A Comparative Study of Space Access Capabilities in China and Russia

Sheng Zhong[a], Wen'an Zhong*, Yuchao Wang

Xichang Satellite Launch Center, Xichang City, Sichuan Province, 615000
[a]*Author:zhongkaikunnudt@163.com*
**Corresponding author: zhongwenan888@163.com*

ABSTRACT
During the Cold War, the Soviet Union developed its aerospace industry rapidly, thereby achieving great achievements and building strong technological capabilities. After the disintegration of the Soviet Union, Russia has inherited the vast majority of the former Soviet Union's defense industry and defense technology power, which has kept it at the forefront of the world. Accurate space access capability is the basis for the utilization and development of space technology as well as a symbol of comprehensive national strength. Therefore, in this study, the advantages of Russia (the Soviet Union) are analyzed by comparing the space access capability of the two countries, and relevant suggestions and recommendations are made, which are of reference value for grasping the current opportunities of China's space development and formulating its future development strategies in a targeted manner.

Keywords: *Space in China and Russia; Space Technology Guarantee; Space Technology; Carrying Capacity*

1. INTRODUCTION

This paper expounded the development process of aerospace between China and Russia. Then, the aerospace strength of the two countries was systematically compared from the aspects of aerospace landmark events, carrying capacity, liquid engine level, funding investment, launch number, recent entry into space capacity and aerospace capacity development assessment, then further analyzed the advantages of space development in the Soviet Union, and put forward some suggestions for China 's future space development, so as to provide some reference for the construction of China 's space power.

2. THE HISTORY OF SPACE DEVELOPMENT IN CHINA AND RUSSIA

(I) The History of Space Development in China

China's aerospace industry has been developing for over 60 years since 1956, when the famous scientist Xuesen Qian put forward a *Proposal on the Development of China's Aviation Industry for National Defense* to the Central Government. According to the report *Review of 60 Years' Development of China's Space Transportation System* presented by Academician Long Lehao of China Aerospace Science and Industry Corporation Limited (CASIC) at the first China Space Transportation System Forum in 2017, China's space transportation system has gone through seven phases[1]: In the first stage (1965-1975), China started on the basis of strategic missiles, typically represented by CZ-1 and CZ-2 rockets; in the second stage (1975-1984), China developed CZ-3, CZ-3A and CZ-4 series rockets successively according to its own development law; in the third stage (1985-1991), China developed CZ-2E rockets with bundled technology for international commercial launches, and used CZ-2E, CZ-3A series and other rockets to carry out international commercial satellite launches; in the fourth stage (1992-2006), China developed CZ-2F rockets for manned spaceflight needs; in the fifth stage (2006-), China has developed CZ-5, CZ-6, CZ-7, CZ-8 and other new generation launch vehicles to meet the needs of environmental protection and major national strategies; in the sixth stage (2008-), China has developed YZ-1, YZ-1A, YZ-2 and other upper stage orbital transfer vehicles to improve the adaptability; in the seventh stage (2012-), China has developed CZ-11 and KZ series rockets for rapid response.

After more than 60 years of development, China has formed a complete carrier rocket type spectrum from room-temperature toxic propellant to low-temperature non-toxic propellant, from small rockets to small, medium, and large rockets, and from low-orbit space to high-orbit deep space, and built a launch site layout that combines coastal and inland, high and low dimensions, various shooting ranges, and multiple configurations of large, medium and small rockets to test the launch capability, which has pushed China's aerospace industry forward continuously.

(II) The History of Space Development in Russia

Since the end of World War II, both the former Soviet Union and the U.S. have developed up their own rocket and missile industries and accumulated engineering experience in developing rocket systems. Besides, the former Soviet Union developed the aerospace industry at a fast pace, being at the forefront of the world for a long time and creating many firsts. The Soviet Union made a glorious history by sending the first man-made Earth satellite, the first lunar probe, the first cosmonaut, and the first space station into space. During the Cold War, the former Soviet Union's space development level was even stronger than that of the U.S. By the disintegration of the Soviet Union, it still accounted for three-quarters of the world's annual launches (By 2006, this proportion had fallen to a quarter[1].

In 1991, the Soviet Union collapsed and the Russian Federation was established. At that time, its development of the aerospace industry basically rested on its laurels; Soyuz and Proton rockets remained its main models. According to the *2014 Space Competitiveness Index* released by Futron, Russia's space industry has been stagnant for nearly 20 years[2-4], and its economic downturn has directly affected the advancement of the space industry. However, Russia still has a large advantage in the overall carrying capacity of spaceflight, and particularly, its engine technology has always been a world leader. As of today, Russia (the former Soviet Union) still has the highest number of spacecraft launches in the world. Russia inherited most of the Soviet Union's space base and has a well-developed space system. In addition to being the world leader in the number of spacecraft launches for a long time, Russia also has the task of transporting crew and cargo to the International Space Station. As a result, Russia still has a strong foundation in the development of both launch vehicles and spacecraft[5-8]. In particular, Russia has always been a world leader in the advancement and economy of liquid rocket engines[2]. However, due to political turmoil, ethnic divisions, and economic crisis, Russia's space budget has been reduced from the "priority guarantee" during the period of Soviet Union to the current "slightly lurching". The economic downturn and political instability have, on the one hand, created a domestic talent shortage in Russia, with many of the industry's experienced experts and practitioners leaving the country; on the other hand, directly hindered the process of research and development of new technologies and projects. Over the past 20 years, Russia has been slow to develop space technology, resting on its laurels to maintain the status quo; the inadequate funding and talent shortage has caused Russia to miss several opportunities to upgrade its technology; consequently, it has gradually changed from being the top space power to a second-tier space country, and its space industry base is increasingly weakened[3].

In recent years, Russia adjusts its national strategy, moving away from pursuing overall strategic space goals but targeting priority goals; besides, it seeks to preserve the strength of its space science and technology industry in a difficult economic situation and to maintain its space dominance in several directions[7].

3. COMPARISON OF SPACE ACCESS CAPABILITIES IN CHINA AND RUSSIA (THE SOVIET UNION)

(I) Landmark Events

According to the history of space development in both China and Russia (the Soviet Union), with its early start, rapid development, and strong foundation, Russia made many achievements in space. At present, China is still out of reach in some aspects, and it is even decades behind the Soviet Union in landmark events in space development.

Table 1 A Comparison of Landmark Events in the History of Space Development in China and Russia

Event	Russia (the Soviet Union)	China	Year Gap (Year)
The first man-made satellite	1957	1970	13
First lunar exploration	1959	2007	48
First Mars exploration	1962	2020	58
First manned launch	1961	1999	38
First space station construction	1971	2021	50

Event	Russia (the Soviet Union)	China	Year Gap (Year)
First heavy rocket launch	1962	-	-

(II) Carrying Capacity

China has already implemented a new generation of launch vehicles and switched from toxic propellant rockets to new ecological ones; in particular, the CZ-5 rocket has made a historic leap in carrying capacity. The former Soviet Union's N1 rocket and the Energja rocket both used non-toxic and non-polluting propellant, and their LEO carrying capacity had reached 100t class. However, Russia's current carrier rocket is weaker than its previous models, and its space activities now rely mainly on Proton and Soyuz rockets. The Angara rocket is a newly developed Russian rocket, and the LEO carrying capacity of Angara-A5 is comparable to that of China's CZ-5B rocket; however, the GTO carrying capacity is only 7.5t, which is weaker than the 14t of the CZ-5 rocket. From 2014 to now, Angara-A5 has been launched only 2 times. Overall, Russia's current rocket capability has lagged behind the new generation of China's new-generation rockets, such as CZ-7 and CZ-5.

(III) Liquid Engine Level

Initially, China mainly used 80t YF-20 rocket engines (dinitrogen tetroxide/unsymmetrical dimethylhydrazine) and 8t YF-75D (liquid hydrogen/liquid oxygen) rocket engines, and few models were developed. It was not until the successful maiden flights of the CZ-5 and CZ-7 new generation rockets in 2016 that China had the YF-100 (liquid oxygen/kerosene) and 50t YF-77 (liquid hydrogen/liquid oxygen) engines with a ground thrust of less than 120t. Russia (the Soviet Union) has developed more than 60 kinds of liquid rocket engines, and its most powerful 800t RD-170 (liquid oxygen/kerosene) and 200t RD-0120 (liquid oxygen/liquid oxygen) engines were successfully verified in 1987. The YF-130 (500t) engine, currently under development in China, is still not as powerful as the RD-170 (800t) in terms of thrust; with the successful development of the YF-90, China can rival Russia in terms of hydrogen-oxygen engine capability.

(IV) Fund Investment

Since 1989, the space investment of the U.S. had accounted for about 0.5% of the gross national economic output, reaching 10-20 billion US dollars; the Soviet Union had accounted for 1-2% of the gross national economic output, reaching 10-35 billion US dollars. However, China's investment in space (including missiles) was only 30 billion yuan over the past 30 years, and it is not easy to achieve great results with less cost. China is the fifth country in the world after the Soviet Union, the U.S., France, and Japan to launch its own satellite with homemade rockets, the third country after the Soviet Union and the U.S. to master the technology of recovering satellites, the fourth country to master the technology of launching one rocket with multiple satellites, the third country to master the technology of hydrogen and oxygen rockets, and the fifth country to launch geostationary orbit satellites independently. From the ranking order, China is only a few places behind, but in terms of the technological level, China's gap is still very large. The most important factor behind China's backward space technology is an insufficient investment, which has prevented many development projects from landing. Overall, China's space technology is still 20 years behind that of the U.S. and the Soviet Union[9-11]. According to Western estimates, the Soviet Union spent 20 billion US dollars on space in 1985 and more than 30 billion US dollars in 1987 and 1988, while in 1989 it dropped to 18 billion US dollars. In May 1989, Mikhail Gorbachev told the Soviet People's Congress that "spending on the space program has been partially reduced, and further measures to reduce costs should be taken"[12].

The disintegration of the Soviet Union and the ensuing general economic crisis only worsened Russia's space activities. Over 10% of the ground command and monitoring facilities, the main space launch site Baykonur and almost 20% of the rocket enterprises remained in other CIS countries. To add insult to injury, Russia's space industry lost its luster and was reduced to an ordinary sector as its economy deteriorated. Russia's national space program no longer enjoyed preferential privileges in the government and parliament, and budget allocations were greatly reduced. Civilian and military allocations were reduced by more than 80% from 1989, and even the military space program did not receive 1/10th of its original funding. Consequently, most of the clusters of satellites in orbit were old, and 67% of spacecraft were in overdue service; in particular, the communication satellites were in critical condition, the number of spacecraft launches was decreasing year by year, and the products were not delivered as scheduled [9]. From 1989 to 1994, Russian investments decreased by 4/5 in the civil space program and by 9/10 in the military space program. In order to get out of the predicament, make up for the shortage of space funds and develop the space industry, Russia took advantage of its long-accumulated technological reliability and low cost in space development, and cooperated with foreign companies; developed the space market by launching commercial programs such as space travel and space advertising, vigorously contracted commercial launches, organized space tourism, and used satellites to provide exploration and mapping for foreign users. After Putin came to power, the Russian economy gradually improved and government investment in the space sector continued to increase. In 2012, the budget of Roscosmos (the Russian Federal Space Agency) increased to about 4.79 billion US dollars, an increase of 52.7% from the previous year. According to the *Special Federal Planning for Space Launch Site Development 2006-2015*, the budget for 2012 increased by 45.5% year-on-year, and investing 8.4 billion US dollars in the construction of the Vostochny launch site. According to Russia's *Federal Space Program for 2006-2015*, the budget for 2012 increased by 37.9% year-on-year, and the budget of the *Federal Special Program Glonass* increased by 6.7% [13].

Since the reform and opening up in 1978, China's economy has entered a period of rapid development, and the aerospace industry has also flourished. China has implemented a series of major space projects, including the Manned Space Program, the Lunar Exploration Project, the BeiDou Navigation Project, and the Planetary Exploration Project, which have created brilliant achievements that have made the nation proud and attracted the world's attention.

(V) Number of Launches

During the Cold War, the U.S. and the Soviet Union engaged in a "space race", and spaceflight activities were intense. By the end of 1987, the total number of spacecraft launched in the world had reached 3,627, of which the Soviet Union had the most with 2,337, followed by the U.S. with 1,048. On the other hand, China had launched only 25 satellites by the end of 1988, apparently very few[11]. According to statistics, by November 17, 1989, the Soviet Union had 64 space launches and estimated more than 70 launches this year; the Soviet Union conducted 944 space launches during 1979-1988, an average of 94.4 launches per year [13]. After the disintegration of the Soviet Union, due to domestic political and economic reasons, the number of space launches declined significantly compared with that of the Soviet Union and showed a gradual downward trend, but the number of annual launches remained at around 30 until 2015, after which it dropped to around 20.

It took China 37 years from the launch of the Long March Rocket 1 in 1970 to the first 100 launches (June 1, 2007), with an average of 2.7 launches per year; it took China 7.5 years to complete its second 100 launches (2014), with an average of 13.3 launches per year; it took China just over 4 years to complete its third 100 launches (March 10, 2019), with an average of 23.5 launches per year. Compared to the previous two 100-launch records, not only did the completion time become shorter, but the tasks performed became more varied. After 2010, the entire spaceflight entered a state of high-density launch. Especially after 2018, China's annual number of launches remained above 30, ranking the first globally in 2018 and 2019; the number of launches in 2020 was behind the U.S.' 44 launches, ranking the second.

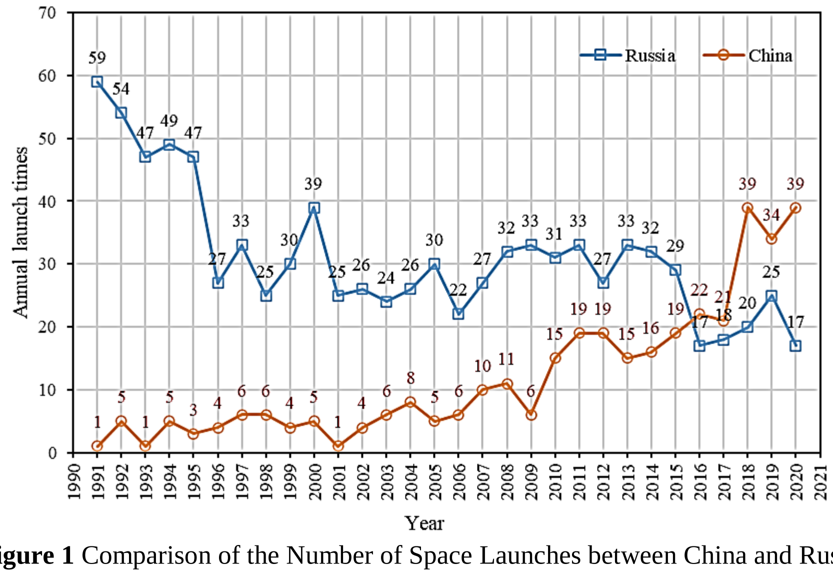

Figure 1 Comparison of the Number of Space Launches between China and Russia

(VI) Recent Space Access Capabilities

The number and weight of annual launches reflect, to a certain extent, a country's rocket research and production capabilities and test launch capabilities. In order to compare the space access capabilities of China and Russia more objectively, the space launch weight of the two countries is compared. Launch weight refers to the total tonnage of payloads carried into various orbits by the carrier rocket, and mainly represents the sum of the carrying capacity of various types of rockets in a country, that is, the space access capability.

The annual launch weight of the Soviet Union remained stable between 300-400 tons for many years. Due to the setback in the development of heavy rockets, the average launch weight of the Soviet Union was later consistently maintained between 3-4 tons per launch. After the disintegration of the Soviet Union, the decline of its power affected its space development, and the number of launches and launch weights declined rapidly. Until the initiatives such as the implementation of ISS launches through Soyuz and the execution of international launches by Proton in 1996 were taken, Russia’s annual launch weight gradually stabilized at around 140 tons. However, due to the frequent rocket quality problems in recent years and the decrease in operational volume, its launch weight fell back to below 100 tons[14]. By theoretically calculating the sum of rocket carrying capacity (based on the maximum carrying capacity), the launch weights in 2018, 2019, and 2020 were 139.5 tons, 170 tons, and 137.4 tons, respectively.

In China, the average annual number of launches and launch weight have been at a low level for a long time. In the 21st century, the average annual number of launches has shown a significant upward trend. In particular, after 2015, the number of launches increased year by year, averaging more than 20 launches per year, gradually tying with the U.S. and Russia, and maintaining an average annual launch weight of about 50 tons [14]. Furthermore, the launch weights in 2018, 2019, and 2020 were 142.495 tons, 106.325 tons, and 173.265 tons, respectively.

Table 2 Theoretical Annual Launch Weight of China and Russia in Recent Three Years

Year / Country	2018			2019			2020		
	Rocket	Number of launches	Theoretical Launch Weight (t)	Rocket	Number of launches	Total Theoretical Launch Weight (t)	Rocket	Number of launches	Total Theoretical Launch Weight (t)
China	CZ-2C	6	23.1	CZ-2C	1	3.85	CZ-2C	3	11.55
	CZ-2D	8	32	CZ-2D	1	4	CZ-2D	7	28
	CZ-3A	2	5.3	CZ-3B	11	60.5	CZ-2F	1	8.6
	CZ-3B	11	60.5	CZ-3C	1	3.9	CZ-3B	8	44
	CZ-3C	1	3.9	CZ-4B	4	7.6	CZ-4B	5	9.5
	CZ-4B	1	1.9	CZ-4C	3	8.4	CZ-4C	1	2.8
	CZ-4C	5	14	CZ-5	1	14	CZ-5	2	28
	CZ-11	3	1.26	CZ-6	1	0.5	CZ-5B	1	25
	KZ-1A	1	0.235	CZ-11	3	1.26	CZ-6	1	0.5
	ZQ-1	1	0.3	KZ-1A	5	1.175	CZ-7A	1	7
	-	-	-	Hyperbola-1	1	0.3	CZ-8	1	4.5
	-	-	-	OS-M	1	0.5	CZ-11	3	1.26
	-	-	-	SD-1	1	0.34	KZ-1A	3	0.705
	-	-	-	-	-	-	KZ-11	1	1.5
	-	-	-	-	-	-	CERES-1	1	0.35
	Total Launches	**39**	**142.495**	**Total Launches**	**34**	**106.325**	**Total Launches**	**39**	**173.265**
Russia	Soyuz-ST	3	24.6	Soyuz-ST	3	24.6	Soyuz-ST	2	16.4
	Soyuz-FG	5	37	Soyuz-FG	3	22.2	Soyuz-2-1a	5	41
	Soyuz-2-1a	4	32.8	Soyuz-2-1a	5	41	Soyuz-2-1b	8	65.6

Year / Country	2018			2019			2020		
	Rocket	Number of launches	Theoretical Launch Weight (t)	Rocket	Number of launches	Total Theoretical Launch Weight (t)	Rocket	Number of launches	Total Theoretical Launch Weight (t)
	Soyuz-2-1b	3	24.6	Soyuz-2-1b	5	41	Proton-M	1	6.9
	Soyuz-2-1v	1	2.8	Soyuz-2-1v	2	2.8	A5 Angara-A5	1	7.5
	Proton-M	2	13.8	Proton-M	5	34.5			
	Ро□кот	2	3.9	Ро□кот	2	3.9			
	Total Launches	**20**	**139.5**	**Total Launches**	**25**	**170**	**Total Launches**	**17**	**137.4**

According to the theoretical launch weight data of China and Russia for the recent three years, China has caught up with and surpassed Russia in terms of theoretical launch weight. Observing the specific data again, Russia mainly uses Soyuz and Proton-M rockets to launch manned and cargo spacecraft and large mass navigation, communication, and electronic satellites, all with larger launch weights. In contrast, China has not achieved a significant comparative advantage in theoretical launch weight, despite a significantly higher number of launches and the number of rocket models used; the main reason is that China's new-generation rocket carrier rockets have not yet matured and entered the high-density launch period, and still concentrated on using traditional rockets to complete the urgent tasks. With the intensive launch of the new-generation rockets, the upgrading of rockets, and the gradual rise of commercial spaceflights, China will gradually gain an advantage in space access capability.

(VII) Space Development Assessment

According to the *Global Space Development Assessment* released in 2018[15], the report adopted the comprehensive index evaluation method and the hierarchical analysis method to construct an assessment model from five dimensions, including government support, technical capability, security capability, industrial development, and innovation development, and to quantitatively assess and analyze the level of space development of each country or region. The results show that the U.S. retains a commanding lead, Europe, China, Russia, Japan, and India are ahead of the world average, and China maintains its lead over Russia. According to Table 5, China has the same score as Russia in terms of government support and industrial development, lags behind Russia in terms of technology and security capabilities, and has a comparative advantage in terms of innovation development. This also confirms the previous description that Russia has been stagnant for 30 years despite inheriting a strong space base from the Soviet Union.

Table 3 Global Space Development Assessment Score (Based on data prior to 2018)

Ranking	Country	Government Support	Technical Capability	Security Capability	Industrial Development	Innovation and Development	Total Score
1	The U.S.	19.00	28.98	18.95	12.44	14.84	94.22
2	Europe	13.34	16.12	8.04	9.03	10.83	57.35
3	China	10.52	17.74	9.21	1.53	8.06	47.07
4	Russia	10.70	20.37	11.03	1.17	2.55	45.82

5	Japan	10.07	8.81	5.70	0.81	4.03	29.42
6	India	8.16	5.77	4.92	1.13	2.19	22.17

To sum up, after 60 years of development, China's space access capability is gradually improving and has caught up with or even surpassed Russia to a certain extent. At present, the Angara rocket has not yet formed a high-density launch capability, the Vostochny launching site has not yet been fully built, and the renovation of the Plesetsk launching site has not yet been completed. Combined with a solid foundation of space technology, Russia's future space strength cannot be underestimated. Only by continuously enhancing its comprehensive national power, promoting continuous high-density launches, shortening the single rocket measurement and launch cycle, improving the comprehensive measurement and launch capabilities of the four launching sites, intensively launching a new generation of rockets, breaking through the development and application of heavy rocket technology and supporting the rapid development of commercial spaceflight, can China maintain its comparative advantage over Russia in accessing space and stride forward to becoming a space power.

4. MAIN ADVANTAGES OF SPACE DEVELOPMENT IN RUSSIA (THE SOVIET UNION)

There are many reasons why the Soviet Union created so much space brilliance, but the main advantages are as follows:

(I) Systematic Top-level Planning

The space industry management system in the Soviet Union is characterized by the strict centralized management of the space industry complex by the Central Committee of the Communist Party of the Soviet Union and the state leadership, which allows the development and production of the most complex and advanced space systems in the shortest possible time by maximizing the concentration of state financial, material and human resources[16]. The Soviet and Russian leaders and successive governments, including Khrushchev, Yeltsin, and Putin, attached great importance to their space development. In 1955, Khrushchev instructed the Soviet Union to set up the "Sputnik Committee" to organize the development of manned satellites and carrier rockets. During Khrushchev's rule, the Soviet Union made a qualitative change and leap in space technology, successfully launching the world's first intercontinental missile, becoming the first country to put a man-made object into orbit around the Earth, and successfully launching the Vostok manned spacecraft carrying cosmonaut Gagarin, weighing 4.5 tons, into space[16-17].

Russia gives priority to national security in its national strategy and regards space superiority as an important means to ensure national security. Since the 1990s, Russia has undertaken a series of major reforms to revitalize its space industry. For example, Russia formed Roscosmos in 1992, established the United Rocket and Space Corporation (URSC) in 2013, and merged the Russian Space Agency with the URSC in 2015 to form the Roscosmos State Corporation. During this period, a series of space laws, policies, and plans were launched. In 1993, Yeltsin signed the *Law of the Russian Federation About Space Activities*, the first law in Russian history to coordinate space activities; the law begins by emphasizing that "in the Russian Federation the research and use of space, including the Moon and other celestial bodies, are the most important priorities of state interests." Russia has followed up with a series of strategic plans, including the *Space Plan of the Russian Federation for 1999-2005*, the *Space Plan of the Russian Federation for 2006-2015*, the *Space Plan of the Russian Federation for 2016-2025*, the *National Security Strategy of the Russian Federation*, the *National Plan of Russian Space Activity for 2013-2020*, the *Unified National Plan of Russian Space Activity for 2021-2030*, the *Basic Principles of State Policy in the Field of Space Activities until 2030 and Beyond* and the *General Principles of the State Policy for the Use of Aerospace Achievements to Serve the Economic Modernization of the Russian Federation and its Regional Development until 2030*. The above-mentioned plans were issued in the form of governmental decrees, which define in legal form the key directions and stages of future development of the Russian space sector and are of great significance for guiding space development. In addition, the Russian government has formulated special plans for the development of the space sector, which are taken into account in the formulation of the annual space budget statement[17].

(II) Abundant Human Resources

An important reason why Russia is a world leader in the aerospace field is that Russia has attached great importance to the construction of aerospace talents since the former Soviet Union. For decades, the Soviet Union had made the military industry and the space industry an important national project, forming a space industry production sector with a complete range of categories, professional support, advanced equipment, and a large number of talents. The Soviet Union owned more than 2.1 million scientific and technical personnel and skilled workers, nearly 10,000 senior cosmonaut specialists, and 100,000 senior technicians, so it is a world leader in technical strength[18-19]. After the disintegration of the Soviet Union, Russia faced a serious loss of scientific and technological talents due to a sharp decline in state funding for scientific research and a significant shrinkage in domestic demand, and the loss of scientific and technological human resources in its aerospace industry was also very serious. However, in recent years, Russia has begun to recover its science and technology and a number of specialists in the aerospace field (especially young specialists) began to flock in large numbers. In order to promote the rapid development of the space industry, the Russian government has adopted various policies, which are gradually achieving results. Besides, Russia has made long-term plans for personnel training, adopted a professionally-oriented personnel training model, implemented joint school-enterprise training, made efforts to improve the current situation of an aging workforce and improved remuneration packages, and reform the distribution system. According to the Russian Military Industry Network in August 2013, the current number of scientific and technical personnel in the Russian space industry was about 244,000, 67% of which were scientists. In October 2005, the Russian government proposed to define a new strategy for the development of the Russian space industry for the next 30 years, as well as priority directions for its development, to include in the state space budget funds for education and educator activities, specialized training of professionals and further training of cadres, and to launch the “Training of Modern Information Technology Specialists in Aerospace Systems” as a pilot program in the field of the high-tech industry.

(III) Outstanding Technical Capability

The Soviet Union created many firsts in the history of human spaceflight, and many technologies and achievements left the Western countries in the dust. During the Cold War, the Western countries phased out liquid-fuel rocket engines and replaced them with solid-fuel engines. However, Moscow never gave up the research of liquid-fuel rocket engines. Since 1960, the U.S. had not developed any new liquid rocket engine except for the space shuttle engine; but Moscow had developed 10 times more types of liquid-fuel rocket engines than the U.S. Besides, Russia’s rocket technology has been constantly improved, and the performance and reliability of rocket engines were in the leading position. For example, the single drive shaft of Russian rocket engines typically rotates the fuel and oxidizer turbopumps simultaneously, a technology that reduces the number of moving parts in the engine, thus reducing the probability of possible engine failure[19]. In 2019, Russian space launch technologies persistently moved forward in innovation. In the field of the overall design, Russia is transforming to digital design, completing the preliminary design of the Yenisei heavy carrier rocket for specific projects and continuing the development of ultra-lightweight reusable carriers; in the field of power technology, Russia has introduced the design concept of PLM systems, replaced the emergency protection system with an operational diagnostic system, and improved the test stand and put into operation a new metrology system; in the field of launch technology, Russia has conducted tests of a new mobile filling system for the upper stage low-pressure tanks at the Baykonur launch site, while the construction of the Vostochny launch site and the Angara launch site progressed on schedule[20].

(IV) Solid Industrial Foundation

The Soviet Union had built a powerful industrial complex during its development period, leading the world in the production of more than 20 major industrial products, even surpassing the U.S.[21]. The Soviet Union industrialized rapidly and became one of only a few (3-4) countries in the world that could manufacture all industrial products at that time. Russia inherited about 90% of the Soviet Union’s aerospace industry. The legacy of the aerospace industry from the Soviet period laid a solid industrial foundation for the Russian aerospace industry. The Soviet Union’s strength in space technology, equipment production, testing, and technology applications provided a broad platform for Russia to rapidly complete the renewal and transformation of its development model after independence[22]. The N1 rocket, the energy rocket, and the test and launch facilities supporting the rocket are all known for their complex mechanical structures and strong support and security capabilities. Taking the nickel-magnesium alloy used in the N1 rocket project as an example, the melting point of nickel is 1452℃, and the melting point of magnesium is 650℃, which is far different from each other. Moreover, magnesium metal is also characterized by high vapor pressure and non-induction, so it is very difficult to complete the actual production of rockets. The Soviet smelters risked fire, smoke, and even explosions in vacuum smelting, which was extremely difficult. Besides, Russia has also carried out a lot of work in the field of materials and manufacturing technology, such as producing various types of titanium alloy cylinders to replace the pressurized cylinders imported from Ukraine for subsequent use in Angara rockets; new pipeline assembly equipment, new alloy hydrogen analyzers, general-purpose automated heat treatment devices, and other equipment are put into use to support the enhancement of basic capability[23].

5. CONCLUSIONS

The top-level planning and management, abundant human resources, strong economic power, and solid industrial foundation that underpinned the rapid development of the Soviet Union’s space have become the main drivers of China’s space development. By comparing the space access capabilities of Russia and China and drawing on the experience of the rapid space development of the Soviet Union and the current situation where the U.S. is significantly ahead, the following outlook is presented in this study for the future space development of China.

First, the synergistic development of military and civilian businesses should be promoted. The initial primary mission of space was to meet military purposes and then to spread to civilian purposes. From the late Soviet Union to today's Russia, and based on the current direction of U.S. space development, China is actively promoting the development of civilian commercial spaceflight while fulfilling its military space mission. This can bring great economic value on the one hand, and on the other hand, it can take full advantage of the flexibility and innovation of civilian spaceflight to push the whole space technology forward. Under the leadership of the National Space Leadership Group, China should strengthen top-level coordination and planning, which will help give full play to the superiority of the socialist system and the functional mission of the aerospace system, pooling resources and forming synergies. In addition, while fulfilling the national space mission, China should support the development of commercial space, form a sound competitive environment, and strengthen the overall strength of China's aerospace industry.

Second, an excellent aerospace talent echelon should be built. China's space development has gone through the stage of "those who work on missiles are not as good as those who sell tea eggs", leading to personnel loss. With the increasing popularity of basic and higher education in China and the improvement of the overall level of education, the number and quality of space personnel have been comprehensively improved. At the same time, China's aerospace talents are young and innovative, and the talent development echelon is reasonable. However, Chinese aerospace personnel is still low-income compared to those in Europe, the United States, and Japan. The material and spiritual incentive policies of the U.S. and Soviet Union during the Cold War are worth learning from, but it is difficult to completely copy them. The development of the aerospace industry depends on scientific and technological innovation, which is inseparable from human resources. Especially with the increasingly fierce global competition for human resources in science and technology, adjusting the policy on scientific and technological talents so as to cultivate and attract a large number of high-quality scientific and technological talents will play a crucial role in the development of aerospace and other high-tech fields. How to better retain talents is one of the crucial issues for China's future aerospace development. Therefore, it is essential to constantly strengthen the construction and training of aerospace talents, build a reasonable talent echelon, and introduce relevant safeguards to ensure the sustainable development of aerospace.

Third, the renewal of the technology level should be promoted. At present, Chinese rockets have basically achieved renewal, but the new generation of rockets is still stuck in the reality that rockets can only be launched in the designated stations and fail to realize the multi-station launch of a single rocket and the launch of multiple types of rockets from the same station, which adversely affects the deployment and effective use of launch resources. Meanwhile, the repeatable launch technology is still in exploration and has not yet achieved an effective breakthrough. Therefore, it is necessary to effectively realize the generalization, modularization, and combination of rockets of the same scale or the same technology in the subsequent rocket product development and launch site construction transformation, play the linkage testing mechanism of the site and launch site, reduce the invalid testing of the launch site, shorten the testing and launch cycle, and improve the launch efficiency; commitment is made to accelerate the breakthrough of reusable rocket technology, reduce the space transportation cost, effectively increase the product development efficiency, and improve China's space access capability through various ways.

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