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Initial Analysis of Two Chinese Satellite Series: Shi Jian and Shi Yan

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The Chinese satellites with the Shi Jian (SJ) and Shi Yan designators are just two categories of Chinese space vehicles on which Beijing has not elaborated in recent years.[i] This paper reviews their history up to 2013 to provide space watchers with an initial framework for analyzing these satellites' on-orbit behavior. It is too early to determine if the framework can also accurately describe more recently launched SJ and Shi Yan satellites. This is an initial review to support follow-on studies of these and China's other technology satellites.

Key Take-Aways

The SJ and Shi Yan designators seem to categorize satellites with distinct functions. According to publicly available information, China has historically used the SJ series to establish operational best practices and procedures for systems or techniques already adopted. For example, China has used these satellites multiple times for optimizing technologies first flown on other Chinese systems. The Shi Yan satellites appear to play an earlier role in the space systems development process. China has used this series to pilot multiple new technologies on one satellite bus specifically to develop a platform for efficient payload integration, as well as to determine the applicability of the payloads. Distinguishing between the SJ and Shi Yan series by their different roles in the technology development process would also be consistent with a more nuanced explanation of the Mandarin words used for their names. "Shi Jian" indeed means "practice" but as a noun, such as "best practice", or as in "put into practice." Some Chinese linguists argue against translating "Shi Yan" as "experiment," so "pilot" or "trial" are more applicable. See Figure 1 and 2 in the last section for more detail.

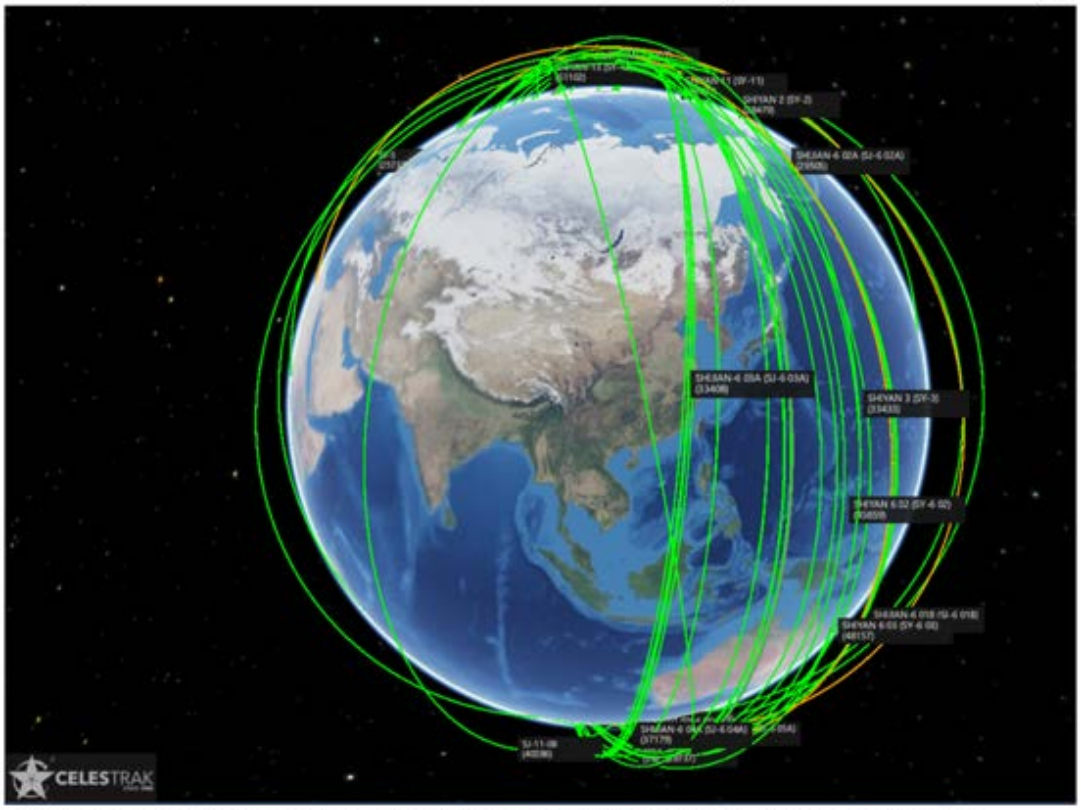
Regarding their payloads, both the SJ and Shi Yan series have for decades contributed to what Beijing now refers to as the China High-resolution Earth Observation System (CHEOS). Many examples illustrate a distinction between SJ and Shi Yan's contribution to remote sensing, with SJ having primarily improved methods for radar and infrared payloads and Shi Yan having primarily enabled testing of other optical payloads. A role in remote sensing for each series could explain why over half of their satellites are in sun-synchronous orbit (SSO)[ii], which is commonly

[i] Throughout this paper we abbreviate Shi Jian (SJ) and not Shi Yan to help readers distinguish between the two. Shi Yan is elsewhere often abbreviated as (SY).

[ii] SSO is a type of polar orbit, which is approximately 200-1,000 km from Earth, like traditional low Earth orbits (LEO). However, satellites in SSO pass over the North and South Poles rather than traveling West to East like other satellites in LEO. SSO satellites are in a fixed position relative to the Sun.

used for remote sensing (see Map 1 and Table 1). Apart from this shared legacy in remote sensing, the SJ series has 30 more years of history and a corresponding larger variety in missions and payloads. For example, it has also regularly played a role in establishing best practices for data transmission and communications, and on-orbit satellite constellation guidance and control. SJ-8 and SJ-10 were return capsules which carried Chinese and international experiments.

Map 1: Shi Jian and Shi Yan Satellites in Sun-Synchronous Orbit Only*



*Sun-synchronous orbit (SSO) Shi Jian and Shi Yan satellites from Zarya.info's SSO satellite list, plotted in CelesTrak's orbit visualization tool. Orbits are for illustrative purposes and may not be precise.

Nascent signs of potentially emerging trends for the SJ and Shi Yan series have started to surface since 2010, but it is too early to make broad judgements on the information. In 2013, after being jointly launched, the SJ-15 and Shi Yan-7 conducted their only publicly known rendezvous and proximity operation (RPO), which seemed to be coordinated. This may indicate deepening ties between the two series. Another trend may be an increasing opportunity for technology developers to push innovative capability adoption, rather than developing to specific end user requirements. For example, the Chief Designer of the SJ-9 A and B in a 2013 interview said he was using SJ-9 to demonstrate new operational practices to potential users. The Chief Designer of the three Shi Yan-6 satellites indicated in 2020 that he was using the series' heritage in Earth observation to pilot an on-orbit space situational awareness capability from SSO looking at geosynchronous Earth orbit (GEO).

Table 1: Shi Jian and Shi Yan Satellites in Sun-Synchronous Orbit By Launch*

Shi Jian Number (ID)	Launch	Selected Highlights	Shi Yan Number (ID)	Launch	Selected Highlights
Shi Jian 5 (25731)	May--1999	Support Hai Yang 1	Shi Yan 1 (28220)	Jan--2004	stereoscopic imaging
Shi Jian 6-01A (28413)	Sep--2004	SAR paired with possible optical	Shi Yan 2 (28479)	Nov--2004	stereoscopic imaging
Shi Jian 6-01B (28414)	Sep--2004	SAR paired with possible optical	Shi Yan 3 (33433)	Nov--2008	stereoscopic and other optical
Shi Jian 7 (28737)	July--2005	Infrared push-broom camera	Shi Yan 4 (37931)	Nov--2011	stereoscopic and other optical
Shi Jian 6-02A (29505)	Oct--2006	SAR paired with possible optical	Shi Yan 7 (39208)	July--2013	robotic arm
Shi Jian 6-02B (29506)	Oct--2006	SAR paired with possible optical	Shi Yan 6-01 (43711)	Nov--2018	SSA
Shi Jian 6-03A (33408)	Oct--2008	SAR paired with possible optical	Shi Yan 6-02 (45859)	April--2020	SSA
Shi Jian 6-03B (33409)	Oct--2008	SAR paired with possible optical	Shi Yan 6-03 (48157)	April--2021	SSA
Shi Jian 12 (36596)	June--2010	RPO and satellite inspection, inter-satellite coms	Shi Yan 11 (49501)	Nov--2021	
Shi Jian 6-04A (37179)	Oct--2010		Shi Yan 13 (51102)	Jan--2022	
Shi Jian 6-04B (37108)	Oct--2010				
Shi Jian 11-05 (39202)	July--2013	infrared sensor			
Shi Jian 15 (39210)	July--2013	collision avoidance			
Shi Jian 11-06 (39624)	March--2014				
Shi Jian 11-07 (40261)	Sep--2014				
Shi Jian 11-08 (40286)	Oct--2014				
Shi Jian 6-05A (49961)	Dec--2021				
Shi Jian 6-05B (49962)	Dec--2021				

*Table 1 includes the Shi Jian and Shi Yan satellites in sun-synchronous orbit (SSO) because it is the location of over 50% of current satellites in each series. IDs are from CelesTrak and the selected highlights are discussed and sourced in the paper.

SJ's Decades Of Establishing Best Practices For Space Operators and Developers

Beijing initiated the SJ series early in its spacefaring history with SJ-1 being China's second satellite, launched in 1971. Information on these early launches illustrates that China's focus for the SJ series was on establishing best practices and operational procedures to enable the development of China's space program. This of course could be said of any country's first satellites, but over three decades, the Chinese continued to use SJ as a dedicated series for improving space systems' performance.

From 1971 to 1999, China launched six SJ's on short missions primarily to increase Chinese engineers' understanding of the space environment and its impact on domestic satellite components. SJ-2 tested onboard data storage and early digital cameras.[1,iii,iv] One example of

[iii] Charge-coupled device (CCD) cameras

[iv] The launch of SJ-2, SJ-2A and SJ-2B in 1981 was China's first launch of three satellites on one launch vehicle. There is significant information on the lessons learned for the ground station operators. This was their second

China using this knowledge to improve other satellites being developed simultaneously is in the example of its meteorological satellites, known as the Feng Yun series. China's first Feng Yun satellites in the late 1980s experienced radiation damage, which significantly shortened their lifespan.[2] According to a Chinese publication, early SJ satellites flew instrumentation to measure radiation exposure and its effect on various domestic components, specifically to learn mitigation measures.[3,v] Engineers implemented improvements on the SJ-5 (1999) using China's first small satellite bus, the CAST 968, which also supported payloads for China's first ocean monitoring satellite, the Hai Yang-1 (2004).[4,5,6] Similarly, to begin professionalizing Chinese space operators, engineers used lessons learned from the first four SJ satellites to publish Mandarin space operations manuals such as the *Handbook of the Artificial Satellite Environment* and *Handbook on Low Earth Orbit Space Environment* to use in training China's growing cadre of space professionals.[7]

Beijing released its first Space Activities White Paper in 2001, which noted that one of its priorities for the following decade was to establish an Earth observation system to "include both stereoscopic observation and dynamic monitoring."[8] By the early 2000s, Beijing had already launched four separate satellite series, namely the recoverable, telecommunications, meteorological and SJ series. While the recoverable satellites enabled early imagery tests, China still needed to make significant advances in order to build a suite of remote sensing satellites.[9] Specifically, Chinese engineers needed to first learn best practices for stabilizing and maintaining a satellite's orientation or "attitude," to point sensors. Second, they needed to develop or gain access to the range of sensors for capturing Earth observation data to then build techniques for interpreting the data.

The SJ series contributed to the first task by honing methods for satellite control after launch, a general requirement that is especially necessary for enhanced imagery with two satellites flying in formation.[10] Chinese leaders may have recognized a need to improve China's satellite stabilization for formation flying when they first tried the technique (already demonstrated by NASA) with its natural resource satellites Zi Yuan 2A and B in 2002.[11] Operators likely experienced problems, leading to the launch of the first SJ-6s two years later in 2004. The Deputy Designer of the first set of SJ-6s and later the Chief Designer of SJ-7 (2005), Yang Zhihao, said in an interview that these three satellites played a key role in establishing satellite control and recovery techniques specific to SSO.[12] In particular, he said they enabled engineers to "master 3-axis stabilization," probably still with thrusters and by leveraging China's first indigenously developed star tracker, still paired with GPS.[13] Best practices from the first set of SJ-6s probably enabled early SSO RPOs in 2010 with SJ-12.[14,vi]

According to the Chief Designer of the first six SJ-6s (launched in pairs in 2004, 2006, and 2008), Lu Zili, he had begun work on the SJ-6 concept in the 1960s but was pulled away to

attempt after a launch failure in 1979. Work from SJ-3 was merged with the China-Brazil Earth Resources Satellite (CBERS) first launched in 1999. SJ-4 was the first in the series launched to geosynchronous Earth orbit (GEO).

[v] A few Feng Yun satellite designers later worked on SJ-6 and led SJ-7.

[vi] SJ-6 01 (2004), 03 (2008) and 04 (2010) supported development of practices for satellite close approaches and formation flying with orbit changes, with SJ-12 (2010). Formation flying has many applications, and China's early focus was on using the technique to improve remote sensing.

work on the Feng Yun-1 and 2, which were a higher national priority. After Feng Yun 1C's success in 1999, he was able to return to the SJ-6 project to "design all six satellites in parallel," indicating the first three launches of SJ-6s may have the same onboard payloads.[15] According to a blogger recounting Lu's career, he has said that the SJ-6s inherited Feng Yun-1's technology with massive improvements and one new payload.[16]

The Chinese National Space Administration, and several academic publications, reported at the time that China was working on the use of satellite pairs for synthetic aperture radar (SAR) and combining a SAR satellite with an optical satellite flying in formation.[17,18] Some papers discuss SJ-6 and describe how SJ-6B carried a radar imaging system, the accuracy of which was enhanced by measuring the timing of the radar pulses on the accompanying SJ-6 A.[19,20,21,22,23]

Some western analysts have speculated that the SJ-6s could also contribute to an electronic or signals intelligence capability.[24] While not linked with a discussion on paired satellites, so not necessarily related to SJ-6, some Chinese researchers have written about military applications of SAR. For example, authors from a PLA Air Force academic institution in 2007 discussed using SAR to "track ships" and enhance "anti-jamming."[25,26,27] Separately, the team that worked on the early SJ-6s said in interviews that they felt significant stress to meet the launch timeline and the needs of the "end user."[28]

Enter Shi Yan To Support The Broadening Remote Sensing Goal

As China formalized its plan to build a full suite of remote sensing satellites in the early 2000s, Beijing was also enabling an expansion of university engineering teams participating in satellite development. The first Shi Yan was initiated and designed by the Harbin Institute of Technology and launched in 2004, nearly 30 years after the start of China's space program.[29,30,vii] The emergence of the Shi Yan series is one mark of the slow start of China's efforts to increase state-owned enterprise (SOE) competition in the space sector, and China's efforts to engage in the growing international market for smaller satellites.

Many Chinese media interviews with the various Shi Yan 1-4 designers indicate that they were all committed to staying below the size of China's first small satellite bus, the CAST 968, which was 375-400 kg, as well as contributing to a remote sensing architecture.[31,32,viii] Indeed, Shi Yan-1 was China's first stereoscopic imaging satellite for terrain mapping, and the first ten years of the series saw Shi Yan 1-5 focused on piloting as many payloads as possible, probably optical sensors, on one satellite close to 200 kg.[33,34,35] Chinese media has lauded Shi Yan-3 (2008) for its "flexible satellite platform for multiple payloads."[36] Technologies piloted on the first four Shi Yans helped operators select payloads for the high-resolution environmental

[vii] To help the reader distinguish between the SJ and Shi Yan series, this discussion of their similarities and differences will spell out "Shi Yan," not use the elsewhere used acronym SY.

[viii] Up until Shi Yan's first launch in 2004, the vast majority of Chinese satellites had been designed and manufactured by state-owned enterprises (SOEs) and national research institutes. This began to change in the late 1990s with the global trend towards satellite miniaturization and academic spin-offs. For example, the success of the United Kingdom's Surry University spin-off called Surry Satellite Technology Ltd. (SSTL) plays a prominent role in several Chinese university small satellite program histories.

satellite, Zi Yuan-3, launched in 2012.[37,38] One of the Shi Yan-5 developers has since started a Chinese satellite startup company called Minospace focused on smaller satellites.[39]

Other successes of the university teams working on the Shi Yan 1-5 include their engagement with experts across China and overseas to pilot multiple technologies never used before by the Chinese space industry. By one Chinese accounting, fifty percent of technology on Shi Yan 1 and 2 were new in China, such as software for satellite "autonomous management and control" and the use of reaction wheels rather than thrusters for on-orbit maneuverability.[40,ix] Shi Yan 3 and 4 designers worked closely with the Chinese Academy of Science's (CAS) Chuang Xin-1 02 and 03 satellite designers, probably because both series focused on applications of optical sensors. They twice shared the same launch vehicle in 2008 and 2011, and their joint remote sensing work was published in a report by China's National Commission for Disaster Reduction in late 2011.[41]

At the same time, the SJ series was also continuing its support to the remote sensing architecture. Chinese engineers were not only using it to develop SAR techniques as discussed above, but also using the series to optimize methods for collecting infrared signatures. China flew its first infrared sensors on the joint China-Brazil Earth Resources Satellite (CBERS) in 1999, and in 2005, flew an improved infrared push-broom camera on SJ-7, according to Chinese media.[42,43,44] China continued to use the SJ series for establishing infrared sensor techniques on SJ-11 (2009) and SJ-9B (A and B in 2012), launched out of numeric order.[45,46] Some western analysts and Chinese media have speculated that the infrared sensors on SJ-11 were designed for establishing practices for an initial space-based ballistic missile early warning system.[47,48] One Chinese blogger said bluntly that the SJ-11 series is for a conflict in the East and South China Seas and further speculated that the United States was behind the failed launch of SJ-11 04 in 2011.[49]

According to Chinese researchers and media reports, SJ-9B's infrared payload is complimented with a SAR payload on SJ-9A, probably for developing integrated remote sensing practices.[50,51] Also notable is what China has more actively publicized about the SJ-9s, particularly their use in developing techniques for inter-satellite datalinks, satellite-to-ground high-speed laser communication, and electric propulsion. China has elevated these successes in its third Space Activities White Paper in 2011 and at the Zhuhai Air Show in 2012.[52,53] A 2013 interview in The People's Daily with the SJ-9 Chief Designer, Guo Baozhu, described that the SJ-9s are some of China's first practice satellites to develop methods not yet requested by an end user.[54] Guo argued that China needed to launch more technology satellites, comparing the U.S., EU, and Japan's rate of 10 application satellites to 1 technology satellite as far higher than China's rate. He further stated that the Chinese government should do a better job supporting technology demos and corralling potential users.[55]

[ix] At the same time, the SJ series was also working on improving satellite control but with thrusters to achieve 3-axis stabilization. Shi Yan 1 and 2's demonstration of reaction wheel technology, if it was in fact China's first use, was not doubt leveraged on later SJs.

Nascent Signs Of Emerging Trends

The interview with the SJ-9 Chief Designer is just one example of what seems to be a trend in China's aerospace industry in the early 2010s towards broadening the use of technology satellites. By the end of the decade, China had constructed the foundation for CHEOS, to include Beijing's first dedicated military remote sensing satellite called Yao Gan in 2006 and the civilian high-resolution optical series called Gao Fen later in 2013. [56] It would seem reasonable to assume that there could be a shift in user requirements, as well as an opportunity for technology developers to push new applications. Interestingly, in 2013 the SJ and Shi Yan series conducted their first RPO, potentially indicating growing ties between the two series. It is unclear if there was an active datalink between the two during the RPO, or if the teams shared information during or after the operation.

Even in this case, Shi Yan maintained its role as a platform for piloting new technologies, with Shi Yan-7 flying China's first miniaturized robotic arm on a satellite, in a joint launch with Chuang Xin-3 and SJ-15 in 2013. [57,58] The developer of Shi Yan-7's miniaturized robotic arm also developed the Tian Gong-2 space station's larger arm.[59] When China launched the three satellites, Chinese media announced that they would "test space maintenance technologies such as space debris tracking and robotic arm operations."[60] Indeed, in August of 2013, space watchers identified that SJ-15 had maneuvered to within a few kilometers of Shi Yan-7 and Chuang Xin-3 before leaving to conduct other close approaches. [61] Either the operators or the designers of the SJ-15 won a PLA General Armaments Department Military Science and Technology Progress Award in 2014 for that satellite's work on "collision avoidance."[62] In October, Shi Yan-7 released a subsatellite presumably to test its robotic arm with Chuang Xin-3 nearby to support imagery or communications.[63] The Shi Yan designers had previously worked with the CAS Chuang Xin team, but the earlier RPO is the first publicly known example of them potentially working with the SJ series.

The Deputy Chief Designer of the Chuang Xin-3 is also the Chief Designer of the Shi Yan-6 trio (01, 02, and 03 launched in 2018, 2020, and 2021, respectively).[64] In an interview in 2020, posted on the CAS website in 2021, he described the Shi Yan-6 as a constellation of satellites built on Chuang Xin's work tracking debris and "shooting stars at 36,000 km." [65] It is reasonable to interpret him as saying Chuang Xin and most likely Shi Yan-6 are testing technologies to enable a space-based satellite tracking effort in SSO looking at GEO.[x] GEO is regularly described as being 36,000 km from Earth and satellites there would look like "shooting stars" from SSO.

[x] According to Marlon Sorge at The Aerospace Corporation, "Satellites in sun-synchronous orbit (SSO) can look up and away from the sun and see geosynchronous Earth orbit (GEO) objects. From that range, satellites can likely just track GEO satellites, not try to see them more clearly than dots. The reason one might use SSO for GEO observation is that the orbit maintains its orientation relative to the sun the whole year. If you orient a satellite right, you can look at GEO in an orientation where the sun is lighting up the satellites pretty much all the time. If the orbit runs along the terminator going over dawn and dusk, it will stay that way all the time. The satellite can then turn sideways in its orbit looking away from the sun so that the sun is at its back and see the sun-lit sides of satellites in GEO." (February 2022 email exchange, published with approval)

What Is In A Mandarin Satellite Name?

It is actually not a far analytic reach to conclude SJ's role as a space best practices developer and Shi Yan's role as a technology pilot platform from the Chinese words "Shi Jian" and "Shi Yan" when used as satellite names. Spacecraft names in English are often so specific of their function, and long in title, that their names are abbreviated. For example, the name of the U.S.'s Geosynchronous Space Situational Awareness Program satellites indicates both their location and function in space, and are referenced with the acronym "GSSAP."[66] In an example of a foreign and non-Chinese system, the Indian Chandrayaan lunar mission translates as "Moon vehicle," according to the Indian space agency ISRO.[67]

When western media or analysts use the transliteration of Chinese satellite names to help non-Mandarin readers pronounce and recognize them, and then use the transliteration's acronym, they are essentially further shortening an already abbreviated name (from the Mandarin), and loosing much of its specificity. This is particularly unfortunate when the transliterated name and the English translation of two different satellite series are very similar. Shi Jian (SJ) is usually translated by space watchers as "practice" and Shi Yan (SY) as "test or experiment." [68,69]

Below, we attempt to give a non-Mandarin reader and space operator a more nuanced description of these two satellite names. Our intention is to leverage the specificity conveyed in the Mandarin words as a way to better describe their meaning when used as a spacecraft name. This is not intended to be a thorough linguistic analysis of Mandarin characters, but a reminder that satellite names are often selected intentionally to reflect the series' function, though the meaning of the name should only be considered in context with its known payloads and observed behavior. While satellite names are one of the easiest things to use for masking the spacecraft's intention or true operator, the above initial review of the SJ and Shi Yan series' histories actually indicates these names may not have been used for deceptive purposes, at least in the early years.[70,71]

To interpret Figure 1 and 2, first look on the bottom of the Mandarin to find the definition of the individual character components, which are used in many other related words. Below that is the combined definition of the two character word, based on several Chinese dictionaries. For "Shi Jian" in Figure 1, "to carry out" is also listed with the noun "practice" in dictionaries, but the former is more specific. Same with "Shi Yan" in Figure 2. "Verify and confirm" are included with "test" as descriptors, but again, the former is more specific.[72] Above the Mandarin characters, is the suggested meaning when the words are used as satellite names, based on the series' histories.

Figure 1

Figure 2

Lastly, to check this characterization is accurate for even every-day usage in China, consider the regularly used: "Pilot (Shi Yan) free trade zones are a relatively new practice (Shi Jian) in China."[73] This and other examples indicate Figure 1 and 2 are a fair interpretation of the use of these terms as satellite names.

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