace Tsinghua Satellite Technology Company" (original in Chinese), *Aerospace China* (August 2002): 11–13.

28 Unless otherwise specified, this and the following four paragraphs are derived from "Hangtian Tsinghua Satellite Co. Approaches Satellite Market," *Zhongguo Hangtian Bao* (May 28, 2004): 4, OSC# CPP20040610000201.

29 Xia Guohong et al., "Attempt."

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Appendix 14.1 PRC Small Satellite Projects

Abbreviation/ English Designation	Chinese name	Equipment/Function	Weight (kg)	Manufacturer	Launch Date (PRC time)	Launcher, Site	Orbit
DFH-1 (Dong Fang Hong 1) East is Red 1	东方红一号 dōngfāng hóngyīhào	Radio transmitter	173		4/24/1970	Long March (LM)/ CZ-1 Jiuquan	439×238/ 68.5/114
SJ-1 (Shi Jian-1) Practice-1	实践一号 shíjiànyīhào	Measure space environment parameters, e.g., high-altitude magnetic field; magnetometer, particle detectors • cosmic and x-rays	221		3/3/1971	CZ-1 Jiuquan	266×1826/ 69.9/106
SJ-2 (Shi Jian-2) Practice-2	实践二号 A shíjiànèrhào	Detect solar activities, charged particles in near-Earth space, infrared & UV radiation background of Earth & atmosphere; beacon transmitter • ionosphere study	257	Beijing Institute of Spacecraft Systems Engineering	9/20/1981	FB-1 Jiuquan	237×1622/ 60/103 or 232/1598, 59.5?
SJ-2A (Shi Jian-2A)	实践二号甲 shíjiàn 2 èrhàojiǎ				9/20/1981	FB-1 Jiuquan	237×1622/ 60/103 or 232/1608, 59.4?

(continued)

Appendix 14.1 PRC Small Satellite Projects *(continued)*

Abbreviation/ English Designation	Chinese name	Equipment/Function	Weight (kg)	Manufacturer	Launch Date (PRC time)	Launcher, Site	Orbit
SJ-2B (Shi Jian-2B) Practice-2B	实践二号乙 shíjiàn 2 èrhàoyǐ	Passive radar calibration test • measure atmospheric density	28		9/20/1981	FB-1 Jiuquan	237×1622/ 60/103 or 232/1608, 59.4
STTW-2 (Shiyong Tongbu Tongxin Weixing) **DFH-2A** Zhongxing 2		Operational geostationary communications satellite	441		3/7/1988	CZ-3	
SY-1 (Shiyan 1)	试验卫星一号 shìyànwèixīng yīhào	Communications performance and new technology tests • "partially successful"	461		1/29/1984	CZ-3 Xichang	474×6480/ 36/161
SYTXW (Shiyan Tongxin Weixing)	试验通信卫星 shìyàntōngxìn wèixīng	After completing communications experiments, provided applications from fixed position above the equator at 125 degrees east longitude	461		4/8/1984	CZ-3 Xichang	35599× 35792.8/0.6 2/1431.5
SYTXGBWX-1 (Shiyong Tongxin Guangbo Weixing 1) **DFH-2**	实用通信广播卫星一号 shíyòngtōngxìn guǎngbōwèixīng yīhào	On February 20, fixed position above the equator at 103 degrees east longitude	433		2/1/1986	CZ-3 Xichang	35783× 35792/ 0.09/1436
SYTXW-2	实用通信卫星二号	Operational geostationary	441		3/7/1988	CZ-3	35786.4×

Guangbo Weixing 1) **DFH-2**	shíyòngtōngxìn guǎngbōwèixīng yīhào	position above the equator at 103 degrees east longitude				Xichang	35792/ 0.09/1436
SYTXW-2 (Shiyong Tongxin Weixing 2)	实用通信卫星二号 shíyòngtōngxìn wèixīngèrhào	Operational geostationary communications satellite; on March 23, fixed position above the equator at 87.5 degrees east longitude	441		3/7/1988	CZ-3 Xichang	35786.4× 35862.6/ 0.07/1438
SYTXW-3 (Shiyong Tongxin Weixing 3) **DFH-2A** Zhongxing 3	实用通信卫星三号 shíyòngtōngxìn wèixīngsānhào	Operational geostationary communications satellite; on December 30, fixed position above the equator at 110.5 degrees east longitude	441		12/22/1988	CZ-3 Xichang	35782.5× 35790.2/ 0.56/1436.1
SYTXW-4 (Shiyong Tongxin Weixing 4) **DFH-2A**	实用通信卫星四号 shíyòngtōngxìn wèixīngsìhào	Operational geostationary communications satellite; on February 14, fixed position above the equator at 98 degrees east longitude			2/4/1990	CZ-3 Xichang	35783.3× 35797.8/ 0.11/1436.3
DQ-1A Da Qi-1	大气一号 dàqìyīhào	Research balloon • atmospheric density measurement	2.6		9/3/1990	CZ-4A Taiyuan	789/811, 99
DQ-1B Da Qi-2	大气二号 dàqìèrhào	Research balloon • atmospheric density measurement	3.3		9/3/1990	CZ-4A Taiyuan	596/629, 99
SJ-4 (Shi Jian-4)	实践四号 shíjiànsìhào	Acquired space environment parameters @ 20–36,000 km altitude, a PRC first • cosmic ray detection	400		2/8/1994	CZ-3A Xichang	200× 36000/ 28–28.5? or 36092/28.2

(continued)

Appendix 14.1 PRC Small Satellite Projects *(continued)*

Abbreviation/ English Designation	Chinese name	Equipment/Function	Weight (kg)	Manufacturer	Launch Date (PRC time)	Launcher, Site	Orbit
SJ-5 (Shi Jian-5) Practice-5	实践 5 号 shíjiànwǔhào	Magnetosphere research, space-charged particle measurement, S-band high-speed data-link transmitter tests, large-capacity solid-state storage test, fluid science experiments • first PRC small scientific experiment satellite designed based on common bus (CAST968A)	300/ 298*	Joint development with Brazil Aerospace by East is Red Corporation (est. 2001) of China Academy of Space Technology (CAST); and China Academy of Sciences	5/10/1999	CZ-4B Taiyuan	849×868/ 98.79/ 102.11
HTQH-1 (Qinghua-1)	航天清华一号 qīnghuáyīhào	Earth observation, communications • Bus: SSTL Microsat-70	49/50	Built by Surrey Satellite Technology Limited Corp (SSTL) for Tsinghua/Surrey University	6/28/2000	Plesetsk, Russia	683×706/ 98.13/98.66
HY-1A (Haiyang-1A) Ocean 1-A	海洋 1 号 A hǎiyángyīhào	Marine remote sensing • CAST968B Bus	365	CAST/DFH Aerospace Corporation Components from Satlantic (Canada) and CIMEL (France)	5/15/2002	CZ-4B Taiyuan	793×798 km fixed orbit, 98.80°
HTQH-2/	航天清华二号	Multispectral Earth	50/	SSTL?/PRC partner	9/15/2002	Kaituozhe-1	Failed;

		[illegible] Bus		Corporation Components from Satlantic (Canada) and CIMEL (France)			orbit, 98.80°
HTQH-2/ HTSTL-1/ KT-1PS (Tsinghua-2)	航天清华二号 qīnghuáèrhào	Multispectral Earth imaging, experimental communications payload	50/ 35.8/34	SSTL?/PRC partner	9/15/2002	Kaituozhe-1 Taiyuan	Failed; second stage mal-function before could attain 300 km polar orbit
PS-2		Guidance system, fairing separation and satellite-launcher separation succeeded; fourth stage failed to ignite	40		9/16/2003	Kaituozhe-1 Taiyuan	300 km × 300 km polar orbit
CX-1 (Chuangxin-1) Innovation-1	创新1号 chuàngxīnyīhào	Digital store and rebroadcast communications • data retransmission	75–99	CAST, Chinese Academy of Sciences, Shanghai (?), Shanghai Academy of Space Technology, Shanghai Telecommunications	10/21/2003	CZ-4B Taiyuan	
DSP-E (Double Star Equator)	探测一号 tàncèyīhào	Plasma science	330	European Space Agency (ESA)/CAST, China Aerospace Science and Technology Corp.	12/30/2003	CZ-2C/CTS Xichang	

(continued)

Appendix 14.1 PRC Small Satellite Projects *(continued)*

Abbreviation/ English Designation	Chinese name	Equipment/Function	Weight (kg)	Manufacturer	Launch Date (PRC time)	Launcher, Site	Orbit
SY-1 (Shi Yan-1) Experimental Satellite 1 or, Explorer-1	实验卫星一号 shíyànwèixīng yīhào 探索1号 tànsuǒyīhào	Optical remote sensing land resource survey; stereo mapping: • 10 m resolution observation capacity	204/ 250*	Harbin Institute of Technology, CAST, China Space Technology Research Institute, Chinese Academy of Sciences, Changchun Light Technology Institute, Xi'an Mapping Research Institute, Astrium?	4/18/2004	CZ-2C	Polar orbit
NX-1 Nano-satellite 1	纳星1号 nàxīngyīhào	Hi-tech experiments: • CMOS camera, inertia survey, data transmission, remote sensing photography, attitude control, track maintenance and axial change	<=25	Tsinghua University, Aerospace Tsinghua Satellite Co. Ltd.	4/18/2004	CZ-2C	
DSP-P (Double Star Polar)	探测二号 tàncèèrhào	Plasma science	270*	EuropeanSpace Agency (ESA)/PRC	7/25/2004	CZ-2C Taiyuan?	
SJ-6A/6-01B (Shi Jian-6A) Practice-6A	实践六号A shíjiànliùhào A			*Prime Contractor:* DFH Satellite Co., Ltd., CAST	9/8/2004	CZ-4B Taiyuan	578 km × 593 km, 97.7°

(Double Star Polar)	tàncèèrhào	Plasma science	270*	EuropeanSpace Agency (ESA)/PRC	7/25/2004	CZ-2C Taiyuan?	
SJ-6A/6-01B (Shi Jian-6A) Practice-6A	实践六号 A shíjiànliùhào A			*Prime Contractor:* DFH Satellite Co., Ltd., CAST	9/8/2004	CZ-4B Taiyuan	578 km × 593 km, 97.7°
SJ-6B/6-01A (Shi Jian-6B) Practice-6B	实践六号 B shíjiànliùhào B	Probe cosmic environment, radiation, related space experiments, • ELINT technology • CAST968 Bus	350	*Prime Contractor:* DFH Satellite Co., Ltd., CAST *Operator:* China Aerospace Science and Technology Corp.	9/8/2004	CZ-4B Taiyuan	593 km × 602 km, 97.7°
SY-2 (Shi Yan-2) Experimental Satellite 2	实验卫星二号 shíyànwèixīng èrhào	Satellite technology testing, land, resources, and environmental surveying from sun synchronous 700 km orbit • Bus: CAST2000	300	*Operator:* DFH Satellite Company *Prime:* CAST	11/18/2004	CZ-2C Xichang	
SJ-7 (Shi Jian-7) Practice-7		Scientific experiments; nonrecoverable satellite	???		7/5/2005	CZ-2D Jiuquan	547 km × 580 km, 97.6°
BJ-1 Beijing-1	北京一号	Earth observation • 4m, image, 32 m resolution imager in 3 spectral bands • Bus: SSTL Microstat-100 (enhanced) • Resistojet propulsion	166	*Operator:* Beijing Landview Mapping Information Technology Ltd. (BLMIT) *Contractor:* SSTL	10/27/2005	Kosmos-3M Plesetsk, Russia	
SJ-6C/6-02B (Shi Jian-6C) Practice-6C				DFH Satellite Co., Ltd., CAST	1/24/2006	CZ-4B Taiyuan	
SJ-6D/6-02A (Shi Jian-6D) Practice-6D		CAST968 Bus		DFH Satellite Co., Ltd., CAST	1/24/2006	CZ-4B Taiyuan	

(continued)

Appendix 14.1 PRC Small Satellite Projects *(continued)*

Abbreviation/ English Designation	Chinese name	Equipment/Function	Weight (kg)	Manufacturer	Launch Date (PRC time)	Launcher, Site	Orbit
HY-1B (Haiyang-1B) Ocean-1B	海洋 1 号 B hǎiyángyīhào	Ocean color mapping • 10-band ocean color scanner • 4-band CCD imager/ 250 m resolution • infrared water profile radiometer		CAST	4/11/2007	CZ-2C	782×815/ 98.60°/ 100.80 min
HJ-1A (Huanjing-1A) Environment-1A	环境一号 A huánjìngyīhào A	In constellation w/ HJ-B/C; to be 1 of 8 disaster reduction and environmental monitoring constellation satellites • 4 cameras: 2 CCD cameras w/ 30 m resolution & 700 km breadth; IR camera w/ 150 m (near, center infrared) resolution & 720 km breadth; & hyperspectral imager w/ 100m/50km resolution/ breadth & spectrum 5 nm resolution	470	DFH Satellite Co.*	9/6/2008	LM-2C Taiyuan	650 km sun synchronous orbit; 48-hour revisit interval for China & surrounding area
HJ-1B	环境一号 B	In constellation w/ HJ-B/C;	470	DFH Satellite Co.*	9/6/2008	LM-2C	650 km sun

HJ-1B (Huanjing-1B) Environment-1A	环境一号B huánjìngyīhào B	In constellation w/ HJ-B/C; to be 1 of 8 disaster reduction and environmental monitoring constellation satellites • 4 cameras: 2 CCD cameras w/ 30 m resolution & 700 km breadth; IR camera w/ 150 m (near, center infrared) resolution & 720 km breadth; & hyperspectral imager w/ 100m/50km resolution/ breadth & spectrum 5 nm resolution	470	DFH Satellite Co.*	9/6/2008	LM-2C Taiyuan	650 km sun synchron-ous orbit; 48-hour revisit interval for China & surround-ing area
BX-1 (Banxing-1) Companion Satellite	伴飞小 卫星 / 伴星 bànfēixiǎo wèixīng/ bànxīng	2 CCD cameras, orbital maneuvering, liquid ammonia propellant • 0.4m cube	30–40	Shanghai Institute of Technical Physics, under the Chinese Sciences	9/27/2008	Shenzhou 7 spacecraft	
SJ-6E/6-03B (Shi Jian-6E) Practice-6E	实践六号E shíjiànliùhào	2 yr.+ design life • optical camera • survey space environment, space radiation environment and its effects, parameters of physical space environment, space experiments • CAST 968 or FY-1 bus	~300	SAST group in Shanghai or the DFH Co. in Beijing	10/25/2008	LM-4B Taiyuan	580×604 ×97.7°

(continued)

Appendix 14.1 PRC Small Satellite Projects *(continued)*

Abbreviation/ English Designation	Chinese name	Equipment/Function	Weight (kg)	Manufacturer	Launch Date (PRC time)	Launcher, Site	Orbit
SJ-6F/6-03A (Shi Jian-6F) Practice-6F	实践六号F shíjiànliùhào	2 yr.+ design life • optical camera • survey space environment, space radiation environment and its effects, parameters of physical space environment, space experiments • CAST 968 or FY-1 bus	~300	SAST group in Shanghai or the DFH Co. in Beijing	10/25/2008	LM-4B Taiyuan	580×604 ×97.7°
Chuangxin 1-02	创新一号02星 chuàngxīnyīhào 02 xīng	Collect and relay hydrological and meteorological data and data for disaster relief		Chinese Academy of Sciences	11/5/2008	LM-2D Jiuquan	
SY-3 (Shi Yan-3) Experimental Satellite 3	试验卫星三号 shìyànwèixīng sānhào	Experiments on new technologies in atmospheric exploration		Harbin Institute of Technology	11/5/2008	LM-2D Jiuquan	
SJ-11-01		Technology demonstration		*Major Contractor:* ADSC *Operator:* CASC	11/12/2009	LM-2C Jiuquan LA-4, SLS-2	Sun-synchronous; 699.9× 690.5× 98.3°
XW-1 (Xiwang-1)		China's first public science satellite; provides radio			12/15/2009		

							690.5× 98.3°
XW-1 (Xiwang-1) Hope-1		China's first public science satellite; provides radio amateurs w/ space communications functions; beacon voice & data transmission, terrestrial panoramic color imaging & observing state of 5-color soil grains in microgravity environment			12/15/2009		
SJ-12		Scientific research; rendezvous technology & satellite inspection; rendezvous w/ SJ-6F 2010.08; possible physical contact		SAST	6/15/2010	CZ-2D Jiuquan	
SJ-6G/6-04B (Shi Jian-6G) Practice-6G				DFH Satellite Co., Ltd., CAST	10/6/2010	CZ-4B Taiyuan	
SJ-6H/6-04A (Shi Jian-6H) Practice-6H		CAST 968 bus		DFH Satellite Co., Ltd., CAST	10/6/2010	CZ-4B Taiyuan	

Note: "Small satellites" are defined here as those weighing less than 500kg.
Data in appendix 14.1 are derived from sources cited elsewhere in text.
The symbol * indicates that data are uncertain.