telecommunications coverage of mountainous hinterlands without prior landline investment. These recognized civilian uses for satellites have greatly facilitated PRC access to foreign satellite technology, beginning in the 1980s. Since Operation Desert Storm in 1991, they have been emphasized increasingly as critical supporters of real-time long-range targeting, particularly maritime.

Establishing Satellite Programs

Following Moscow's orbiting the world's first satellite in 1957, "some well-known Chinese scientists actively advocated" that Beijing begin satellite R&D, and some universities started offering relevant specialties and training personnel.[235] Many in China's space industry wanted to launch a satellite. In 1958, CAS sent a satellite delegation to the USSR on an inspection tour, which underscored the fact that satellite launch involves sophisticated engineering, advanced technology, and a powerful industrial foundation. It must therefore proceed "from small to large, from low to high, [and] in an orderly way."[236] In January 1958, Qian initiated Project 581 to build China's first satellite when, with other scientists, he drafted a satellite development program and designated a working group.[237] In 1958, Mao called for satellite development as a top priority. "We too should produce man-made satellites," he told fellow leaders on 17 May.[238] On 29 May, Nie convened a meeting to discuss satellite development. Following the Soviet launch of *Sputnik-3* in 1958, Project 581 became a top national priority. In August 1958, SC's Scientific Planning Commission issued a report enumerating satellite benefits, including "build[ing] up the missile technological reserve" and serving as "an open signal" of ICBM capability. Nie asked CAS and 5th RA leaders to draft a satellite program plan. Developing a satellite was regarded as being of "pivotal importance" for scientific development, making Project 581 CAS's foremost design task for 1958. CAS established a New Technology Office (subsequently Bureau) to handle satellite and other R&D,[239] as well as three design institutes, for: satellite and launcher general systems design, telemetry instrumentation, and space physics.[240]

A still-impoverished China could not do everything simultaneously. Limited economic and technological capabilities forced temporary privileging of missiles and atomic energy, and the suspension of research on a heavy SLV and satellite. The PRC lacked necessary rocket technology, and in 1958, the GLF limited funds and materials. Following brief unrealistic calls to launch a heavy satellite immediately, therefore, PRC planners decided to slow satellite R&D to concentrate more forces on rocket technology.[241] In 1959, there was a larger course correction. Deng judged satellite launch beyond China's extant capacity; space research tasks should be modified accordingly. The CAS Party Committee decided to suspend heavy launcher and satellite research, and shift focus to sounding rockets, while simultaneously constructing space environment simulation labs and conducting R&D on ground tracking and telemetry equipment. Limited economic and technological capabilities thus forced the prioritization of missiles and atomic energy to meet "urgent defense needs." China had just started short-range missile licensed copy production; SLV self-design was still impossible. It thus made sense to build a space technology foundation, and develop major technology particular to satellites. By preparing research and testing, and making progress in rocket technology, a satellite could eventually be developed and launched.[242]

This realistic course of action in fact put satellite development on the path to becoming a top national priority within just a few years. In 1962, Qian began to train four Shanghai Institute of Machine and Electrical Design engineers for Project 581. In January 1965, Qian and others proposed to the CPCCC that a satellite should be added to the state plan, as China already had a strong ballistic missile foundation, "intermediate-long-range" rockets capable of lofting satellites with further development, and a "long-range" rocket in development with similar potential capabilities. This milestone yielded a new program moniker, "Project 651."[243] Qian's timing was astute. The stage for accelerated space technology development in general, and the development of a satellite and launcher in particular, had been set by several factors. These included (1) national economic readjustment, (2) "major breakthroughs" in missiles and atomic energy, (3) the formation of the 7th MMB and a "rocket industrial system," (4) CAS achievements in new satellite-relevant technology, components, materials and equipment, and (5) as the establishment of effective launch sites, tested several times.

Nie therefore asked Zhang to convene a symposium to assess China's relevant capabilities thoroughly, and it was determined that the conditions were ripe.[244] A formal "Report on the Development of Artificial Satellites" submitted by COSTND in March 1965 was approved in May by the CSC for inclusion in the state plan.[245] On 29 April, the Defense Science and Technical Commission (COSTND) submitted a proposal to launch China's first satellite in 1970–1971.[246] CAS was charged with satellite R&D, the 7th MMB with SLV R&D; CAS and the 4th MMB (Ministry of Electronics Industry) with ground observation, tracking, and telemetry facilities development; and COSTND with coordination work and building space event support ships. CAS soon formed a small task group, headed by Qian, to design China's first satellite. In July CAS, at COSTND's behest, formulated the "Proposal on Development Program for China's Artificial Satellite." This was approved by the CSC, listed among State tasks, and embodied in the long-range planning and annual plans of "relevant departments."[247] On 10 August, Zhou Enlai formally approved the plan, which stipulated "that the satellite should be visible from the ground and that its signals should be heard all over the world."[248]

In May 1966, Qian and his scientific colleagues solidified plans for China's first satellite launch, agreeing on a name (*DFH-1*), a launcher (*CZ-1*)—developed from the *DF-4* missile,[249] and a deadline (the end of 1970).[250] As an indication of Project 651's importance, it would be coordinated by the 7th Academy (today the Sichuan Academy of Aerospace Technology) and CAS, which together would form CAST. Project 651's high prioritization was also indicated by the risks the leadership took in backing the initiative. The *CZ-1* launcher had failed several months before the key launch date, was only partially-tested, and still had technical problems. Qian himself had "warned Chinese officials" in 1965 "that the work involved would be arduous."[251] *DFH-1* satellite and *CZ-1* launcher R&D began in November 1966.

The CR paralyzed satellite and space infrastructure temporarily. It produced "calamity" with numerous costs and setbacks. Struggle targeted Nie directly. The "14 Articles for Scientific Research" endorsed by central authorities and the policies for building the 5th RA were "vilified as 'revisionist.'" In 1966, the CR was "disastrous" everywhere, including in satellite development units. CAS was hit first, and soon "paralyzed." The 7th MMB was attacked, all departments were "paralyzed," and all leading cadres were criticized and removed from their posts. This left research and production "in chaos."[252] Space industry staff split into factions, halting research and production. Ground stations witnessed violent struggles. Communications were severed, material supply was stopped, construction work halted. Warring factions delayed testing, prompting Zhou to "call in the personnel concerned four times to persuade and educate" them.[253] Unrealistic goals led to dead ends: under pressure from ideologues, excessive numbers of satellites and launches were planned. Some important projects were brought to "comprehensive development" without thorough feasibility study or proper procedures; prohibitive costs would force their suspension. Serious losses were reversed, but only after astronomical waste. The CR also led to poor facilities construction requiring remedy: most CR-era space industry facilities construction was hasty, excessively dispersed, and hydrologically and geologically inappropriate. Scattered, over-stretched distribution of R&D bases caused construction redundancy and poor utilization rates and investment results. Resulting waste and inconvenience necessitated subsequent remedial measures to increase production and improve living conditions.[254]

Within a year, however, Zhou, Nie, and the CSC brought the relevant organizations under PLA control and thus protected Project 581 from the CR's worst excesses. Zhou and Nie "took a series of measures to protect" and "to ensure progress as planned" on *DFH-1*. They "tried by every means to keep the losses at a minimum in these departments."[255] When the 4th MMB's 10th Institute, responsible for assembling and debugging the satellite transponder, was "seriously affected" by chaos, Zhou had the technicians airlifted to Beijing to complete "emergency assignment."[256] In 1967, Nie proposed to the CPCCC the establishment of CAST to bring space research units under the PLA's aegis for protection and specifically under unified COSTND leadership; the CPCCC, the SC, and Mao accepted in March. Accordingly, on 17 March 1967, Zhou transferred the 7th MMB and other defense industry ministries to PLA control. COSTND took over CAS's New Technology Bureau and other satellite R&D units. Ground station construction was transferred to COSTND's experimental bases. In 1968, CAST was established and put in charge of realizing *DFH-1*. PLA control over the 7th MMB and its affiliates largely stabilized the situation.[257] Thus protected, space projects continued largely as planned, and satellite development made "smooth progress."[258]

Several performance parameters were compromised to make *DFH-1* visible and audible (via radio) on Earth. Its concept design was scaled back radically in early 1967 to accommodate the political objective of broadcasting the revolutionary melody and then unofficially used national anthem "The East Is Red," thus giving the satellite its official name. To make this possible,

> only the scheme of power supply with silver-zinc chemical battery was adopted, and the infrared horizon sensor and solar angle sensor used for attitude measurement were retained, while the solar cell plus cadmium-nickel batter power supply in the power system and the scientific exploration system, remote control system, attitude control part of attitude measurement and control system were cancelled.

To facilitate visual observation of the satellite's orbital track, a reflective "observational skirt" was affixed to the SLV's third stage.[259]

In a major victory for Zhou, Qian, and China's aerospace industry, *DFH-1* was successfully launched from Jiuquan on 24 April 1970.[260] *DFH-1* enjoyed such political protection that armed guards spaced just two utility poles apart guarded the satellite during its rail trip to the launch site. *DFH-1*'s mission was political, as its sole function was to broadcast "The East Is Red."[261] Still, it made China only the fifth country to launch a satellite.[262] China received significant international attention, and Mao congratulated Qian personally. Though its power supply ran out twenty-eight days later, *DFH-1* still orbits Earth.[263]

Despite major protection and progress, periodic ideological upheavals caused serious political and ideological damage, disrupted R&D, and wasted precious time. According to an official PRC space development history, it happened when the "Office of the Military Commission," controlled by the "Lin Biao clique," distorted the 1971–1975 Defense R&D and Production Plan severely with unrealistic goals.[264] In this way, in 1970 the slogan "catching up in three years, overtaking in two" was adopted. China was to reach "advanced international levels" in 1971–1973, and surpass them in 1974–1975. Thus "space development program was completely divorced from reality." The launch and application of fourteen kinds of spacecraft in three to five years (nine satellites per year) was demanded, an obvious technical and economic impossibility: "Such a gigantic plan was far beyond China's capability." The commission initiated large projects and excessive targets for the most advanced defense technologies, and "issued confused orders in violation of the laws of scientific research." This disrupted Nie's "three moves" RDA process, as well as advanced research. As a result, some satellite projects were impracticable and required cancellation. Semi-completed products, equipment, and capital construction items proved useless. Unrealistic goals were exacerbated by serious national economic losses; engineering and capital construction projects were cancelled after they were started. Inappropriate changes were made to the 7th MMB's setup, orientation, and tasks. In 1970, for instance, tactical missile units were shifted away. "As a result, the R&D forces were scattered, repeated construction increased, and research and production [a]ffected."[265]

Satellite Initiatives Bearing Fruit

In 1978, as part of major rectification and reforms, Deng directed focus on projects that could support civil economic construction, with special emphasis on satellites. The Ministry of Space Industry's official history describes his vision:

> China, as a developing country, was not to take part in the space race. At present, it was not necessary for China to land on the moon, but most essential to concentrate on application satellites that were urgently needed.... These instructions provided the orientation for the subsequent readjustment and reform of the space industry.[266]

As Deng knew only too well from wide-ranging experience, China's communications infrastructure was insufficient. There were economic and technical difficulties, geographical barriers, and remote land and sea areas. Comsats therefore offered the most effective communications as well as an economical solution for China's civil, diplomatic, and military needs.[267] Their successful adoption would modernize communications, radio, and TV efforts and space technology development. Communications authorities advocated comsat development for nationwide coverage, including of remote border areas, TV transmission for cities, and relaying broadcast programs domestically and internationally; as well as for "resolving communications problems for military purposes and for ocean-going…and measurements ships."[268] Accordingly, launching a geostationary comsat became China's most sophisticated megaproject of the early 1980s.

In pursuing this approach, China was able to exploit earlier satellite development efforts. In 1965, the Central Ad Hoc Committee had approved establishing a satcom system, and directed relevant organizations to engage in exploratory research. In 1970, the CMC decided to initiate engineering R&D. CAST and CALT organized research on technology for the *DFH-2* comsat and its launcher. The Institute of Spacecraft Systems Engineering proposed a tentative general scheme. But progress lagged and the satellite remained in the conceptual development phase until 1975 because the CR did not support the complex systems engineering required, including "such a colossal amount of technical coordination, performance index allocation, planning and sharing of work among various systems as well as the coordination between the satellite mass and the launching capability."[269]

In 1974, the Ministry of Posts and Telecommunications wrote to Zhou advocating comsat development. To accelerate what had been slow progress, about which he was "quite concerned," Zhou ordered the SPC and COSTND to convene "relevant departments" to determine comsat manufacturing and applications principles, and formulate and implement a concrete development program. As part of this process, CAST held a design feasibility symposium in 1974, and the 4th MMB held a symposium on "Tentative General System Scheme of Communications System."[270] The SPC and COSTND met jointly to resolve key issues, and submitted a "Report on Development of China's Satellite Communications." The proposal entailed launching directly and thereby skipping medium- and high-altitude orbital and technical tests, steps other countries typically employed. This leapfrog development approach is particularly significant given the aforementioned complexity, and testifies to the project's prioritization.

The CMC Standing Committee discussed the proposal on 31 March 1975; the CPCCC and Mao and Zhou approved it.[271] The comsat and its SLV; Xichang Satellite Launch Center; telemetry, tracking, and command (TT&C); and ground stations were added to the national plan. The resulting "331" satcom project was supervised by COSTND, with the 7th MMB responsible for developing the launcher and comsat, and other organizations responsible for other aspects.[272] In 1975 CAST held a meeting regarding the division of work on the satellite's "non-standard test equipment," as well as a "space technology development direction planning meeting." Zhang instructed: "Put emphasis on the communications satellite. As it has both political and economic values, concentrate resources to develop it."[273]

Consistent multi-level leadership prioritization spurred comsat progress. Zhou's major support had revived efforts; now with official approval development was "on the right track."[274] In 1977, satcom was listed as a "Three Grasps" project. CAST implemented the "chief designer and commander system," and Ren Xinmin was appointed CD. This assured financial support and other benefits to ensure that technical problems were resolved expeditiously.

From 1975–1977, the focus was on conceptual design. To direct the large-scale interdepartmental effort, the SC and CMC approved the formation of a "Satellite Communications Project Leading Group." The 7th MMB developed the comsat and SLV, and developed the ground TT&C system with the 4th MMB, which was responsible for the satellite ground station.[275] COSTND constructed the launch site. In 1977, China registered with the International Telecommunication Union for a GEO satellite position.[276] Prototype development occurred from 1977–1979. In 1979, all subsystems prototype products passed relevant tests, and the project entered the "flight model development phase," followed by launching.[277] The "critical work phase" lasted from 1980–1983, with test preparations beginning in 1983.[278]

The first "experimental" (试验) *DFH-2* comsat launch from Xichang, on 29 January 1984, made China "the third (after the United States and the European Space Agency) to employ a cryogenic [liquid oxygen/hydrogen] upper stage"[279] but suffered a third-stage failure. The satellite was sent to parking orbit, then adjusted to elliptical orbit; some scientific tests were conducted.[280] To meet the next launch deadline for this high priority project, COSTND's newly established successor, Commission for Science, Technology and Industry for National Defense (COSTIND), recalled the *Yuanwang* space event support ships immediately, and dispatched an airplane to retrieve telemetry record tapes. After three weeks of round-the-clock efforts, comprehensive telemetry analysis and multiple verification tests pinpointed a fault in the hydrogen-oxygen engine's turbo pump. Five short- and one long-term engine test runs determined that the problem had been solved.[281] On 8 April 1984, China launched its first "experimental" *DFH-2* comsat successfully. This made China the fifth nation in the world to launch a geostationary comsat, and demonstrated what for China were breakthroughs in space, electronics, and materials technologies.[282] Under CD Qi Faren, a "practical" (实用) *DFH-2* communications and broadcast satellite followed in 1986, with three more launched by ~1992.[283] To meet end users' needs, the 7th MMB's 5th Academy accelerated development. Having leapfrogged "traditional development phases," China's comsats were credited with delivering "remarkable economic and social benefits."[284] They also allowed the PLA Signal Corps to establish a National Defense Communications Network, which enhanced operational command, and facilitated nuclear submarine and ship communications as well as missile testing.[285] By 1984, China completed a missile and satellite measurement and control network covering its mainland and proximate sea areas.[286] Together with *Yuanwang* space event support ships and microwave communications, this completed a "high-accuracy" TT&C system whose construction for missiles had begun in the 1950s with Soviet assistance and that for satellites in the 1960s, with a radio tracking system developed in the early 1970s. By the late 1980s, China would be able to provide TT&C to foreign customers in conjunction with satellite launch.[287]

For the next three decades, satellite development and testing gradually increased in volume and sophistication. China developed and launched the *DFH* large satellite series, the *SJ* small experimental satellite series, the *FSW* recoverable remote sensing satellite series, and the *Fengyun* (*FY*) meteorological satellite series. For Cold War China, application technology was challenging and expensive. Therefore, some complex technologies were first tested on cheaper experimental satellites. In the early 1970s, the *SJ*-series was put on the agenda. Based on *DFH-1*, possibly including some of its previously-discarded aspects, *SJ-1* had its development procedure simplified in 1965, its conceptual design initiated in 1968, its configuration determined, and its launch on 3 March 1971, operating normally for more than eight years.[288] In 1971–1972, "relevant departments" investigated space physics abroad, and suggested that China develop its first space physics exploration satellite. The substantially more sophisticated 250kg *SJ-2* was subsequently developed, and launched on 20 September 1981.[289] *SJ-1* through *4* performed manifold scientific experiments.[290]

In 1975, China launched its first 1,800 kg *FSW* satellite, with improved versions following in 1976 and 1978, thereby becoming only the third country to master satellite recovery. By 1989, it would launch a total of eleven.[291] *FSW* provided China's SAC, PLAN, PLAAF necessary operational information. The PLA formed special organs to utilize satellite remote sensing information.[292] China's first "serviceable telecommunications and broadcast satellite" was launched in February 1986, followed by another two such satellites in 1988.[293] In the early 1980s, China began to lay the groundwork for real-time remote sensing.[294] China began prototype development for the 750kg *FY-1* experimental meteorological satellite in 1981. In its first use of the *CZ-4* launcher, China orbited *FY-1* on 7 September 1988, though control failures limited its operational duration to thirty-nine days.[295]

By the Cold War's end, China established a comprehensive space infrastructure, with launch sites in Jiuquan, Taiyuan, and Xichang. It 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 [and] communications network, with services for launching and TT&C of foreign satellites starting to be provided.[296]

By 1991, China had launched thirty-five satellites into LEO, solar-synchronous and geostationary orbits from a range of SLVs.[297]

Through the Cold War's end, PRC satellites continued to suffer multiple limitations: varieties were incomplete, service lives short, payloads small, and ground systems still limited.[298] China therefore took a cautious approach to satellite development: "Each satellite in [a given] category is a variation of a baseline design."[299] This suggests a methodical program supporting long-term comprehensive national development. It may also represent recognition of the fact that while China's defense industrial base had strengthened significantly by the end of the Cold War, it is only now beginning to play a leading role in the microelectronics revolution that has driven international satellite development.[300]

Still, microcomputers for missiles and satellites that China were for some time more advanced than those China developed for aircraft. This is partially a product of the prioritization of electronics for the "Three Grasps."[301] From the late 1970s–mid-1980s, for instance, China developed a batch of special purpose computers for satellites, rockets, and missiles. High-speed computers supported "second generation" strategic weapons and new types of aerospace vehicles.[302] Similarly, "China's satellite capabilities [were] less impressive than its launch capabilities"[303]—but still better than those of its aircraft. PRC analysts rightly believed that their nation's "technologies of satellite telemetry and recovery, [and] launch[ing] of geostationary satellite[s] [have] ranked among [those of] the world's most advanced countries."[304]

Present Capabilities

Beijing's satellite capabilities, both military and civil, are improving rapidly. China still has only a fraction of the U.S.'s overall space capability, has significant coverage gaps in every satellite application, and relies considerably on technology acquired through non-military cooperation with foreign companies and governments. Work with foreign partners has been central to PRC satellite development and vital component of China's development strategy. Nearly every satellite in recent years has benefited significantly from technology, know-how, and managerial and organizational influence acquired from foreign governments (particularly Russia and Brazil), organizations (the European Space Agency), and corporations (especially the UK's Surrey Satellite Technology Limited). Without these contributions, China would likely have achieved considerably less progress in satellites to date. For the foreseeable future, China's satellite development will continue to exhibit significant foreign influence. China will likely purchase commercial imagery products to supplement its current reconnaissance capabilities until it is able to deploy a more advanced set of reconnaissance satellites in the coming decade.

But China has been careful to diversify its development partners, and there is no chance of a Sino-Soviet split-scale disruption. China is cultivating a new generation of extremely talented engineers who are learning from foreign partnerships while developing indigenous capabilities. China's satellite developers are combining foreign knowledge with increasingly robust homegrown capabilities to produce significant advances of their own. For instance, they are experimenting with a new workplace culture that emphasizes modern management, standardization, quality control and emerging mass production ability—part of a larger trend in China's dual-use military-technological projects.[305]

In June 2000, Qinghua University Enterprise Group joined CASIC and Qinghua Tongfang Company, Ltd. to fund and jointly establish Aerospace Qinghua Satellite Technology Company, Ltd. In September 2001, China Yintai Investment Company became the fourth shareholder by providing venture capital.[306] Aerospace Qinghua bills itself as "China's first satellite development and manufacturing company established in accordance with a modern industrial system." The corporate ethos is "standardized management," and the company practices "quality control, account management, logistics, and [the use of] research and development flowsheets." Aerospace Qinghua has implemented ISO 9000 standards since 2002.[307] It

> has prepared more than six hundred system documents including quality control handbooks, procedural documents, major operations documents, requirements of purchase of satellite-use component and device and quality grades, requirements of engineering management of satellite projects and technological documents, and so on.

As a result of these efforts, apparently, "There has not been any quality problem during any satellite launch process of the company."[308]

In addition to high quality standards, Aerospace Qinghua is successful due to its managing and hiring practices. It has used accounting and logistics management system software "to enhance management efficiency, promote information exchange and sharing, and intensify internal management." The company's management structure is composed of "a vertical technological line and a horizontal project line." Employees are carefully selected and mentored, and their average age in 2004 was under thirty-one. "Employees can select departments to work with according to their own disciplines and ambitions, and the company would assign a department head as a coach for an entry employee with a term of three to six months," after which the candidate may be promoted rapidly, promoted slowly, or terminated. As part of training, the budget for which is calculated precisely in relation to employee salaries, the company brings in outside experts to give talks and supports employee education and specialized training.[309]

Founded by CAST and its parent company CASC in August 2001, Aerospace DFH Satellite Co., Ltd. is China's foremost satellite manufacturer. A decade ago, it implemented

> a completely new team deployment plan [for] managing space satellite development and manufacturing. It also represents new exploration in reform for satellite project management systems. Not long after this scheme was put into operation, three features had been observed as follows: First, both vertical and horizontal aspects were able to communicate and exchange directly with each other while both aspects were controllable. As a result, the model management was neither [excessive] bureaucracy nor anarchy, making it possible to use fewer human resources to complete more projects. Second, [under] the company's model management all command and manage their corresponding model teams [both horizontally and vertically], thus making it possible to make various decisions quickly, accurately and in a timely manner. Third, both expertise development and model background preliminary research [coordinate] closely and proceed smoothly.

This approach has yielded advantageous R&D characteristics:

> clearly specified responsibilities, high management efficiency, convenient coordination, improved usability of both equipment and manpower, and so on. It has played an important role in significantly reducing the development and manufacturing cost while shortening satellites' development and manufacturing cycle. Under such a model, one person may be responsible for multiple projects. As a result, it increases both the effectiveness and flexibility in human resources management. In the meantime, personnel's work enthusiasm has also been mobilized. Furthermore, it is advantageous for each individual employee to be self-fulfilled.[310]

In a development that mirrors Western efforts to reduce costs and enhance quality control and reliability but is being implemented more thoroughly and cheaply, satellite buses (mission-optimized, standardized platforms around which high-volume-production units are built) will quite literally constitute the backbone of China's future satellite efforts, particularly with respect to microsatellites. As part of a larger trend in China's dual-use military technological projects, China is developing multiple variants of multiple satellite buses. Additionally, China is perhaps better-positioned to fully incorporate technological advancements without incurring the conventional time delay that has been experienced by other similar programs. In other words, China may not be further down on the curve today than the U.S. and other advanced economies, but tomorrow it may be far more nimble, more agile and far better equipped from both a human and technical resource standpoint to skip over generation(s) of satellite technology developed by other nations.

Already, these factors are permitting China to increase its in-orbit assets rapidly. China has developed and orbited a full range of military, civilian, and dual-use satellites of various mission areas and sizes. New iterations of the *DFH* series are being developed to this day, primarily for communications functions. *SJ* satellites continue to test new technologies of increasing variety and sophistication. China's reconnaissance-capable satellites include electro-optical (EO), multi- and hyperspectral, and radar, especially synthetic aperture radar (SAR). Series include *Fengyun* (*FY*) meteorological satellites, China-Brazil Earth Resources Satellites (CBERS), *Ziyuan* (*ZY*) surveying and monitoring satellites, the Disaster Monitoring Constellation (DMC), *Haiyang* (*HY*) ocean monitoring satellites,[311] *Huanjing* (*HJ*) disaster monitoring satellites, and *Yaogan* (*YG*) experimental and remote sensing satellites, *Tianhui* stereoscopic imaging satellites, and *Gaofen* remote sensing satellites.[312] China's *YG* series of approximately twenty-three advanced, paired or trio SAR and EO remote-sensing satellites, operating in near-polar SSO, "may provide multiwavelength, overlapping, continuous medium resolution, global imagery of military targets."[313]

China's second data-relay satellite, *Tianlian-1-02/B,* provides "near real-time transfer of data to ground stations from manned space capsules or orbiting satellites."[314] *Tianlian-1-03*, launched on 25 July 2012, further extends and strengthens this capacity.[315] China has made great progress in small-satellite development; its satellites under 500 kilograms now boast high performance, in addition to low weight. The 9.3 kg *Tiantuo-1* nanosatellite, launched on 10 May 2012, receives signals from China's shipborne Automatic Identification System.[316]

China achieved eighteen space launches in 2012 that lofted eleven new remote sensing satellites, six Beidou navigation satellites, five experimental small satellites, three comsats, one meteorological satellite and one data relay satellite.[317] Of greatest scale and sophistication, China's *Beidou-1* positioning, navigation, and timing (PNT) constellation achieved regional navigation and communications coverage by the end of 2012.

Meanwhile, China is beginning to realize lucrative sales and geostrategic benefits by exporting larger, simpler remote sensing and comsats as well as components and launch and training services to such developing nations as Venezuela, Nigeria, and Laos.

Future Plans and Projections

To ensure reliable independent access in the future, and to support broader operations, China is deploying a thirty-five-satellite (five geostationary, thirty medium earth orbit) constellation—*Beidou-2/Compass* (北斗卫星导航定位系统)—that will provide much-improved accuracy, with global navigation coverage anticipated by 2020.[318] This could well precede deployment of Europe's Galileo system, making China only the third country after the U.S. and Russia to have its own PNT system. Given limitations in the commercial utility of Russia's GLONASS system, China's *Compass* would likely exceed it in overall capability. The director of the China Satellite Navigation and Locating Applications Management Center, Yang Baofeng, terms *Compass* "the largest scale, most complex, most technically demanding, and most widely applicable space-based system in Chinese aerospace history."[319]

Further prioritization ensures top leadership support and tremendous institutional, financial, and human resources for PRC satellite development. Developing a "high-resolution earth observation system," to include an "airborne remote sensing system" and a "national satellite remote sensing (ground) network system," is among sixteen national megaprojects prioritized in China's Eleventh Five-Year Plan (2006–2010) and the "Outline of National Medium- and Long-Term Science and Technology Development" (2006–2020).[320] While proceeding cautiously with respect to establishing overseas ground stations, China plans by 2030 to have established "network nodes" at the North Pole, South Pole, and in Brazil as part of a "Digital Earth Scientific Platform."[321] In parallel to China's own public statements, DoD projects that "China will continue to increase its on-orbit constellation with the planned launch of 100 satellites through 2015. These launches include imaging, remote sensing, navigation, communication, and scientific satellites, as well as manned spacecraft."[322] DoD further assesses that "In the future China may expand its national early warning network to protect China's territorial air space and waters farther from the mainland, as well as to provide space defense. This effort would include China's growing constellations of reconnaissance, data relay, navigation, and communications satellites."[323]

Conclusion: China's "Two Bombs and One Satellite"

China built its space industry on a foundation of American and Soviet knowledge and Soviet hardware, and pursues foreign technology inputs actively to this day. Yet its Cold War achievements in rockets and secondary progress in satellites, as encapsulated in the "Two Bombs and One Satellite" (两单一星)

rubric, demonstrate its capacity to achieve national military-technological goals through highly-prioritized megaprojects. These feats have been extolled as a model for future initiatives by such PRC leaders as Jiang Zemin, an electrical engineer by training who spent years rising through management in China's state-owned electronics industry, making him well-placed to understand the requirements of modern civilian and military technology development. The official CCP Press-published reader on Jiang's thought concerning national defense and military construction showcases his speeches in this area. Under the rubric of "firmly emphasizing doing some things while not doing others and concentrating forces on bringing forth key equipment," he emphasized the importance of focusing initial investment on achieving breakthroughs concerning key technologies that promised disproportionate cost-effectiveness and military impact. Jiang "stressed the need to stand in the forefront of the world technological revolution."[324] He made similar points at a General Assembly on the Recognition of Science and Technology Experts Who Have Made Outstanding Contributions to the Development of "Two Bombs and One Satellite."[325]

The evolution of China's aerospace programs from 1949 through the end of the Cold War suggests that leadership goals, driven in part by perceptions of strategic threat and lack of access to foreign technology—rather than inherent technological limitations or economic considerations per se—best explain this hierarchy of achievement. These political decisions have taken the form of great national financial and human capital commitments since the 1950s. By allocating the necessary physical and human capital, political decisions shaped the specific capabilities needed to achieve these goals. PRC politics over Cold War decades thus shaped relative progress in different aerospace subsectors, and caused Beijing to indigenize some aerospace areas ahead of others.

Under Mao and Zhou's direction and the guidance of Qian and other military-industrial technocrats, China devoted much of its limited technical resources to producing nuclear weapons and missiles to deliver them; missile development became China's top aerospace priority. Political decisions, not technological capacity, made Beijing prioritize nuclear weapons development, "unwaveringly [lend] strong support [to missile development] from beginning to end,"[326] and to begin satellite development and launching. In practice, this led to a redoubling of emphasis on rocket/missile development. Nuclear weapons lie at the mercy of aerospace capabilities: they cannot provide credible deterrence without effective delivery systems. Satellites likewise rely on effective launch systems.

Top level support for rockets and satellites persisted despite political and technical challenges. According to the definitive official history of China's Cold War space program,

> Experts in charge of the technical work usually got nervous when an experiment failed, sensing the pressures on their shoulders. However, Deng Xiaoping, Ye Jianying, and Nie Rongzhen always came with the words "Failure is the mother of success" and "A lesson from failure can be more valuable than success."[327]

Particularly during the early Cold War years, specific strategic threats influenced Chinese aerospace development significantly. Mao and other PRC leaders prioritized the pursuit of capabilities they perceive as most urgently needed to address pressing strategic threats as determined by their perceptions of danger, at the expense of capabilities (e.g., aircraft) that could not address China's most critical needs. They thus diverted scarce resources to developing nuclear weapons and the ballistic missiles to deliver them to counter nuclear coercion. Later short-range missiles were developed to address security concerns vis-à-vis foreign overflights and Soviet forces. Though satellite work started later than that for rockets, satellites were also prioritized for military reasons and because they could not be purchased from abroad following the Sino-Soviet split.

Beijing's relative prioritization of rockets and satellites was revealed in even starker relief during the GLF and the CR, which undermined organizations and exacerbated resource competition—particularly for other programs such as aircraft. Initially one of China's defense industry's few early "pockets of adequacy," and subsequently one of its leading "pockets of excellence," China's rocket/missile production has become relatively well-organized and capable.

China's current aerospace growth is part of a larger technological transformation fueled by dramatically increased spending on research and development and access to foreign technology to a degree that was simply impossible during the Cold War. Now a potent combination of world-class technological competence and commercial dynamism is propelling development in ways that China's government could not achieve alone. No longer solely reliant on state prioritization or even domestic development, programs enjoy consistent access to high-level PRC and foreign personnel, funding, and technology. Chinese strategic industrial sectors across the board are benefiting from these dynamics. However, the advanced nature of China's rocket industry and the growing flexibility of its satellite industry suggest that they will remain leading sectors.

References and Notes

[1] The views expressed here are solely those of the author, who is grateful for invaluable suggestions from Michael Chase, two anonymous reviewers, and a former U.S. official. An earlier version of the present argument was published as Andrew S. Erickson, "China's Space Development History: A Comparison of the Rocket and Satellite Sectors," *Acta Astronautica* 103 (October/November 2014): 142–167.

[2] It will not address China's successful human spaceflight program. While earlier efforts failed for lack of funding and prioritization, the *Shenzhou* program (Project 921) initiated in January 1992 allowed China to become the third nation to orbit an astronaut independently in 2003 and achieve its first (the world's third independent) extra vehicular activity in 2008. In 2011, a three astronaut-mission docked with the *Tiangong*-1 target module in preparation for building a full-fledged space station. For details, see the 中国载人航天科普丛书 [China Manned Space Science Book Series] published by 中国宇航出版社 [China Astronautics Press].

[3] For additional background on Qian, see "航天事业开拓者—钱学森" [Space Industry Pioneer—Qian Xuesen], 国防科技工业 [Defense Science & Technology Industry] 3 (2005): 35.

[4] "Qian Xuesen," *People's Daily*, March 30, 2010, http://english.people.com.cn/90001/90782/99727/6934489.html.

[5] While Qian was informed of and even involved in areas of China's defense industrial development besides aerospace, such as the nuclear program, it appears that he did not play a decisive role. Iris Chang, *The Thread of the Silkworm* (New York: Basic Books, 1995), 228–229. This is the leading English-language biography of Qian.

[6] COSTND was established in 1958 to manage China's burgeoning strategic weapons base. Led by Nie, it reported directly to the Politburo and CMC. In 1982, COSTND and related organizations were subsumed into the newly created Commission for Science, Technology and Industry for National Defense (COSTIND), with comprehensive responsibility for managing programs and facilities for both strategic and conventional weapons and reporting lines to the State Council and CMC. In March 2008, COSTIND was renamed the State Administration for Science, Technology and Industry for National Defence (SASTIND) as part of its absorption into a new bureaucratic super entity, the Ministry of Industry and Information Technology (MIIT).

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[10] China has officially pledged never to use nuclear weapons in a first strike and emphasized the comparatively limited size of its nuclear arsenal as evidence of its second-strike focus. The inaccuracy of China's initial ICBMs necessitated a focus on counter-value, as opposed to counter-force, targeting. Throughout most of the Cold War, including hostilities with the Soviet Union in the late 1960s—during which Moscow reportedly considered surgical strikes on China's nuclear facilities—it was far from certain that China had been able to establish a fully reliable second strike capability given its relative paucity of weapons, and their relative lack of sophistication (e.g. liquid fuel, etc.). China's leaders were concerned that their second strike capability might be unreliable, and hence not fully credible to a potential opponent. In the short term, the PLA attempted to make the most of its arsenal by dispersing and concealing its ICBMs in caves and hardened silos and by constructing decoy silos. China's long-term strategy was to gradually and methodically modernize its nuclear

arsenal and delivery systems in order to achieve eventual improvements in nuclear deterrence without alarming its neighbors and thereby triggering a regional arms race. Hoping to exploit post-Cold War disarmament and power diffusion to make time for its strategic modernization, Beijing adopted the Anti-Ballistic Missile (ABM) Treaty as a key link in its arms control strategy.

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