Chapter 13

Six Decades of Chinese Space History: A Comparative History of Rocket and Satellite Development*

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China's first space achievements were in military/civilian rockets and satellites. Nuclear power status and deterrence required missiles to credibly deliver warheads. Satellites were also prioritized for strategic reasons and lack of import options. Foreign heritage and prioritized domestic efforts enabled progress amid obstacles. China now has many increasingly-advanced and -supported systems, some cutting-edge.

China is the most recent great power to emerge in aerospace. It has become the first developing nation to achieve comprehensive aerospace production capability. 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

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

Transferring and Developing a Space 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, enhanced organizational efficiency and increased 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 8 October 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 the 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 1958–1970. 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. It tested the *Dongfeng* (*DF*)*-2A* (CSS-1) medium-range ballistic missile (MRBM) 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 9,300 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.

Rockets: Leading Chinese Space Programs from the Start

Nuclear Programs: Initial Missile Booster

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 and deterrence writ large 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 15 January of that year. The following year, Mao prioritized its funding at other programs' expense. On 6 March 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 develop atomic bombs—"if we don't want to be bullied, we must have these things." Despite short-term decreases in overall government and military spending, the budget for advanced 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 16 October 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).

Qian Xuesen: Missile and Satellite Program Progenitor

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 "It 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 allowed 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 using 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. PERT "was disrupted" from 1966–1978, but was reinstated and made a major contribution to the "Three Grasps" (三抓) missile and satellite projects of the 1970s–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]

Initial 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]

Qian's Influential Backing

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 5 January 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 20 January 1956: "We must solve the problems of rocket air defence and rocket launching from the sea. We will develop it ourselves even if the Soviet Union doesn't help."[27] On the basis of his well-received advice, on 17 February 1956, Qian submitted a proposal to China's leadership 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."[28] Following a special meeting to examine Qian's outline, chaired by Zhou on 14 March, China's leaders acted to 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.[29]

Accordingly, on 8 October 1956, China established the 5th RA with Qian as director.[30] 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."[31] Already, at a 29 May meeting, convened under Zhou's authority, Nie and thirty-three agency heads had agreed to transfer thirty 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.[32]

Aid from Moscow

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 13 September 1956, Moscow agreed to send China two R-1 missiles and five professors, while receiving fifty 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 lengthy 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 seventy-seven senior PRC students studying there to missile technology.[33]

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 1958–1959, 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."[34]

In December 1956, the two P/R-1 missiles arrived in Beijing.[35] Assisted by Soviet specialists, 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 15 October 1956, China signed an agreement under which Russia would provide missiles, blueprints, and experts. In 1957-1958, Moscow delivered eleven 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.[36] 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.[37]

Technological Autarky

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 20 June 1959.[38] By 24 August 1960, all Soviet advisors left China.[39] 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.[40] In convening a CMC meeting on 20 January 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."[41] In July 1959, the PLA established its first S-S missile force unit. A Chinese source emphasizes the modesty of this initial endeavor: "there were only three battalions; the force could not conduct campaign training."[42]

PRC leaders had anticipated Soviet experts' departure and ordered technicians at the Northwest Comprehensive Missile Test Base to learn everything possible from them beforehand.[43] China's rocket industry nevertheless encountered many difficulties concerning materials and processing. 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.[44] 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 CMC-convened meeting, it was further made clear that the development policy for the most advanced technology of national defence 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.[45]

Just seventeen days after Soviet advisors' withdrawal, on 10 September 1960 China launched a Soviet P/R-2 with PRC-produced propellant.[46] On 5 November 1960, Project 1059 successfully launched a copied Soviet P/R-2, designating the resulting product "*DF-1*."[47]

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 among overall systems and subsystems as well as research, development, and acquisition (RDA). A 31 March 1962, experimental launch of a liquid-fueled surface-to-surface MRBM, the *DF-2*, failed because of general design flaws, allowing elastic vibrations to compromise a weak engine structure.[48] 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).[49] Qian flew in by "special aircraft" to direct test failure analysis.[50] Prior to the failure, the 5th RA had already started summing up R&D experience per Nie's technical guidance.[51] The CMC and CPC Central Committee (CPCCC) 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.[52] 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 essential procedures such as anti-contamination, quality control, and testing.[53] As a result of these process improvements, the *DF-2* finally achieved its first successful launch on 29 June 1964,[54] with all eight tests in 1964–1965 successful, including of a version with 20 percent greater range.[55] 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,[56] 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."[57]

Achievements despite Political Impediments

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.[58] 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."[59] 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.[60] 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.[61] 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.[62] In 1961, Nie intervened to stop overzealous political vetting and politicized expulsion of 5th RA recruits and recalled key experts from rustication.[63] 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."[64] Nie also persuaded PLA organizations to distribute food "among experts and technical people in the name of CPCCC and CMC" to the 6, 7, and 10th RAs and test bases.[65] 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."[66]

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 licensed copy production proceeding simultaneously. The number of technical experts kept increasing.[67] 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.[68] 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!"[69] 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.[70]

With the impending creation of a PRC nuclear bomb, National People's Congress Central Special Committee (CSC)—which would emerge as a key organization for decision-making concerning technological megaprojects—determined on 5 December 1963 that the ballistic-missile delivered nuclear bomb should be prioritized over the airdropped variant.[71] In January 1964, the CSC called for "speeding up the development of…medium and short range surface-to-surface missile[s]."[72] 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.[73] Then, on 16 October 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."[74]

On 23 November 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).[75] Wang's organization was responsible for all aspects of missile design and production. On 14 May 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, CPCCC timely made a decision that [in addition to] the atomic bomb industry and nuclear weapon, CSC should also control the missile development."[76] Accordingly, the CSC "immediately decided to put off trial production of the airdropped nuclear bomb and focus on the development of nuclear missile[s]."[77] To enable the requisite innovation, repeated sweeping top-level efforts were made to optimize missile development organization.[78] Meanwhile, to ensure continued progress, the CMC approved test sites for missiles and nuclear weapons, among other areas.[79] To facilitate missile breakthroughs, CPCCC agreed to allocate 5th RA 100 technical personnel, 4,000 undergraduates and 2,000 polytechnic graduates.[80] 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.[81] 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.[82] "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 details about the missile quality and the flight safety measures adopted." Despite Zhou's close attention, the initial 16 November 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 1976–1980, the *DF-4* passed certification tests.[83]

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.[84] 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.[85] 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.[86] By 1965 more than 10,000 items of various materials could meet more than 96 percent of requirements for missile research and production.[87]

From 1964–1966, the PLA established six missile bases and twelve 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."[88] China's strategic rocket force, the Second Artillery Corps (SAC), was formally established on 1 July 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.[89] In September 1966, China deployed the ~1,000km-range *DF-2* MRBM, its first nuclear-armed ballistic missile. During the 1970s, it would deploy approximately ninety *DF-2*s.[90]

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.[91] On 27 October 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.[92] The warhead detonated in the air above its intended target, demonstrating combat capability and enabling the *DF-2A* to begin certification for batch production.[93] In another demonstration of nuclear prioritization and accomplishment, China tested its first hydrogen bomb on 17 June 1967.[94]

During the "ten chaotic years" of 1966–1976, the Cultural Revolution (CR) threatened China's national security and even its nuclear and missile programs, although 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.[95] Two ICBM test failures were blamed on CR problems.[96] 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."[97] 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 failed repeatedly."[98] 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, political factionalism hindered *CZ-1*.[99] 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 levels 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."[100] 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.[101] This triggered a "comprehensive quality rectification campaign,"[102] and *FB-1* launched the *Shijian* (*SJ*)-*2*, *2A*, and *2B* satellites successfully on 20 September 1981.[103] *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 far more severely.[104] 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 ensured that young and middle aged technical personnel were not dispersed.[105]

> 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.[106]

Though Zhou could not always overcome the Gang of Four, he intervened frequently. Throughout the CR, he "showed greatest concern" for China's space industry. Zhou held more than thirty 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 compile a list of experts meriting State protection. To ensure smooth progress for *DFH-1*, he demanded that specialists 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."[107] Ye issued "Special Passports" to ensure missile trains' safe transit to bases.[108] 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 variants, unification of plans, practicality of efforts, and making breakthroughs in key areas. Mao and Zhou approved the resulting long-range-missile-borne nuclear R&D plan, the CPCCC and Mao authorized COSTND's report on China's space industry. This improved the space industry's situation, and enabled strategic missiles, LVs, and satellites to achieve "preliminary results."[109] 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.[110] Starting in 1976, thorough reforms were launched, pre-CR management systems were restored, and R&D focused on the "Three Grasps."[111]

PRC missiles continued to progress. The single-stage liquid propellant *DF-3* (CSS-2) 3,000-km range intermediate-range ballistic missile (IRBM) had its maiden flight on 26 December 1966, and was deployed in May 1971.[112] In 1980, China deployed the liquid-fueled *DF-4* ballistic missile, whose 5,500+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 the Pacific 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.[113] 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 *DF-5* variant, although only four would be deployed in silos by the early 1990s.[114]

Rocket Initiatives Bearing Fruit

Thanks to Deng's pragmatic reforms, after an initial consolidation period that the CIA detected accurately,[115] China's missiles and SLVs have progressed steadily over the last four decades. The *FB-1* launcher, first tested on 18 September 1973, and apparently designed for launching military satellites, seems to have been a developmental dead end.[116] But for the most part, China's rocket industry achieved success after success in both the military and civilian realms.

Grasping Reform and Priorities

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.[117] 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, with powerful results.[118]

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.[119] 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 CPCCC issued a document outlining specific solutions, including reshuffling its leading body.[120] 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.[121]

Political setbacks followed, however, beginning 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" initiated 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."[122] 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.[123] 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.[124]

Active bureaucratically for the second time in two decades, from 1977–1984 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."[125] From 1980–1985, 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 chapter); and (3) a solid propellant SLBM, the *JL-1*. During 1977–1979, economic realities forced further concentration on these three major projects, with Deng placing ICBM development first.[126]

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 "Three Grasps" project. Military representatives were reinstated in factories to monitor product quality and ensure fulfillment of PLA requirements. 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.[127] All relevant schools were reopened (they had been closed during the CR, eliminating a source 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.[128] 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.[129] Also in 1979, the CPCCC 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.[130]

Thanks to a well-established foundation, with the experienced Tu Shou'e—a first-generation foreign-educated expert—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."[131] Regarding ICBMs as a critical indicator of national capability, China had begun liquid-fuelled ICBM RDA with official planning approval in 1965, necessitating mastery of many new technologies.[132] During the CR, the majority of science and technology personnel were rusticated, virtually halting development work for a prolonged period. In 1970, however, the 7th MMB achieved trial production, ground tests, and final assembly.[133] The CR "seriously affected" ICBM development; partial test failures ensued in 1971, 1972, and 1973.[134] 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, promoted missile quality control and technical breakthroughs, and inspected inland factories and research institutes developing the ICBM. By the mid-1970s, most technical problems were resolved, and land-based flight tests validated the general scheme. In 1975, when Mao, Zhou, and other leaders approved a report that emphasized the *DF-5*'s military importance,[135] the CMC decided to accelerate its development and defined its range and launch mode.[136] 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 SAC. COSTND transferred solid missile development from 7th MMB's 1st RA to its 2nd RA. This freed the 1st RA to assume overall responsibility for and concentrate on ICBM development, and accelerate construction of production facilities. ICBM designers were exempted from relocating to remote Third Line areas in China's hinterlands, a Maoist approach that disrupted much of the rest of China's defense industry. In 1979, flight test preparations began.[137] Since political turmoil had delayed work progress, the CPCCC's deadline of 1980 required further rocket development, overland flight tests, construction of space event support ships, and selection of an ocean test area.[138] Thanks to the contributions of 611 regiments, stations, labs, teams; more than 69,300 people; and 6,820 equipment sets, a successful 9,000 km test flight followed on 18 May 1980.[139]

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 their development. There was no prototype to copy, forcing China to develop its own solid rocket technology.[140] 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.[141] In the late 1960s, China began R&D.[142] In March 1965, the CSC decided to proceed with solid missile development, and China's space industry began work in this area.[143] 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.[144] Motor R&D long represented 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, including a mixer explosion in 1974.[145] Through 1975–1976 there were many more difficulties than with liquid-fueled rocket technology and research: China lacked special materials, instrument miniaturization imperatives challenged China's 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 CPCCC decided that the SLBM "should be developed actively."[146] When it was listed as a major national task in 1977, no major technical breakthroughs had been made, particularly with respect to the engine.[147] In 1979, COSTND and the 7th MMB made the latter's 2nd RA responsible for overall management of ~100 institutions', factories', and test bases' combined efforts. 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. About 30,000 direct participants and 40,000 staff members supported preparations for the underwater launch test.[148] A 7 October 1982 SLBM test failure was followed by a non-submerged 12 October success.[149] 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. Increased foreign visibility coincided 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 15 and 27 September 1988,

> Thousands of militiamen were moved into position to protect every installation, including every electrical pole, connected to the test; one militiaman stood every 50m 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.[150]

Tests succeeded when the missile-testing submarine launched missiles from underwater in Test Range 2 off Lüshun to their intended targets in Western China.[151]

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.

Military Progress

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 concerned Chinese leaders significantly 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 4 January 1966.[152] 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 sophisticated 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 10 November 1983, MIRV R&D resumed.[153] U.S. initiation of the Strategic Defense Initiative reportedly spurred reemphasis, and "The first test of a multiple-warhead missile took place in September 1984."[154] 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.[155] PRC experts have carefully studied Russia's Topol-M as the model of an advanced BMD-defeating missile.[156]

Commercial Satellite Launch Services

Like its American and Soviet counterparts, China's space program accelerated progress by modifying ballistic missiles into commercial launchers, establishing a pattern of developmental interaction that continues today. The interface 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, fiscally-conservative era.[157] The CSC concentrated LM-1 efforts under the 7th MMB to exploit its strategic missile R&D.[158] The *DF-3* thus furnished the basis for China's first SLV, *CZ-1*.[159] 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,"[160] though it was initially difficult to overcome differences in military and civilian payloads and requirements.[161] Work commenced in 1965, with tens of thousands of people from more than 500 organizations participated in research, design, production, and testing.[162] Zhou ordered an extraordinary mobilization to avoid interruption of work on *CZ-1*: 3,456 personnel from twenty-nine departments were required to remain on-post, 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.[163] In 1970, as documented earlier, *CZ-1* launched China's first satellite.[164]

That same year, China began to develop the *CZ-2* SLV based on the *DF-5* ICBM.[165] Difficult design choices were required; it was not always feasible to select or pursue the most advanced option, although decisions could cut both ways.[166] The CR delayed *CZ-2* development "a little bit."[167] The first *CZ-2* model was tested on 5 November 1974. From 1982–1988, a 2,500-kg *CZ-2C* variant was used.[168] 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.[169] *CZ-4*, its conceptual design initiated in 1978, launched *FY-1* successfully in 1988.[170] 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.[171]

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. 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 commercial satellite launch monopoly. That changed in 1986, when the Space Shuttle *Challenger*'s 28 January 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 U.S. 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 31 December 2001.[172] 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 provided CGWIC with $427.7 million in loans for commercial satellite launches.[173]

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 7 April 1990, when it lofted *Asiasat*—a Hughes HS 376 satellite—into orbit atop a *CZ-3* SLV.[174] In the early 1990s, China won 10 percent of the commercial launcher market. Such European corporations as Daimler-Benz Aerospace and Aerospatiale collaborated closely with 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 twenty-eight launches of Western-, primarily U.S.-manufactured, satellites. Twenty of China's attempts to launch U.S. satellites were successful; four ended in failure.[175] Because some SLVs launched two satellites simultaneously, China orbited twenty-six U.S. satellites during this period.[176]

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[177] that affects Sino-American space relations and U.S. technology transfer policy to this day.[178] It prompted a Congressional investigation, an official report,[179] and a range of policy recommendations, many subsequently implemented.[180] 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 Chinese soil.

In response to these concerns, on 18 June 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.[181] On 10 December 1998, the committee unanimously approved a 700-page Top Secret report (H. Rept. 105-851), issued on 3 January 1999; and released a declassified version, the three-volume "Cox Report," on 25 May 1999.[182]

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.[183] 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 protecting 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.[184] 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.[185]

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. The terms of the licenses were unquestionably violated, but that is a legal determination, not a substantive one. The precise details are thus far unavailable in open sources. However, the virtually failure-free PRC launch record following the three incidents, with twenty-eight consecutive commercial and government/military launch successes from 1997–2003 alone, suggests that the technology transfer probably helped China's SLV program not to repeat the mistakes that it had made in those cases.[186] Both committee members and outside analysts disagreed about the military implications of the technology transfer.[187] 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 American security disaster. 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."[188]

While the incidents did not produce a more stringent set of ITAR restrictions per se to this author's knowledge, Congress, by legislation, placed comsats under 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 2000–2003. It also cost the U.S. commercial comsat industry considerable market share. These events, together with China's 2007 ASAT test (detailed later), helped precipitate 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 manifold space issues.[189]

Present 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), namely, the capability to conduct nuclear or conventional strikes, either independently or as part of a joint campaign.[190] 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."[191] The first conventional ballistic missile force unit was established in 1993. During the 1995–1996 Taiwan Strait Crisis, China's conventional missile force conducted two "large-scale conventional deterrence firing exercises," "Magic Arrow-95" and "Joint 96-1,"[192] launching *DF-15* (CSS-6) short-range ballistic missiles (SRBMs) into waters to the island's north and south.[193] PRC sources generally evaluate the missile launches as a successful display of force that deterred Taiwan from moving further toward formal independence.[194]

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.[195] 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.[196] Most publicly available estimates place China's nuclear arsenal at several hundred warheads, with one of the more nuanced studies offering a figure of ~250.[197] 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."[198]

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).[199] In 2014, DoD assessed that "China…is developing and testing several new classes and variants" of such missiles.[200] In 2011, it stated: "Some [Chinese weapon] systems, particularly ballistic missiles, incorporate cutting-edge technologies in a manner that rivals even the world's most modern systems."[201] 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 benefited from "upgrades to primary final assembly and rocket motor production facilities."[202]

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.[203]

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."[204] This includes one of the world's largest advanced long-range surface-to-air missile (SAM) forces, though these "systems lag behind global leaders."[205] 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,"[206]—more than 1,000 by November 2013.[207] 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.[208]

China is deploying multiple 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.[209] 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)."[210] 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."[211] 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."[212] 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."[213]

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 defenses to preserve Beijing's nuclear deterrent.[214] The U.S. Office of Naval Intelligence (ONI) assesses that China's 3 Jin-class SSBNs soon commence deterrent patrols, building on a recent trend of extended submarine patrols and the successful development and testing of the 4,000+nm-range *JL-2* SLBM.[215] DoD projects that "up to five may enter service before China proceeds to its next generation SSBN (Type 096) over the next decade."[216]

Two new types of conventional ballistic missiles stand out as particularly significant. On 11 January 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 long-standing 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 23 January 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.[217]

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.[218] China has also developed, and deployed in limited numbers, the world's first anti-ship ballistic missile (ASBM).[219] 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.[220] 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)."[221] 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."[222] 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.[223]

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."[224] Responsible for rocket development, on 26 May 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 recently opened its fourth launch facility, Wenchang Satellite Launch Center. From there, an initial launch is soon planned for the *CZ-5*, which will increase by more than twofold the size of payloads China can send into LEO and Geosynchronous Orbit (GEO).[225] Next-generation variants under development reportedly include the *CZ-6* strap-on booster SLV and the *CZ-7*, *-9*, and *-11* heavy lift SLVs.[226]

Chinese Satellite Development: Second Only to Rockets

Beijing prioritized satellites, like missiles, because they offered broad, 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 returning 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, domestic and foreign information collection and adopted as many new technologies as possible.[227] 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.[228]

Following implementation of the 1965 "Plan for the Development of China's Artificial Satellites,"[229] satellite development has been a consistent Chinese priority.[230] Manifold facilities were developed to support PRC satellite development. CAS's Beijing Scientific Instrument Factory, subordinate to CAST since 27 February 1968, and subsequently renamed Beijing Satellite Manufacturing Factory (BSMF), has been involved in the assembly of a wide variety of satellites since before 1970.[231] Since 1978, satellites have been regarded as key to China's strategy of efficient investment that leapfrogs traditional technological development stages.[232] They have provided China with tremendous benefits in "land survey, meteorological observation, space environmental exploration, communications and broadcasting, [and] scientific and technical experiments."[233] These functions are regarded as vital for national modernization, given China's vast, largely mountainous territory, complex terrain, and imbalanced economic development.[234] Wireless technology, for example, offers China comprehensive