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China's SJ-21 Framed as Demonstrating Growing On-Orbit Servicing, Assembly, and Manufacturing (OSAM) Capabilities

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China launched its most recent practice satellite ShiJian-21 (SJ-21) into geosynchronous transfer orbit (GTO) on October 24, 2021, Beijing time and Chinese state media indicated the satellite would "test and verify debris mitigation technology."[1,i] SJ-21 has since entered geosynchronous Earth orbit (GEO) and moved into close proximity with another object, which is either its apogee kick motor (AKM) or a sub-satellite, according to the U.S. Space Force's 18th Space Control Squadron and other space watchers. [2,3]

A historical examination of publicly available Chinese language materials, when framed with knowledge of trends in the global space industry, reveals that one can reasonably argue that SJ-21 is probably going to be China's second On-Orbit Servicing, Assembly, and Manufacturing (OSAM) practice-series satellite (Shijian) in GEO. One could also reasonably expect SJ-21 to advance work China has already done in lower orbits to practice rendezvous and proximity operations (RPOs) and the use of a robotic arm. This time, China might practice using multiple arms, a different type of debris mitigation technology such as that needed for refueling or deorbiting, or a combination of those, based on Chinese academic publications discussed below.

China's activities in OSAM have not been examined in depth to date. When China has previously demonstrated RPO and robotic arm maneuvers in space, some Western analysts have discussed only the military and reconnaissance applications of these capabilities and technologies.[4,5] Some reputable American government and non-governmental organizations have mentioned that the technologies could be related to China's OSAM ambitions, but have also focused their attention on the applications for weapons and reconnaissance. [6,7,8,9,ii] Recent reports that explain the OSAM sector have only briefly discussed China. [10] Even Chinese media,

[i] The use of the Chinese launch vehicle LM-3B out of the launch site in western China's Sichuan Province—Xichang Satellite Launch Center—was noted in the Chinese announcement, which indicated SJ-21 would be headed beyond low Earth orbit (LEO), usually to geosynchronous Earth orbit (GEO).

[ii] The Defense Intelligence Agency and Secure Word Foundation have also noted China's RPO activity is not necessarily directed at advancing anti-satellite technology, but could also be related to its development of capabilities for inspection, repair, and space debris removal. The Office of the Director of National Intelligence's National Intelligence Council predicted that by 2040 OSAM will become a routine space activity in its recent Global Trends report.

academics, and bloggers agree with Western analysts that RPO capabilities and robotic arm technologies are dual-use; these capabilities and technologies could support national defense goals as well as strengthen economic competitiveness and global influence.[11,12,13] Here we attempt to fill the gap by focusing on China's stated interest in strengthening its on-orbit servicing sector. Our intention is to support space policymakers and operators in their threat calculations and deterrence strategies.

No Current Differences in Definitions

Chinese technologists and academics define OSAM similarly as described in Western reports, based on a review of Chinese language academic articles, state media, and a Chinese academic lecture on the topic.[14,15,16,17,iii] Both communities also agree that the first technology step to learn OSAM methods is usually to demonstrate remote survey of a spacecraft, to include survey at very close distances, also known RPOs. China's potential future tests with SJ-21 to verify debris mitigation technology could fall under any of the OSAM categories, but Chinese and Western studies most frequently categorize debris mitigation as a type of "service" to either active, damaged or decommissioned satellites in any orbit.[iv] While there are only a handful of past examples, these services typically include one or a combination of relocation, repair, refueling and replacement services to either extend a satellite's ability to function in space or to ensure it is removed from orbit, thereby mitigating space debris. [18,v]

When Might Have China Become Interested in OSAM?

After Beijing initiated research and development for technologies to construct and operate the Chinese Space Station (CSS) in the early 90s, and had achieved several milestones by the early 2000s, several factors probably influenced the Chinese decision to further leverage the technology for other on-orbit services like debris mitigation, as early as 2006. [1920,21,22,23,24,25]

- **Growing International Problem**: After the explosion of the second stage of an Ariane 1 launch vehicle in 1986, NASA initiated international collaboration with the Europeans, Russians and Japanese to discuss the growing problem of rocket body explosions at what came to be called the Inter-Agency Space Debris Coordination Committee in 1993. China joined two years later in 1995.[26]

[iii] "Servicing" includes remote survey, repair, replacement, relocation or refueling of crewed and uncrewed spacecraft and the Chinese lecture agreed that remote survey is globally and in China the most advanced OSAM service, primarily because it is necessary for all follow-on OSAM activities. A popular example of "assembly" is the crewed and robotic assembly of the ISS and the future Chinese Space Station (CSS). Global space agencies' research on using lunar resources to make rocket propellent and water are popular examples of "manufacturing."
[iv] For a detailed overview of the categories under OSAM see The Institute for Defense Analysis, Science and Technology Policy Institute's review.
[v] Satellite life extension missions could include a refueling mission to extend the time a satellite can carry out its mission or could include using a robotic arm to repair or replace a broken system while still on-orbit.

- **Development of Global Norms and Standards**: The United Nations (UN) Committee on the Peaceful Uses of Outer Space (COPUOS) began in 1994 to prioritize the topic of space debris.[27] China has been a member of COPUOS since 1980 and played a role in approving the elevation of space debris as a priority.[28] China followed IADC and COPUOS recommendations in 2000 by deorbiting a GEO meteorology satellite (FengYun-2A) and later published its domestic debris mitigation guidelines in 2005.[29,30,vi]
- **PRC Domestic Need for Satellite On-Orbit Servicing**: In 2006, China launched a communications satellite to GEO, SinoSat-2, which failed to open its solar panels, rendering it inoperable. Chinese academics have used this example to explain the usefulness of OSAM in a Chinese context, indicating an on-orbit robotic arm could have been used to open the panel.[31] Chinese academics since 2010 have published articles discussing the economic demand drivers for GEO debris removal.[32,33]
- **Global Industry and Military Space Technology Developments**: Chinese publications indicate that Chinese space academics and technologists have closely tracked international developments aimed at strengthening commercial services in outer space, particularly to government customers. Many Chinese writings discuss Japan's low Earth orbit (LEO) robotic arm demonstration in 1997, the Air Force Research Lab's XSS-10 and XSS-11 (2003 and 2005, respectively) RPO tests and DARPA's 2007 Orbital Express demonstration to name a few.[34,35,36,37,38,39]

China's First Non-CSS On-Orbit OSAM Tests in LEO

According to international and U.S. space observers, China conducted its first non-CSS RPO in 2010 from sun synchronous orbit with SJ-12 (launched in 2010) and SJ-06F (launched in 2008).[40,vii] The satellites approached to within less than 300 meters, and a change in SJ-06F's orbital trajectory indicated that the satellites bumped similar to a U.S. on-orbit test in 2005, both of which did not generate debris.[41] In 2008, a representative of the Chinese Academy of Engineering announced that China would strive to launch its first satellite with a robotic arm by 2011 to test track, grasp, and release technology.[42] The representative mentioned the success of the 2008 crewed Shenzhou-7 mission as a stepping stone to the robotic arm test, but not the RPO test between the BX-1 satellite and the crewed capsule.[43]

The track, grasp, and release robotic arm test seems to have been conducted in 2013 when China launched three satellites into roughly similar orbits: Shiyan-7 (SY-7), Chuangxin-3 and SJ-15. Chinese media announced that the mission was to "test space maintenance technologies such as space debris tracking and robotic arm operations."[44] According to China's

[vi] China did not follow IADC and COPUOS guidelines in 2007 when it conducted its first kinetic anti-satellite (ASAT) weapon test in low Earth orbit (LEO). The information we reviewed did not indicate a connection between the development of OSAM capabilities and China's ASAT test, however a more tailored, in-depth look would be needed to rule it out.

[vii] China would probably argue it conducted its first RPO between the BX-1 satellite and the Shenzhou-7 spacecraft. (See: http://www.china.org.cn/china/shenzhouVII_spacewalk/2008-10/06/content_16568297.htm)

announcement and international space observers, SY-7 launched with the robotic arm and the other satellites were probably used to observe and transmit test data to ground operators.[45] A Chinese professor at the Beihang University in 2017 described SY-7 and the Tiangong space stations as examples of China's on-orbit servicing tests. She listed other countries' tests as well, to include the US maintenance of the Hubble Space Telescope and AFRL's XSS-10 and 11.[46]

These probable successes and China's awareness of global trends may have incentivized Beijing to significantly broadened its science and technology (S&T) support for OSAM beyond specific technologies to support the CSS in 2016. In China's 13th Five-Year Plan (FYP) for Science and Technology Innovation (2016-2020), the FYP of the Ministry of Science and Technology, Beijing set a goal to achieve breakthroughs in technologies like on-orbit servicing and "transport" by 2030.[47] China also listed this intent in its 2016 Space Activities White Paper.[48]

The expanded support seems to have enabled other researchers to test different OSAM methods in orbit. Chinese academics launched their first robotic arm in LEO in June 2016 called the Aolong-1, which may have also tested another OSAM technology: a space tether, according to a Chinese blogger describing a university's restricted website.[49] In 2019, a Chinese State Owned Enterprise under the Chinese Aerospace Science and Technology Corporation (CASC) called the Shanghai Academy of Spaceflight Technology (SAST) launched a solar sail to test electromagnetic methods for expediting satellite deorbiting.[50,51,52] Chinese companies have also tested in-space 3D printing and other grappling methods, according to Chinese and Western media.[53,54]

China's Potential First GEO OSAM Tests

Another possible outcome of China's expanded support for OSAM was the first tests of RPOs in higher orbits. In November 2016, China launched SJ-17 which over several years inspected, and may have conducted other service tests, on several Chinese satellites. Some Chinese researchers and media outlets have framed SJ-17's activities as related to debris mitigation.[55,56] A review of the satellites with which SJ-17 conducted RPOs also seems to support a debris mitigation mission.

SJ-17 conducted RPOs with a Chinese satellite about to reach end-of-life: ChinaSat-5A in 2016 (launched in 1998, manufactured by Lockheed Martin, and moved to graveyard orbit two years later in 2018) and three Chinese satellites probably experiencing anomalies: ChinaSat-1C in 2018 (launched in 2015 and had been drifting at the time of RPO), a dedicated military satellite ChinaSat-20 also in 2018 (launched in 2003 and had been experiencing anomalies at time of RPO), and ChinaSat-6B in 2020 (launched in 2007 and had experienced a power outage in 2009, but is expected to operate until at least 2022, manufactured by Thales Alenia).[57,58,59]

The public information available on China's GEO RPO activities does not indicate SJ-17 has a robotic arm. Chinese and global S&T developments of OSAM technologies in LEO however indicate testing a robotic arm in GEO would be the logical next step. Chinese

academics have since 2004 published several feasibility studies looking at enabling the use of multiple arms on a satellite, even in GEO.[60,61,62,63,64] A multi-arm debris mitigation test would seem likely considering NASA and ESA both have plans to have 3 or 4 robotic arms on upcoming OSAM missions and one of China's proposed tests requires a minimum of 3 robotic arms in GEO.[65,66,67]

Could SJ-21 Test On-Orbit Refueling and Debris Removal?

On November 1, the U.S. Space Force's 18th Space Control Squadron cataloged a new object alongside SJ-21, potentially its AKM but also potentially a sub-satellite released after arriving in GEO, according to U.S. media and space watchers.[68,69] An avid space watcher in an email explanation to another U.S. media outlet noted that SJ-21 and its possible AKM were staying 60 km apart just above GEO, and as of November 15 this space watcher noted the two had moved to within 5 km of each other.[70,71] If the object is SJ-21's AKM, industry experts have discussed them as useful companions for OSAM refueling missions.[72,73] The 2019 Northrup Grumman Mission Extension Vehicle-1 also connected with its target satellite to add extra power in the orbit above GEO where satellites are moved at the end of their mission, called the graveyard orbit.[74]

Chinese academics have written several articles examining how to conduct on-orbit refueling, most likely to support research for the CSS in LEO. However, some have focused on GEO refueling operations.[75] Another reason to consider a refueling test with SJ-21 in GEO is that the SAST, which designed SJ-21 (as well as SJ-12 and the solar sail test), displayed a space refueling vehicle at the recent Zhuhai Air Show.[76,77] SAST in 2019 also won a national S&T award for the guidance, navigation and control system for an active space debris removal system, which could also be useful for a refueling mission.[78,viii]

There are some indications that different debris mitigation technology might be tested instead. A Chinese blogger with a good understanding of the space industry and the OSAM field has speculated that SJ-21would probably not need to verify a robotic arm based on earlier LEO technology verification. The blogger instead hypothesized that different OSAM technologies under research in China and globally are likely in need of verification, such as a debris capture net or debris lasing technology.[79] Both technologies have been researched in China and elsewhere, according to academic publications.[80],[81] In particular, space-based lasers to incinerate debris smaller than 10cm or bump the debris trajectory to expedite deorbiting is an area of active research outside of the United States, to include in Europe.[82,83] However, a laser would not be useful for an AKM, but may be more practical for a space net test. A 2017 article

[viii] Some U.S. media commentators have speculated that SJ-21 and its AKM could test the potential spoofing measures that some believe a different GEO satellite series used with its U.S. catalogued AKM in 2018. However, that satellite, called Tongxing Jishu Shiyan 3, has not been described in Chinese or English as having a space debris mitigation mission. (see: https://spacenews.com/an-object-is-now-orbiting-alongside-chinas-shijian-21-debris-mitigation-satellite/)

proposed using 3 robotic arms in GEO for testing debris capture and 3D printing, which if used to print a tool to repair a satellite, might be a debris mitigation test.[84]

Summary

An investigation into China's stated OSAM goals and activities helps contextualize SJ-21 as a satellite to further test on-orbit debris mitigation technologies. On-orbit services to mitigate debris come in many forms, such as through refueling or relocation, and could eventually support a range of customers, including Chinese military, government and emerging commercial players, which would be consistent with OSAM activities globally. Related on-orbit behavior can be reasonably argued as not only demonstrating a dual-use technology to potentially enable weapons or reconnaissance capabilities, but also revealing a potential future economic and global influence competition in the emerging OSAM sector. Using a wider lens with which to view Chinese on-orbit activities is intended to support space policymakers and operators in their deterrence planning and risk calculations.

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