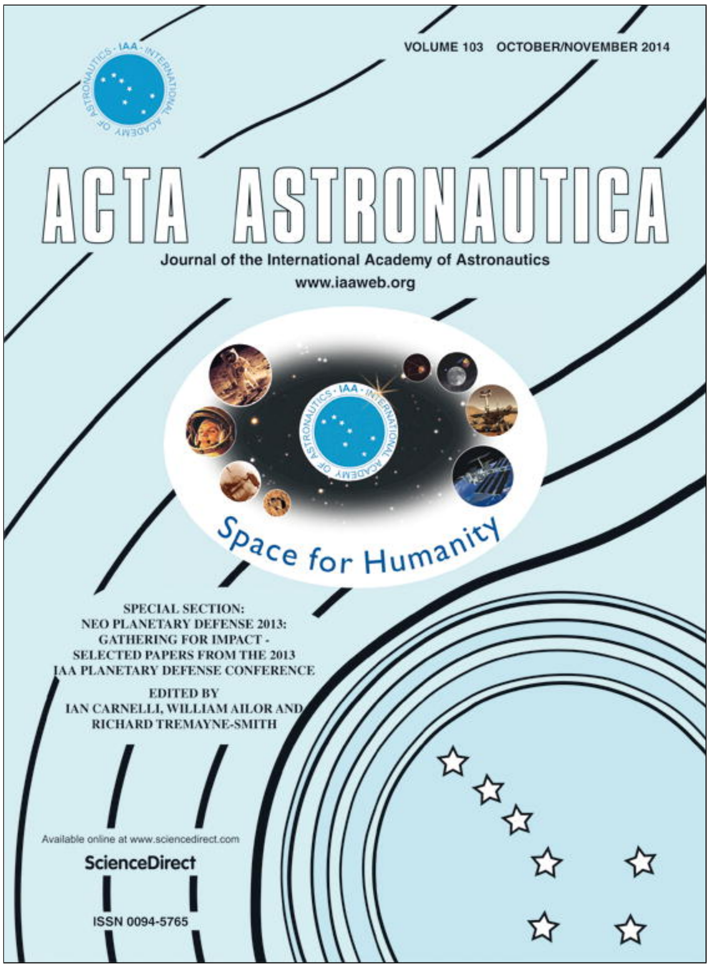
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China's space development history: A comparison of the rocket and satellite sectors☆

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ABSTRACT

China is the most recent great power to emerge in aerospace. It has become the first developing nation to achieve some measure of aerospace production capability across the board. Outside the developed aerospace powers, only China has demonstrated competence concerning all aspects of a world-class aerospace industry: production of advanced rockets, satellites, and aircraft and of their supporting engineering, materials, and systems. As an emerging great power during the Cold War, China was still limited in resources, technology access, and capabilities. It thereby faced difficult choices and constraints. Yet it achieved increasing, though uneven, technological levels in different aerospace sub-sectors. Explaining this variance can elucidate challenges and opportunities confronting developing nations sharing limitations that previously constrained China.

Rockets (missiles and space launch vehicles/SLVs) and satellites (military and civilian) were two areas of early achievement for China, and represent this article's two in-depth case studies. Initial import of American and Soviet knowledge and technology, coupled with national resources focused under centralized leadership, enabled China to master missiles and satellites ahead of other systems. Early in the Cold War, great power status hinged on atomic development. China devoted much of its limited technical resources to producing nuclear weapons in order to “prevent nuclear blackmail,” “break the superpowers' monopoly,” and thereby secure great power status. Beijing's second strategic priority was to develop reliable ballistic missiles to credibly deliver warheads, thereby supporting nuclear deterrence. Under Chairman Mao Zedong's direction and the guidance of the American-educated Dr. Qian Xuesen (H.S. Tsien), missile development became China's top aerospace priority. Satellites were also prioritized for military-strategic reasons and because they could not be purchased from abroad following the Sino-Soviet split. By the Cold War's end, China had achieved comprehensive rocket and satellite capabilities. Today it is pursuing cutting-edge systems in both areas, continuing formidable indigenous development while absorbing

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foreign technology where possible. To understand the reasons for China's aerospace development trajectory it is necessary to consider closely its specific history and larger context.

The article will therefore examine the decision-making, organization, and technological development that made such progress possible.[2]

1. Transplanting and nurturing an industry

Aerospace has been a strategic sector for China: its development has been critical to fulfilling Beijing's great power ambitions and represents the cutting edge of larger technological development. In the early years of the People's Republic of China (PRC) under Mao's leadership, aerospace development addressed important national interests including nuclear deterrence, military modernization, and international status. Broader infrastructure development and resource management would become important following Deng Xiaoping's post-1978 reform and opening up of China. These efforts, together with civil–military integration, increased organizational efficiency and heightened emphasis on commercial launchers and satellites.

Lacking even relevant raw materials and trained personnel initially, China had to both import and further develop an aerospace industry. The Communist Party of China (CCP) launched its first Five Year Plan for industrial and agricultural development and production in 1949 determined to address these and other limitations. Lingering deficiencies necessitated significant Soviet guidance and assistance, which were secured by the February 1950 Treaty of Friendship, Alliance, and Mutual Assistance. Soliciting extensive Soviet aid and focusing on development of heavy industrial plants and equipment, China doubled industrial capacity within five years.

By this time, U.S.-educated missile scientist Qian Xuesen[3] had returned to his home country via politically-charged McCarthyist deportation on October 8, 1955. Qian brought with him considerable knowledge developed as master's student and professor at MIT; a doctoral student, faculty member, the Robert H. Goddard Professor of Jet Propulsion, and the first director of the Daniel and Florence Guggenheim Jet Propulsion Center at Caltech; and a founder of Jet Propulsion Laboratory. His expertise was further honed as a consultant to the United States Army Air Forces, for which he was temporarily assigned the rank of Colonel, and inspecting German rocket scientists, their facilities, and V-2 rockets. In naming Qian its Person of the Year in 2007, Aviation Week & Space Technology wrote of his interrogation of Wernher von Braun, “No one then knew that the father of the future U.S. space program was being quizzed by the father of the future Chinese space program.”[4] Qian would parlay this unique experience and technology transfer, coupled with internationally-recognized genius, into a critical role in establishing China's aerospace program and directing its progress. While Qian was by far the most prominent Chinese space expert of his generation, one hundred Western-educated and -trained compatriots who returned simultaneously rounded out the indigenous pillars of the transplanted foundation upon which China built its initial space industry.[5]

Marshal Nie Rongzhen was the first major People's Liberation Army (PLA) technocrat, heading the National Defense Industry Office and its successor, the Commission of Science and Technology for National Defense (COSTND)[6] from 1958 to 1970. Nie and his organization would be critical to establishing and supporting China's rocket and satellite programs and keeping them on track through years of domestic political upheaval. Other guardians of these top-priority aerospace programs included Premier Zhou Enlai; military leader, military industry builder, and Defense Minister (1982–1988) General Zhang Aiping; Vice Premier and holder of top military positions General Luo Ruiqing; and Marshall Ye Jianying, who helped coordinate the ouster of the Gang of Four (first lady Jiang Qing and her radical political allies Wang Hongwen, Yao Wenyuan and Zhang Chunqiao) in 1976, and served as Defense Minister (1975–1978). Less-prioritized programs, such as China's politically-ill-fated aviation industry, would not receive such nurturing or protection. Less firmly-rooted institutionally to begin with, they would subsequently suffer greatly from ideological infighting and disarray.

Thanks largely to high-level prioritization, China accrued a broad array of rocket and satellite successes.

[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, 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).

It tested the *Dongfeng* (DF)-2A (CSS-1) medium-range ballistic missile in 1964 and deployed it in 1966. In 1970, using the *Changzheng* (CZ)-1 SLV, China became the fifth nation to launch a satellite; *Dongfanghong* (DFH)-1's mass exceeded that of the of the four previous countries' first satellites combined. The DF-5 (CSS-4 Mod 1) intercontinental ballistic missile (ICBM) was test-flown in 1971, tested for its full-range of 9300 km over water in 1980, and deployed in 1981. In 1984, China launched the DFH-2 geostationary communications satellite (comsat). In 1988, China successfully test-launched the *Julang* (JL)-1 (CSS-N-3) submarine-launched ballistic missile (SLBM). Most of these systems were not cutting-edge in capability, but no other developing nation could boast such a comprehensive array of them.

2. Rockets: longtime chinese aerospace leader

2.1. Nuclear program: early missile driver

There were two major areas in which the Soviet Union proved unwilling to provide substantial assistance, even in the heyday of Sino-Soviet cooperation. Early in the Cold War, great power status hinged on atomic development. China devoted much of its limited technical resources to producing nuclear weapons and missiles to deliver them credibly, in part because Moscow would not furnish these critical technologies despite conducting its own initial nuclear test in 1949. During the Korean War of 1950–1953 and the Taiwan Strait crises of 1954–1958, the United States threatened to use nuclear weapons against China. From the start, therefore, Beijing decried arms control as imperialist monopolism.[7] According to retired PLA General Pan Zhenqiang, "Faced with U.S. nuclear blackmail in the 1950s, China had no alternative to developing its own nuclear capability so as to address the real danger of being a target of a nuclear strike. But even so, Beijing vowed that having a nuclear capability would only serve this single purpose."[8] The official politburo decision to pursue a nuclear weapons program came in 1955, following Mao's personal approval on January 15 of that year. The following year, Mao prioritized its funding at the expense of other programs. On March 6, 1956, Defense Minister and State Council (SC) Vice Minister Peng Dehuai advocated developing "new weapons, such as nuclear weapons, missiles… which China could not produce at that time." In April 1956, Mao declared that China would have atomic bombs—"if we do not want to be bullied, we must have these things." Despite short-term decreases in overall government and military spending, the budget for sophisticated military technology development was increased—a focused approach indicating prioritization of limited resources to advanced weapons development.[9]

Mao's dialectical vision shaped Beijing's nuclear policy. Mao condemned nuclear weapons as a "paper tiger" and vowed not to stockpile a large arsenal.[10] He declared that "nuclear weapons and their delivery systems could not alter the basic nature of warfare or require the revision of his People's War doctrine."[11] Yet he ordered the expenditure of resources that China scarcely had and the exploitation of technological capabilities that China would have to develop rapidly.[12] The U.S. Central Intelligence Agency made analytical mistakes that it later attributed to "lack of appreciation for Chinese technical skills, innovativeness, and determination, in the absence of Soviet help."[13] Beijing's second strategic priority after producing nuclear weapons was developing successful ballistic missiles to credibly deliver them to increasingly-distant targets, thereby supporting nuclear deterrence. Thus missile development would become China's top aerospace priority, stunting other programs, including aircraft production.[14] On October 16, 1964, China would successfully detonate its first atomic bomb, becoming only the fifth nation to do so (after the United States, the Soviet Union, the UK, and France).

[7] 周宝根 [Zhou Baogen], "中国与国际核不散机制的一种建构主义分析" [A Constructivist Analysis of China and the International Nuclear Non-Proliferation Regime], [世界经济与政治] *World Economics & Politics* 2 (2003) 23–27.

[8] Pan Zhenqiang, "China's Insistence on No-First-Use," *China Security* 1 (Autumn 2005) 5.

[9] Xie Guang, editor-in-chief, *China Today: Defence Science and Technology* 1 (Beijing: National Defence Industry Press), 28 [Hereafter, *China Today* 1 or 2].

[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.

[11] John Wilson Lewis and Hua Di, "China's Ballistic Missile Programs: Technologies, Strategies, Goals," *International Security* 17.2 (Autumn 1992) 20.

[12] For the most detailed accounts to date, see John Wilson Lewis and Xue Litai, *China Builds the Bomb* (Stanford, CA: Stanford University Press, 1988); Qian Sanqiang, 钱三强年谱 [Chronicles of Qian Sanqiang] (Shandong: Friendship Press, 2002); Qian Sanqiang, 钱三强科普著作选集 [Selection of Writings on Popular Science by Qian Sanqiang] (Shanghai: Shanghai Education Press, 1988); 中国原子能科学研究院大事记 (1950–2011) [Major Events at the China Institute of Atomic Energy (1950–2011)], http://www.ciae.ac.cn/subpage/dashiji_1.htm; "白银时代–核弹本记 (二)," [The Silver Age – Remembering the Nuclear Bomb (Part II)], blog.sina.com.cn/s/blog_5400d6a30100y17n.html.

[13] "Report on a Study of Intelligence Judgments Preceding Significant Historical Failures: The Hazards of Single-Outcome Forecasting," Memorandum for the Director of Central Intelligence, NIC 9079-83/1, December 16, 1983; "The Chances of an Imminent Communist Chinese Nuclear Explosion," Special National Intelligence Estimate 13-4-64, August 26, 1964; "The Chinese Communist Atomic Energy Program," National Intelligence Estimate 13-2-60, December 13, 1960.

[14] *China Today* 1, 46–47.

2.2. Qian fathers missile and satellite programs

From the late 1950s through the 1970s, Qian played an instrumental role in leading China's missile and satellite development efforts.[15] Through a range of top positions, including as an influential member of China's State Council for Scientific Planning, he helped to secure the support of PRC leaders such as Mao and Zhou, which was instrumental in allocating scarce material and human resources. Qian played an important role in mapping out plans for early PRC space technology development, training Fifth Research Academy (5th RA) S&T personnel, and establishing the Chinese Academy of Space Technology (CAST).[16]

Qian made four significant contributions to the PRC missile program in particular: "he inspired and goaded his underlings to produce, introduced them to key theoretical formulas which they adapted for practical purposes, developed a systems management technique to minimize bureaucracy, and shaped the organizational and technical direction for China's first generation of missiles."[17] Qian's former subordinate Li Jin recalls that "…[I]t was his overall vision and organization that mattered… He was the one who made the proposals and gave advice to Mao and Zhou Enlai. They listened to him. He got us the funding."[18] Qian was so respected by China's leadership that in 1964 he would be given the opportunity to personally tutor Mao in science.

Bringing his invaluable MIT-Caltech education and U.S. government experience with him, Qian applied considerable American technology to China's aerospace programs. This included *Toward New Horizons*, a blueprint for U.S. air defense on which he had worked at the end of World War II. In 1962, Qian would advocate use of the American Program Evaluation and Review Technique (PERT). Used in the late 1950s for the storied Polaris SLBM program, this was a dynamic scheduling approach in which all work items were incorporated into a program flow chart.[19] By bringing PERT to China, Qian gave it an advantage that even the USSR lacked. It "was disrupted" from 1966 to 1978, but was reinstated and made a major contribution to the "Three Grasps" (三抓) missile and satellite projects of the 1970s to 1980s.[20]

Qian played a critical role in ensuring that missiles, and also satellites, were prioritized over aircraft. No matter where in China it was deployed from, the H-6 bomber—originally tasked with nuclear weapons delivery—could not hope to reach Moscow or Washington, two key targets for deterrence. While it underestimated aspects of PRC nuclear progress, the CIA grasped Beijing's prioritization of ballistic missiles and satellites, to the point of anticipating slightly prematurely in 1967 that "For political effect, China will probably attempt to launch an earth-satellite as soon as possible. This might be accomplished this year…."[21]

2.3. Early missile development

In the mid-1950s, China's missile industry was established, with a focus on ballistic missiles to provide an independent capacity for nuclear counterattack. To lay the foundation for future SLV development, China engaged in simultaneous R&D of spacecraft, ground telemetry, and telecontrol.[22]

2.3.1. Promotion by Qian

Within a few months of returning to China, during which the government treated him as a national treasure, Qian advised Peng concerning short-range guided missiles as well as missile research and development.[23] On January 5, 1956, Qian became director of the concurrently established Institute of Mechanics.[24] The Beijing-based center was devoted to defense applications research concerning mechanics and high-speed aerodynamics. It was staffed by China's most talented scientists, a core group of whom—like Qian—had been trained in America and other technologically-advanced nations. In the late 1950s, Zhou stated that while years of Sino-American ambassadorial talks had yielded little else, "We had won back Qian Xuesen. That alone made the talks worthwhile. Apart from Qian, there were quite a number of specialists returning from abroad. All of them have been placed on various leading technical posts to contribute to the space industry. Among them were Yao Tongbin, specialist in materials sciences, Zhuang Fenggan in aerodynamics, Yang Jiachi in automatic control, and Huang Chang in microelectronics."[25]

Qian "also talked with other high-level military officials, urging them to make satellite and launching vehicle development a national priority."[26] They quickly did so, with Peng stating on January 20, 1956: "We must solve the problems of rocket air defense and rocket launching from the sea. We will develop it ourselves even if the Soviet Union does not help." (see footnote 23). On the basis of his advice, which was well-received, on February 17, 1956, Qian sent to China's leadership a proposal entitled "Suggestions on Setting up Our Country's National Defense and Aviation Industry" "on the leadership, R&D, and design and production for the development of aviation and rocket technology and missile production." (see footnote 23). Following a special meeting to examine Qian's proposal, chaired by Zhou on March 14, China's leaders acted to

[15] For Qian's role in initiating satellite development in China, see 朱毅麟 [Zhu Yilin], "钱学森指导下的早期卫星准备工作" [Early Satellite Preparation Work Under the Guidance of Qian Xuesen], 国际太空 [International Space] (March 2002) 1–5; 侯深渊 [Hou Shenyuan], "钱学森与中国卫星事业" [Qian Xuesen and China's Satellite Industry], 中国空间科学技术 [Chinese Space Science & Technology] 1 (2002) 1–3.

[16] Liu Jiyuan, editor-in-chief, *China Today: Space Industry* (Beijing: Astronautics Press, 1992), 452 [Hereafter, *China Today: Space Industry*].

[17] Iris Chang, *The Thread of the Silkworm* (New York: Basic Books, 1995), 220.

[18] Li Jin, quoted in Chang, *The Thread of the Silkworm*, 209–210.

[19] *China Today: Space Industry*, 442.

[20] *China Today: Space Industry*, 443.

[21] "Communist China's Strategic Weapons Program," National Intelligence Estimate 13-8-67, August 3, 1967.

[22] *China Today: Space Industry*, 4.

[23] *China Today* 1, 29.

[24] 中国人民解放军总装备部政治部组织撰写 [Written by the Political Department of the PLA General Armament Department], 奚启新 [Xi Qixin], ed., 钱学森传 [Qian Xuesen: A Biography], (Beijing: 人民出版社 [People's Press], 2011), 231–232.

[25] *China Today: Space Industry*, 452.

[26] Iris Chang, *The Thread of the Silkworm*, 212.

launch aerospace, particularly missile, development. Nie subsequently submitted to the SC and Central Military Commission (CMC) "Preliminary Ideas on Setting up the Chinese Missile R&D." In response, "on May 26, Zhou Enlai made the decision to develop missiles during a CMC meeting. He said China could not wait until all was ready for the start of missile R&D. We should concentrate our efforts for a breakthrough at one point. It was also decided at the meeting to set up a missile administration and a missile research institute." (see footnote 23). Accordingly, on October 8, 1956, China established the 5th RA with Qian as director.[27] On Zhou's order, the 5th RA was allocated top personnel despite overall scarcity and demand for technical experts in other sectors: "Chen Geng, president of the Military Engineering Institute, promised that the [5th RA] could have whichever specialists they named to the list, and besides, they could even have some more."[28] Already, at a May 29 meeting, convened under Zhou's authority, Nie and 33 agency heads had agreed to transfer 30 top specialists from the 2nd Ministry of Machine Building (MMB/Ministry of Nuclear Industry), the CAS, the Military Engineering Institute, Qinghua University, and other leading centers, as well as more than a hundred university graduates.[29]

2.3.2. Soviet assistance

China's fledgling aerospace program drew initially on significant Soviet expertise, and here too Qian played a major role. In August 1956, to expedite missile development, Vice Minister Li Fuchun wrote to Nikolai Bulganin, Chairman of the Soviet Council of Ministers, requesting missile assistance. On September 13, 1956, Moscow agreed to send China two P/R-1 missiles and 5 professors, while receiving 50 PRC students. In October 1956, Nie presided over a meeting at which it was decided that China would develop missiles using the hybrid technology development and acquisition approach that he would champion throughout his long career as a defense-industrial technocrat: "relying mainly on our own efforts while trying hard to use foreign aid and scientific achievements in capitalist countries." Mao and Zhou approved. In early 1957, the Soviet Union agreed to transfer 77 senior PRC students studying there to missile technology.[30]

With development of missile licensed production through Sino-Soviet cooperation, in 1957 the CMC accelerated construction of a 5th RA 1st Branch (responsible for missile integration), a 2nd Branch (responsible for rocket engine/control/guidance system), a test station, and an Aerodynamics Research Institute. Various SC ministries assigned equipment and materials development and production top priority. From 1958 to 1959, the 5th RA received several thousand each of military cadres/engineers and demobilized soldiers. In 1960, several thousand polytechnic school and college graduates joined them. By 1961, China's fourteen missile factories employed over 15,000. In this way, a "foundation for missile research and development had been laid."[31]

In December 1956, the two P/R-1 missiles arrived in Beijing.[32] Under Soviet specialists' assistance, China started copy-producing surface-to-surface (S-S), surface-to-air, air-to-air and anti-ship missiles. Finding the P/R-1s to be unsophisticated replicas of German V-2s, however, Mao six months later sent Qian to Moscow as part of a secret military delegation. On October 15, 1956, China signed an agreement under which Russia would provide missiles, blueprints, and experts. In 1957–1958, Moscow delivered 11 P/R-2 rockets and 100 experts to China, and China began copy production in 1958. In the late 1950s, PRC experts learned management skills for liquid rocket R&D through licensed copy production, though systems management was still unknown in China.[33] Soviet assistance enabled China to follow parallel tracks of importing, substituting, and self-development of previously-unavailable raw materials and equipment, machine tools, large-high precision machine tools and welding machines to fill key capacity gaps.[34]

2.3.3. Self-reliance

Due to diplomatic discord surrounding Soviet Premier Nikita Khrushchev's recanting of his promise to provide China with sample nuclear weapons, however, suspension of nuclear weapons assistance started on June 20, 1959,[35] and all Soviet advisors left China by August 24, 1960.[36] The Sino-Soviet split of 1960 left China's leaders feeling increasingly isolated internationally and limited technologically. They therefore directed a significant proportion of national capital and talent to China's nuclear and ballistic missile industries, with Qian's 5th RA a major beneficiary. Defense industry leaders pressed forward, determined to succeed in light of external security threats and the unavailability of foreign assistance.[37] In convening a CMC meeting on January 20, 1956, Peng had declared, "We must solve the problems of rocket air defense and rocket launching from the sea. We will develop it ourselves even if the Soviet Union does not help." (see footnote 23). In July 1959, the PLA established its first S-S missile force unit. A Chinese source emphasizes the modesty of this initial endeavor:

[27] Stephen Isakowitz et al., *International Reference Guide to Space Launch Systems*, fourth ed. (Reston, VA: American Institute of Aeronautics and Astronautics, 2004), 261.

[28] *China Today: Space Industry*, 452.

[29] *China Today* 1, 33–34.

[30] *China Today* 1, 30.

[31] *China Today* 1, 35.

[32] Chang, *The Thread of the Silkworm*, 214.

[33] *China Today: Space Industry*, 430.

[34] *China Today* 1, 258.

[35] *China Today* 1, 41.

[36] 武卫东 [Wu Weidong] et al., Eds., 中国战略导弹部队百科全书 [China Strategic Missile Force Encyclopedia], (Beijing: 中国大百科全书出版社 [China Encyclopedia Press], 2012), 835–837, 844; 吴卓 [Wu Zhuo], 航天新员工必读 [Required Reading on Space for New CASC Employees], (Beijing: 中国宇航出版社 [China Astronautics Press], 2011), 20–33.

[37] 王桁 [Wang Heng], 原航天工业部067基地11所（北京）副所长 [Former Deputy Director, 11th Institute, 67th Base, Ministry of Aerospace Industry], "钱学森指导我们研制火箭发动机" [Qian Xuesen Guided Our Rocket Research and Development], in 马兴瑞 [Ma Xingrui] et al., Eds., 钱学森的大帅风范 [Qian Xuesen's Master Elegance], (Beijing: 中国宇航出版社 [China Astronautics Press], 2011), 133–334.

"there were only three battalions; the force could not conduct campaign training."[38]

PRC leaders had anticipated the departure of Soviet experts and ordered technicians at the Northwest Comprehensive Missile Test Base to learn everything possible from them before their departure.[39] China's rocket industry encountered many materials and processing difficulties. Non-metallic materials and electronic devices lagged. Nie therefore prioritized them in a unified national plan that stressed the investigation and trial manufacturing of key items.[40] The impending Sino-Soviet split motivated further PRC prioritization of missiles. In early 1960, the CMC put missile development first, before even the atomic bomb: "In early 1960, at an enlarged meeting called by the CMC, it was further made clear that the development policy for the most advanced technology of national defense was 'taking missile[s] and atomic bomb[s] as [the] major task, putting missile[s] in first place' and it was required that all work in equipment construction of the services should follow this policy, putting major efforts on the focal point and making reasonable arrangements and concentrating human, material, and financial resources to ensure the development of missile and atomic bomb in order to make breakthroughs in the most advanced technology within the shortest time period."[41] Just 17 days after Soviet advisors' withdrawal, on September 10, 1960 China launched a Soviet P/R-2 with PRC-produced propellant (see footnote 39). On November 5, 1960, Project 1059 successfully launched a copied Soviet P/R-2, designating the resulting product "DF-1."[42]

In 1960, China moved from licensed copying to "independent design" (making some improvements on the copied model), but had yet to learn how to design rockets. Experts lacked a thorough understanding of the intrinsic relations between overall systems and subsystems as well as research, development, and acquisition (RDA). A March 31, 1962 experimental launch of a liquid-fueled medium-range surface-to-surface ballistic missile, the DF-2, failed because of general design flaws, allowing elastic vibrations to compromise a weak engine structure.[43] Nie assured test base workers that failure was a necessary part of technological development: "A fall into the pit, a gain in your wit" (我们要吃一堑长一智).[44] Qian flew in by "special aircraft" to direct test failure analysis.[45] Prior to the failure, the 5th RA had already started summing up R&D experience per Nie's technical guidance.[46] The CMC and CPC Central Committee (CCCPC) studied the failure report, Zhou and Deng were supportive. The SC and Beijing municipality shifted funds from other fields to missile development. Ministries, commissions, and the Beijing municipality accelerated the 5th RA's construction, especially of key test facilities, to ensure the supply of needed materials, instrumentation, and equipment.[47] The 1962 failure increased impetus, and furnished a lesson in space technology complexity and sophistication, as well as the importance of general system design and following necessary procedures such as testing, quality control, and protection from contamination.[48] As a result of these process improvements, the DF-2 finally achieved its first successful launch on June 29, 1964,[49] with all eight tests in 1964–1965 successful, including of a version with 20% greater range.[50] Completing development of China's first S-S strategic missile laid the foundation for future missiles. Personnel had been trained, a management system formed, and a systematic RDA process mastered,[51] the last based on Nie's "three moves in a chess game" (三步棋) spiral development approach, wherein "within a set period, there should be three different models, each in a different stage. One should be under trial manufacture and test, another a new model being designed, while the third the latest model under research."[52]

2.3.4. Progress amid domestic obstacles

During 1957–1961, ideological excesses such as the Anti-Rightist Movement and Great Leap Forward (GLF) harmed China's development, though the military-technological impact varied significantly by program. Nie resisted GLF-inspired arguments to develop new, unrealistically-ambitious missile designs.[53] While events influenced technical personnel adversely, political movements in the 5th RA were "kept to a minimum scale, and its intellectuals suffered much less than those in other units."[54] In 1960, Nie led in-depth investigation of 5th RA (rockets) and Chinese Academy of Sciences (CAS) research academies (satellites) and implemented "Fourteen Points of Opinions on Current Work in Scientific Research Organizations" to correct GLF excesses.[55] Nie helped to achieve these conditions by defining space intellectuals as "workers" to combat Party/government cadres' anti-intellectual biases, and clarifying that 5/6ths of the 5th RA's working hours were to be devoted to research as opposed to politics or labor.[56] Related reforms included an improved management system, a research-friendly environment, open intellectual discourse within defined parameters, and the rectification and appointment of "backbone intellectuals" to leading positions.[57] In 1961, Nie intervened to

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[38] "Statement of the Government of the People's Republic of China, October 16, 1964," reprinted in *Break the Nuclear Monopoly, Eliminate Nuclear Weapons* (Beijing, 1965), 1–5, John Wilson Lewis and Xue Litai, *China Builds the Bomb* (Stanford, CA: Stanford University Press, 1988), 241–243.

[39] *China Today* 1, 291.

[40] *China Today: Space Industry*, 403.

[41] *China Today* 1, 42.

[42] 刘纪原 [Liu Jiyuan], chief Ed., 中国航天事业发展的哲学思想 [The Development Philosophy of China's Space Industry], (Beijing: 北京大学出版社 [Peking University Press], 2013), 17.

[43] *China Today* 1, 260.

[44] 谢光 [Xie Guang, editor-in-chief], 当代中国的国防科技事业 [China Today: National Defense Science and Technology], 上 (vol. 1) (Beijing: 当代中国出版社 [Modern China Press], 1992), 320.

[45] *China Today* 1, 294.

[46] *China Today: Space Industry*, 431. See also *China Today* 1, 53, 259.

[47] *China Today* 1, 66.

[48] *China Today: Space Industry*, 430; *China Today* 1, 260.

[49] 涂元李, 莹莹 [Tu Yuanli and Ying Ying], Eds., 钱学森故事 [Stories of Qian Xuesen], (Beijing: 解放军出版社 [PLA Press], 2011), 123.

[50] *China Today* 1, 261, 295.

[51] *China Today* 1, 67.

[52] *China Today: Space Industry*, 431. See also *China Today* 1, 53, 259.

[53] *China Today* 1, 58.

[54] *China Today: Space Industry*, 463.

[55] *China Today* 1, 53.

[56] *China Today: Space Industry*, 464.

[57] *China Today* 1, 55.

stop overzealous political vetting and politicized expulsion of 5th RA recruits and recalled key experts from rustication.[58] During The Three Years of Great Chinese Famine (1958–1961), Qian and other 5th RA personnel were entitled to special food rations from the Navy and the Beijing, Guangzhou, Jinan, Shenyang military regions "to be distributed among the scientific and technological personnel only."[59] Nie also persuaded PLA organizations to distribute food "among experts and technical people in the name of CCCPC and CMC" to the 6th, 7th, and 10th RAs and test bases (see footnote 57). Luo had COSTND Secretary General An Dong "go to the [5th RA] to investigate the housing, heating and foodstuff supply problems of the technical people."[60]

While the GLF hurt China's economy substantially, missile development was thus prioritized to the point that its progress proved unstoppable. Ministries and commissions under the SC "gave all-out support." Task forces were organized to trial-produce new special-requirements materials and equipment on schedule. The 5th RA continued large-scale missile construction and development, with four engineering projects and missile licensed copy production proceeding simultaneously. The number of technical experts kept increasing.[61] Top leadership support for, and prioritization of, China's missile industry were reaffirmed amid GLF economic difficulties. Debate emerged concerning whether China's embattled economy could sustain "top technology"; Mao explicitly supported continuing. In August 1962, Vice-Premier Chen Yi declared that China should "make its own sophisticated weapons even with the last penny" as it needed "'missiles and atomic bombs'" to back up its diplomacy.[62] Specifically, he declared to Nie and Luo, "producing atomic bomb[s], missile[s] and supersonic aircraft would put me, the Minister of Foreign Affairs, in a better position!"[63] At the Beidaihe conference in 1961, a consensus emerged to proceed; this was reported to and approved by Mao, Zhou, and other top leaders. Large-scale rocket industry construction and development thus transcended political and economic difficulties (see footnote 64).

With the impending creation of a PRC nuclear bomb, the National People's Congress Central Special Committee (CSC)—which would emerge as a key organization for decision-making concerning technological megaprojects—determined on December 5, 1963 that the ballistic-missile delivered nuclear bomb should be prioritized over the airdropped variant.[64] In January 1964, the CSC called for "speeding up the development of … medium and short range surface-to-surface missile [s]." (see footnote 51). Mao approved the plan. In June 1964, China constructed its first missile base. In September 1964, the CSC approved the 2nd MMB's suggestion to develop a smaller variant of the existing nuclear weapon for a ballistic missile warhead.[65] Then, on October 16, 1964, China detonated its first nuclear weapon and issued an enduring encapsulation of its official nuclear policy: "… China cannot remain idle in the face of ever-increasing nuclear threats from the United States. … The Chinese government solemnly declares that China will never at any time or under any circumstances be the first to use nuclear weapons. …The Chinese government will… exert every effort to promote, through international consultations, the… complete prohibition and thorough destruction of nuclear weapons." [66]

On November 23, 1964, in an effort to "speed up the development of the missile industry," Wang Bingzhang was appointed minister of the newly-founded Ministry of Space Industry (7th MMB).[67] Wang's organization was responsible for all aspects of missile design and production. On May 14, 1965, after China successfully tested an air-dropped atomic bomb, ballistic missiles were prioritized as the bomb delivery vehicle: "it was urgently needed to solve the problem of a launch vehicle for the bomb. In March 1965, CCCPC timely made a decision that [in addition to] the atomic bomb industry and nuclear weapon, CSC should also control the missile development."[68] Accordingly, the CSC "immediately decided to put off trial production of the airdropped nuclear bomb and focus on the development of nuclear missile[s]."[69] To enable the requisite innovation, repeated sweeping top-level efforts were made to optimize missile development organization.[70] Meanwhile, to ensure continued progress, the CMC approved test sites for missiles and nuclear weapons, among other areas.[71] To facilitate missile breakthroughs, CCCPC agreed to allocate, 5th RA 100 technical personnel, 4000 undergraduates and 2000 polytechnic graduates (see footnote 74). Now there could be no doubt that China had prioritized missiles over aircraft, and even over satellites, which still represented a nascent technology.

In 1965, the CSC approved a program proposed in 1964 to develop liquid propellant "intermediate-long-range" S-S missiles, China's first with storable liquid propellant, "as fast as possible" to meet PLA needs.[72] This effort catalyzed PRC development of the DF-4 (CSS-3) with an unprecedented multi-stage architecture and a second-stage engine capable of functioning in a quasi-vacuum, high-precision inertial devices with accuracy "several times stricter," a high-heat-tolerant nose cone for reentry, high-strength aluminum alloy, and chemical milling to reduce body weight.[73] "Since this kind of missile was developed during the 'Great Cultural Revolution' and it was its first flight test, for the sake of safety and reliability and to prevent the missile from flying beyond [China's] territory, Zhou Enlai listened to the report specially before the launch and inquired in detail about the missile

58 *China Today* 1, 49.
59 *China Today: Space Industry*, 468.
60 *China Today* 1, 56.
61 *China Today: Space Industry*, 10.
62 *China Today: Space Industry*, 12.
63 *China Today* 1, 60.
64 *China Today* 1, 67, 226.
65 *China Today* 1, 68.
66 "Statement of the Government of the People's Republic of China, October 16, 1964."
67 *China Today* 1, 47. This article uses the terms "7th MMB" and "space industry" interchangeably.
68 *China Today* 1, 46.
69 *China Today* 1, 68.
70 *China Today* 1, 47.
71 *China Today* 1, 48.
72 *China Today* 1, 265.
73 *China Today* 1, 262–265.

quality and the flight safety measures adopted." Despite Zhou's close attention, the initial November 16, 1969 launch suffered a second-stage ignition failure. In 1970, a short-range flight test succeeded and the CSC approved a range increase, but there was a subsequent test failure because the missile was "misoperated and treated improperly during inspection at the Test Base, which led to abnormal operation." Zhou therefore "required that the experience should be summed up seriously to strive for the success of the future test." While initially the CR "kept development almost at a standstill," in 1971 troubleshooting began to pay off. Rapid progress began in 1975. There were many flight tests, and in 1978 efforts were made to increase the range. From 1976 to 1980, the DF-4 passed certification tests.[74]

Driven by Mao's concerns about Soviet and American pressure, China's nuclear and missile programs enjoyed rapid resource and organizational growth. Assiduously supported, they were allowed to assume risks to accelerate progress. In 1961, COSTND and CAS established coordination and problem solving teams to fully leverage CAS resources for missile development.[75] Throughout the 1960s, missile industry materials supply was a national priority. Organizations were established in the metallurgy, machinery, chemicals, petroleum, construction, light industry, and textile industries to ensure missile success.[76] During 1962–1963 Politburo member Bo Yibo called the State Planning Commission (SPC), the State Economic Commission, Office of Industry of National Defence (OIND), COSTND and related Ministries of Industry to study how to ensure steady supply of materials to 5th RA for short-to-medium-range missiles.[77] By 1965 more than 10,000 items of various materials could meet more than 96% of requirements for missile research and production.[78]

From 1964 to 1966, the PLA established six missile bases and 12 missile regiments. Nevertheless, "each missile regiment was separately managed by relevant schools and academies and the artillery forces in the military area command while implementing separate missile technology and tactical training." China's missile force thus still "did not have the capability to conduct training at the campaign-level."[79] China's strategic rocket force, the Second Artillery Corps (SAC), was formally established on July 1, 1966, "signifying that the establishment and development of the missile forces had entered an important phase." Now formally incorporated into one of the corresponding missile bases, each missile regiment implemented relevant technical and tactical training. This, in turn, laid the requisite groundwork for campaign training.[80] In September 1966, China deployed the ~1000 km-range DF-2 medium-range ballistic missile (MRBM), its first nuclear-armed ballistic missile. During the 1970s, it would deploy approximately ninety DF-2s.[81]

With tense Sino-Soviet relations making Moscow a primary target for Beijing, MRBMs such as the DF-2A "short/medium-range surface-to-surface missile"—designed to strengthen nuclear deterrence under perceived strategic threat—had become a priority.[82] On October 27, 1966, following a determination by COSTND and the 2nd MMB that a "hot" flight test was necessary for realism, China conducted the world's second test to date of a live nuclear warhead atop a missile. Protected to some extent with a self-destruct mechanism and arming barrier locked to prevent unintended fission, the missile flew 800 km over an area populated by 10,000 civilians.[83] The warhead detonated in the air above its intended target, demonstrating combat capability and enabling the DF-2A to begin certification for batch production.[84] In another demonstration of nuclear prioritization and accomplishment, China tested its first hydrogen bomb on June 17, 1967.[85]

During the "ten chaotic years" of 1966–1976, the Cultural Revolution (CR) threatened China's national security and even its nuclear and missile programs, though these systems—together with satellites—were given still higher relative priority. Even medium- and senior-ranking nuclear weapons personnel and cadres were persecuted, and even nuclear base workers suffered malnutrition.[86] Two ICBM test failures were blamed on CR problems.[87] By 1967, the CR had seized even China's nuclear program as China's Second Ministry divided into rival factions. Base workers, inspired by principles of 'self-reliance,' cobbled together dangerously ineffective nuclear monitoring instruments. Fortunately, Zhou, Nie, and other powerful bureaucrats intervened to prevent further excesses.

Space industry management "suffered seriously." RDA of specific models "was disrupted": "The technical commanding line, the administrative commanding line, and the designer system for the model R&D were all shattered."[88] An official account of PRC space development describes the extent of the damage: "The 'Cultural Revolution' had effected serious political and ideological damages on the space industry contingents. On the other hand, it had disrupted research and production, wasting precious time for the development of China's space technology." Acolytes of Jiang Qing and Vice Premier and Defense Minister Lin Biao "whipped up ideological confusion," "put research and production into disorder," and "abolished rules and regulations." As a result, "precious data and documents were lost," instruments fell into disrepair, civilized production was abandoned, product quality declined rapidly, many incidents occurred, and large-scale experiments

[74] *China Today* 1, 267, 299.
[75] *China Today* 1, 50.
[76] *China Today* 1, 51–52.
[77] *China Today* 1, 51.
[78] *China Today* 1, 52.
[79] 于际训 [Yu Jixun, chief editor], 中国人民解放军第二炮兵 [PLA Second Artillery Corps], 第二炮兵战役学 [The Science of Second Artillery Campaigns] (Beijing: 解放军出版社 [PLA Press], 2004), 53. [Hereafter, SSAC].
[80] SSAC, 53.
[81] Shirley A. Kan, *China: Ballistic and Cruise Missiles* 97-391 F (Washington, DC: Congressional Research Service, August 10, 2000), 3.
[82] *China Today* 1, 69, 201, 227, 232.
[83] *China Today* 1, 227.
[84] 聂荣臻元帅回忆录 [The Memoirs of Marshall Nie Rongzhen], (Beijing: 解放军出版社 [PLA Press], 2005), 653; *China Today* 1, 68–69, 201, 232.
[85] Lewis and Xue, *China Builds the Bomb*, 205–206; Report of the Joint Committee on Atomic Energy, Congress of the United States, *Impact of Chinese Communist Nuclear Weapons Progress on United States National Security* (Washington, DC: U.S. Government Printing Office, 1967).
[86] *China Today* 1, 187.
[87] *China Today* 1, 302.
[88] *China Today: Space Industry*, 431.

failed repeatedly.[89] From 1968 to 1970, even the prioritized CZ-1 launcher and DFH-1 satellite were delayed to the point of "standstill status." COSTND's official history maintains that without CR disruption China could have launched its first satellite by the end of 1968. In 1969, CZ-1 tests were hindered by factionalism.[90] The CR caused "severe harm" to engine development through violation of "development law," undue schedule emphasis, excessive design changes, and failure to address ground firing test failures properly and to accept technical experts' professional judgment. In 1970, for example, some suggested taking specific impulse solid propellant to world advanced level within three years, and high-energy propellant to production in five years, thereby forcing more practical intermediate-energy propellant research to stop, an error that was later reversed because of "high cost."[91] Out of political considerations, the Gang of Four and its "agents" in Shanghai hastily launched *Fengbao* (FB)-1 in July 1979, despite signs of hidden engine trouble and "correct opinions" of technical personnel. The Ministry of Space Industry's official account blames this CR legacy of schedule over quality explicitly for FB-1's launch failure, in which the second-stage Vernier engine malfunctioned.[92] This triggered a "comprehensive quality rectification campaign,"[93] and FB-1 launched the SJ-2, 2A, and 2B satellites successfully on September 20, 1981.[94] CZ-2 likewise encountered failure stemming from poor quality and reliability, before being fixed effectively in similar fashion.

Mao (intermittently, as both part of the overall problem and its space-specific solution), Zhou, Nie, Zhang, and Ye actively protected nuclear and ballistic missile programs from political campaigns that disrupted other programs to a far greater extent.[95] Zhang issued an order prohibiting violence within prioritized defense sector areas, including in particular the Ministry of Space Industry and Qian's 5th RA, one of its important subordinate organizations. Zhou charged the 7th MMB's Military Control Committee with recommending a list of scientists to receive state protection, and made sure young and middle aged technical personnel were not dispersed.[96] "Zhou particularly wanted to protect scientists working on the missile and satellite projects and dispatched bodyguards to protect them from physical harm. While other scientific agencies were temporarily disbanded, research on missiles continued as a top national priority. [Qian] was one of only fifty top scientists who received protection from the state in Beijing."[97] Though he could not always overcome the Gang of Four, Zhou intervened frequently. Throughout the CR, Zhou "showed greatest concern" for China's space industry. He held more than 30 meetings with the 7th MMB "leading cadres and mass representatives," and "worked to unite factions." In 1968, he instructed the 7th MMB's Military Control Committee to make a list of experts for State protection. To ensure smooth progress for DFH-1, he demanded that the list of persons involved "be protected by leaders at all levels against attack and slander." During the spring 1969 CZ-1 ground test, he prohibited interference and factionalism. During this period, he also summoned relevant personnel multiple times, called numerous CSC meetings to hear reports, "checking on every link" and "issuing clearly defined requirements."

Finding some launch preparation inadequate in April 1970, the CSC emphasized the need to consider all contingencies, including technical failure and political disruption. At its instruction, the GSD had all relevant military area commands deploy "several hundred thousand militiamen" (数十万民兵) for round-the-clock protection of vulnerable open-wire communication lines, as well as special teams from "various provinces, municipalities and autonomous regions" to ensure "timely and reliable data transmission."[98] Ye issued "Special Passports" to ensure missile trains' safe transit to bases.[99] In 1972 Zhou and party leaders visited the Launch Vehicle Assembly Works, inspected CZ-2 and the *Fanhuishi* (FSW) recoverable remote sensing satellite, and stressed a scientific approach and product quality. In 1972, with Deng's full support, Zhang was reappointed to COSTND. He led a delegation to inspect factionalized 7th MMB units, and emphasized correct guiding principles for rocket development: reduction of different types, unification of plans and concentration of efforts, and making breakthroughs in key areas. Mao and Zhou approved the resulting long-range missile borne nuclear R&D plan, the CCCPC and Mao authorized COSTND's report on China's space industry. This improved the space industry's situation, and enabled strategic missiles, SLVs, and satellites to achieve "preliminary results."[100] All in all, the CR slowed progress, but otherwise missile, SLV, and satellite development enjoyed top attention, planning, and resources—in stark contrast to the utter devastation wrought on China's aviation industry, for instance.[101] Starting in 1976, thorough reforms were launched, pre-CR management systems were restored, and R&D focused on the "Three Grasps."[102]

PRC missiles continued to progress. The single-stage liquid propellant DF-3 (CSS-2) 3000 km-range intermediate-range ballistic missile (IRBM) had its maiden flight on December 26, 1966 and was deployed in May 1971.[103] In 1980, China deployed the liquid-fueled DF-4 ballistic missile, whose 5500 km range covered Moscow and Guam. But China still lacked an ICBM, which was required to deliver a nuclear payload to the continental United States or to deter the Soviet Union in a sophisticated fashion—then a core objective of PRC planners. Following two successful full-range flight tests from Western China into

[89] *China Today: Space Industrys*, 43.
[90] *China Today* 1, 97.
[91] *China Today: Space Industry*, 480.
[92] *China Today: Space Industry*, 169.
[93] *China Today: Space Industry*, 171.
[94] *China Today* 1, 380–381, 403.
[95] *China Today* 1, 80, 202; *China Today: Space Industry*, 8.
[96] *China Today: Space Industry*, 463.
[97] Chang, *The Thread of the Silkworm*, 237–238, 248–251, 253, 254.
[98] 谢光 [Xie Guang, editor-in-chief], 当代中国的国防科技事业 [China Today: National Defense Science and Technology], 上 (vol. 1), 438; *China Today* 1, 97, 401.
[99] *China Today* 1, 81.
[100] *China Today* 1, 89.
[101] *China Today: Space Industry*, 31.
[102] *China Today: Space Industry*, 431.
[103] NASIC, *Ballistic and Cruise Missile Threat 2013* (Wright-Patterson Air Force Base, OH, 2013), 17, http://www.fas.org/programs/ssp/nukes/nuclearweapons/NASIC2013_050813.pdf [Hereafter, NASIC].

the Pacific Ocean in May 1980, the 13,000 km-range DF-5 was delivered to SAC in December of that year for "trial operational deployment" before being hurriedly deployed in two silos in August 1981.[104] The liquid-propellant, two-stage, DF-5 would undergird PRC intercontinental nuclear deterrence for the next two decades, and has remained an important component to the present even after Beijing deployed more advanced ICBMs. In the mid-1980s, China began to develop the DF-5A, an extended-range variant of the DF-5, though only four would be deployed in silos by the early 1990s.[105]

2.4. Maturing programs

Thanks to Deng's pragmatic reforms, after an initial consolidation period that the CIA detected accurately,[106] China's missiles and SLVs have progressed steadily over the last four decades. The FB-1 launcher, first tested on September 18, 1973 and apparently designed for launching military satellites, seems to have been a developmental dead end.[107] But for the most part, China's rocket industry achieved success after success in both the military and civilian realms.

2.4.1. Reform trajectory

After initial vicissitudes, the mid-to-late 1970s finally saw China's space program placed firmly on the path to its current development. After the "Lin Biao clique" fell, Zhou made reductions, layoffs, and postponed projects. But setbacks followed. In 1974, the Gang of Four's "Criticize Lin and Confucius" campaign again disrupted reforms.[108] During this turbulent time, Ye is credited with convening four CMC meetings and bypassing Jiang Qing and the Gang of Four to put missiles and satellites directly on Mao's agenda, to good effect.[109]

In 1975, with the Gang of Four eclipsed, Zhou terminally ill, and Mao entering his last year of life, a rehabilitated Deng assumed charge, and started to rectify the situation. Missile and nuclear weapons focus was retained, solid propellant missile development was accelerated, comsat development was added, and many other programs were deprioritized to compensate (see footnote 111). Zhang became COSTND minister, and worked to correct CR errors in China's space industry. Deng and others issued general instructions in this regard; the CCCPC issued a document outlining specific solutions, including reshuffling its leading body.[110] The resulting decrease in "factionalism and anarchism" fostered "smooth development" in research and production. In July 1975, the SC and CMC established the General Bureau of Missile Industry (8th General Bureau of MB) to unify management over production and development of tactical missiles.[111]

Political setbacks followed, however, starting with the "Criticize Deng and Conterattack the Rightist Wind of Reversing Correct Verdicts" campaign. Even Zhou, Deng, and Zhang were criticized and attacked (as Nie had been earlier). In the 7th MMB specifically, the "Jiang Qing clique" started the "Criticize Deng Xiaoping and Zhang Aiping" movement. Cadres and staff were persecuted and divided into factions, sending the ministry into chaos, and causing "enormous loss" (see footnote 114). In 1976, space industry rank and file joined memorial activities for Zhou to protest the Gang of Four. Finally, in October 1976 Party elites led by Hua Guofeng crushed the extremist cabal decisively, and China and its space industry entered a new era.[112] In 1979 technical titles were reinstated. A group of middle-aged "backbone" technical personnel were named Senior Engineers, while several tens of thousands of technical personnel were named Engineers.[113]

Active bureaucratically for the second time in two decades, from 1977 to 1984 the pragmatic Deng presided over another consolidation and adjustment of China's once-again-overextended space industry. Ambitious CR programs had strained R&D, with dispersion and an excessive number of variants progressing too slowly. Zhang drafted an agenda for development of new strategic missiles and space technology centering on three focal point programs approved in 1977, the "Three Grasps."[114] From 1980 to 1985, China would launch (1) "a long-range rocket to the Pacific," the DF-5 ICBM; (2) an experimental comsat (to be addressed later in this article); and (3) a solid propellant SLBM, the JL-1. During 1977–1979, economic realities forced further focus on these three major projects, with Deng placing ICBM development first.[115]

To ensure success in these prioritized areas, comprehensive reforms were implemented. Technical certification and product quality assurance, which had suffered significantly in the CR, was a major focus, particularly given the sophisticated electronics and other components needed in all "Three Grasps" systems. In 1977, the Chief Designer (CD) system was restored in the 7th MMB, and CDs were appointed for each of the "Three Grasps" projects. Military representatives were reinstated in factories to monitor product quality and ensure that PLA requirements were met. In 1978, as part of rectification, China's space industry discarded "erroneous policies and slogans," restored technical titles and the CD system, appointed CDs for major projects, reconstituted and installed S&T committees at all levels, instituted an administrative system for planning and dispatching, reinstated rules and regulations, and established quality control and logistics systems.[116] All relevant schools were reopened (they had been closed during the CR, eliminating a source

[104] John Wilson Lewis and Hua Di, "China's Ballistic Missile Programs: Technologies, Strategies, Goals," *International Security* 17.2 (Autumn 1992).

[105] See Lewis and Hua, "China's Ballistic Missile Programs," 19.

[106] "China's Strategic Attack Programs," National Intelligence Estimate 13-8-74, June 13, 1974.

[107] Isakowitz et al., *International Reference Guide to Space Launch Systems*, 261.

[108] *China Today* 1,79.

[109] *China Today* 1, 88.

[110] *China Today: Space Industry*, 45.

[111] *China Today* 1, 90.

[112] *China Today: Space Industry*, 46.

[113] *China Today: Space Industry*, 468.

[114] 谢光 [Xie Guang, editor-in-chief], 当代中国的国防科技事业 [China Today: National Defense Science and Technology], 上 (vol. 1), 124.

[115] *China Today* 1, 120.

[116] *China Today: Space Industry*, 50.

of college graduates, and thereby causing “a serious shortage of successors to the ranks of technical personnel”). COSTND worked with the 4th and 5th MMBs (Ministries of Electronics Industry, and Tank Equipment and Artillery, respectively) to implement a “seven specials” quality control and feedback approach. Considerable quality control progress was achieved by 1979, when all three programs met requirements.[117] Still, that same year, Wang Zhen, Zhang, and Song Renqiong intervened personally to “rectify” the 7th MMB, stressing in particular improvements to organization, R&D management, and product quality. They “liberated” persecuted specialists through administrative intervention, recalled specialists forced to civilian positions during previous ideological extremism, and improved political treatment and living standards to align incentives with programmatic progress.[118] Also in 1979, the CCCPC defined a new industrial policy that attempted to bring the strengths of China's strategic defense industry sector to its lagging but massive and economically-vital conventional and civilian counterparts: “combine military with civilian, combine peacetime with wartime, prioritize military production, and support the military with the civilian.” The space industry therefore focused further on R&D for the “Three Grasps.” Other development was slowed or suspended—construction stopped for many large/medium non-prioritized projects, many at Third Line bases.[119]

Thanks to a well-established foundation, with the experienced Tu Shou'e—a first-generation expert educated abroad—as CD, DF-5 test preparations made rapid progress. Conducting a full-up ICBM test in 1980 required several hundred thousand components to interact reliably —“an indication… of the scientific and technical capability of a country.”[120] Regarding ICBMs as a critical indicator of national capability, China had begun liquid-fueled ICBM RDA with official plan approval 1965, necessitating mastery of many new technologies.[121] During the CR, the majority of science and technology personnel were sent down to the countryside, virtually halting development work for a prolonged period. In 1970, however, the 7th MMB achieved trial production, ground tests, and final assembly. (see footnote 123). The CR “seriously affected” ICBM development; partial test failures resulted in 1971, 1972, and 1973.[122] Zhou followed the situation closely, and in 1973 approved postponing the development and test plan while the 7th MMB conducted troubleshooting. Zhang led a COSTND working group to the space industry, promoting missile quality control and technical breakthroughs, and visiting inland factories and research institutes developing the ICBM. By the mid-1970s, most technical problems had been solved, and land-based flight tests showed the general scheme to be correct. In 1975, when Mao, Zhou, and other leaders approved a report that emphasized the DF-5's military importance,[123] the CMC decided to accelerate its development and defined its range and launch mode (see footnote 126). In 1977, Luo called SC ministries and commissions to guarantee materials support for ICBM development for military deployment. In 1978, the CSC further required acceleration of ICBM development to equip armed forces. COSTND transferred solid missile development from 7th MMB's 1st RA to its 2nd RA so that the former could assume overall responsibility for and concentrate on ICBM development, and accelerate construction of production facilities. ICBM designers were exempted from moving to remote Third Line locations in China's hinterlands, a Maoist approach that disrupted much of the rest of China's defense industry. In 1979, flight test preparations began.[124] Since political turmoil had delayed work progress, the CCCPC's deadline of 1980 required further rocket development, overland flight tests, construction of space event support ships, and selection of an ocean test area.[125] Thanks to the work of 611 regiments, stations, labs, teams; >69,300 people; and 6820 equipment sets, a successful 9000 km test flight followed on May 18, 1980.[126]

JL-1 SLBM development, with Huang Weilu appointed CD in 1977 after a decade of CR disruption, started from a lower baseline. In the 1950s, the USSR had provided China with assistance with liquid rockets; as in other areas, China focused simultaneously on reverse engineering and indigenous design. While in theory solid propellants offered the clear advantages of “simpler structure, better reliability, maneuverability and survivability,” shorter launch preparation, and ease of operation, in practice no foreign assistance was available for solid rocket development. There was no prototype to copy, forcing China to develop its own solid rocket technology.[127] Starting in the late 1950s, China engaged in a decade of preliminary exploration. Experts searched “between the lines” of foreign literature, e.g., for propellant information.[128] In the late 1960s, China began R&D.[129] In March 1965, the CSC decided to proceed with solid missile development, and China's space industry began work in this area.[130] In 1967, the CSC decided to skip single-stage short-range solid-fueled SLBM development in favor of a two-stage medium-range S-S missile. COSTND assigned SLBM development to the 7th MMB's 4th Department. Two-stage solid rocket R&D began that year, but registered slow progress through 1974 thanks to insufficient advanced study and CR-induced technical difficulties.[131] Motor R&D was long the “weakest link” of solid rocket development, mainly because the CR halted production repeatedly. The two-stage solid rocket and other motors were “considerably slowed down,” and there were occasional accidents,

[117] *China Today* 1, 115, 117.
[118] *China Today* 1, 114–115.
[119] *China Today: Space Industry*, 51.
[120] *China Today: Space Industry*, 100.
[121] *China Today* 1, 268–272.
[122] *China Today* 1, 302.
[123] *China Today* 1, 125.
[124] *China Today* 1, 126.
[125] *China Today: Space Industry*, 47.
[126] 陆其明, 范敏若 [Lu Qiming and Fan Minruo], 张爱萍与两单一星 [Zhang Aiping and the “Two Bombs, One Satellite” Program], (Beijing: 解放军出版社 [PLA Press], 2011), 374–417; *China Today* 1, 305.
[127] *China Today* 1, 267.
[128] *China Today: Space Industry*, 475.
[129] *China Today: Space Industry*, 106.
[130] *China Today* 1, 338.
[131] *China Today* 1, 128, 275.

including a mixer explosion in 1974.[132] Through 1975–1976 there were many more difficulties than with liquid-fueled rocket technology and research: China lacked special materials, instrument miniaturization imperatives challenged the precision machine and electronic device industries, and there were repeated leadership and R&D base changes. These three factors were exacerbated by unrealistic targets in 1967.

In 1975, the CCCPC decided that the SLBM "should be developed actively."[133] When it was listed as a major national task in 1977, no major technical breakthroughs had been made, particularly with respect to the engine.[134] In 1979, COSTND and the 7th MMB made the latter's 2nd RA responsible for overall management of the joint efforts of ~100 institutions, factories, and test bases. Three launch mode tests were planned, from a ground launch stand, a ground launch tube, and a submerged Type 092 *Golf*-class diesel missile-testing submarine. Preparation for the underwater launch test involved the support of 30,000 direct participants and 40,000 staff members.[135] An October 7, 1982 SLBM test failure was followed by a non-submerged October 12 success.[136] In 1984, four model SLBMs were launched from underwater in the Bohai Sea. In 1985, the first three attempts to conduct a true underwater SLBM launch failed, but a 1986 SSBN aiming accuracy test succeeded. The stakes grew higher as the 1980s progressed, with increased foreign visibility coupled with civilian looting of "electrical cable and equipment" from the SLBM-relevant Bases 23 and 25. Police substations were therefore established. For certification tests on September 15 and 27, 1988, "Thousands of militiamen were moved into position to protect every installation, including every electrical pole, connected to the test; one militiaman stood every 50 m along the communications lines to guard the cables. Security was especially tight at Test Range 2. Everyone had to carry a numbered pass, which was coded for the locales and levels of his or her authorized access."[137] Tests succeeded when the missile-testing submarine launched missiles from underwater in Test Range 2 off Lüshun to their intended targets in Western China.[138]

In addition to the JL-1, China produced many types of solid motors for tactical missiles and space flight projects, including the CZ-1's third-stage motor, the retro-rocket for FSW satellites, the apogee motor for launching comsats.

2.4.2. Military advancement

From its establishment in 1966 until the late 1980s, SAC controlled what by leading edge standards was a limited, obsolescent, potentially negatable nuclear missile force. To strengthen its nuclear deterrent, whose vulnerability was a significant concern for PRC leaders through at least the 1980s, China attempted to generate specialized aerospace technology. Qian first called for "the development of an advanced DF-5 warhead with penetration aids" on January 4, 1966.[139] Thanks to a Cold War era need to deter Russia with its Moscow-based ballistic missile defense (BMD) system, China had long ago established a record of developing and testing various BMD countermeasures to improve ICBM survivability. Early approaches focused primarily on improving pre-launch survivability through more rapid fueling of liquid propellants and more clever means of concealment. These pragmatic measures were periodically interrupted with ambitious plans to address U.S. and Soviet advances. A U.S. Congressional Research Service report states that "China first decided to develop MIRVs [multiple independently targetable reentry vehicles] for deployment in 1970," but lack of miniaturization technology delayed the initiative, and it was deprioritized in 1980. As part of DF-5 modification efforts, on November 10, 1983, MIRV R&D resumed.[140] According to a Carnegie Endowment study, U.S. initiation of the Strategic Defense Initiative spurred reemphasis, and "The first test of a multiple-warhead missile took place in September 1984."[141] In April 1999, CIA Director George Tenet released a report stating that China had the "technical capability" to develop MIRVs for its presently-deployed ICBMs but had not implemented it.[142] PRC experts have carefully studied Russia's *Topol*-M as the model of an advanced BMD-defeating missile.[143]

2.4.3. Commercial space launch

Like its American and Soviet counterparts, China's space program accelerated advancement by modifying ballistic missiles into commercial launchers, establishing a pattern of developmental interaction that continues today. The interaction is clear in the overall design of the ballistic missiles and SLVs and in certain subsystems, such as propulsion. Here China has pursued a synergistic course that all established and developing aerospace powers, with the noteworthy exception of militarily-constrained Japan, have pursued. Many of the components and much of the technology and expertise for SLVs are extremely similar to those of ballistic missiles.

In a common military–civil rocket spinoff pattern, China developed SLVs from ballistic missiles. The fact that most SLV and ballistic missile technology is interchangeable, manufacturing technology is nearly identical, and it is relatively straightforward to modify ballistic missiles for SLV use saved China time and money in a pragmatic,

[132] *China Today: Space Industry*, 114.
[133] *China Today* 1, 128.
[134] *China Today: Space Industry*, 48.
[135] *China Today* 1, 129.
[136] *China Today* 1, 130.
[137] John Wilson Lewis and Xue Litai, *China's Strategic Seapower: The Politics of Force Modernization in the Nuclear Age* (Stanford, CA: Stanford University Press, 1994), 202–205.
[138] *China Today* 1, 350–355.
[139] Lewis and Hua, "China's Ballistic Missile Programs," 21.
[140] Shirley A. Kan, *China: Ballistic and Cruise Missiles* 97-391 F (Washington, DC: Congressional Research Service, August 10, 2000), 5.
[141] Joseph Cirincione et al., *Deadly Arsenals: Tracking Weapons of Mass Destruction* (Washington, DC: Carnegie Endowment for International Peace, 2002), 144.
[142] CIA, "The Intelligence Community Damage Assessment on the Implications of China's Acquisition of U.S. Nuclear Weapons Information on the Development of Future Chinese Weapons" (unclassified release), April 21, 1999.
[143] 石艳霞 [Shi Yanxia], "'白杨' M 对付反导弹防御系统的技术特点分析" [How Topol-M Deals with U.S. NMD] 中国航天 [Aerospace China] (December 2002) 39–41.

fiscally-conservative era.[144] The CSC concentrated LM-1 efforts under the 7th MMB to exploit its strategic missile R&D.[145] The DF-3 thus furnished the basis for China's first SLV, CZ-1.[146] Specifically, the DF-3 was "modified and then used as the first and second stages of the three-stage SLV, while the third stage would be a solid rocket,"[147] though it was initially difficult to overcome differences in military and civilian payloads and requirements.[148] Work commenced in 1965, with tens of thousands of people from more than 500 organizations participated in research, design, production, and testing.[149] Zhou ordered an extraordinary mobilization to avoid stoppages of work on CZ-1: 3,456 personnel from 29 departments were required to be stationed at posts, and obey commands regarding design, production, and testing. The central government wrote special letters to "relevant departments" for urgently needed items, ensuring timely, comprehensive support.[150] In 1970, as documented earlier, CZ-1 launched China's first satellite.[151]

That same year, China began to develop the CZ-2 SLV based on the DF-5 ICBM.[152] Difficult design choices were required; it was not always feasible to choose or develop the most advanced option, though decisions could cut both ways.[153] The CR delayed CZ-2 development "a little bit."[154] The first CZ-2 model was tested on November 5, 1974. From 1982 to 1988, a 2500 kg CZ-2C variant was used.[155] This launcher subsequently became China's "most reliable and frequently used," demonstrating that China's rocketeers were able to develop top quality products even in the CR's latter stages. To support focus on geostationary comsats, development of a higher-capacity CZ-3 launcher was accelerated in 1977. Following initial engine and tank problems, and a January 1984 launch failure, it successfully inserted two experimental comsats into geostationary transfer orbit in April 1984, with further successful launches in 1986 and 1988.[156] CZ-4, its conceptual design initiated in 1978, launched FY-1 successfully in 1988.[157] COSTIND's official history of PRC military-technological development even claims that CZ rockets "also promoted the development" of ballistic missiles, a spin-on technology benefit.[158]

Since their origin, China's missile and commercial launch programs have been intimately linked and subordinate to the same ministry and state-owned corporation. The various academies and institutes in China involved in ballistic missile and SLV design also share design and production responsibilities; many personnel support both missile and commercial SLV programs. China's launch infrastructure is militarily oriented: all launch facilities are at PLA bases. China Great Wall Industry Corporation (CGWIC), the national commercial space company since 1986, uses SLVs developed by such state aerospace institutions as the Shanghai-based China Academy of Launch Vehicle Technology (CALT). Both CGWIC and CALT fall under the aegis of the China Aerospace Science and Technology Corporation (CASC), the China's space program's main contractor. Established in 1993 as the 7th MMB's successor organization, CASC controls China's vast network of aerospace research institutions, factories, and companies. It thus runs all PRC space initiatives, from domestic and foreign satellite launch to piloted space flight.

In keeping with Deng's directives to develop the commercial economy, and his restrictions on defense spending to maximize resources for this effort, in the 1980s China's space industry became increasingly interested in launching foreign satellites. Through the mid-1980s, however, NASA and Europe's Arianespace enjoyed a monopoly on commercial satellite launches. That changed in 1986, when the space shuttle *Challenger*'s January 28 explosion grounded U.S. commercial satellite launches; and failures of Titan and Delta rockets in April and May respectively, together with Atlas rockets' similarity to them, delayed military launches. This prompted the Reagan administration to permit exports of satellites to China for launch. In 1989, the U.S. and China signed a six-year bilateral launch services trade agreement. A seven-year agreement, concluded in 1995 and amended in 1997, expired without renewal on December 31, 2001.[159] Beijing made development of its commercial space launch industry a major priority, allocating $1.38 billion for its civilian space budget in 1995. The Export-Import Bank of China

[144] *China Today: Space Industry*, 482.
[145] *China Today* 1, 97.
[146] For background on the development of China's first space launch vehicle, see 许达哲, 王宗银 [Xu Dazhe and Wang Zongyin], "不断创造奇迹为国增光添彩—纪念长征一号火箭成功发射东方红一号卫星30周年" [Continually Producing Miracles, Enhancing the Nation's Prestige—Commemorating the 30th Anniversary of the Long March 1 Rocket's Successful Launch of the DFH-1 Satellite], 中国航天 [Aerospace China], 5 (2005) 5–7, 20; 许达哲, 王宗银 [Xu Dazhe and Wang Zongyin], "不断创造奇迹 为国争光添彩—纪念长征一号火箭成功发射东方红一号卫星30周年" [Continually Producing Miracles, Enhancing the Nation's Prestige—Commemorating the 30th Anniversary of the Long March-1 Rocket's Successful Launch of the DFH-1 Satellite], 导弹与航天运载技术 [Missiles & Space Vehicles] 3 (2000) 1–4; 金兑 [Jin Dui], "长征一号—中国航天第一箭" [The Long March-1—China's First Rocket for Spaceflight], 太空探索 [Space Exploration] 1 (2001).
[147] *China Today* 1, 358.
[148] *China Today* 1, 373.
[149] *China Today: Space Industry*, 126, 373.
[150] *China Today: Space Industry*, 142.
[151] For technical details concerning CZ-1's development, see 韩厚健 [Han Houjian], "长征系列运载火箭介绍: 长征一号系列 (一)" [An Introduction to the Long March Carrier Rocket Series: The CZ-1 Series (Part 1)], 中国航天 [Aerospace China] 5 (May 1997) 28–30, 34; 韩厚健 [Han Houjian], "长征系列运载火箭介绍: 长征一号系列 (二)" [An Introduction to the Long March Carrier Rocket Series: The Long March 1 Series (Part 2)], 中国航天 [Aerospace China] 6 (June 1997) 9–11; 韩厚健 [Han Houjian], "长征系列运载火箭介绍: 长征一号系列 (三)" [An Introduction to the Long March Carrier Rocket Series: The Long March 1 Series (Part 3)], 中国航天 [Aerospace China] 7 (July 1997) 27–30. For the subsequent evolution of the CZ-1 space launch vehicle as compared to its foreign counterparts, see [Han Houjian], "小型运载火箭的中兴及长征一号丁新火箭" [The Resurgence of Small Launch Vehicle and the New Long March 1D (CZ-1D) Rocket], 导弹与航天运载技术 [Missiles & Space Vehicles] 1 (1999) 1–7.
[152] *China Today* 1, 374.
[153] *China Today: Space Industry*, 144.
[154] *China Today: Space Industry*, 149.
[155] *China Today* 1, 376.
[156] *China Today* 1, 377–379.
[157] *China Today* 1, 381.
[158] *China Today* 1, 99.
[159] Carl E. Behrens, *Space Launch Vehicles: Government Activities, Commercial Competition, and Satellite Exports* IB93062 (Washington, DC: Congressional Research Service, March 20, 2006), 2, 10.

provided CGWIC with $427.7 million in loans for commercial satellite launches.[160]

China achieved its first commercial market success in 1987, when Matra of France contracted to orbit a scientific payload aboard a CZ-2C launcher. China's first commercial launch occurred on April 7, 1990 when it lofted *Asiasat*—a Hughes HS 376 model satellite—into orbit atop a CZ-3 SLV.[161] In the early 1990s, China won 10% of the commercial launcher market. Such European corporations as Daimler-Benz Aerospace and Aerospatiale worked closely with their PRC counterparts to develop—not merely to launch—satellites in China. American firms launched satellites in China for British, Australian, Swedish, and Philippine corporations. By 1999, in addition to its military launch schedule, China had attempted 28 launches of Western-, primarily U.S.-manufactured, satellites. Twenty of China's attempts to launch U.S. satellites were successful; four ended in failure.[162] Because some SLVs launched two satellites simultaneously, China orbited 26 U.S. satellites during this period.[163]

While China's space program has always sought to incorporate foreign technology, its apparent efforts to do so in conjunction with the launching of American satellites generated tremendous controversy and a major political event in the 1990s[164] that affects Sino-American space relations and U.S. technology transfer policy to this day.[165] It prompted a Congressional investigation, an official report,[166] and a range of policy recommendations, many of which were subsequently implemented.[167] The controversy did not center on the satellites *per se* but rather the fact that they were launched on PRC vehicles. In the case of a successful launch, the satellite and all its technology ended up in space outside the reach of any party who might want acquire them. There were, however, three cases involving two American satellite companies—Hughes and Loral—in which the launches failed, the rockets exploded, and debris was scattered on the ground in China.

In response to these concerns, on June 18, 1998, via H. Res. 463, the U.S. House of Representatives formed the bipartisan Select Committee on U.S. National Security and Military/Commercial Concerns with the People's Republic of China (PRC), commonly known as the "Cox Committee" after its leading Republican member. The committee conducted a six-month investigation into whether U.S. satellite export policy had generated technology transfers to China. It also examined transfers of high-performance computer and nuclear weapons technology.[168] On December 30, 1998, the committee unanimously approved a 700-page Top Secret report (H. Rept. 105–851), issued on January 3, 1999; and released a declassified version, the three-volume "Cox Report," on May 25, 1999.[169]

Initially, there were worries that PRC recovery of classified FAC-3R encryption boards from satellite debris might reveal critical technology, but the National Security Agency determined that there was "no risk" of such an outcome.[170] The issue of primary concern was rather the sharing of valuable, if less tangible, diagnostic processes that could increase launch reliability, an area of general Chinese weakness and hence a substantial benefit. In the accident investigations after each launch failure, which were driven by insurance companies each seeking to make the other party liable, U.S. and PRC engineers met to discuss the reasons for the failure. In that process, technology was transferred that violated the terms of the export licenses that had been granted (Hughes was licensed by the Commerce Department, Loral by the State Department), as well as International Traffic in Arms Regulations (ITAR). Following the failure to launch the Australian Optus-B2 satellite in 1992 and the Asian *Apstar-2* satellite in January 1995, the Committee found, Hughes "illegally" recommended to the PRC improvements to the CZ-2E launcher's fairing (the nose cone that protects the payload). Following the 15 February 1996 failure to launch Loral's Intelsat 708, Loral and Hughes helped Chinese counterparts improve the CZ-3B's guidance.[171] Both companies would ultimately acknowledge what had happened and pay significant penalties. Loral paid a $20 million fine in a 2002 civil settlement, Hughes and Boeing accepted a $32 million civil penalty in early 2003. In addition, the committee found that U.S. satellites were not provided consistent physical security in China, and that U.S. authorities "may not be adequately enforcing" export control laws.[172]

What has rarely been discussed in detail was the nature of the technology that was transferred and the extent to which it mattered from a national security perspective. There is no question the terms of the licenses were violated, but that is a

[160] Marcia S. Smith, "China's Space Program: A Brief Overview Including Commercial Launches of U.S.-Built Satellites," *Congressional Research Service*, September 3, 1998.

[161] Hua Di, "China's Case: Ballistic Missile Proliferation," in William C. Potter and Harlan W. Jencks, Eds., *The International Missile Bazaar: The New Suppliers' Network* (San Francisco, CA: Westview Press, 1994), 172.

[162] Hua Di, "China's Case: Ballistic Missile Proliferation," in William C. Potter and Harlan W. Jencks, Eds., *The International Missile Bazaar: The New Suppliers' Network* (San Francisco, CA: Westview Press, 1994), 208.

[163] Marcia S. Smith, Glenn J. McLoughlin, and William C. Boesman, *Technology Transfer to China: An Overview of the Cox Committee Investigation Regarding Satellites, Computers, and DOE Laboratory Management* RL30231 (Washington, DC: Congressional Research Service, June 8, 1999), 2–3.

[164] Jonathan D. Pollack, "The Cox Report's 'Dirty Little Secret'," *Arms Control Today* (April/May 1999), https://www.armscontrol.org/act/1999_04-05/jpam99.

[165] The author gratefully acknowledges the opportunity to consult with a former U.S. official in preparing this section.

[166] U.S. Congress, House, Select Committee on U.S. National Security and Military/Concerns with the People's Republic of China, *U.S. National Security and Military/Commercial Concerns with the People's Republic of China*, 106th Congress, 1st Session (Washington, DC: U.S. Government Printing Office, 1999) [hereafter, Cox Report].

[167] Cox Report, v. 1, xxiv; v. 3, 170–172.

[168] Shirley A. Kan, *China and Proliferation of Weapons of Mass Destruction and Missiles: Policy Issues* RL31555 (Washington, DC: Congressional Research Service, January 3, 2014).

[169] Shirley A. Kan, *China's Technology Acquisitions: Cox Committee's Report—Findings, Issues, and Recommendations* RL30330 (Washington, DC: Congressional Research Service, June 8, 1999), 2.

[170] Shirley A. Kan, *China's Technology Acquisitions: Cox Committee's Report—Findings, Issues, and Recommendations* RL30330 (Washington, DC: Congressional Research Service, June 8, 1999), 5.

[171] Cox Report, v. 1; xiv; xvii; xix.

[172] Cox Report, v. 1, xxi, xxiii.

legal determination, not a substantive one. The precise details are unavailable in open sources at this time. However, the virtually failure-free PRC launch record following the three incidents, with 28 consecutive commercial and government/military launch successes from 1997 to 2003, suggests that the technology transfer probably helped China's SLV program not to repeat the mistakes that it had made in those cases.[173] Both committee members and outside analysts disagreed about the military implications of the technology transfer.[174] These were commercial comsats, not nuclear weapons, and while there are similarities in the launchers for each, there are also some substantive differences. Most likely, the truth lies somewhere in the middle: the Hughes-Loral actions were neither a meaningless technical infraction nor a worst-case security disaster for the United States. With respect to PRC missile enhancement, the committee concluded, "There is agreement that any such improvement would pertain to reliability and not to range or accuracy."[175]

While the incidents did not produce more stringent set of ITAR restrictions *per se* to this author's knowledge, Congress, by legislation, placed comsats on the ITAR, thus returning their licensing to State from Commerce. Simultaneously, State—responding to Congressional concerns—did not approve further PRC launches. This virtually halted China's commercial launch business for a decade, with no commercial launches from 2000 to 2003. It also cost the U.S. commercial comsat industry considerable market share. These events, together with China's 2007 ASAT test (detailed later), helped to set the stage for the current absence of cooperation on space issues between Washington and Beijing. More recently, the U.S. Congress has imposed a ban on NASA collaboration with China on a range of space issues.[176]

2.5. *Current and projected capabilities*

Building on this powerful foundational legacy, today China has achieved world-class missile and SLV capabilities. On the military side, since the early 1990s SAC has added a conventional strike mission and strengthened its nuclear deterrent capabilities. Following the Gulf War, the CMC assigned SAC the task of "dual deterrence and dual operations" (双重威慑, 双重作战), namely, the capability to conduct nuclear or conventional strikes, either independently or as part of a joint campaign.[177] According to the authoritative handbook *Science of Second Artillery Campaigns*, "During future joint combat operations the Second Artillery will not merely act as the main force in providing nuclear deterrence and nuclear counter-strike power, but will also act as the backbone force in conventional firepower assaults."[178] The first conventional ballistic missile force unit was established in 1993. During the 1995-96 Taiwan Strait Crisis China's conventional missile force conducted two "large-scale conventional deterrence firing exercises," "Magic Arrow-95" and "Joint 96-1,"[179] launching DF-15 (CSS-6) short-range ballistic missiles (SRBMs) into waters to the island's north and south.[180] PRC sources generally evaluate the missile launches as a successful display of force that deterred Taiwan from moving further toward formal independence.[181]

Deployment of more survivable mobile ICBMs in particular is increasingly credible retaliatory capability, bringing Beijing closer to possessing a secure second strike. Beijing is rapidly improving its missile forces qualitatively and to a lesser extent quantitatively; developing and testing several new missile classes and variants; exploring new types of conventional and nuclear options and forming new missile units; "upgrading older missile systems"; and developing and testing many new systems, including penetration aids and other countermeasures against various missile defenses.[182] SAC has deployed SRBMs opposite Taiwan and other proximate flashpoints; mobile, conventionally-armed MRBMs for regional deterrence and conventional strike operations; and new mobile, nuclear-armed ICBMs for strategic deterrence.

Echoing official and unofficial statements across decades, General Jing Zhiyuan (SAC commander, 2003–2012) asserts that while China's "limited development" of nuclear weapons "will not compete in quantity" with the nuclear superpowers, it will remain sufficient to protect China's national security.[183] Most publically available estimates place China's nuclear arsenal at several hundred warheads, with one of the more nuanced studies offering a figure of ~250.[184] When meeting with SAC officers in December 2012, paramount leader Xi Jinping described the force as "the core strength of China's strategic deterrence, the strategic support for the country's status as a major power, and an important cornerstone safeguarding national security."[185]

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[173] Shirley A. Kan, *China: Possible Missile Technology Transfers under U.S. Satellite Export Policy—Actions and Chronology* 98-485F (Washington, DC: Congressional Research Service, October 6, 2003), 1.

[174] See, for example, Alastair Iain Johnston, W. K. H. Panofsky, Marco Di Capua, and Lewis R. Franklin, edited by M. M. May, *The Cox Committee Report: An Assessment* (Palo Alto, CA: Center for International Security and Cooperation, Stanford University, December 1999), http://iis-db.stanford.edu/pubs/10331/cox.pdf.

[175] Cox Report, v. 2, 4.

[176] Jeffrey Logan, *China's Space Program: Options for U.S.–China Cooperation* RS22777 (Washington, DC: Congressional Research Service, September 29, 2008).

[177] 赵锡君 [Zhao Xijun, chief editor], 慑战–导弹威慑纵横谈 [Intimidation Warfare: A Comprehensive Discussion of Missile Deterrence] [Hereafter, IW] (Beijing: 国防大学出版社 [National Defense University Press], 2005), 13; SSAC, 54.

[178] SSAC, 138.

[179] SSAC, 54.

[180] Andrew Scobell, "Show of Force: The PLA and the 1995–1996 Taiwan Strait Crisis," 5, http://iis-db.stanford.edu/pubs/10091/Scobell.pdf;; Ron Christman, "Conventional Missions for China's Second Artillery Corps," *Comparative Strategy* 30.3 (2011) 200.

[181] 赵泽宽 [Zhao Zekuan], "新时期核威慑理论与实践的新发展" [New Development of Nuclear Deterrence Theory and Practice in the New Period], 中国军事科学 [China Military Science] 103.1 (2009) 16–20.

[182] U.S. Department of Defense, *Military and Security Developments Involving the People's Republic of China 2014*, annual report prepared for Congress (June 5, 2014), 6-7, 37, http://www.defense.gov/pubs/2014_DoD_China_Report.pdf. [After first mention, all such reports will be cited as follows: DoD (201X)].

[183] Jing Zhiyuan, "建设净杆有效战略导弹军队为维护世界 核安全做出贡献力量" [Creating a Lean and Effective Strategic Missile Troop Contributing to International Nuclear Security], 中国军队 [*China Armed Forces*] 6 (2010) 4–5.

[184] Hans M. Kristensen and Robert S. Norris, "Chinese Nuclear Forces, 2013," *Bulletin of the Atomic Scientists* 2013 69 79, http://bos.sagepub.com/content/69/6/79.full.pdf+html.

[185] "Xi Jinping Calls for Powerful Missile Force," *Xinhua*, December 6, 2012, http://english.peopledaily.com.cn/90786/8047587.html.

Such efforts have given China the world's premier conventional ballistic and cruise missile force. “China has the most active land-based ballistic and cruise missile program in the world,” according to both the U.S. Department of Defense (DoD) and National Air and Space Intelligence Center (NASIC).[186] In 2014, DoD assessed that “China… is developing and testing several new classes and variants” of such missiles.[187] In 2011, it added: “Some [Chinese weapon] systems, particularly ballistic missiles, incorporate cutting-edge technologies in a manner that rivals even the world's most modern systems.” In 2014, DoD determined China's ballistic and cruise missile industries to be “comparable to other international top-tier producers” and well-positioned for further development. China's missile and space industry has benefitted from “upgrades to primary final assembly and rocket motor production facilities.”[188]

China continues to favor missiles and space systems over other types of military systems in terms of resource allocation and production trends. DoD judges that “Many of China's primary final assembly and rocket motor production facilities have received upgrades over the past few years, likely increasing production capacity. In addition to supplying China's military, complete systems and missile technologies could also be marketed for export. Surge production for these systems could result in a significantly higher output of SRBMs and perhaps double the number of MRBMs per year.”[189]

These powerful development capabilities are paying off in the form of fielded systems. China has “the largest deployed conventional ballistic missile force of any nation.”[190] This includes one of the world's largest advanced long-range surface-to-air missile (SAM) forces, though these “systems lag behind global leaders.”[191] China also boasts the world's foremost, most numerous theater ballistic missile force. Following rapid numerical growth in the early-mid 2000s, NASIC documents that “China has deployed a very large force of modern solid-propellant SRBMs in the vicinity of Taiwan,”[192]—more than 1000 by November 2013.[193] China's SRBMs continue to grow increasingly accurate, and capable, sophisticated, and diverse in ranges and payloads, with the DF-16 the latest variant fielded and older models being replaced by improved versions.[194]

China is deploying a number of new strategic nuclear systems, both land- and sea-based. This combination may finally give PRC leaders confidence that their nuclear forces are fully survivable and thus capable of providing a secure second strike. NASIC assesses that “China is strengthening its strategic nuclear deterrent force with the development and deployment of new ICBMs.” Road-mobile, solid-propellant DF-31 and DF-31A ICBMs—the latter 11,200 km-range—have been fielded in small numbers since 2006 and 2007, respectively.[195] DoD adds that “China also is developing a new road-mobile ICBM known as the Dong Feng-41 (DF-41), possibly capable of carrying multiple independently targetable re-entry vehicles (MIRV).”[196] Organizationally, the DF-41 will help the land-based SAC maintain its position at the vanguard of nuclear deterrence despite the emergence of a dyad with an undersea component. Developing MIRVs can augment the number of warheads China could use to overwhelm U.S. missile defense capabilities by targeting major cities and large military installations. As NASIC explains, “Mobile missiles carrying MIRVs are intended to ensure the viability of China's strategic deterrence. MIRVs provide operational flexibility that a single warhead does not.”[197] MIRV advantages of particular appeal to China include “simultaneously increasing their ability to engage desired targets while holding a greater number of weapons in reserve.”[198] Through such developments as these, China's ICBM force will continue to grow by size and type, with “the number of warheads on Chinese ICBMs” able to reach “the United States is expected to grow to well over 100 in the next 15 years.”[199]

PRC nuclear-powered ballistic missile submarine (SSBN) development is likely driven by organizational interests, long-term force development, and desire to exploit vulnerabilities in foreign missile defences to preserve Beijing's nuclear deterrent.[200] The U.S. Office of Naval Intelligence (ONI) assesses that China's 3 *Jin*-class SSBNs “will likely commence deterrent patrols in 2014,” building on a recent trend of extended submarine patrols and the successful development and testing of the 4,000 nm-range JL-2 SLBM.[201] DoD projects that “up to five may enter service before China proceeds to its next generation SSBN (Type 096) over the next decade.”[202]

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[186] DoD (2010), 1; NASIC, 3.

[187] DoD (2014), 36.

[188] DoD (2014), 46.

[189] DoD (2010), 42.

[190] Prepared Statement of Bruce S. Lemkin, Deputy Under Secretary of the Air Force, International Affairs, Hearing on “China's Emergent Military Aerospace and Commercial Aviation Capabilities,” U.S.–China Economic and Security Review Commission, Washington, DC, May 20, 2010, 6, http:http://www.uscc.gov/hearings/2010hearings/written_testimonies/10_05_20_wrt/10_05_20_lemkin_statement.pdf..

[191] DoD (2014), 46.

[192] NASIC, 10.

[193] DoD (2014), 6.

[194] NASIC, 10.

[195] NASIC, 18 (for quotation), 3, 21.

[196] (2014), 7; “中国首次具备对美国有效的水下战略核威慑” [China Has an Effective Under Strategic Nuclear Deterrent Vis-à-vis the United States for the First Time], 环球网 [Global Net], October 29, 2013, http://mil.huanqiu.com/mlitaryvision/2013-10/2714866.html.

[197] Donald L. Fuell, Technical Director for Force Modernization and Employment, National Air and Space Intelligence Center, “Broad Trends in Chinese Air Force and Missile Modernization,” Testimony before the U.S.–China Economic and Security Review Commission, “China's Military Modernization and its Implications for the United States” hearing, Washington, DC, 30 January 2014, http://www.uscc.gov/sites/default/files/Lee%20Fuell_Testimony1.30.14.pdf.

[198] Fuell, “Broad Trends in Chinese Air Force and Missile Modernization.”

[199] NASIC, 19.

[200] Hans M. Kristensen, “China SSBN Fleet Getting Ready—But For What?” Federation of American Scientists *Strategic Security Blog*, April 25, 2014, http://blogs.fas.org/security/2014/04/chinassbnfleet/.

[201] Jesse Karotkin, Senior Intelligence Officer for China, Office of Naval Intelligence, “Trends In China's Naval Modernization,” Testimony before the U.S.–China Economic and Security Review Commission, January 30, 2014, http://www.uscc.gov/sites/default/files/Karotkin_Testimony1.30.14.pdf..

[202] DoD (2014), 7.

Two new types of conventional ballistic missiles stand out as particularly significant. On January 11, 2007, China demonstrated a direct ascent ASAT capability using a transporter-erector-launcher (TEL)-fired two-stage solid-fuel SC-19 kinetic kill vehicle (KKV) to destroy the FY-1C satellite in Low Earth Orbit (LEO), 850 km altitude. History's greatest single human generation of space debris, the event represented a head-on collision with world opinion and the longstanding treatment of space as sanctuary (Washington and Moscow had not conducted debris-producing in-orbit ASAT tests following the Cold War). Yet China offered no advance warning; its foreign ministry waited until January 23 to issue a brief statement stating that no other nation was targeted and advocating peaceful use of space; and to date Beijing has offered no further explanation.[203]

Three years later to the day, and in January 2013 as well, China demonstrated an anti-ballistic missile (ABM) capability by using a ground-based missile to intercept a ballistic missile mid-course.[204] China has also developed, and deployed in limited numbers, the world's first anti-ship ballistic missile (ASBM).[205] In doing so, China has achieved what Tai Ming Cheung terms an "architectural innovation," creating a novel assembly of existing systems to yield a new use with unprecedented maneuverability and accuracy.[206] In a hint that Beijing may build longer-range ASBMs, DoD states: "China is investing in military programs and weapons designed to improve extended-range power projection… Key systems that have been either deployed or are in development include ballistic missiles (including anti-ship variants)…."[207] Other advanced technologies that China will likely continue to develop to augment the capabilities of its missile force and counter missile defenses include hypersonics and "MIRVs, decoys, chaff, jamming, and thermal shielding."[208] Meanwhile, in a sign that it is recognized internationally for its competence, China has sold ballistic missiles and "ballistic missile technology to other countries" such as Saudi Arabia and Pakistan.[209]

Realizing small satellites' cost and rapid replenishment benefits requires a nation to develop low-cost, reliable, and responsive space access. China's low-cost launchers may allow it to achieve a combination of rapid turnaround and efficiency. Chinese military sources have shown considerable interest in using small rockets such as its *Kuaizhou* SLV to launch small satellites, citing "diverse launch methods" and "short launch preparation time."[210] Responsible for rocket development, on May 26, 2000, China Aerospace Science and Industry Corporation (CASIC) established Space Solid Fuel Rocket Carrier Co. Ltd. as the primary contractor for its solid-propellant SLV program, reportedly with a focus on research, development, and production of solid transport rockets and commercial launch services for small satellites. Solid motors are provided by the 6th Space Academy in Inner Mongolia.

On the civilian side, the CZ series, developed by CASC, boasts a range of capable variants. The CZ-2F is used to launch *Shenzhou* piloted spacecraft. The CZ-2C and -4B are used to launch satellites into LEO and Sun-Synchronous Orbit (SSO). The CZ-3A and CZ-3B/3BE are used to launch large spacecraft into Geostationary Transfer Orbit (GTO). China completed its fourth launch facility, Wenchang Satellite Launch Center, in 2014. By early 2015, an initial launch is planned for the CZ-5, which will increase by more than two-fold the size of payloads China can send into LEO and Geosynchronous Orbit (GEO).[211] Next-generation variants under development reportedly include the CZ-6 strap-on booster SLV and the CZ-7, -9, and -11 heavy lift SLVs.[212]

3. Chinese satellite development: successful second to rockets

Beijing prioritized satellites, like missiles, because they offered manifold, irreplaceable strategic benefits, yet could not be imported. Qian's second largest contribution to China's aerospace development, after missiles, was in the field of satellite development, which he had championed since his return to China in 1955. Compared with rocket development, that of PRC satellites started later, without any Soviet aid or hardware and documentation for reference. China began self-design immediately, which imposed additional challenges. To address this lack, China engaged in extensive, if rudimentary, information collection from home and abroad and adopted as many new technologies as possible.[213] By the mid-1960s, China's first satellite and SLV were "in full swing" and programs were "merged to work under a unified plan of the state," accelerating progress even further.[214]

Following implementation of the 1965 "Plan for the Development of China's Artificial Satellites,"[215] satellite development has been a consistent priority for China.[216] A range of facilities were developed to support PRC

[203] Shirley A. Kan, *China's Anti-Satellite Test* RS22652 (Washington, DC: Congressional Research Service, April 23, 2007).

[204] DoD (2013), 36.

[205] For comprehensive analysis, see Andrew S. Erickson, *Chinese Anti-Ship Ballistic Missile Development: Drivers, Trajectories, and Strategic Implications*, Jamestown Occasional Paper (Washington, DC: Jamestown Foundation, May 2013), http://www.jamestown.org/programs/recentreports/single/?tx_ttnews%5Btt_news%5D=40962&tx_ttnews%5BbackPid%5D=7&cHash=d6b463c8e45eb13052a81c8923eebf11#.UiTlyTashcY.

[206] Tai Ming Cheung, "The Chinese Defense Economy's Long March from Imitation to Innovation," *Journal of Strategic Studies* 34.3 (June 2011), 330.

[207] DoD (2014), 27.

[208] DoD (2014), 30.

[209] NASIC, 30.

[210] 卓凌, 主编 [Zhuo Ling, chief editor], 空间武器装备和技术 [Space Weapons Equipment and Technology], (Beijing: 军事科学出版社 [Military Science Press], 2006), 25.

[211] DoD (2013), 9-10.

[212] "Long March (Chang Zheng)," *Jane's Space Systems and Industry*, February 5, 2014, http://www.janes.com.

[213] *China Today: Space Industry*, 478.

[214] *China Today: Space Industry*, 4.

[215] 闵桂荣 [Min Guirong], "Review of Chinese Space Programs," in 献身航天造福人类: 闵桂荣院士文集/闵桂荣著 [Devotion to Spaceflight in the Benefit of Humanity: The Collected Works of Academician Min Guirong], (Beijing: China Aerospace Press, 2003), 188.

[216] Min Guirong, "Aspects of China's Recoverable Satellite-Platform," paper presented at the 44th Congress of the International Astronautical Federation, IAF-93-552, in *The Collected Works of Academician Min Guirong*, 274.

satellite development. CAS's Beijing Scientific Instrument Factory, subordinate to CAST since February 27, 1968 and subsequently renamed Beijing Satellite Manufacturing Factory (BSMF), has been involved in the assembly of a wide variety of satellites since before 1970.[217] Since 1978, satellites have been regarded as key to China's strategy of efficient investment that leapfrogs traditional technological development stages.[218] They have provided China with tremendous benefits in "land survey, meteorological observation, space environmental exploration, communications and broadcasting, [and] scientific and technical experiments…."[219] These functions are regarded as vital for national modernization, given China's vast, largely mountainous territory, complex terrain, and imbalanced economic development.[220] Wireless technology, for example, offers China comprehensive 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 enablers of real-time long-range targeting, particularly maritime.

3.1. Launching satellite development

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.[221] 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."[222] 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.[223] In 1958, Mao called for satellite development as a top priority. "We too should produce man-made satellites," he declared to his fellow leaders on May 17.[224] On May 29, 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, the SC Scientific Planning Commission issued a report enumerating the benefits of a satellite, 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,[225] as well as three design institutes, for: satellite and launcher general systems design, telemetry instrumentation, and space physics.[226]

A still-impoverished China could not do everything at once. 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.[227] In 1959, there was a larger course correction. Deng Xiaoping judged that satellite launch was beyond China's extant capacity, and space research tasks should be modified. The CAS Party Group 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 telemetering 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. Therefore, it 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.[228]

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 CCCPC 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."[229] Qian's timing was astute. National economic readjustment, "major breakthroughs" in missiles and atomic energy, the

[217] See "Beijing Satellite Manufacturing Factory (BSMF)," CAST, September 17, 2003, http://www.cast.cn/CastEn/Show.asp?ArticleID=17384.

[218] Min Guirong, "Review of Chinese Space Programs," 189.

[219] Min Guirong, "Spin-off from Space Technology in China," paper presented to the 43rd Congress of the International Astronautical Federation, IAF-92-0180, in *The Collected Works of Academician Min Guirong*, 253. See also *China Today* 1, 172–176.

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

[221] *China Today* 1, 30, 356.

[222] *China Today: Space Industry*, 480.

[223] 石磊, 王春河, 张宏显, 陈中青 [Shi Lei, Wang Chunhe, Zhang Hongxian, and Chen Zhongqing], chief Eds., 钱学森的航天岁月 [Qian Xuesen's Aerospace Career], (Beijing: 中国宇航出版社 [China Astronautics Press], 2012), 488–498.

[224] 王礼恒 [Wang Liheng], chief Ed., 中国航天腾飞之路: 亲历, 亲见, 亲闻 [Experiencing, Seeing, and Smelling the Soaring Trajectory of Chinese Aerospace], (Beijing: 中国文史出版社 [Chinese Literature and History Press], 1999), 680.

[225] *China Today* 1, 30.

[226] *China Today: Space Industry*, 20.

[227] *China Today: Space Industry*, 480.

[228] *China Today* 1, 56; *China Today: Space Industry*, 21.

[229] 孔祥言 [Kong Xiangyan], ed., 钱学森的科技人生 [Qian Xuesen's Scientific Lifetime], (Beijing: 中国宇航出版社 [China Astronautics Press], 2011), 259–264.

formation of the 7th MMB and a "rocket industrial system," CAS achievements in new satellite-relevant technology, components, materials, and equipment; as well as the establishment of effective launch sites, tested several times, had all set the stage for accelerated space technology development in general, and the development of a satellite and launcher in particular.

Nie therefore asked Zhang to convene a symposium to assess China's relevant capabilities thoroughly, and it was determined that the conditions were ripe.[230] 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.[231] On April 29, the Defense Science and Technical Commission (COSTND) submitted a plan to launch China's first satellite in 1970–71.[232] 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, entrusted by COSTND, 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."[233] On August 10, 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."[234]

In May 1966, Qian and his scientific colleagues solidified the plans for China's first satellite launch, agreeing on a name (DFH-1), a launcher (CZ-1)—developed from the DF-4 missile,[235] and a deadline (the end of 1970).[236] As an indication of its importance, Project 651 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."[237] 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 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."[238] 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 4 times to persuade and educate" them.[239] 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 tremendous 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.[240]

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

[230] *China Today: Space Industry*, 29.

[231] *China Today* 1, 96.

[232] 巩小华 [Gong Xiaohua], ed., 中国航天政策内幕 [Inside China's Space Policy], (Beijing: 中国文史出版社 [China Literature and History Press] 2006), 155.

[233] *China Today: Space Industry*, 29.

[234] Isakowitz et al., *International Reference Guide to Space Launch Systems*, 261.

[235] 陈寿椿 [Chen Shouchun], 中国航天科技集团公司长征工业总公司原副总经 [Former Deputy General Manager, Long March Industrial Corporation, CASC], "钱老对中国运载火箭的发展功不可没" [Qian Contributed to the Development of China's Carrier Rockets], in Ma Xingrui et al., Eds., *Qian Xuesen's Master Elegance*, 102–106.

[236] For additional information on DFH-1's development, see 李迁, 侯季光 [Li Qian and Hou Jiguang], "为了祖国的富强—访东方红一号卫星技术负责人之一, 中国工程院院士戚发轫" [For a Prosperous and Strong Motherland: A Visit With a Designer of the Dong Fang Hong 1 Satellite—China Engineering Academician Qi Faren], 国防科技工业 [Defense Science & Technology Industry] 4 (2004) 24–25; 庞之浩 [Pang Zhihao], "华夏第一星: 东方红一号—纪念我国第一颗人造地球卫星发射35周年" [China's First Satellite: DFH-1—Commemorating the 35th Anniversary of China's Launch of its First Artificial Earth Satellite], 卫星电视与宽带多媒体 [Satellite Television & Broadband Multimedia] 8 (2005) 34–35; "继承 '两弹一星' 精神 再树空间事业新丰碑—中国空间技术研究院院长袁家军在 '东方红' 一号卫星诞生地纪念碑揭幕仪式上的讲话" [Carrying on the Drive for the "Two Bombs and One Satellite," Erecting a New Monument in Aerospace Enterprise—The Speech of President Yuan Jiajun of the China Space Technology Research Institute at the Unveiling Ceremony for a Monument to Commemorate the Creation of the DFH-1 Satellite], 航天工业管理 [Aerospace Industry Management] 5 (2005) 4–6; 陈士祥 [Chen Shixiang], "回顾 '东方红' 一号卫星研制与总装的历程" [Reviewing the Course of DFH-1's Development and Assembly], 航天工业管理 [Aerospace Industry Management] 5 (2005) 10–11; 王立 [Wang Li], "我们是开路先锋—记 '东方红' 一号卫星空间环境模拟器研制历程" [We Were the Trailblazers—Remembering the Development of the Space Environmental Simulator for the DFH-1 Satellite], 航天工业管理 [Aerospace Industry Management] 5 (2005) 15"光辉的一刻永远激励著我们—经念 '东方红' 一号卫星发射成功35周年" [A Glorious Moment that Will Forever Inspire Us—Commemorating the 35th Anniversary of the Successful Launch of the DFH-1 Satellite], 航天工业管理 [Aerospace Industry Management] 5 (2005); 裴高才 [Pei Gaocai], "东方红一号卫星上天的台前幕后" [Behind the Flight of the DFH-1 Satellite], 武汉文史资料 [Wuhan Historical Documentary Material] 9 (2000) 18–22.

[237] Chang, *The Thread of the Silkworm*, 226.

[238] *China Today: Space Industry*, 43.

[239] *China Today* 1, 96–97.

[240] *China Today: Space Industry*, 37, 480–482.

"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."[241] 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."[242] In 1967, Nie proposed to the CCCPC the establishment of CAST to bring space research units under the PLA's aegis for protection and specifically under unified COSTND leadership; the CCCPC, the SC, and Mao accepted in March. Accordingly, on March 17, 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.[243] Thus protected, space projects continued largely as planned, and satellite development made "smooth progress."[244]

DFH-1's 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 battery 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.[245]

In a major victory for Zhou, Qian, and China's aerospace industry, DFH-1 was successfully launched on April 24, 1970 from Jiuquan.[246] Such was the political protection DFH-1 reportedly enjoyed that armed guards positioned 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."[247] Several performance parameters had been compromised to make the satellite visible and audible (via radio) on Earth (see footnote 258). Still, it made China only the fifth country to launch a satellite.[248] China received significant international attention, and Mao congratulated Qian personally. Though its power supply ran out 28 days later, DFH-1 orbits Earth to this day.[249]

Despite major protection and progress, periodic ideological upheavals caused serious political damage, disrupted R&D, and wasted precious time. According to an official history of PRC space development, 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.[250] 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 14 kinds of spacecraft in 3–5 years (9 satellites per year) was called for, 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 had to be abandoned. 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 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."[251]

3.2. Maturing programs

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."[252] As Deng knew only too well from wide-ranging experience, China's communications infrastructure was inadequate. 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 requirements.[253] Their successful adoption would modernize communications, radio, and TV efforts and space technology development.

[241] *China Today: Space Industry*, 32.
[242] *China Today* 1, 81.
[243] *China Today: Space Industry*, 43.
[244] *China Today* 1, 96. See also *China Today: Space Industry*, 33.
[245] *China Today* 1, 358.
[246] *China Today* 1, 98.
[247] See 史建中 [Shi Jianzhong], "太空中传来了《东方红》乐曲—回忆'东方红'一号卫星短波发射机的研制过程" [The Song "East is Red" Was Transmitted from Space—Recording the Process of Developing "Dong Fang Hong" 1's Shortwave Transmitter], 航天工业管理 [Aerospace Industry Management] 5 (2005) 12–13.
[248] Roger Cliff, *The Military Potential of China's Commercial Technology* (Arlington, VA: RAND, 2001), 28. Previous nations were the Soviet Union, the U.S., France, and Japan.
[249] Isakowitz et al., *International Reference Guide to Space Launch Systems*, 261–262.
[250] *China Today* 1, 78.
[251] *China Today: Space Industry*, 43–44, 480.
[252] *China Today: Space Industry*, 50.
[253] I*China Today: Space Industry*, 306–307.

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 ships and measurements ships."[254] Accordingly, launching a geostationary comsat became China's most sophisticated megaproject of the early 1980s.

In pursuing this approach, China was able to draw on earlier satellite development efforts. In 1965, the Central Ad Hoc Committee had approved establishing a satcom system, and directed the relevant departments to engage in exploratory research. In 1970, the CMC decided to proceed with 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."[255]

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 principles for comsat manufacturing and applications, and formulate and implement a concrete development program. As part of this process, in 1974 CAST held a design feasibility symposium, and the 4th MMB held a symposium on "Tentative General System Scheme of Communications System."[256] 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 March 31, 1975; the CCCPC and Mao and Zhou approved it.[257] 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.[258] 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."[259]

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" (see footnote 273). 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 to 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.[260] COSTND constructed the launch site. In 1977, China registered with the International Telecommunication Union for a GEO satellite position.[261] Prototype development occurred from 1977 to 1979. In 1979, all subsystems prototype products passed the relevant tests, and the project entered the "flight model development phase," followed by launching.[262] The "critical work phase" lasted from 1980 to 1983, with test preparations beginning in 1983.[263]

The first "experimental" (试验) DFH-2 comsat launch from Xichang, on January 29, 1984, made China "the third (after the United States and the European Space Agency) to employ a cryogenic [liquid oxygen/hydrogen] upper stage"[264] but suffered a third-stage failure. The satellite was sent to parking orbit, then adjusted to elliptical orbit; some scientific tests were conducted.[265] To meet the next launch deadline for this high priority project, COSTND's newly-established successor organization, 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 more than 20 days 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.[266] On April 8, 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 technology.[267] Under CD Qi

[254] *China Today: Space Industry*, 307–308.

[255] *China Today: Space Industry*, 308. See also *China Today* 1, 369.

[256] *China Today: Space Industry*, 308.

[257] *China Today* 1, 369; *China Today: Space Industry*, 309.

[258] *China Today* 1, 130.

[259] *China Today: Space Industry*, 309.

[260] *China Today: Space Industry*, 48.

[261] *China Today: Space Industry*, 50.

[262] *China Today: Space Industry*, 307, 311.

[263] *China Today* 1, 131.

[264] Cliff, *The Military Potential of China's Commercial Technology*, 28. For an overview of Chinese rocket development, see Ruan Chongzhi and Li Jing, "Twenty Years of Apogee Kick Motor Applications in China, 1984–2004," Xi'an, China: Academy of Solid Propulsion Technology, October 2005, IAC-05-E4.3.06.

[265] 谢光 [Xie Guang, editor-in-chief], 当代中国的国防科技事业 [China Today: National Defense Science and Techynology], 上 (vol. 1), 401; *China Today* 1, 132, 371.

[266] *China Today* 1, 415–416.

[267] *China Today*, 133, 371.

Faren, a "practical" (实用) DFH-2 communications and broadcast satellite followed in 1986, with three more launched by ~1992.[268] 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."[269] 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.[270] By 1984, China completed a missile and satellite measurement and control network covering its mainland and proximate sea areas.[271] 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.[272]

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 *Shijian* (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 March 3, 1971, operating normally for more than eight years.[273] In 1971–1972, "relevant departments" investigated space physics abroad, and suggested that China develop its first space physics exploration satellite. The substantially more sophisticated 250 kg SJ-2 was subsequently developed, and launched on September 20, 1981.[274] SJ-1 through 4 performed manifold scientific experiments.[275]

In 1975, China launched its first 1800 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 11.[276] FSW provided China's SAC, PLAN, PLAAF necessary operational information. The PLA formed special organs to utilize satellite remote sensing information.[277] China's first "serviceable telecommunications and broadcast satellite" was launched in February 1986, followed by another two such satellites in 1988.[278] In the early 1980s, China began to lay the groundwork for real-time remote sensing.[279] 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 September 7, 1988, though control failures limited its operational duration to 39 days.[280]

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."[281] By 1991, China had launched 35 satellites into LEO, solar-synchronous and geostationary orbits from a range of SLVs.[282]

Through the end of the Cold War, PRC satellites continued to suffer multiple limitations: varieties were incomplete, service lives short, payloads small, and ground systems still limited.[283] China therefore took a cautious approach to satellite development: "Each satellite in [a given] category is a variation of a baseline design."[284] This suggests a methodical program designed to serve China's 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.[285]

Still, microcomputers for missiles and satellites that China has developed have for some time been more advanced than those China has developed for aircraft. This is partially a product of the prioritization of electronics for the "Three Grasps."[286] From the late 1970s- to mid-80s, for instance, China developed batch of special purpose computers for satellites, rockets, and missiles. High-speed computers supported "second generation" strategic weapons and new types of aerospace vehicles.[287] Likewise, "China's satellite capabilities are less impressive than its launch capabilities"[288]—but are 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."[289]

[268] 谢光 [Xie Guang, editor-in-chief], 当代中国的国防科技事业 [China Today: National Defense Science and Technology], 上 (vol. 1), 404; *China Today: Space Industry*, 307.

[269] *China Today: Space Industry*, 340, 372.

[270] *China Today* 2, 732-37, 752; *China Today* 1, 384–85.

[271] *China Today* 1, 141.

[272] *China Today* 1, 421–453.

[273] *China Today*, 360, 402.

[274] *China Today: Space Industry*, 258.

[275] Brian Harvey, *China's Space Program—From Conception to Manned Space Flight* (New York: Springer Praxis, 2004), 88–91.

[276] *China Today* 1, 173, 363.

[277] *China Today* 1, 173, 383.

[278] *China Today* 1, 174.

[279] *China Today: Space Industry*, 304.

[280] *China Today* 1, 174, 366–368.

[281] *China Today* 1, 176.

[282] *China Today: Space Industry*, 64.

[283] *China Today: Space Industry*, 529.

[284] Min Guirong, "Review of Chinese Space Programs," 189.

[285] See *China Today* 2, 752.

[286] *China Today* 2, 806.

[287] *China Today* 2, 141–142.

[288] Cliff, *The Military Potential of China's Commercial Technology*, 28.

[289] *China Today* 2, 889. For a complete listing of China's sixty satellites and launched between 1970 and April 18, 2004 and their SLVs, see "东方红一号卫星概况" [A Survey of the Dong Fang Hong 1 Satellite], 国防科技工业 [Defense Science & Technology Industry] 4 (2004), 28.

3.3. Current capabilities

Beijing's satellite capabilities, both military and civil, are improving rapidly. China still has only a fraction of the overall space capability of the U.S., has significant coverage gaps in every satellite application, and relies to a considerable extent on technology acquired through non-military cooperation with foreign companies and governments. Work with foreign partners has been central to PRC satellite development and an important part of China's development strategy. Nearly every satellite in recent years has benefitted 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). PRC advances in satellites would have been limited without these contributions. 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 their own capabilities. China's satellite developers are combining foreign knowledge with increasingly robust indigenous 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.[290]

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.[291] 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.[292] 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." [293]

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 31. "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.[294]

Founded by CAST and its parent company CASC in August 2001, Aerospace Dongfanghong Satellite Co., Ltd. is China's foremost satellite manufacturer. A decade ago, it implemented "a completely new team deployment plan [for] the management of 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

[290] For detailed analysis, see Andrew S. Erickson, "Microsatellites: A Bellwether of Chinese Aerospace Progress?" in Lisa Parks and James Schwoch, Eds., *Down to Earth: Satellite Technologies, Industries, and Cultures* (New Brunswick, NJ: Rutgers University Press, 2012), 254–279.

[291] 夏国洪, 优政, 孟波, 信沛华 [Xia Guohong (CASIC General Manager), You Zheng (Qinghua University Professor and Aerospace Qinghua Satellite Technology Company, Ltd. General Manager), Meng Bo and Xin Peihua], "中国航天企业体制创新的尝试—航天清华卫星技术有限公司" [An Attempt by China's Spaceflight Enterprise System to Blaze New Trails—Aerospace Qinghua Satellite Technology Company], 中国航天 [Aerospace China] (August 2002) 11–13.

[292] Aerospace Qinghua considers the ISO 9000 standards, for which it successfully registered in 2002 and passed review the following year, to be "its development and survival pillar."

[293] "Aerospace Qinghua Satellite Co. Approaches Satellite Market," 中国航天报 [China Aerospace News], May 28, 2004, 4.

[294] 夏国洪 [Xia Guohong] (CASIC General Manager), 尤政 [You Zheng] (Qinghua University Professor and Aerospace Qinghua Satellite Technology Company, Ltd. General Manager), 孟波 [Meng Bo] and 信沛花 [Xin Peihua], [Aerospace Qinghua Satellite Technology Company, Ltd.], "中国航天企业体制创新的尝试—航天清华卫星技术有限公司介绍" [An Attempt at Innovation in the Chinese Aerospace Enterprise System—An Introduction to Aerospace Qinghua Satellite Technology Company, Ltd.], 中国航天 [Aerospace China], (August 2002) 11–13.

and manufacturing cost while shortening the development and manufacturing cycle for satellites. Under such a model, one person may be responsible for multiple projects. As a result, it increases both effectiveness and flexibility in human resources management. In the meantime, the work enthusiasm of personnel has also been mobilized. Furthermore, it is advantageous for each individual employee to be self-fulfilled."[295]

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 take full advantage of 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,[296] *Huanjing* (HJ) disaster monitoring satellites, *Yaogan* (YG) experimental and remote sensing satellites, *Tianhui* stereoscopic imaging satellites, and *Gaofen* remote sensing satellites.[297] China's *Yaogan* series of ~23 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."[298]

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."[299] *Tianlian-1-03*, launched on July 25, 2012, further extends and strengthens this capacity.[300] China has made great progress in small-satellite development; its satellites under five hundred kilograms now boast high performance, in addition to low weight. The 9.3 kg *Tiantuo-1* nanosatellite, launched on May 10, 2012, receives signals from China's shipborne Automatic Identification System.[301]

China achieved 18 space launches in 2012 that lofted 11 new remote sensing satellites, six *Beidou* navigation satellites, five experimental small satellites, three comsats, one meteorological satellite and one data relay satellite.[302] 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.

3.4. Future plans and projections

To ensure reliable independent access in the future, and to support broader operations, China is deploying a 35-satellite (5 geostationary, 30 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.[303] This could well precede deployment of Europe's Galileo system, making

[295] 赵山山 [Zhao Shanshan], "未来10个月将有四颗小卫星发射" [Four Small Satellites Will Be Launched in the Next Ten Months], 中国航天报 [China Aerospace News], December 24, 2003, http://www.china-spacenews.com/News/news_detail.asp?id=7670; 赵屾 [Zhao Shen], "航天东方红卫星公司靠什么长大成人" [What Will Aerospace DFH Satellite Company Rely On to Grow into Adulthood], 中国航天报 [China Aerospace News], December 24, 2003, 4.

[296] For details on China's ocean monitoring satellites, see 朱彧 [Zhu Yu], "国家海洋局《2013年中国海洋卫星应用报告》显示我国海洋卫星在轨运行稳定 '海洋一号B' 创造新纪录 '海洋二号A' 持续实时监测全球" [State Oceanic Administration's "2013 China Ocean Satellite Application Report" Shows that China's Maritime Satellites Are in Stable Orbits: "Ocean-1B" Sets a New Record, "Ocean-2A" Continuously Monitors the Globe in Real-Time], 中国海洋报 [China Ocean News], April 17, 2014, http://www.soa.gov.cn/xw/dfdwdt/jsdw_157/201404/t20140417_31694.html.

[297] 贺明霞，贺双颜，王云飞，杨倩；中国海洋大学海洋遥感研究所 [He Mingxia, He Shuangyan, Wang Yunfei, and Yang Qian; Ocean Remote Sensing Research Institute, Ocean University of China]; 唐军武, 国家卫星海洋应用中心 [Tang Junwu, National Satellite Oceanic Application Center];

(*footnote continued*)
and 胡传民, 中国海洋大学海洋遥感研究所, 美国南佛罗里达大学 [Hu Chuanmin, Ocean Remote Sensing Research Institute, Ocean University of China and University of South Florida], "中国卫星海洋观测系统及其传感器 (1988–2025)" [Chinese Spaceborne Ocean Observing Systems and Onboard Sensors (1988–2025)], 中国海洋大学学报 [Periodical of Ocean University of China] 41.12 (December 2011) 93–95.

[298] "Yaogan Series," *Jane's Space Systems and Industry*, November 12, 2013, www.janes.com.

[299] DoD (2012), 9. See also 董英隼 [Dong Yingsun], "我中继卫星系统初步实现陆海空天电多维应用" [Our Relay Satellite System Tentatively Realizes Land, Sea, Air, Outer Space, and Electron Multi-Dimensional Applications], 中国军工报 [China Military Industry News], November 3, 2012, 1.

[300] "Tianlian 1-03," "Real Time Satellite Tracking," *ITPROSTAR*, http://www.n2yo.com/satellite/?s=38730.

[301] 刘俊, 王握文 [Liu Jun and Wang Wowen], "国防科大在微小卫星研制领域取得重要突破" [National University of Defense Technology Gains Important Breakthroughs in the Field of Microsatellite Research and Development], 解放军报 [Liberation Army Daily], May 10, 2012, news.xinhuanet.com/mil/2012-05/11/c_123113209.htm.

[302] DoD (2013), 9.

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

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."[304]

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 16 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).[305] 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."[306] 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."[307] 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."[308]

4. Conclusion

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…."[309] 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."[310]

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

[304] 扬志远 [Yang Zhiyuan], "中国北斗耀星空—写在中国北斗导航系统走进百姓生活之际" [China's Beidou Glitters in the Starry Sky: China's Beidou Satellite Navigation System Enters the World of Ordinary People], 中国军工报 [China Military Industry News], January 3, 2013, 3; 李筱梅 [Li Xiaomei], "高为广: 心系北斗不了情" [Gao Weiguang: Forever Dedicates Heart and Soul to Beidou], 中国军工报 [China Military Industry News], December 1, 2012, 3; 魏锦文 [Wei Jinwen], "10项关键技术助力 '北斗' 卫星导航系统组网" [10 Key Technologies Assist in "Beidou" Satellite Navigation System Networking], 中国军工报 [China Military Industry News], November 3, 2012, 1; 詹先龙, 刘瑞华, 杨兆宁 [Zhan Xianlong, Liu Ruihua, and Yang Zhaoning], "北斗系统格网电离层延迟算法研究" [A Study on the Grid Ionospheric Delay Algorithm in Beidou], 航天控制 [Aerospace Control] 30.1 (February 2012) 15–19.

[305] 国家科技重大专项 [National S&T Mega-Project] website, http://www.nmp.gov.cn/zxjs/dxfj/; "11. National Defense IV. Major Special Items," in "国家中长期科学和技术发展规划纲要" [Guidelines for the Medium- and Long-Term National Science and Technology Development Program (2006–2020)], *Xinhua*, February 9, 2006; Huadong Guo, Ji Wu, (Eds.), *Space Science & Technology in China: A Roadmap to 2050* (Beijing: Science Press, 2010), 37.

[306] Huadong Guo and Ji Wu, *Space Science & Technology in China*, 76.

[307] DoD (2014), 65.

[308] DoD (2014), 68.

[309] 江泽民 [Jiang Zemin], 江泽民国防和军队建设思想学习读本 [A Study Reader of Jiang Zemin's Thought on National Defense and Military Construction], 中国人民解放军国防大学军队建设研究所 [China People's Liberation Army National Defense University Military Construction Research Institute], 中国人民解放军国防大学 "十五" 科研规划课题 [China People's Liberation Army National Defense University Research and Planning Issues for the Tenth Five Year Plan], (Beijing: 中共党出版社 [Chinese Communist Party Press], 2002), 164–165.

[310] 江泽民 [Jiang Zemin], "在表彰为研制 '两弹一星' 作出突出贡献的科技专家大会上的讲话 [Speech In The General Assembly on the Recognition of Science and Technology Experts Who Have Made Outstanding Contributions to the Development of "Two Bombs and One Satellite"], Speech given September 18, 1999, in 江泽民 [Jiang Zemin], 论国防和军队建设 [On National Defense and Military Construction] (Beijing: 解放军出版社 [People's Liberation Army Press], 2003), 401–409.

[lend] strong support [to missile development] from beginning to end,"[311] 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.'"[312]

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 resist 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 benefitting 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.

[311] Wang Xiaoqiang, "Whither China's Aviation Industry?" *Ta Kung Pao*, August 25, 1999, C1.

[312] *China Today: Space Industry*, 464.