CHINA AEROSPACE STUDIES INSTITUTE

China's Space Capability and What This Means for the West

David Chen

The People's Republic of China (PRC) has rapidly advanced in the space domain on several fronts simultaneously. Gen. Stephen Whiting, commander of U.S. Space Command testified in early 2024 that, "The PRC is moving breathtakingly fast in space. America must rapidly increase the timeliness, quality and quantity of our critical national space and missile defense systems to match China's speed and maintain our advantage."[1] The revelation in February that Russia was developing a nuclear-enabled anti-satellite weapon led to speculation about whether it was a fission reactor-powered electronic warfare satellite or a nuclear detonation device, with the latter seeming to be the more likely, despite Russia's treaty commitments.[2] Such developments have also stoked anxieties about China's intentions in space, including after its demonstrations of a so-called "fractional orbital bombardment system" and the deployment of a reusable spaceplane. PRC researchers have themselves studied the effects of upper atmospheric nuclear detonation on LEO, modeling radiological effects based on altitude for optimal strategic utility.[3] [4] While Russia has garnered much of the spotlight with its employment or threatened employment of novel weapons systems, China's development of similar emerging technologies deserves as much or more scrutiny.

On the other hand, there have been signs of internal frictions and underlying problems within the PRC defense and aerospace establishment. Several high-ranking officials and former officials have been caught up in the latest round of Chairman Xi Jinping's anti-corruption campaign. These include figures as high as politburo members, like the Minister of Foreign Affairs and the Minister of Defense, with repercussions including expulsion from the Chinese Communist Party (CCP), and prosecution. More recent disclosures at the recent "Two Sessions" of the Chinese People's Political Consultative Conference (CPPCC) and the National People's Congress (NPC) revealed several defense industry leaders had been stripped of their seats, a step which clears the way for state charges and other disciplinary actions. The PRC remains a hard analytic target requiring scrutiny of both its triumphs and its points of weakness. Understanding

this mix of factors is key for assessing how to best cooperate and compete with this rising space power, and the various implications for space domain awareness.

A Challenging Adversary

Foremost in the minds of many in the community are the achievements and capabilities that PRC military space programs have developed in recent years. These include development and maturation of reusable space plane operations, the possibility of an alarming return to the Cold War with a potential Fractional Orbital Bombardment hypersonic vehicle, ongoing rendezvous and proximity operations particularly targeting the GEO belt, the prospect of using nuclear weapons in an anti-satellite capacity, and cyber-electronic warfare (EW) threats. U.S. defense leadership has also sounded the alarm at the steady rise in the number of intelligence satellites China has placed in orbit: "As of January 2024, the PRC has deployed a fleet of 359 intelligence satellites, [Gen. Stephen Whiting] said, 'more than tripling its on-orbit collection presence since 2018.'"[5] After the establishment of the People's Liberation Army (PLA) Strategic Support Force (战略支援部队) in 2015, it was clear that space as a domain would be an important strategic focus for future developments, and as the PRC builds out its satellite operational support networks along with the projects below, the military continues to play a key role in driving space development. Researchers at institutions affiliated with the Aerospace Force and former Strategic Support Force have called for using a "combination of soft and hard kill methods" to hold at risk orbital assets, including commercial satellites like the Starlink constellation.[6]

Reusable Experimental Spacecraft

PRC scientists, defense industry engineers, and military analysts have long been fascinated by the concept of a reusable spaceplane, particularly after NASA retired the space shuttle and the U.S. Air Force operationalized the long dormant concept of an uncrewed reusable spaceplane in the X-37B project. When first launched, PRC analyst speculated about whether it could serve as a platform for grappler arms, high-power microwave weapons, or laser weapons. China Aerospace Science and Technology Corporation

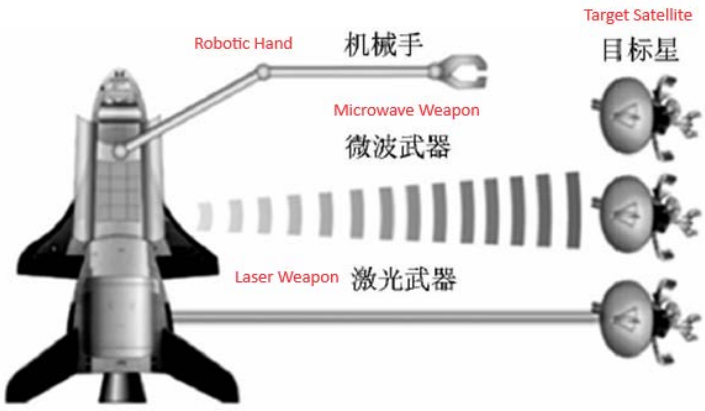

Figure 1. Notional spaceplane capabilities (Winged Missiles).

(CASC) first launched the “Reusable Experimental Spacecraft” (可重复使用试验器) in 2020 and has launched subsequent missions in 2022 and 2023, with the turnaround between recovery in May 2023 and launch in October demonstrating rapid redeployment capabilities.[7] Little has been revealed in public about the payloads of the missions, other than their use as an experimental platform to test reusable aerospace technologies and to promote “the peaceful uses of outer space.”[8] Each of the three missions to date, however, have released payloads in orbit, assessed by Western observes to be RPO (rendezvous and proximity operations)-capable micro-satellites that were able to maintain station with their mothership.[9] The latest spaceplane launch resulted in at least six objects in orbit, with two that “gave off radio signals.”[10] While the applications of this or any other PRC spaceplane platform have been kept confidential, there are implications for development of hypersonic flight technology, RPO, directed energy, satellite-to-satellite ISR (intelligence, surveillance, and reconnaissance), signals intelligence, and more. The tacit message from the PRC seems to be, whatever the X-37B vehicle can do, we can do, as well, including keeping mission details private, making independent tracking and observation of the vehicle a vital mission. For space situational awareness purposes, maintaining observations of a maneuverable vehicle with long endurance will necessitate greater investment in both terrestrial and on-orbit tracking and characterization assets across the geographic and spatial domain.

Fractional Orbital Bombardment System

PRC efforts to revive space technology concepts like a reusable spaceplane may be harkening back to the Space Shuttle or Buran, but China has seemingly reached even further back to revive the Soviet-era concept of a “fractional orbital bombardment system” (FOBS), in the form of a hypersonic boost-glide system.[11] The original rationale for launching a nuclear weapon on a fractional orbital trajectory was to evade early warning radars by taking a different approach vector than traditional ICBM launchers. Public details on the capabilities of the PRC’s system are still closely guarded secrets and the Foreign Ministry simply indicated the test was of a hypersonic spaceplane, but may have been referring to a different test altogether that occurred around the same time as the July 2021 launch.[12] PRC military doctrinal writings indicate that developing an orbital bombardment capability could be part of a deterrence and compellence strategy aimed at holding assets at risk in expanded regions:

> The use of an orbital bombardment system could increase PLA power projection capabilities against bases and territories globally, including targets in the 50 states. The use of an orbital bombardment system can complicate U.S. missile defenses by forcing the U.S. to defend against joint and combined arms attacks from multiple directions.[13]

If the PRC hypersonic vehicle is intended to carry a nuclear payload and conducts a full orbit, such a system would be in violation of the 1967 Outer Space Treaty, to which the PRC is a signatory. Demonstrating such a system would be a sharp break from both PRC diplomatic commitments as well as longstanding positions it has taken in the Conference on Disarmament and the Committee on the Peaceful Uses of Outer Space, where both China and Russia have

consistently held that weaponizing the space domain was undesirable. The likelihood that the PRC would invest prestige and sustained funding into a new weapons system that undid those previous international commitments seems incongruous and uncharacteristically risky.

An alternative explanation could be found in the strange operational behavior of the reentry vehicle observed by U.S intelligence and as reported in the media. U.S. analysts were apparently surprised enough to characterize the test as having "def[ied] the laws of physics" when the primary vehicle appeared to have fired a secondary munition—possibly a countermeasure, air-to-air missile, or something else—while traveling at hypersonic speeds.[14] This would be a capability no other nation has demonstrated or has claimed to be pursuing:

> Experts at DARPA, the Pentagon's advanced research agency, remain unsure how China managed to fire countermeasures from a vehicle travelling at hypersonic speeds. … Military experts have been poring over data related to the test to understand how China mastered the technology. They are also debating the purpose of the projectile, which was fired by the hypersonic vehicle with no obvious target of its own, before plunging into the water.[15]

Through the nuclear lens, such a secondary payload could represent a MIRV/MaRV (multiple independently targetable reentry vehicle/maneuverable reentry vehicle) warhead, an atmospheric countermeasure, or a self-defense capability. Yet, Secretary Kendall admitted in his initial disclosure that this interpretation was colored by Cold War history. The original Soviet FOBS did not include a maneuvering hypersonic glide vehicle, much less a secondary vehicle.

Looking at PLA doctrinal evolution, PLA strategists place an increasing emphasis on autonomy and convergence of the "reconnaissance-strike complex", in Chinese "查打一体". A

Figure 2. DF-17 ballistic missiles on military parade in 2019 mounted with hypersonic vehicles (AP).

hypersonic glider has advantages in evading early detection and air defenses but upon reentry generates a hot plasma envelope that both illuminates itself to sensors and prevents radio communications with the global satellite communications network, making the employment of such weapons most practical against fixed targets like airbases and runways, but not mobile high-value targets like ships.[16]

If the PRC FOBS is not a new nuclear leg, but rather a conventional strike capability, the secondary payload could be part of a solution for striking mobile targets like aircraft carriers. This could demonstrate the intention of, "a convergence of sensor and weapon, a 'detect-destroy' singularity moment for achieving a resilient and independent kill chain."[17] Integrating artificial intelligence capability into a weapon system and providing local sensor data at close range could enable the warhead to find and fix a mobile target independent of mission controllers. The ability to hold such targets at risk using a variety of anti-ship cruise, ballistic, and hypersonic missiles has been a longstanding aim for PLA weapons development. Adding a fractional orbital bombardment hypersonic glide option would enable new ways to conduct coordinated multi-vector saturation attacks against key targets. Notably, on their way to splashdown the hypersonic vehicle and its companion overflew the South China Sea region.

Whether for nuclear or conventional deterrence, the FOBS hypersonic vehicle certainly merits further engagement with official PRC interlocutors. The commitment of the PRC to its "no-first use" nuclear doctrine and the 1967 Outer Space Treaty is called into question by these developments and it is increasingly important for China to reify those commitments in public international fora. From a technical perspective, such a FOBS-hypersonic platform places greater urgency on the Space Development Agency and Missile Defense Agency to prove out and field the Hypersonic and Ballistic Tracking Space Sensor system to orbit and initial operational capability, which is about to begin a 2-year on-orbit testing phase.[18] Combining technical analysis with diplomatic engagement, and a deep understanding of the evolution of PRC strategic doctrine will be necessary for properly characterizing these emerging capabilities and mitigating the threat to global security.

Rendezvous and Proximity Operations

China's space endeavors have long included RPO as a safety and operations assurance feature. For instance, during China's third human spaceflight mission in 2008, the crew of Shenzhou-7 deployed a companion satellite, the Banfei Xiaoweixing-1 (BX-1), to co-orbit with the capsule while relaying images back to mission control.[19] BX-2 was deployed from Shenzhou-11 as part of the process for assembling the Tiangong space station. The Shanghai Aerospace Technology Corporation (SAST), a subsidiary of CASC, has demonstrated key competencies in designing and operating RPO vehicles for the civil space program. Since CASC is also the state-owned enterprise with overall control of China's space development, including military programs, this also benefits military RPO applications.

PRC Mission Nomenclature

China's satellite missions are usually named in series depending on the mission and the manufacturer of the satellite.

Banfei Xiaoweixing (伴飞小卫星) means "flight companion small satellite", usually shortened to *Banxing*. BX-1 and -2 accompanied crewed *Shenzhou* missions. They have been produced by SAST's small and micro-satellite research center.

Shijian (实践) means "practice" or "experience" and refers to a long-running series of satellites since the 1970s used for technology demonstration purposes. Manufacturers of the series include state-owned enterprises and institutes.

Shiyan (实验) means "experiment" or "experimental" and refers to a series of satellites that began launching in the 2000s with technology demonstration missions. Manufacturers of the series include a mix of state-owned enterprises and commercial providers.

Aolong (遨龙) means "roaming dragon", while Aolong-1 was apparently named as part of a series, no subsequent mission has been announced. Aolong was developed by CALT.

Tongxin Jishu Shiyan (通信技术实验) means "communications technology experiment" and is a satellite series that first launched in 2015. The series is manufactured by CAST and SAST, with some missions appearing to act as cover for military purposes.

China has demonstrated satellite-to-satellite RPO activities in both LEO (low earth orbit) and GEO (geostationary orbit), with implications for other orbital regimes. China conducted a series of rendezvous and proximity experiments in LEO through the Shijian-12 (2010), Shiyan-7 (2013), Shijian-15 (2013), and Aolong-1 (2016) satellite missions.[20] In 2016, China brought these RPO capabilities into the GEO belt. Shijian-17 was launched to GEO in 2016 described as a "technical experiment satellite" carrying both chemical and electric propulsion and conducted rendezvous and proximity operations with an out-of-service communications satellite.[21] In 2023, the US DOD "China Military Power Report" disclosed that, "Shijian-17 was the PRC's first satellite with a robotic arm, technology that could be used in a future system for grappling adversary satellites."[22] Shijian-21 (SJ-21), which was launched in October 2021, not only demonstrated rendezvous capabilities against targets in the GEO belt, it apparently grabbed a defunct Beidou satellite and raised it to an unusually high super-sync graveyard orbit.[23] Shiyan-

12 was launched to the GEO belt in 2021, composed of not one, but two inspector satellites, which engaged in evasive maneuvers when a US inspector satellite approached: “the Chinese inspection satellites took off in opposite directions with Shiyan-12-02 moving into position to get a sunlit view of the US surveillance satellite.”[24] Such close maneuvers between spacecraft in a non-cooperative manner could be interpreted as hostile engagement of like-for-like capabilities in space. As more state and commercial operators deploy servicing capabilities in orbit, these encounters and interactions are likely to become more common and establishing norms and rules-of-the-road for such encounters is becoming increasingly urgent.

China is continuing its aggressive launch schedule, particularly to higher orbits. In January 2024, the Tongxin Jishu Shiyan-11 (TJS-11) mission was launched to GEO on a Long March 5 rocket, capable of lifting 14,000 kg to GTO (geostationary transfer orbit).[25] Officially described as a communications satellite, previous satellites in the TJS series have exhibited behaviors inconsistent with simply being a communications satellite. A pair of satellites under the Tongxin Jishu Shiyan-3 mission were observed in GEO to have maneuvered with their apogee kick motor in such a way as to suggest they are inspector satellites and that they may have attempted to elude observers by using the still-active booster as a decoy during the terminator phase of orbit.[26] The TJS-3 satellites were also observed to perform cyber-electronic operations, such as signal spoofing.[27] These examples illustrate the growing challenges for SSA and SDA as not only are new technical capabilities emerging, but so are new tactics, techniques, and procedures (TTPs). Keeping track of these activities requires not just technical capability, but also analytical insight into how future platforms might be used in potentially creative and novel ways.

Cyber-Electronic Warfare

Space services operators were given a practical lesson in the intersection of cyber and space domains at the onset of the Russian invasion of Ukraine in 2022. Within the first week of the invasion, ViaSat terminals were systematically attacked across the theater of operations and beyond, effecting users in third-party countries as well.[28] Russia has also deployed a cyber weapon against Starlink, described in media reports as the “Tobol electronic warfare system,” which may have been responsible for Starlink outages experienced by Ukrainian troops beginning in late 2022.[29] The space domain is becoming increasingly contested and is no longer a benign operational environment. PRC research into similar capabilities is concerning, especially in light of the launch cadence of missions with unclear or potentially multiple purposes. PRC researchers have described methods for overcoming jam-resistant communications platforms, including AEHF (Advanced Extremely High Frequency), WGS (Worldwide Global System), GBS (Global Broadcast Service), and DCSC III (Defense Satellite Communications Series III) satellite systems using proximity operations to achieve improved EW effects.[30] Proximity reduces the power requirements based on the inverse-square law of

propagation, which PRC researchers have noted: "if the jamming range is reduced to 1/10, then its strength of interference is amplified by 100."[31] Not only are PRC satellites suspected to have inspector and manipulator functions, the emerging TTPs demonstrated in the TJS-3 case could be only the beginning. Researchers at the Nanjing University of Aeronautics and Astronautics have proposed ways to reduce the radar signatures of small and micro-satellite platforms using a variety of methods, such as an automated "attitude planning algorithm" to dynamically reduce RCS returns based on known space surveillance radar sites.[32] Being able to approach a target satellite undetected could be a key factor in conducting both kinetic and cyber-EW operations in orbit, particularly in the context of evasive TTPs as demonstrated in prior encounters. Space domain awareness now requires greater precision than ever before.

Academic researchers in China have also investigated various methods for conducting cyber operations against aerospace platforms, including standard satellite bus architectures. These include the development of fault-injection attack methods against onboard processors and memory units,[33] software vulnerabilities in VxWorks, a common operating system for satellite operators,[34] and multi-layer fault injection testing against the MIL-STD-1553B bus architecture.[35] This is a sample of academic research related to cyber vulnerabilities of space systems. In a December 2023 in-depth analysis relying on extensive open source research, CASI identified five key PLA units that engage in cyber operations against space entities: PLA units 61486, 75770, 32082, 927262, and 91746.[36] These units were identified as historically engaged in cyber operations against space operators and contractors and likely continue to play a role in developing cyberattack methodologies against satellites. Many have been absorbed by the former Strategic Support Force (SSF) and likely transferred to the Aerospace Force (ASF) with lineages originating from the General Staff Department's Third Department (signals intelligence) and Fourth Department (electronic warfare). With access to PRC academic databases becoming increasingly difficult and a general clampdown on publishing sensitive research (as illustrated below), PRC cyber anti-satellite research will likely become more difficult to fully assess, even as it plays an increasingly important role in the PRC's overall strategic posture.

With the advent of proliferated architectures, PRC strategic thinkers have recognized that attempting to hold assets at risk using kinetic means is a losing proposition. In a 2022 article, authors from the ASF-affiliated Beijing Institute of Tracking and Telemetry as well as the Beijing Institute of Radiation and Measurement Technology, analyzed the threat from the Starlink constellation and proposed various methods for countering Starlink and proliferated architectures in general:

> Based on the particular characteristics of targets, carry out target discrimination and threat analysis of Starlink satellites carrying different payloads. Integrate intelligence and historical data in order to support the understanding of current constellation posture and predict future conditions.[37]

基于采集的目标特性信息，针 对搭载不同载荷的星链卫星，开展目标识别与威胁分析，结合情报信息与历史数据，支撑形成对当前 星链星座空间形势的理解和对未来状况的预测。

The authors of the paper warn of the difficulties of holding such large constellations at risk in an operationally significant manner and recommend new ways of combining “soft kill” and “hard kill” methods to incapacitate a large portion of Starlink satellites in order to retain “space superiority” (空间优势). Of note, the paper was picked up by English-language media and has subsequently been removed from the China National Knowledge Infrastructure journals database, although Western sources retained archival copies of the original.[38] Part of the concern over a nuclear detonation anti-satellite capability is that with the advent of proliferated constellations, area effect weapons become more relevant to the strategic calculus. PRC researchers identified ways of modulating the shape and size of a nuclear radiological cloud in LEO by adjusting detonation altitude and yield.[39] PRC researchers and strategists are hard at work reconsidering the strategic environment of space considering new proliferated architectures and approaching the problem from a multi-dimensional and combined arms perspective. Weak points in the space enterprise, such as cyber exploitation of defense contractors, technical infiltration of ground stations, and other angles of attack must be considered when defending against the threat. Novel methods of attacking satellites in orbit must also be part of the equation and detailed understanding of operator processes and procedures should be safeguarded.

These developments pose an increased risk of confrontation in space or through space, a risk that is compounded by the suspension of strategic dialogues on a variety of issues between the United States, its partners, and China. Previous high-level official engagements included the US-China Civil Space Dialogue (2015), the establishment of an orbital conjunction hotline between the US Joint Space Operations Center and Beijing (2015), the US-China Space Security Exchange (2016), and a presidential meeting between then-President Barack Obama and General Secretary Xi Jinping to discuss bilateral space cooperation (2016).[40] The last US-China space dialogue occurred in 2017 in Beijing, with no further rounds of discussion scheduled. Reviving high-level meetings to discuss civil and security space issues would be an important step toward greater transparency and lessen the risk of confrontation in space. European and Asian partners could also further engage constructively with their PRC counterparts to help establish dialogue on these issues and convey the norms and values of freedom of space navigation to the benefit of all.

What It Means for the West

China continues to push development of its national space enterprise at breakneck speeds. While we have focused on the military dimension, commercial space applications from PRC companies are also accelerating. Commercial launch vehicles,[41] [42] [43] proposed Starlink

competitors,[44] [45] and faster radiation-hardened chips[46] are just part of the milieu of commercial activity emanating from China. The PRC national civil space program also continues to push into new frontiers. CASC plans this year to launch the China National Space Administration's (CNSA) Chang'e-6 lunar sample return mission to the lunar far-side, along with building out a cis-lunar relay architecture with additional Queqiao and Tiandu satellites.[47] [48] Tiangong, China's first continuously crewed space station, has been feature complete since 2022, but there are plans for expanding the station with a multipurpose module that could enable commercial docking, new experimental modules, and international cooperation.[49] National policy is also supporting the establishment of new "space development zones" under various regional governments to establish a more robust supply chain for the burgeoning space sector.[50] As a domain, space continues to be an important policy focus for PRC leadership and all signs point to 2024 being a significant milestone year for China's space ambitions.

Even so, there have been signs of internal turmoil within the Party-State apparatus, particularly as relates to the aerospace sector. In recent years and months, several high-ranking leaders and former leaders in China's defense industrial base have been stripped of their titles and privileges within the CCP. These cases appear to be part of a renewed wave of Xi Jinping's anti-corruption campaign, particularly with the high-profile dismissals and replacements of the PLA Rocket Force commander and deputy commander, the Minister of Defense, and the Minister of Foreign Affairs in 2023.[51] Some lesser known figures who most recently faced disciplinary action include the chairman of CASC, the deputy manager of China Aerospace Science and Industry Corporation (CASIC), and chairman of the board of NORINCO, a major defense supplier.[52] The opaque political system of China means the specific reasons for much of this turmoil may never be disclosed, but this could indicate loss of confidence from central leadership in key areas of the defense sector or it could indicate underlying problems within national defense institutions. These internal rumblings bear watching, even as China reaches for the stars.

The threat of military action around Taiwan, the South China Sea, and the East China Sea means that increased vigilance is required on the space domain as relates in such terrestrial scenarios. As Xi Jinping approaches the midpoint of his historic third term as party secretary, he will be increasingly set on cementing his legacy. Much will depend on whether he wants to be remembered most as the anti-corruption fighter, the economic guru who managed China's demographic shift, or the nationalistic defender of China's sovereignty on earth and in the heavens.

Endnotes

[1] Sandra Erwin, "Space Force general warns of 'window of vulnerability' in satellite defense," *Space News*, 29 February 2024, https://spacenews.com/space-force-general-warns-of-window-of-vulnerability-in-satellite-defense/.
[2] Todd Harrison, Clayton Swope, "Russia Is a Serious Threat in Space, But There's No Need to Panic," *National Interest*, 27 February 2024, https://nationalinterest.org/blog/buzz/russia-serious-threat-space-there%E2%80%99s-no-need-panic-209720.
[3] Liu Li, et al, "Motion characteristics and laws of the debris from a near-space nuclear detonation," *Nuclear Techniques*, October 2022, https://oversea.cnki.net/kcms/detail/detail.aspx?dbcode=CJFD&filename=HJSU202210010&dbname=CJFDLAST2022; Liu Li, et al., "Numerical Simulation of Debris Motion from a Near-space Nuclear Detonation," *Chinese Journal of Computational Physics*, 2022 (05), https://cnki.net/kcms/detail/detail.aspx?filename=JSWL202205003&dbcode=CJFQ&dbname=DKFXTEMP&v=.
[4] Stephen Chen, "Chinese physicists simulate nuclear blast against satellites," *South China Morning Post*, 20 October 2022, https://www.scmp.com/news/china/science/article/3196629/chinese-physicists-simulate-nuclear-blast-against-satellites.
[5] Sandra Erwin, "Space Force general warns of 'window of vulnerability' in satellite defense," *Space News*, 29 February 2024, https://spacenews.com/space-force-general-warns-of-window-of-vulnerability-in-satellite-defense/.
[6] Stephen Chen, "China military must be able to destroy Elon Musk's Starlink satellites if they threaten national security: scientists," *South China Morning Post*, 25 May 2022, https://www.scmp.com/news/china/science/article/3178939/china-military-needs-defence-against-potential-starlink-threat?module=inline&pgtype=article.
[7] Andrew Jones, "China launches mystery reusable spaceplane for third time," *Space News*, 14 December 2023, https://spacenews.com/china-launches-mystery-reusable-spaceplane-for-third-time/.
[8] "China successfully launches reusable experimental spacecraft" [我国成功发射可重复使用试验航天器], CCTV-7, 15 December 2023, https://tv.cctv.com/2023/12/15/VIDEfg14cCIFP3vjiZTIvhui231215.shtml.
[9] Andrew Jones, "China's mystery spaceplane releases object into orbit," *Space News*, 2 November 2022, https://spacenews.com/chinas-mystery-spaceplane-releases-object-into-orbit/.
[10] Ling Xin, "China's secret space plane emits strong signal to the ground when passing North America: satellite tracker," *South China Morning Post*, 21 December 2023, https://www.scmp.com/news/china/science/article/3245815/chinas-secret-space-plane-emits-strong-signal-ground-when-passing-north-america-satellite-tracker.
[11] Demetri Sevastopulo, "China tests new space capability with hypersonic missile," *Financial Times*, 16 October 2021, https://www.ft.com/content/ba0a3cde-719b-4040-93cb-a486e1f843fb.
[12] Demetri Sevastopulo, "China conducted two hypersonic weapons tests this summer," *Financial Times*, 20 October 2021, https://www.ft.com/content/c7139a23-1271-43ae-975b-9b632330130b.
[13] Kevin Pollpeter, "Coercive Space Activities: The View From PRC Sources," China Aerospace Studies Institute, February 2024, https://www.airuniversity.af.edu/Portals/10/CASI/documents/Research/Space/2024-02-19%20Coercive%20Space%20Activities.pdf.
[14] Demetri Sevastopulo, "China conducted two hypersonic weapons tests this summer," *Financial Times*, 20 October 2021, https://www.ft.com/content/c7139a23-1271-43ae-975b-9b632330130b.
[15] Demetri Sevastopulo, "Chinese hypersonic weapon fired a missile over South China Sea," *Financial Times*, 21 November 2021, https://www.ft.com/content/a127f6de-f7b1-459e-b7ae-c14ed6a9198c.
[16] Akhil Kadidal, "China's DF-17 designed to strike Pacific bases: US," *Janes*, 9 December, 2022, https://www.janes.com/defence-news/news-detail/chinas-df-17-designed-to-strike-pacific-bases-us.
[17] David Chen, "'Joint Sword' Exercises Around Taiwan Suggest a Shift in PLA Operational Doctrine," *China Brief*, Jamestown Foundation, 5 May 2023, https://jamestown.org/program/joint-sword-exercises-around-taiwan-suggest-a-shift-in-pla-operational-doctrine/.
[18] "MDA, SDA Announce Upcoming Launch of the Hypersonic and Ballistic Tracking Space Sensor and Tranche 0 Satellites," US Department of Defense, 14 February 2024, https://www.defense.gov/News/Releases/Release/Article/3676902/mda-sda-announce-upcoming-launch-of-the-hypersonic-and-ballistic-tracking-space/.

[19] "BX satellite photographs Shenzhou-7" [伴飞小卫星拍摄的神七], CCTV-4, 28 September 2008, https://www.youtube.com/watch?v=hoUHVyLUJEk.
[20] David D. Chen, "Testimony before the U.S.-China Economic and Security Review Commission," Hearing on China's Advanced Weapons, US-China Security Review Commission, 23 February 2017, https://www.uscc.gov/hearings/hearing-chinas-advanced-weapons.
[21] "In-Space Eavesdropping? – China's Shijian-17 completes High-Altitude Link-Up," Spaceflight 101, 9 December 2016, https://spaceflight101.com/shijian-17-rendezvous-with-chinasat-5a/.
[22] "Military and Security Developments Involving the People's Republic of China 2023," Department of Defense, October 2023, https://media.defense.gov/2023/Oct/19/2003323409/-1/-1/1/2023-MILITARY-AND-SECURITY-DEVELOPMENTS-INVOLVING-THE-PEOPLES-REPUBLIC-OF-CHINA.PDF.
[23] Kari A. Bingen, Kaitlyn Johnson, and Makena Young, "Space Threat Assessment 2023," Center for Strategic and international Studies, April 2023, https://aerospace.csis.org/wp-content/uploads/2023/04/230414_Bingen_SpaceThreatAssessment_2023_UPDATED-min.pdf; Kristin Burke, "China's SJ-21 Framed as Demonstrating Growing On-Orbit Servicing, Assembly, and Manufacturing (OSAM) Capabilities," China Aerospace Studies Institute, December 2021, https://www.airuniversity.af.edu/Portals/10/CASI/documents/Research/Space/2021-12-09%20SJ-21%20and%20China's%20OSAM%20Capabilities.pdf.
[24] Debra Werner, "An In-Orbit Game of Cat and Mouse: Close approaches prompt calls for communications and norms," 16 June 2022, https://spacenews.com/an-in-orbit-game-of-cat-and-mouse-close-approaches-prompt-calls-for-communications-and-norms/.
[25] "China successfully launches TJS-11" [我国成功发射通信技术试验卫星十一号], CCTV-7, 24 February 2024, https://tv.cctv.com/2024/02/24/VIDEkdncz3muMV2U6sQSgRnv240224.shtml; Andrew Jones, "China launches classified military satellite towards geostationary belt," *Space News*, 23 February 2024, https://spacenews.com/china-launches-classified-military-satellite-towards-geostationary-belt/.
[26] Colin Clark, "US, China, Russia Test New Space War Tactics: Sats Buzzing, Spoofing, Spying," *Breaking Defense*, 28 October 2021, https://breakingdefense.com/2021/10/us-china-russia-test-new-space-war-tactics-sats-buzzing-spoofing-spying/.
[27] Andrew Jones, "An object is now orbiting alongside China's Shijian-21 debris mitigation satellite," *Space News*, 5 November 2021, https://spacenews.com/an-object-is-now-orbiting-alongside-chinas-shijian-21-debris-mitigation-satellite/.
[28] Christian Vasquez, Elias Groll, "Satellite hack on eve of Ukraine war was a coordinated, multi-pronged assault," *CyberScoop*, 10 August 2023, https://cyberscoop.com/viasat-ka-sat-hack-black-hat/.
[29] Alex Horton, "Russia tests secretive weapon to target SpaceX's Starlink in Ukraine," *The Washington Post*, 18 April 2023, https://www.washingtonpost.com/national-security/2023/04/18/discord-leaks-starlink-ukraine/.
[30] David D. Chen, "Testimony before the U.S.-China Economic and Security Review Commission," Hearing on China's Advanced Weapons, US-China Security Review Commission, 23 February 2017, https://www.uscc.gov/hearings/hearing-chinas-advanced-weapons.
[31] Xiao Yuxiang, et al., "Distributed Jamming System and Its Key Technologies Based on Pico-Satellite," *Aerospace Elecrtonic Warfare*, October 2006, pp. 25-27.
[32] Zhou Mengxiao, et al., "A Static-environment Attitude Planning for Micro-satellite Based on Sparse A* Search," *Fire Control & Command Control*, July 2016, pp. 31-36.
[33] Peng Junjie, Huang Qingcheng, Hong Bingrong, Li Rui, Yuan Chengjun, "A Software Fault Injection Tool for Evaluation of Dependability of Onboard System," *Journal of Astronautics*, November 2005, pp. 823-827; Peng Junjie, Huang Qingcheng, Hong Bingrong, Li Rui, Yuan Chengjun, Wei Zhenhua, "Test Fault Sensitivity of a Digital Processor by a Pure Software Approach," *Journal of Astronautics*, January 2006, pp. 108-112.
[34] Wang Xinsheng, Huang Zhenyuan, Liang Bin, "A Software-Implemented Fault Injection Method for Onboard Computer Based on VxWorks," *Aerospace Control*, October 2010, pp. 84-88.
[35] Lian Meng, Li Xuefeng, "Design and Research of Fault Injection on 1553B Bus," *Aerospace Control*, April 2012, pp. 84-88.
[36] Kristin Burke, "PLA Counterspace Command and Control," China Aerospace Studies Institute, December 2023, https://www.airuniversity.af.edu/CASI/Display/Article/3612979/pla-counterspace-command-and-control/.
[37] Ren Yuanzhen (任远桢), et al., "星链计划发展现状与对抗思考" [The Development Status of Starlink and Its Countermeasures], *Modern Defense Technology*, April 2022, Vol 50., No. 2., pp. 11-17.

[38] Stephen Chen, "China military must be able to destroy Elon Musk's Starlink satellites if they threaten national security: scientists," *South China Morning Post*, 25 May 2022, https://www.scmp.com/news/china/science/article/3178939/china-military-needs-defence-against-potential-starlink-threat?module=inline&pgtype=article.
[39] Liu Li, et al, "Motion characteristics and laws of the debris from a near-space nuclear detonation," *Nuclear Techniques*, October 2022, https://oversea.cnki.net/kcms/detail/detail.aspx?dbcode=CJFD&filename=HJSU202210010&dbname=CJFDLAST2022.
[40] Bruce W. MacDonald, Carla P. Freeman, and Alison McFarland, "China and Strategic Instability in Space: Pathways to Peace in an Era of US-China Strategic Competition," United States Institute of Peace, February 2023, https://www.usip.org/sites/default/files/2023-02/20230209-sr-515-china-strategic-instability-space.pdf.
[41] Ryan Woo, "China launches Jielong-3 rocket as commercial missions pick up pace." Reuters, 3 February 2024, https://www.reuters.com/technology/space/china-launches-powerful-jielong-3-rocket-paves-way-more-commercial-missions-2024-02-03/.
[42] Andrew Jones, "Landspace launches third methane Zhuque-2, targets 2025 launch of new stainless steel rocket," *Space News*, 9 December 2023, https://spacenews.com/landspace-launches-third-methane-zhuque-2-targets-2025-launch-of-new-stainless-steel-rocket/.
[43] Andrew Jones, "China's Landspace conducts first VTVL test for reusable stainless steel rocket," *Space News*, 19 January 2024, https://spacenews.com/chinas-landspace-conducts-first-vtvl-test-for-reusable-stainless-steel-rocket/.
[44] Ling Xing, "China space authorities name Elon Musk's SpaceX an 'unprecedented challenge'," *South China Morning Post*, 6 December 2023, https://www.scmp.com/news/china/science/article/3244086/china-space-authorities-name-elon-musks-spacex-unprecedented-challenge?module=inline&pgtype=article.
[45] Andrew Jones, "Chinese satellite internet mission rounds off record year for global launches." *Space News*, 31 December 2023, https://spacenews.com/chinese-satellite-internet-mission-rounds-off-record-year-for-global-launches/.
[46] Stephen Chen, "China takes its chip war to space as it uses Tiangong space station to test processors and gain a tech edge," *South China Morning Post*, 24 January 2024, https://www.scmp.com/news/china/science/article/3249569/china-takes-its-chip-war-space-it-uses-tiangong-space-station-test-processors-and-gain-tech-edge.
[47] Andrew Jones, "China's 2024 space plans include 100 launches and moon sample return mission," *Space News*, 26 February 2024, https://spacenews.com/chinas-2024-space-plans-include-100-launches-and-moon-sample-return-mission/.
[48] Zhang Tong, "Testing, testing … China to try out new satellite tech for Chang'e 6 lunar mission," *South China Morning Post*, 4 February 2024, https://www.scmp.com/news/china/science/article/3250884/testing-testing-china-try-out-new-satellite-tech-change-6-lunar-mission.
[49] Andrew Jones, "China to expand its space station, international astronaut selection underway," *Space News*, 28 February 2023, https://spacenews.com/china-to-expand-its-space-station-international-astronaut-selection-underway/.
[50] Andrew Jones, "Beijing government releases commercial space action plan," *Space News*, 9 February 2024, https://spacenews.com/beijing-government-releases-commercial-space-action-plan/.
[51] Andrew Jones, "Chinese satellite internet mission rounds off record year for global launches." *Space News*, 31 December 2023, https://spacenews.com/chinese-satellite-internet-mission-rounds-off-record-year-for-global-launches/.
[52] Phoebe Zhang, "Beijing strips 3 aerospace-defence executives of political titles as China cracks down on corruption in crucial sector," 28 December 2023, https://www.scmp.com/news/china/politics/article/3246482/beijing-strips-3-aerospace-defence-executives-political-titles-china-cracks-down-corruption-crucial.