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## *China's Space Robotic Arm Programs*

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On July 20, 2013, China launched three satellites on a Long March 4C launch vehicle, ostensibly to test space debris observation and space robotic arm technologies. The three satellites, Chuangxin-3, Shiyang-7, and Shijian-15, drew the attention of satellite tracking enthusiasts when two of them began conducting orbital maneuvers with each other and an additional satellite that had been launched in 2005.

The maneuvers began on August 1 and involved one satellite acting as the target and another satellite, most likely equipped with a robotic arm, grappling the target satellite. Exactly which two of the three satellites were involved in the maneuvers is unknown. Based on data from the U.S. Strategic Command's Space-Track.org website, however, the largest satellite of the three, possibly the Shijian-15, fired its thrusters to move to the smallest of the three satellites, possibly the Chuangxin-3, which remained in a set orbit.<sup>1</sup> The third satellite, possibly the Shiyang-7, does not appear to be involved in the test. These maneuvers continued until August 17 and resulted in the largest satellite closing in on and then away from the smallest satellite. On August 18, the largest satellite changed orbits and closed in on a completely separate satellite, the Shijian-7, that had been launched in 2005.

These maneuvers have caused concern that the tests go beyond the stated objectives and are actually a cover for testing on-orbit anti-satellite (ASAT) technologies. In fact, space robotic arms, like many other space technologies, have both military and non-military applications and classifying them as a space weapon depends on the intent of the user, not on the inherent capabilities of the technology. China's space robotic arm technology is thus a case study in the challenges of defining "space weapon" and the difficulty in achieving space arms control.

### Space Robotic Arm Technology

China's testing of space debris observation and space robotic arm technologies is part of a program to build a free-floating space robot that consists of a robotic arm mounted on a satellite and a micro target satellite (MTS) in which "a special gripper must be mounted on the end of [a] robot to demonstrate how to capture the MTS in the space."<sup>2</sup> This research was supposed to have resulted in an orbital test of China's first free-floating space robot in 2011 in

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<sup>1</sup> Zarya: Soviet, Russian, and International Space Flight Blog, "Chinese Tag Team (Launch 2013-07): Update," September 27, 2013, <http://www.zarya.info/blog/?p=1547>.

<sup>2</sup> Zhu Yingyuan, Gao Xiaohui, Xie Zongwu and H. Liu, "Development of a Gripper for Chinese Space Robot," *Proceedings of the 2006 IEEE International Conference on Mechatronics and Automation*, June 25–28, 2006, Luoyang, China, p. 1,465.

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which a “large satellite’s robotic arm would grab a small satellite and then let the small satellite go and then chase the small satellite and grab it again.”<sup>3</sup> The August maneuvers appear to be this test, albeit two years behind schedule.

Robotic arms can be used in a variety of space applications. Their most promising application is satellite maintenance. Once launched, satellites in orbit must be abandoned if a critical malfunction occurs or if they run out of fuel. With the use of robotic arms, a spacecraft can capture a satellite and replace faulty components or refuel one that has been depleted of propellant. These activities can extend the service life of a satellite and save hundreds of millions of dollars in replacement costs. However, in order for maintenance to take place, the target satellite must be designed for servicing, for example, with the addition of “handholds” the robotic gripper can attach to, otherwise the satellite can be damaged during the servicing.

Robotic arms can also be used to avoid collisions between spacecraft and space debris by capturing or diverting pieces of space junk. There are more than 500,000 pieces of space debris, which can travel as fast as 17,500 mph.<sup>4</sup> Space debris can come from a variety of sources, such as spent launch vehicles. The largest debris-producing events were the 2007 Chinese ASAT test that destroyed a defunct weather satellite and the 2009 collision of an Iridium communications satellite and a Russian Cosmos satellite. The Chinese ASAT test and the 2009 collision resulted in 3,378 and 2,201 pieces of debris, respectively. Interestingly, Chinese researchers identify the 2009 collision as the major source of space debris and neglect to mention the 2007 ASAT test.<sup>5</sup>

Space debris is an increasingly serious problem, since even small bits of it can seriously damage spacecraft. Debris presents a special danger to manned space platforms. In 2012, the International Space Station was forced to move three times to avoid space debris.<sup>6</sup> These “conjunction events” are expected to increase in the coming years, which makes debris mitigation and removal efforts of increasing salience.

As with many space technologies, robotic arms can also be used for military purposes. The same capability that can be used to capture space debris or satellites for on-orbit repair can also be used to grab a satellite to disable it. It is this application that complicates the development of space robotic arms.

In addition to China, space robotic arms have been developed by a number of countries, including the United States, Canada, Japan, Switzerland, and the European Union. The two most prominent examples of robotic arms are those used on the space shuttle and the International Space Station (ISS). The space shuttle’s robotic arms were used to capture satellites for repair and were most famously used to assist in the repair of the Hubble Space Telescope. The space shuttle’s robotic arm has been used to break ice off the shuttle so that it would not damage the craft on reentry. After the *Columbia* accident the arm was fitted with a camera and a laser measurement device to check for damage to the structure of the shuttle.<sup>7</sup> The ISS, on the other hand, has two robotic arms and will add a third later this year. The best known is the Canadian “Canadarm2,” which has been used to build the ISS, move supplies around the station, and support astronauts doing space walks.

3 “中国空间机器人预计2011年发射” [Chinese Space Robot Estimated to Launch in 2011], October 14, 2008, <http://news.163.com/08/10/14/4078DV66000125L1.html>. See also Hou Zhongcheng, 面向空间捕获的机器人路径规划与控制器设计 [Path Planning and Controller Design for Space Target Capturing Manipulator], PhD diss., Harbin Institute of Technology, 2011, 7.

4 “Orbital Debris Mitigation,” NASA Orbital Debris Program Office, accessed October 7, 2013, <http://orbitaldebris.jsc.nasa.gov/mitigate/mitigation.html>.

5 Ying Lujun, “Space Debris and the Challenge to Humans” [太空垃圾挑战人类], 近日科技 [Today Science and Technology] 2 (2009): 52; and Lin Laixing, “空间碎片现状与清理” [Status and Removal of Space Debris], 航天器工程 [Spacecraft Engineering] 6 (2012): 3.

6 NASA Orbital Debris Program Office, “Another Debris Avoidance Maneuver for the ISS,” *Orbital Debris Quarterly News*, January 2013, <http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv17i1.pdf>.

7 Brandi Dean, “Space Shuttle Canadarm Robotic Arm Marks 25 Years in Space,” [http://www.nasa.gov/mission\\_pages/shuttle/behind-scenes/rms\\_anniversary.html](http://www.nasa.gov/mission_pages/shuttle/behind-scenes/rms_anniversary.html).

No free-floating space robots like the type tested by China have gone beyond testing. Satellites equipped with robotic arms have been developed by the U.S. Department of Defense. The Defense Advanced Research Projects Agency's (DARPA) Orbital Express program tested the ability of two satellites to dock with each other with the help of a robotic arm "to validate the technical feasibility of robotic, autonomous on orbit refueling and reconfiguration of satellites to support a broad range of future U.S. national security and commercial space programs."<sup>8</sup>

According to DARPA, refueling satellites "will enable frequent maneuver to improve coverage, change arrival times to counter denial and deception and improve survivability, as well as extend satellite lifetime." In addition, the ability to upgrade or replace faulty components "can provide regular performance improvements and dramatically reduce the time to deploy new technology on-orbit."<sup>9</sup>

In addition, the U.S. Air Force's Experimental Satellite System-11 (XSS-11) involved a micro-satellite weighing approximately 100 kilograms to test "future military applications such as space servicing, diagnostics, maintenance, space support and efficient space operations." Although the mission of the XSS-11 did not test satellite robotic arm technologies, it did test capabilities to move in close to other spacecraft, skills necessary for the successful use of robotic arms.<sup>10</sup>

## Chinese Robotic Arm Technology

China began researching space robotic arm technology in the 1980s.<sup>11</sup> In 1993, the 863 Program began sponsoring research on telescience and space robotics under the manned space research area of 863-2 when the Telescience and Space Robotics Expert Group (遥科学与空间机器人专家组) was formed.<sup>12</sup> Since then, the Harbin Institute of Technology (哈尔滨工业大学/HIT), the Beijing University of Posts and Telecommunications (北京邮电大学/BUPT), the Beijing University of Aeronautics and Astronautics (北京航空航天大学/BUAA), and the Chinese Academy of Space Technology 502 Research Institute (中国空间技术研究院502研究所/CAST 502 RI) have conducted research on space robotic arms, all of which have been conducted in laboratories on the ground.

China's space robotic arm technology appears to center on two major programs. The most visible is a robotic arm for China's large space station that is to be launched by 2023. The robotic arm is described as a critical technology "that the space station cannot do without" as it supports astronauts' activities outside of the station and helps maintain the space station's safety, reliable operation, and maintenance. The robotic arm for the space station is planned to be 10 meters long, will be capable of handling a load of 25 metric tons, and have a service life of 10 years.<sup>13</sup> In comparison, Canadarm2, the ISS robotic arm, is 17.6 meters long, can handle 116 metric tons, and has been in operation since 2001. Research on the robotic arm began in 2005 and feasibility studies were completed in 2011. Progress on the robotic arm was delayed as additional requirements were added, including a requirement for the robotic arm to possess seven degrees of freedom instead of six degrees of freedom, giving it not only the ability to function like a human arm, but also to rotate its wrist 360 degrees.<sup>14</sup>

8 Defense Advanced Research Projects Agency "Fact Sheet," [http://archive.darpa.mil/orbitalexpress/pdf/oe\\_fact\\_sheet\\_final.pdf](http://archive.darpa.mil/orbitalexpress/pdf/oe_fact_sheet_final.pdf).

9 Defense Advanced Research Projects Agency, "Orbital Express Space Operations Architecture," <http://archive.darpa.mil/orbitalexpress/index.html>.

10 Air Force Research Laboratory "Fact Sheet," <http://www.kirtland.af.mil/shared/media/document/AFD-070404-108.pdf>.

11 Yu Dengyun, Sun Jing, and Ma Xingrui, "空间机械臂技术及发展建议" [Suggestion on Development of Chinese Space Manipulator Technology], *航天器工程 [Spacecraft Engineering]* 7 (2007): 2.

12 Zhang Qiuhaio, 三支机器人运动学建模与运动力学特性分析, [Tri-branch Robot Kinematics Modeling and Dynamics Characteristic Analysis], PhD diss., Beijing University of Posts and Telecommunications, 2005, 4, <http://www.docin.com/p-156967196.html>.

13 Sun Zifa, "珠海航展展示中国未来大型空间站机械臂负载25吨" [The Zhuhai Airshow Displays China's Future Large Space Station's Robotic Arm Capable of Carrying 25 Tons], November 11, 2012, [http://news.ifeng.com/mil/special/zhuhaihangzhan2012/content-3/detail\\_2012\\_11/17/19262218\\_0.shtml](http://news.ifeng.com/mil/special/zhuhaihangzhan2012/content-3/detail_2012_11/17/19262218_0.shtml).

14 "我国未来空间站机械臂研制七年磨剑终硕果" [The Great Achievements of Seven Years of Discipline for Our Country's Future Space Station Robotic Arm], June 2012, [http://www.china.com.cn/news/zhuanli/szjh/2012-06/13/content\\_25638733.htm](http://www.china.com.cn/news/zhuanli/szjh/2012-06/13/content_25638733.htm).

The robotic arm for the space station is being built by the China Academy of Space Technology 502 Research Institute (中国空间技术研究院502研究所/CAST 502 RI), also known as the Beijing Institute of Control Engineering (北京控制工程研究所). CAST 502 RI is a center for space robotics research and is home to the Space Station Robotic Arm Engineering Center (空间站机械臂工程中心), the Intelligent Control and Space Robotics Laboratory (智能控制及空间机器人研究室), and the National Aerospace High Technology Robotics Engineering Research Center (国家高技术航天领域空间机器人工程研究中心).<sup>15</sup> The Space Station Robotic Arm Engineering Center is made up of 20 personnel who can draw upon the expertise of 170 researchers from academia and other research institutes. The robotic arm was reportedly difficult to develop because of the institute's lack of experience in robotics. Normal Chinese practice is to limit the level of new technologies in a project to no more than 20 percent, but for the space station's robotic arm 80 percent of the technologies were new, including remote control, precision control, and visual recognition technologies.<sup>16</sup>

The CAST 502 RI also worked on a program sponsored by the 863 Program entitled "Extravehicular Free-Moving Robotic System" (舱外自由移动机器人系统), which developed a robotic arm called "EMR" or "Mr. E." This third-generation Chinese robotic arm could not only grasp objects but could also crawl like a caterpillar along a surface, such as a spacecraft hull, to reach different locations. Researchers from the Institute stated that they had made inquiries to unknown parties about installing the EMR on the ISS, but this request did not come to fruition for unknown reasons.<sup>17</sup>

China's second space robotic arm program involves the use of a free-floating robotic arm that is the subject of the August test. This project is run by the Harbin Institute of Technology, a university with strong ties to the military and the space industry. In 2010, the China Aerospace Science and Technology Corporation (CASC) invested 500 million yuan, the largest amount ever in an aerospace research institute in China, to establish the Air and Space Science and Technology Innovation Academy (空天科学技术创新研究院) at HIT. During the signing ceremony for the Academy, then CASC president Ma Xingrui praised the school for "basing itself on aerospace and serving the national defense."<sup>18</sup>

HIT also has a robotics emphasis and is home to the State Key Laboratory of Robotics and Systems (机器人技术与系统国家重点实验室). This key laboratory appears to have strong international ties, particularly with the German Aerospace Center (DLR) with which it has established the DLR-HIT Joint Laboratory (德宇航-哈工大联合实验室) focused on space robotics.<sup>19</sup> In 2012, Chinese Premier Wen Jiabao and German Chancellor Angela Merkel visited the HIT booth at the Hanover Fair, the world's largest industrial trade fair, and examined a robotic hand jointly developed by HIT and DLR.<sup>20</sup>

HIT researchers have worked on several space robotic arms projects, including a ground test station for the space station robotic arm and a robotic arm for China's lunar rover. HIT is described as China's leading institution for free-floating space robot research. It began its research on free-floating space robots during the Eighth Five-Year Plan (1991–1995) and based its initial research on the Japanese ETS-VII satellite which was launched in 1997 and was the first satellite to be equipped with a robotic arm.<sup>21</sup> HIT's initial research was on single-armed robots, but

15 ICASC website, <http://www.icasc.cn/005048/company/company.html>.

16 "我国未来空间站机械臂研制七年磨砺终结硕果" [The Great Achievements of Seven Years of Discipline for Our Country's Future Space Station Robotic Arm], June 13, 2012, [http://www.china.com.cn/news/zhuant/szjh/2012-06/13/content\\_25638733.htm](http://www.china.com.cn/news/zhuant/szjh/2012-06/13/content_25638733.htm).

17 "Chinese Space Robot Seeks Employment on ISS," *People's Daily*, December 5, 2002.

18 中国投资最大的空天科学技术创新研究院在校成立, June 5, 2014, <http://news.hit.edu.cn/articles/2010/06-05/06141401.htm>.

19 State Key Laboratory of Robotics and System website, <http://robot.hit.edu.cn/news/main.asp?cataid=A00140001>.

20 "Chinese Premier and German Chancellor Shake HIT's Robotic Hand," May 25, 2012, <http://en.hit.edu.cn/snews.asp?id=355>.

21 Japan Aerospace Exploration Agency, "Engineering Test Satellite VII 'Kiku No. 7,'" accessed October 7, 2013, [http://www.jaxa.jp/projects/sat/ets7/index\\_e.html](http://www.jaxa.jp/projects/sat/ets7/index_e.html).

researchers there began working on two-armed robots during the Ninth Five-Year Plan (1996–2000) and completed a two-armed robot ground test platform during the Tenth Five-Year Plan (2001–2005).<sup>22</sup>

## China's Space Robotic Arm Applications

Chinese press accounts and researchers assign importance to space robotic arm technology. According to one press article, “as space technology develops, especially space stations, space planes and space robots ... space robotic arms ... are receiving increasing attention.”<sup>23</sup> Similarly, according to an article coauthored by former CASC head and current head of the China National Space Administration Ma Xingrui, “as space robotic arm technology improves, it will promote the development of our country's space science, space protection, space construction, and deep space exploration.”<sup>24</sup> According to one researcher, China could have benefitted from the use of a space robotic arm when a Sinosat-2 communications satellite launched in 2006 failed in orbit because its solar panels and antenna did not completely open. The researcher writes that a space robot could have been used to repair the satellite, which cost 2 billion yuan and had a service life of 15 years.<sup>25</sup>

Although the vast majority of Chinese articles refer to the use of space robotic arms in repair, refueling, space station construction, and debris removal functions, some Chinese researchers acknowledge that robotic arms can also perform a military function. According to an article written by the current director of the China Manned Space Engineering Office, space stations can service military satellites in orbit, this includes repair, maintenance, fueling, and replenishment of ammunition, all of which can be done with the use of a robotic arm.<sup>26</sup>

Other articles give a more explicit counterspace role to robotic arms. According to one journal article examining on-orbit servicing of non-cooperative targets, “protecting the normal operation of one's spacecraft while weakening an enemy's space system capabilities is an important question of future wars.” The authors then conclude that in this century there will be multiple types of counterspace weapons and that robotic technologies directed at capturing non-cooperative targets will have great potential.<sup>27</sup>

Chinese researchers also point out that the United States has developed its own robotic arm technologies with counterspace implications. Chinese researchers have noted that the use of the space shuttle's robotic arm to capture satellites has proven that it is possible for a space plane or space station to capture an enemy's satellite.<sup>28</sup> A 2008 article on space weapons that discusses the 2007 Orbital Express program concludes that its operationalization would give the United States the ability to capture other countries' satellites at will and allow it to seize the initiative in space. The author then concludes that not only must China keep abreast of foreign countries' counterspace developments, but also develop its own counterspace technologies to lay the foundation for winning high technology wars.<sup>29</sup>

22 Yuan Jingyang, 多臂自由飞行空间机器人协调操作研究 [Research on Coordinated Operation of Multi-Arm Free Flying Space Robot], PhD diss., Harbin Institute of Technology, 2009, 8.

23 Sun Zifa, “珠海航展展示中国未来大型空间站机械臂负载25吨” [The Zhuhai Airshow Displays China's Future Large Space Station's Robotic Arm Capable of Carrying 25 Tons], November 17, 2012, [http://news.ifeng.com/mil/special/zhuhaihangzhan2012/content-3/detail\\_2012\\_11/17/19262218\\_0.shtml](http://news.ifeng.com/mil/special/zhuhaihangzhan2012/content-3/detail_2012_11/17/19262218_0.shtml).

24 Yu Dengyun, Sun Jing, and Ma Xingrui, “空间机械臂技术及发展建议” [Suggestion on Development of Chinese Space Manipulator Technology], 航天器工程 [Spacecraft Engineering] 7 (2007): 4.

25 Xu Wenfu, Qiang Wenyi, Li Cheng, Liang Bin, and Liu Yu, “自由浮空间机器人路径规划研究进展” [Progress in Path Planning of Free-floating Space Robot], 哈尔滨工业大学学报 [Journal of Harbin Institute of Technology] 11 (2009): 40.

26 Wang Zhaoyao, “军事航天技术及其发展” [Military Space Technology and Its Development], 航天器工程 [Spacecraft Engineering] 1 (2008): 17.

27 Liang Bin, Du Xiaodong, Li Cheng, and Xu Wenfu, “空间机器人非合作航天器在轨服务研究进展,” [Advances in Space Robot on-orbit Servicing for Non-cooperative Spacecraft], 机器人 [Robot] (March 2012): 246.

28 Li Bo and Weng Huaming, “军事航天技术及太空战,” [Military Space Technology and Space Warfare], 国防科技 [National Defense Science and Technology] 1 (2005): 87.

29 Song Yanxue, Zhang Zhifeng, and Qi Lihui, 美国反卫星武器最新发展动态 [Most Recent Developments in U.S. Antisatellite Weapons], 飞航导弹 [Winged Missile Journal] 1 (2008): 26.

## Peaceful, Non-peaceful, or Both?

The ambiguity of Chinese intentions on the use of its space robotic arm technologies is indicative of the overall difficulty in assessing whether a particular technology is a space weapon. As former Strategic Command commander General Kevin Chilton is reported to have said, “Let’s say you build a craft capable of pulling alongside a satellite, extending a robotic arm, and plucking the satellite’s solar panels off, thereby disabling it. Would you consider that a space weapon? Well, if so, that would mean the U.S. space shuttle is a space weapon.”<sup>30</sup> Consequently, the inherent dual-use nature of most space technologies means that whether technologies will only be used for peaceful purposes depends on the intent of the user.

Unfortunately, China’s lack of transparency about its space robotic arm testing as well as its space program overall only exacerbates concerns over its intentions. Several factors, however, suggest that free-floating space robotic arm technologies would be valued for their military applications. First, China’s space program is a military-run program (there is no Chinese equivalent to NASA), suggesting that China’s military will consider using such dual-use technologies, like robotic arms, in defense of what they see are China’s legitimate interests. Second, Chinese military writings on space and counterspace indicate that the Chinese military regards space as a domain that must be fought for and controlled if China is to achieve success on the terrestrial battlefield.<sup>31</sup> Third, China is working on a broad range of counterspace technologies, including direct ascent kinetic kill, directed-energy weapons (such as lasers, high-powered microwave, and particle beam weapons), and communication and GPS jammers. Finally, the test of robotic arm technologies continues a series of tests with ASAT implications since the 2007 direct ascent kinetic kill test. In 2010 and 2013, China conducted missile defense tests which intercepted a target outside the atmosphere.<sup>32</sup> In 2010, a Chinese satellite nudged another satellite in what could have been a test of docking techniques. Finally, in 2013 China conducted a suborbital launch to study the earth’s magnetosphere; this was feared to be a cover for another direct ascent kinetic kill test.<sup>33</sup>

## Conclusion

Similar to the United States, China’s testing of space robotic arm technologies is inherently dual-use. The technologies tested in the August maneuvers have legitimate space debris removal and on-orbit servicing applications, but China’s extensive counterspace programs also indicate that these technologies provide an additional option in its ASAT “toolkit.” As such, defining space weapons is problematic, if not impossible, and it is this definitional issue that has been one of the main stumbling blocks in achieving a space arms control agreement. Indeed, these technologies seem to cloud Chinese leaders’ stance on space arms control, who have for years advocated a prohibition of weapons in space. China’s space robotic arm technologies are also an indicator that China is intent on seeking the full range of space technologies and is continuing its drive to move from being a “major space power” to a “strong space power.”<sup>34</sup>

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30 Andy Grotto, *Arms Control Wonk Blog*, “Gen. Chilton on a Space Weapons Treaty,” October 30, 2008, <http://guests.armscontrolwonk.com/archive/2076/general-chilton-on-a-space-weapons-treaty>.

31 For a more in-depth discussion of Chinese writings on the military use of space, see Kevin Pollpeter, “China’s Space Doctrine” in Andrew S. Erickson and Lyle J. Goldstein, eds., *Chinese Aerospace Power* (Naval Institute Press, 2011), 50–68.

32 Office of the Secretary of Defense, *Military and Security Developments Involving the People’s Republic of China*, 2011, 37.

33 Kevin Pollpeter, “China’s Second Ballistic Missile Defense Test: A Search for Strategic Stability,” SITC Bulletin Analysis, February 2013, <http://igcc.ucsd.edu/research/technology-and-security/innovation-and-technology-in-china/sitc-publications/>.

34 Andrea Shalal-Esa, “U.S. Sees China Launch as Test of Anti-Satellite Muscle,” May 15, 2013, <http://www.reuters.com/article/2013/05/15/us-china-launch-idUSBRE94E07D20130515>.