# UAV SWARMS: CHINA'S LEAP IN CUTTING-EDGE TECHNOLOGIES

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## INTRODUCTION

China's President Xi Jinping has vowed to transform its industry from "mass production" to "mass production with quality" by achieving excellence in science and technology, innovations and military technologies. China's experimentation with niche technologies and its rising innovation index indicate its rising potential to take the lead in futuristic technologies in the military domain. It demonstrated its ability to develop a variety of Unmanned Aerial Vehicles (UAVs) in the last decade or so and simultaneously pursued the development of Artificial Intelligence (AI). Its focus had shifted towards integrating these two capabilities to develop intelligent UAV swarms about a decade ago; however, its UAV swarm programme came into the limelight only when it released a video of its UAV swarm during the Zhuhai Air Show in November 2016.[1] China has made significant progress in UAV swarms since then, which has enormous potential for military and civil applications. China has accorded high-level priority to AI, speech recognition, self-driving cars and other cutting-edge technologies that would enable it to keep pace with the US. It successfully demonstrated

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1. Jeffrey Lin and P.W. Singer, "China's New Fleet of Drones: Airshow Displays the Future of Chinese Warbots and Swarms", *Popular Science*, November 4, 201,6 https://www.popsci.com/chinas-new-fleet-drones-zhuhai-2016-airshow-displays-future-chinese-warbots-and-swarms. Accessed on August 8, 2018.

**China has accorded high-level priority to AI, speech recognition, self-driving cars and other cutting-edge technologies that would enable it to keep pace with the US. It successfully demonstrated the world's largest fixed-wing as well as quadcopter UAV swarms in 2017 and 2018.**

the world's largest fixed-wing as well as quadcopter UAV swarms in 2017 and 2018 respectively. The potential of UAV swarms to transform warfare from "informatised" to "intelligencised" warfare was the key motivating factor for China in developing fixed-wing and multicopter UAV swarms.[2] *The Diplomat*, a current affairs magazine, in an article on February 3, 2018, observed that China has moved beyond the initial steps in progress and the UAV swarm demonstration has placed China ahead of the US in its swarm technology.[3] Chinese military scholars view the UAV swarm to be a 'disruptive technology' in modern war-fighting, which is likely to "change the rules of the game".[4] A researcher at the National Security and Military Strategic Research Centre of the National University of Defence Technology (NUDT) of China observed that the employment of smaller, cheaper and reusable UAVs in a swarm for distributed attacks could lower combat costs and reduce casualties associated with the larger manned combat platforms and combatants.[5] China's rise in the domain of futuristic technologies like the UAV swarm was viewed as the rise of a country which had developed aviation platforms through reverse engineering or by clandestine acquisition of technologies. However, development of emerging technologies like UAV swarms almost during the same timelines as the US could not have been achieved through imitation, espionage or reverse engineering alone.

2. Elsa B. Kania, *Chinese Advances in Unmanned Systems and the Military Applications of Artificial Intelligence—the PLA's Trajectory towards Unmanned, "Intelligentized" Warfare*, Government Publishing Office, US, February 23, 2017, https://www.uscc.gov/sites/default/files/Kania_Testimony.pdf. Accessed on April 27, 2018.
3. "Intel Breaks Drone Record with Olympics Display with a Promise of More to Come," *The Engineer*, February 12, 2018, https://www.theengineer.co.uk/intel-drone-olympics/. Accessed on June 19, 2018.
4. Xiang Bo, "China Launches Record-Breaking Drone Swarm", *Xinhua Net*, June 11, 2017, http://www.xinhuanet.com/english/2017-06/11/c_136356850.htm. Accessed on June 28, 2018.
5 Zhang Qiang, "Smart Drone Bee Swarm will Change the Rules of Battle", March 29, 2017, http://kepu.gmw.cn/2017-03/29/content_24084029.htm. Accessed on April 30, 2018.

The Chinese government's policies and initiatives for excellence in Science and Tecnology (S&T) and futuristic technologies like artificial intelligence, autonomy, robotics, etc. have contributed significantly to the development of UAV swarms. Also, its concerted effort in harnessing the potential of government laboratories, defence forces, private industry and academia have been key enablers for developing UAV swarms. The aspiration of the present Chinese leadership is much higher as it wants its military-civil industry to become a global leader in innovation by 2049.

**China has often been accused by the US policy-makers of resorting to illegal and clandestine means to acquire cutting-edge technologies. However, the US government never imposed sanctions on China and China's clandestine activities did not impact the US-China engagement in aerospace and other high technology sectors.**

China's UAV swarm programme has also been one of the biggest beneficiaries of the brain and technology drain from the US, which was stimulated by the Chinese strategy of leveraging its financial power and investments to acquire technology and talent. A study by the Defence Innovation Unit Experimental (DIUx) of the US Department of Defence (DoD) highlighted the large-scale brain drain from the US to China, singling out certain Chinese venture capital firms, which had been investing in the promising start-up companies of the US in Silicon Valley, taking over their managerial control and transferring some of these technologies to China. The UAV swarm is a domain in which China has exploited gaps in the US trade policies, and yet it has not significantly affected trade relations between these two nations.

China has often been accused by the US policy-makers of resorting to illegal and clandestine means to acquire cutting-edge technologies. However, the US government never imposed sanctions on China and China's clandestine activities did not impact the US-China engagement in aerospace and other high technology sectors. The only exceptions have been when the US Administration used its diplomatic leverage with Israel to block the sale of the Phalcon Airborne Warning and Control System (AWACS) to China in 2000 and thereafter, upgradation of the Harpy loitering drones in 2005. These blocking actions of

the US government were due to the threat posed by these weapons to US forces supporting Taiwan in any confrontation.[6] The response of the US to the acquisition of cutting-edge technology by China through various clandestine means, including coercion and espionage, has been rather subdued. This paper examines China's UAV swarm programme, the significance of its policy initiatives, Military-Civil Integration (MCI), the contribution of the academia, defence forces and private industry and technology acquisition strategy for achieving a leadership position in innovation and cutting-edge technologies.

## CHINA'S UAV SWARM PROGRAMME

A UAV swarm essentially comprises simultaneous operations of multiple 'intelligent' UAVs by utilising the combined capability of the entire group. Some Chinese scholars have used the term 'clustered operations' for collaborative and swarm operations. The interest of military leaders in UAV swarms is increasing as multiple intelligent UAVs can perform various tasks simultaneously. Research on UAV swarms has been going on in the US since the 1990s and China was closely following these developments as well as aggressively pursuing similar projects at home, some of which are discussed below. The earliest indication of the Chinese UAV swarm development programme was seen when Tsinghua University launched a project in collaboration with the research institute of the Chinese Army for developing integrated control of electro-mechanical sensors dedicated to flying micro-engines in 1998 for which a patent was filed in 2011.[7]

**Fixed-Wing Swarm:** China's National Electric Corporation, a company of the large state-owned enterprise, the China Electronic Technology Corporation (CETC), displayed the largest swarm comprising 67 fixed-wing UAVs at the Zhuhai Air Show on November 1, 2016, beating the previous record held

6. Edward Cody, "China Scolds U.S. for Blocking Israeli Arms Sale", *Washington Post*, June 28, 2005, http://www.washingtonpost.com/wp-dyn/content/article/2005/06/27/AR2005062700351.html?noredirect=on. Accessed on July 31, 2018.
7. "Provides Drone Cluster Control Solution, Poisson Technology Wants to Deepen the Market", *Taibo.com*, November 11, 2016, http://www.3snews.net/startup/246000044122.html. Accessed on June 26, 2018.

by the US Navy of a swarm comprising 50 mini UAVs.[8] These UAVs were seen carrying out networked manoeuvres to hunt for missile launchers in an urban area and then diving into missile launchers to destroy them.[9] During this trial, CETC validated the creation of an ad-hoc communication network (dynamic non-centralised network) within the swarm, individual situational awareness, collision avoidance and autonomous control of the group.[10]

In June 2017, CETC tested an even bigger swarm of 119 catapult launched fixed-wing UAVs to improve its previous record of a swarm comprising 67 fixed-wing UAVs[11] as well as to break the world record of a swarm comprising 103 UAVs set by the US in January 2017.[12] The UAV swarm divided into different groups, with each group circling over its intended target and thereafter, manoeuvring as a group to ascertain the viability of carrying out coordinated reconnaissance, distributed surveillance and saturated strikes over ground targets.[13] However, the major difference between the Chinese fixed-wing UAV swarm and the US fixed-wing UAV swarm was that the Chinese swarm was launched from ground-based catapult launchers while the US swarm had been launched from fighter aircraft. The technology gap between the US and Chinese UAV swarms was evident as the US had launched the Perdix UAVs from a fighter aircraft, which is technologically more challenging. China had realised this and the People's Liberation Army Air Force (PLAAF) had launched a UAV swarm challenge in late 2017 with the aim to bridge this gap, which is discussed later in the article.[14]

8. "China Tests 119 Drones, Makes Breakthrough in AI Systems", *Xinhua- Global Times*, http://www.globaltimes.cn/content/1051123.shtml. Accessed on July 19, 2018.
9. Jeffrey Lin and P.W. Singer, "China is Making 1,000-UAV Drone Swarms Now", *Popular Science*, January 9, 2018, https://www.popsci.com/china-drone-swarms#page-3. Accessed on June 19, 2018.
10. Henry Kenhmann, "CETC: Successful Test of a Swarm of 119 Fixed-Eing Drones", *East Pendulum*, June 12, 2017, http://www.eastpendulum.com/cetc-test-reussi-dun-essaim-de-119-drones-a-voilure-fixe. Accessed on June 26, 2018.
11. Xinhua, "China Launches Record-Breaking Drone Swarm," 2017-06-11, Accessed on March 13, 2018, URL: http://www.xinhuanet.com/english/2017-06/11/c_136356850.htm.
12. Chris Baraniuk, "US Military Tests Swarm of Mini-Drones Launched from Jets", *BBC News*, January 10, 2017, https://www.bbc.com/news/technology-38569027. Accessed on July 9, 2018.
13. Kenhmann, n.10.
14. Scott N. Romaniuk and Tobias Burgers, "China's Swarms of Smart Drones Have Enormous Military Potential", February 3, 2018, https://thediplomat.com/2018/02/chinas-swarms-of-smart-drones-have-enormous-military-potential/. Accessed on March 12, 2018.

**Swarm of Quadcopter UAVs:** The aspiration for developing larger quadcopter UAV swarms by the US and Chinese companies brought civil applications to the fore as well as indicated close competition between them for shaping the market sentiment and capturing its business potential. The competition between them commenced when the Chinese company Ehang demonstrated the biggest quadcopter UAV swarm comprising 1,000 Ehang Ghostrider-2.0 mini UAVs on February 11, 2017 night.[15] It broke the previous record of the 500 quadcopter UAVs swarm[16] set by the Intel company in November 2016.[17] Thereafter, Ehang demonstrated a swarm comprising 1,108 mini quadcopter UAVs in December 2017,[18] which was surpassed when Intel demonstrated a larger swarm comprising 1,218 mini UAVs at Pyeongchang, South Korea, in February 2018.[19] Intel became the first company to commercialise UAV swarms by becoming the official sponsor of the Olympics and was entrusted with organising UAV swarm displays as an environment friendly alternative to fireworks displays.[20] Ehang set another world record by flying a swarm comprising 1,374 mini quadcopter UAVs on April 29, 2018.[21] The competition between Ehang and Intel for demonstrating bigger swarms indicated the rising capability for collaborative operations; however, some failures during the public displays also brought their vulnerabilities to the fore, which are discussed later.

## POTENTIAL AND CHALLENGES

UAV swarms have the potential for civil and military applications; however, there are certain challenges, which are yet to be overcome. China, with the

15. Liu Yang, "Drone Swarming Technique May Change Combat Strategies: Expert," *Global Times*, February 13, 2017. Accessed March 13, 2018, URL: http://www.globaltimes.cn/content/1032741.shtml.
16. http://www.guinnessworldrecords.com/news/2016/11/intel-launches-500-drones-into-sky-and-breaks-world-record-in-spectacular-style-449886. Accessed on June 19, 2018.
17. "Ehang 1,000 Drone Light Show Refreshed World Record", Ehang, February 11, 2017, http://www.ehang.com/news/249.html. Accessed on June 19, 2018.
18. Romaniuk and Burgers, n.14.
19. "Intel Breaks Drone Record with Olympics Display with the Promise of More to Come", *The Engineer*, February 12, 2018, https://www.theengineer.co.uk/intel-drone-olympics/. Accessed on June 19, 2018.
20. Romaniuk and Burgers, n.14.
21. "Ehang Egret's 1374 Drones Dancing Over the City Wall of Xi'an, Achieving a Guinness World Records Title", April 29, 2018, http://www.ehang.com/news/365.html. Accessed on June 19, 2018.

development of fixed and rotary-wing UAV swarms, has demonstrated that the past phase of catching up in technology is over and it can develop innovative and futuristic technologies. Chinese military leaders believe that employability of a single platform in a future battlefield is limited and its survivability would be increasingly challenged.[22] Therefore, UAV swarms are being seen as the future of unmanned aviation and UAVs are likely to witness a significant increase in the man-machine integration.[23] The challenge for operators would be to synergise the operation of multiple platforms and sensors, obtain inputs, build a holistic picture and provide information to multiple users in a simple manner and in real-time. A UAV swarm enhances the chances of success in combat operations since it is a self-healing group in which the functions of a defunct or disabled UAV can be taken over by other UAVs, which would enhance the probability of mission execution despite malfunctions or attrition. At present, missiles and air defence guns are employed for providing protection against conventional manned and unmanned aircraft. However, missiles would not be suitable for destroying a UAV swarm comprising tens and hundreds of mini UAVs. Similarly, small arms and anti-aircraft guns too would not be able to ensure destruction of the UAV swarm. Therefore, intensive research is being carried out to develop UAV swarm counter-measures.

China's UAV swarm programme, despite its successes, has faced certain challenges. The vulnerability of its UAV swarms came into the limelight soon after China created the world record for flying a swarm of 1,374 UAVs on April 29, 2018. The technical flaws were first noticed during the rehearsal for the UAV swarm display by Ehang to celebrate International Labour Day at Xi'an on May 1, 2018, when some UAVs malfunctioned and a few of them could not be recovered.[24] The public display of the UAV swarm formation on May 1 also did not go as planned as a total of 496 out of 1,373 UAVs deviated

22. "Airshow China Showcases the World's Largest Cluster of Drones", China Electronics Technology Group Corporation (CETC), November 01, 2016, http://www.cetc.com.cn/zgdzkj/hzzt/wmgz/453128/index.html. Accessed on June 18, 2018.
23. Ibid.
24. Echo Huang, "Watch: In the World's Largest Drone Performance, Some Machines Went Rogue", *Quartz*, May 3, 2018, https://qz.com/1283452/a-cyber-resilient-enterprise-needs-a-cyber-committed-ceo-and-board/. Accessed on June 19, 2018.

**The challenge for the UAV swarm designers has been to develop a faster and secure datalink, which is capable of transmitting a greater volume of data.**

from their intended path, which distorted the swarm formations. Also, some of the UAVs landed back abruptly during the display. These disruptions were attributed to targeted jamming of Global Positioning System (GPS) signals.[25]

The PLA was anticipating an eventuality of GPS jamming and had invited proposals for research and development of self-organising network architecture, control, positioning and anti-jamming technologies for the Colony Drone Datalink Technology in August 2016.[26] It had also initiated a project to develop drone anti-jamming technology under a complex electromagnetic environment.[27] However, disruptions in the UAV swarm display on May 1, 2018, indicated that the Chinese military has either not succeeded in developing anti-jamming capability or not shared it with the private UAV operator (Ehang) involved in the display. UAVs normally use datalinks in the UHF, L, C, X and Ku bands.[28] The challenge for the UAV swarm designers has been to develop a faster and secure datalink, which is capable of transmitting a greater volume of data. The CETC developed a Ku-band UAV datalink for transmission of sensor data up to 300 megabits per second in 2016, which had greater bandwidth and accuracy and was resistant to interruptions and interference.[29] This is likely to enhance the capability of its datalinks to transmit a large amount of data at a much greater speed as well as provide protection against cyber attacks.

25. Gong Zhe, "Why Ehang's Record-Breaking 1,374-Drone Show Became a Disaster?", *CGTN*, May 7, 2018, https://news.cgtn.com/news/3d3d514d35676a4d77457a6333566d54/share_p.html. Accessed on June 19, 2018.
26. Fund - 61403110201 - Colony Drone Data Link Technology (Key), August 01, 2018, http://www.weain.mil.cn/cgxq/yy/yjjsl/526969.html. Accessed on June 23, 2018.
27. "Naval Pre-research, Drone Anti-Jamming Technology in the Complex Electromagnetic Environment," August 1, 2016, *Purchase Command*, *PLA*, http://www.weain.mil.cn/cgxq/yy/yjjsl/526866.html. Accessed on June 23, 2018.
28. İsmet Çuhadar and Mahir Dursun, "Unmanned Air Vehicle System's Data Links", Gazi University, Turkey, http://www.joace.org/uploadfile/2015/1015/20151015021322106.pdf. Accessed on August 20, 2018.
29. Liu Kun, "China's Latest UAV Data Link International Advanced is Extremely Difficult to be Cut Off", *Global Network Military*, November 2, 2016, http://mil.huanqiu.com/china/2016-11/9624313.html. Accessed on August 20, 2018.

Another limitation of the Chinese UAV swarm programme was its narrow scope as compared to that of the US. The US carried out trials of aerial launch and recovery of a UAV prototype in May 2018,[30] which China lacked. It has also launched the Gremlins project to develop operational UAV swarms that can undertake combat operations up to 300 nautical miles (NM) in GPS denied areas and be retrieved by an aircraft. The capability to recover UAVs in the air, and operation of UAV swarms in GPS denied areas are two crucial technologies whose success could significantly enhance the employability of the UAV swarms in combat operations. The US is aiming to utilise Gremlins in an Anti-Access/ Area Denial (A2/AD) environment.[31]

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**PLAAF Unmanned Swarm Challenge:** To overcome some of the limitations of the Chinese UAV swarm programme, the PLAAF, in collaboration with the China Electronics Research Institute, Tsinghua University, Beijing Institute of Technology, Yuangwang think-tank and other organisations held the first "Unmanned Swarm Challenge or Smart UAV Cluster System Challenge" in 2018. The challenge indicated the key role of the PLAAF in the development of UAV swarms. It was meant to harness the potential available within the country for developing enabling technologies for UAV swarms and was open to military scientific research units, military units, Chinese Academy of Sciences related research institutes, universities, state-owned enterprises, private enterprises, UAV related teams and individuals who could participate with their fixed and rotary-wing electric UAVs weighing less than 7 kg. The challenge for autonomous UAVs was divided into two parts, i.e. open challenge and invitational challenge.

30. Aaron Gregg, "Pentagon Moves Closer to 'Swarming Drones' Capability with New Systems Test", *The Washington Post*, May 6, 2018, https://www.washingtonpost.com/business/capitalbusiness/pentagon-moves-closer-to-swarming-drones-capability-with-new-systems-test/2018/05/04/61ec01d6-4fc8-11e8-af46-b1d6dc0d9bfe_story.html?noredirect=on&utm_term=.01a6e6175664. Accessed on August 20, 2018.
31. "Gremlins on Track for Demonstration Flights in 2019", DARPA, May 9, 2018, https://www.darpa.mil/news-events/2018-05-09. Accessed on July 31, 2018.

The open challenge was aimed at developing wide-ranging UAV swarm capabilities, bridging technology gaps and facilitating their optimum exploitation for military applications. There were three competition topics: the first was the Intensive Formation Crossing Race (IFCR); the second competition was the Formation Cooperative Reconnaissance Attack (FCRA); and the third competition was the Self-Recovery and Aerial Docking (SRAD) on another UAV. In the IFCR, each team was to field at least four fully autonomous UAVs, which were required to pass through four door frames of the size of 7.32m x2.44 m and return to the landing zone. This would enable UAV swarms to autonomously navigate to a destination by avoiding obstacles. If we relate the development of the UAV swarm with the designing of the Ehang-184 unmanned passenger drone, China could integrate these two programmes and employ UAV swarms for logistics supply, troop insertion and extraction, and Combat Search and Rescue (CSAR) operations in obstacle prone areas. The FCRA competition, allowing participants to field 2-10 autonomous UAVs carrying out cluster search, identifying and locating true and false targets (two circular targets having diameters of 7m and 2m) and dropping sandbags on the target was aimed at assessing the capability of intelligent UAV swarms to undertake Intelligence, Surveillance, Reconnaissance (ISR) tasks, differentiate between dummy and actual targets, and strike them. The SRAD competition required teams to field 2-10 autonomous UAVs comprising both piloted and autonomous UAVs, in which autonomous UAVs were expected to dock with the piloted UAVs flying at specified speeds (fixed-wing flying at 70 km/h and rotary-wing flying at 20 km/h) and fly a route in a sequential manner. The focus of this competition was to bridge the gap in technology vis-à-vis the US and develop the capability for precise positioning of aerial vehicles and their docking on piloted UAVs. The decision of the PLAAF not to allow the use of differential GPS, differential Beidou and other differential positioning methods appeared to be aimed at developing inbuilt systems, which would increase the autonomy of UAV swarms and allow them to undertake operations in GPS denied areas.[32]

32. "In June, the Air Force will Host the Unmanned Challenge Smart UAV Cluster System Challenge", https://mp.weixin.qq.com/s/xfw3hZkCiPJa-gX3GExEcQ. Accessed on June 24, 2018.

The second phase of the competition was the invitational challenge, which was a non-public competition in which the open competition winning team and the nominated invitational teams were to participate. The final phase involving competition among the invitational teams was planned to be held at the China Electronic Science and Technology Park at Hebei province in June 2018.[33] The results of these competitions have not been made public so far. However, development of the above technologies was important for China to transform its prototype UAV swarm into operational systems.

**LEADERSHIP SUPPORT, POLICY INITIATIVES AND KEY PLAYERS**

China had surprised the world when it created the world record by developing the largest UAV swarm in 2017. Reverse engineering and clandestine means were a part of its grand strategy to acquire elusive technologies and fill the technology gaps. The Western media gave greater credence to its clandestine activities while its industrial and aviation eco-system did not receive due attention, though this played a significant role in its quest for technology development. The credit for its success in innovative technologies like the UAV swarm also goes to the support provided by its leadership and its consistent policy on excellence in science and technology, research and development, and innovation to achieve self-reliance in defence technologies. The Communist Party of China (CPC) has built the defence and aviation industry and academic institutions, and aggressively pursued indigenous development of military equipment since it came to power in 1949. The first significant boost to China's defence industry policy came when Deng Xiaoping introduced the principle of 'Four Modernisations' in 1978.[34] This principle placed the development of four key pillars comprising agriculture, industry, defence, science and technology[35] as central to making China a military and economic power. The three domains comprising science

33. Ibid.
34. The Central Committee of the CPC issued the "Opinions on Deepening the Reform of the Institutional Mechanism of Talent Development", Ministry of Science and Technology of the People's Republic of China, January 17, 2017, http://www.most.gov.cn/kjzc/gjkjzc/kjrc/201701/t20170117_130534.htm. Accessed on April 25, 2018
35. "Deng Xiaoping Theory", *China Daily*, September 15, 2010, http://www.chinadaily.com.cn/china/cpc2011/2010-09/15/content_12474319_8.htm. Accessed on April 25, 2018.

and technology, industry and defence were interrelated and critical for improving the quality of defence products, including defence aviation. To achieve this, China collaborated with leading civil aviation manufacturers to fill technology gaps and improve the quality of its products. Thereafter, Jiang Zemin brought another major reform in China's industrial policies, when he introduced the principle of "Three Represents" in 2000. He was responsible for changing the Party Constitution to allow participation of private entrepreneurs in the industry.[36] This strengthened its aviation eco-system further and new ideas contributed to China's endeavours in developing several advanced civil-military aviation platforms, including UAVs. The incumbent Chinese President Xi Jinping, aiming to take China to even greater heights, introduced the principle of "Four Comprehensives" in February 2015.[37] He emphasised on improving the technology by utilising talent and promoting innovation to develop world-class products. His policy aims to replace the idea of 'mass production' with 'mass production with quality and developing futuristic technologies'.

The articulation of the "Four Comprehensives" was soon followed by the Chinese Ministry of Science and Technology (MOST) launching the "Technology Innovation -2030- Major Projects" programme under the 13th Five-Year Plan in February 2016, which is aimed at initiating projects that indicate the strategic intention of the country. A total of 16 major projects in the high technology domains, including one on Artificial Intelligence (AI-2.0), were shortlisted under this scheme.[38] The "Strategic Plan AI-2.0" plan covering the period up to the year 2030 was formulated in September 2016. The AI-2.0 is aimed at exploring several AI verticals, including big data artificial intelligence, swarm intelligence, perception and cross-media reasoning, hybrid intelligence, autonomous unmanned systems and

36. "Three Represents", Communist Party of China, June 23, 2006, http://english.cpc.people.com.cn/66739/4521344.html. Accessed on April 25, 2018.
37. Song Wei, "Four Comprehensives Light up the Future", *China Daily*, July 10, 2017, http://www.chinadaily.com.cn/opinion/2017-07/10/content_30050292.htm. Accessed on April 25, 2018.
38. China's "Science and Technology Innovation 2030 – Major Projects will add Artificial Intelligence 2.0", Ministry of Science and Technology of the People's Republic of China, February 16, 2017, http://www.most.gov.cn/ztzl/lhzt/lhzt2017/hkjlhzt2017/hkj_fbh02/201702/t20170228_131502.htm. Accessed on March 14, 2018.

innovative applications.[39] Thereafter, China issued the "New Generation Artificial Intelligence Development Plan" in July 2017 to implement AI-2.0, which is focussed on man-machine collaboration, cross-media collaborative processing, self-control and autonomous intelligence systems.[40] The capabilities proposed to be developed under the AI-2.0 project are significant for the development of UAV swarms and their exploitation during combat operations.

**DEFENCE INNOVATION**

Xi's vision is not restricted to civil technologies alone as he had called for "focusing on seizing the commanding height of military competition in the future" in January 2016.[41] This statement indicated the Chinese leadership's aspirations to develop cutting-edge military technologies in similar timeframes as those of the US and other leaders of military technology, and become a leader in some of the futuristic technologies. In May 2016, President Xi Jinping had set the target for China to become the most innovative country by 2020, a leading innovator by 2030, and a leading global power in Science and Technology (S&T) by 2049.[42] China's policy pronouncements for innovation have been supported with the development of infrastructure, formulation of regulations and provision of other enabling capabilities within the country. China's earmarked innovation and comprehensive testing zone at Zhongguancun, East Lake, Zhangjiang and Hehe[43] and special high technology Research and Development (R&D), intellectual property and certification policies of the

39. Dean Feng Jianfeng was appointed as the expert group of the "China Artificial Intelligence 2.0 Project", Institute of Science and Technology for Brain Inspired Intelligence, Fudan University, September 1, 2016, http://istbi.fudan.edu.cn/zh/feng-jianfeng-president-of-the-china-artificial-intelligence-2-plan-the-preparation-of-the-group-of-experts/. Accessed on April 28, 2018.
40. New Generation Artificial Intelligence Development Planning Notice No. 35 [2017], The State Council, The People's Republic of China, July 08, 2017, http://www.gov.cn/zhengce/content/2017-07/20/content_5211996.htm. Accessed on June 24, 2018.
41. Xiaotian Liang, "Follow the Trend of Military Reform and Hold the Initiative of Reform", *PLA Daily*, May 01, 2016, http://jz.chinamil.com.cn/n2014/tp/content_6843416.htm. Accessed on March 6, 2018.
42. "Xi Sets Targets for China's Science, Technology Progress", *Xinhua*, May 30, 2016, http://www.xinhuanet.com/english/2016-05/30/c_135399655.htm. Accessed on June 20, 2018.
43. "Science and Technology Policy", Ministry of Science and Technology of the People's Republic of China, http://www.most.gov.cn/kjzc/gjsdkjzc/. Accessed on April 25, 2018.

central government[44] and regulations and policies of provincial governments[45] are initiatives aimed at providing funds, nurturing of talent and harnessing their innovation potential to let an idea or an innovation pass through the process of prototype development and transform into a viable product.

President Xi, during his visit to the Academy of Military Sciences in 2018 had highlighted the need to intensify innovation in military theory, defence technology and the organisation model of the military scientific research to facilitate military reforms. He urged the Chinese military to pursue "Military Scientific Research Innovation" at full speed.[46] The Chinese military took measures to revitalise the military through science and technology, accelerate the development of modern military science and increase the pace of innovation to usher in a new era of military scientific research.[47] These measures would encourage greater involvement of the Chinese military in scientific research and harness innovations for developing futuristic military technologies.

## CIVIL-MILITARY INTEGRATION

> Implementing the strategy of military-civilian integration is a prerequisite for building integrated national strategies and strategic capabilities and for realising the Party's goal of building a strong military in the new era.
>
> — Xi Jinping
> March 12, 2018[48]

Over the last few years, China has shown willingness to involve private sector companies in manufacturing dual use cutting-edge aviation systems. Ehang, a company founded at Guangzhou, China, in May 2014, is one

44. Ibid.
45. Ibid.
46. Zing Liming, "Department of Defense: Launching the Military Research Innovation Engine at Full Speed", Department of Defence Network, June 1, 2018, http://jz.chinamil.com.cn/n2014/tp/content_8047553.htm. Accessed on June 25, 2018.
47. Ibid.
48. Li Jiayao, "Xi Calls for Deepened Military-Civilian Integration",Xinhuanet, March 12, 2018, http://eng.chinamil.com.cn/view/2018-03/12/content_7969428.htm. Accessed on June 30, 2018.

of the beneficiaries of the military-civil collaboration.[49] The company had earlier created a sensation by unveiling the world's first low-altitude autonomous passenger UAV in January 2016 at Las Vegas within two years of its formation. It could not have achieved such technological feats without the help of the Chinese public sector defence industry, considering its humble background and having commenced its UAV business with the development of the Ghostrider 1.0 mini UAV in 2014.[50] In another case of civil-military integration, the Institute of Electrical Engineering of the China Electronics Technology Corporation (CETC) collaborated with Poisson Technology,[51] a start-up company[52] to develop the world's largest fixed-wing UAV swarm. [53]

**Military-Civil Integration (MCI) has been one of the thrust areas of the present Chinese government. The Chinese Military Strategy White Paper had called for in-depth MCI in 2015. This integration was proposed to establish uniform military and civilian standards for infrastructure, key technologies and industries.**

Military-Civil Integration (MCI) has been one of the thrust areas of the present Chinese government. The Chinese Military Strategy White Paper had called for in-depth MCI in 2015. This integration was proposed to establish uniform military and civilian standards for infrastructure, key technologies and industries.[54] The White Paper was soon followed by the publication of a catalogue for MCI in December 2016, which identified six high technology areas, including new materials, smart manufacturing,

49. "The Military and Civil Integration Development Committee set up a Military Plate to Welcome the Pounds and Bullies", January 23, 2017, http://www.xinhuanet.com/finance/2017-01/23/c_129458492.htm. Accessed on April 28, 2018.
50. http://www.ehang.com/history/. Accessed on June 19, 2018.
51. "Airshow China Showcases the World's Largest Cluster of Drones", China Electronics Technology Group Corporation (CETC), November 01, 2016, http://www.cetc.com.cn/zgdzkj/hzzt/wmgz/453128/index.html. Accessed on June 18, 2018.
52. Henry Kenhmann, "CETC: Successful Test of a Swarm of 119 Fixed-Wing Drones", *East Pendulum*, June 12, 2017, http://www.eastpendulum.com/cetc-test-reussi-dun-essaim-de-119-drones-a-voilure-fixe. Accessed on June 26, 2018.
53. n.7.
54. "China's Military Strategy", The State Council, People's Republic of China, May 27, 2015, http://english.gov.cn/archive/white_paper/2015/05/27/content_281475115610833.htm. Accessed on May 7, 2018.

electronic information, new generation information technology, high-end equipment, new energy, and environmental protection. However, it appears that MCI was facing resistance or was not able to achieve the desired level of integration between the civil and military industry. The Political Bureau of the CPC Central Committee then established a high level "Central Military and Civil Integration Development Committee" under President Xi Jinping on January 22, 2017, to overcome the hurdles faced in achieving military-civil integration. As part of the pilot project for military-civil industry integration, four public sector units had been identified for implementing the mixed ownership, which is expected to act as an example for the defence industry sector.[55]

According to Elsa B Kania, an expert on China, military-civil integration has been the pillar of China's growth trajectory and she attributes the development of AI and UAV swarms by China to increasing coordination between several military-civil institutes, including CETC's 54th Research Institute, China Aerospace Science & Industry Corporation's (CASIC's) Third Institute's UAV Research Institute (302 Institute), Harbin Institute of Technology's National Key Laboratory of Robotic Systems and Engineering, Tsinghua University's Department of Automation, Beijing University of Aeronautics and Astronautics (BUAA), and Northwestern Polytechnic University (NPU).[56]

These reforms have similarities with the initiative of the then US Secretary of Defence, Mr Ash Carter in setting up the Strategic Capability Office (SCO) in 2012 and DIUx in 2015 for achieving military-civil integration.[57] Chinese planners appear to have closely studied the US model of technology development in which complementary capabilities of the public and private

55. n.49.
56. Elsa B. Kania, "Testimony before the U.S.-China Economic and Security Review Commission: Chinese Advances in Unmanned Systems and the Military Applications of Artificial Intelligence—the PLA's Trajectory towards Unmanned, Intelligentized Warfare", February 23, 2017, https://www.uscc.gov/sites/default/files/Kania_Testimony.pdf. Accessed on March 15, 2018.
57. Remarks on "The Path to an Innovative Future for Defense" (CSIS Third Offset Strategy Conference), US Department of Defence, October 26, 2016, https://www.defense.gov/News/Speeches/Speech-View/Article/990315/remarks-on-the-path-to-an-innovative-future-for-defense-csis-third-offset-strat/. Accessed on Jul 10, 2018.

sector entities [including the Defence Advanced Research Project Agency (DARPA)], SCO, DIUx and private industry are optimally exploited to develop, manufacture and export advanced military-civil equipment. China's MCI programme appears to be aimed at emulating the mixed ownership model of the US, in which Raj Shah, a former military pilot and an entrepreneur, was made the head of the Pentagon's DIUx Silicon Valley office in 2016.[58]

**CONTRIBUTION OF PLA**

The PLA and its research institutes have made significant contributions in developing futuristic technologies, including UAV swarms. At the apex level, the Central Military Commission (CMC), Joint Staff Department (JSD) and Equipment Development Department (EDD) [earlier known as General Staff Department (GSD) and General Armament Department (GAD)] play important roles in formulating UAV requirements and R&D policies. The National Institute of Defence Science and Technology of the National University of Defence Technology (NUDT) of China, 60th and 61st Research Institutes of the Equipment Development Department (EDD) of the PLA have been actively involved in strategic research, innovation and development of cutting-edge technologies, including artificial intelligence, autonomous and unmanned UAVs. The short, medium and long-term research objectives of NUDT were aligned with the Chinese government's targets for modernisation of its armed forces by 2020, 2035 and 2050 respectively.[59] As part of the research in UAV swarms, the UAV System Innovation Team of the NUDT carried out cold weather performance testing of autonomous flight and detection of fixed-wing UAV clusters in December 2017. The NUDT team has achieved significant breakthroughs in autonomous navigation, precision guidance and intelligent collaborative strikes.[60]

58. Jane Edwards, "Reports: DIUx Head Raj Shah Steps Down", *ExecutiveGov*, February 27, 2018, http://www.executivegov.com/2018/02/reports-diux-head-raj-shah-steps-down/. accessed on August 12, 2018.
59. "Chinese University Flies a Swarm of Fixed-Wing Drones", *UAV Vision*, January 19, 2018, https://www.uasvision.com/2018/01/19/chinese-university-flies-a-swarm-of-fixed-wing-drones/. Accessed on June 26, 2018.
60. Wang Jianwen and Zhang Yulong, "Pioneering Pioneering Military Intelligence in the New era," China Military Net Defence Department, December 5, 2017, http://www.81.cn/jfjbmap/content/2017-12/05/content_193525.htm. Accessed on June 26, 2018.

## CONTRIBUTION OF ACADEMIA

China's academic institutions not only act as its "eyes and ears" to keep abreast with the latest developments in the field of science and technology in the world but are also partners in the research, design and development of futuristic technologies. China utilises the knowledge base and expertise of academia to chart out its technology development roadmap as well as lay down modalities for its execution. As part of the Chinese government's drive to achieve excellence in futuristic technologies, the Ministry of Education had launched the "China Brain Project" under the "13th Five-Year Plan" in June 2016 to undertake studies on artificial intelligence, brain disease and cerebral protection and super brain functions. Accordingly, Fudan University and Shanghai Jiaotong University conducted a seminar with representatives of 60 universities to lay down the roadmap for the China Brain Project, which was aimed at developing advanced artificial intelligence capabilities, which can imitate the human brain. Chinese medical scientists have been advocating the development of the capability to "know the brain", "protect the brain" and "simulate the brain". Professor Feng Jianfeng of the Brain Research Institute of Fudan University, an expert of artificial intelligence and brain intelligence, was invited by the Chinese Academy of Engineering to join the expert group for laying down the "China Artificial Intelligence-2.0 (AI-2.0) Strategic Plan-2030" in September 2016.[61] The contribution of academia in these projects is important because a higher level of artificial intelligence is essential for enhancing the autonomy of UAV swarms and their employability in military and industrial applications.[62]

## TECHNOLOGY AND TALENT ACQUISITION

Chinese scholars have closely studied the US UAV swarm projects and the contribution of private sector companies, including start-ups under the third offset strategy to draw their lessons. Articles published by Chinese scholars in the recent past had paid special attention towards studying the

61. n.3.
62. "China Brain Project Urgently Needs Direction, China Government Network", http://www.stcsm.gov.cn/xwpt/kjdt/344990.htm. Accessed on April 28, 2018.

advances made by the US in air launch and inflight recovery of UAVs. They deliberated in detail about the soft-capture system employing aerial refuelling hose type of equipment and the hard-capture system having a robotic arm jutting out of the mother aerial platform (C-130 transport aircraft) for recovering UAVs in the air and automatically placing recovered UAVs at the desired location in the mother aerial platform automatically.[63]

**Leveraging Venture Capital for Transfer of Technology**: China has been aggressively investing through its venture capital companies[64] in the US (in start-up companies) to exploit its knowledge capital, infrastructure and an enabling environment for innovation to acquire Intellectual Property Rights (IPRs) in emerging technologies, and recruit talent. A study by the DIUx of the US DoD in January 2018 highlighted the adverse impact of Chinese investments on the technological edge enjoyed by the US, which is helping China in what it termed as "accessing the crown jewels of the US innovations". China made a record investment of 10-16 percent (through Chinese and joint venture firms) during 2015-17 in the venture-backed start-ups of the US that were developing futuristic technologies like artificial intelligence, autonomous vehicles, augmented/ virtual reality, robotics and blockchain technology.

The report views venture capital to be a small part of the massive transfer of cutting-edge technologies from the US to China. Other factors contributing to the transfer of US technology are Chinese students undergoing higher academic education in the US, Chinese investment in the US technology companies, acquisition of start-up companies by Chinese entities, Chinese private equity for financing the US high technology companies, setting up of technology transfer companies in China, Chinese companies sponsoring US associations for recruiting talent in the US, cataloguing foreign innovations, industrial espionage, cyber attacks, and Chinese companies gaining technical expertise from US firms on how to do business deals. The Chinese companies Baidu, Alibaba, etc. being the investors in the US, became the medium for

63. Qiang, n.5.
64. Venture capital is a type of private equity or finances provided by large firms to start up companies during the initial stage while seeking equity or ownership stake in return.

**China leveraged the presence of research laboratories of its major technology companies like Baidu, DJI, Huawei Technologies and Tencent Holdings in the Silicon Valley located in the US west coast to recruit talented scientists and innovators, and employ them to develop emerging and futuristic technologies.**

acquiring talent and elusive technologies through legal means which appeared to have helped China in developing AI, UAV swarm and other emerging technologies.[65]

China has exploited the innovation eco-system of the US to fill capability gaps for developing advanced AI related technologies, especially those related to UAV swarms. China leveraged the presence of research laboratories of its major technology companies like Baidu, DJI, Huawei Technologies and Tencent Holdings in the Silicon Valley located in the US west coast to recruit talented scientists and innovators, and employ them to develop emerging and futuristic technologies. Also, its venture capital companies provided finance to promising US start-up companies, especially those dealing with AI to acquire ownership stakes. These were major sources for acquisition of AI-related technologies and their transfer to China. Another concern for the US has been Chinese companies poaching its key vendors as well as gaining stakes in those companies which have been partnering with the US R&D organisations and military—a case in point is the Chinese venture capital company, Haiyin Capital acquiring a minor stake in Neurala, an AI company having contracts with the National Aeronautics and Space Agency (NASA) and the US Air Force (USAF).[66] The US government is concerned that the ongoing technology transfer to China could adversely impact its technological superiority in the coming decades.[67]

**Reversing the Brain Drain:** Chinese companies have collaborated with international technology leaders to learn and enhance indigenous capability

65. Michael Brown and Pavneet Singh, "China's Technology Transfer Strategy", Defence Innovation Unit Experimental (DIUX), January 2018, https://admin.govexec.com/media/diux_chinatechnologytransferstudy_jan_2018_(1).pdf. Accessed on June 20, 2018.
66. https://asia.nikkei.com/Features/Cover-story/China-gains-in-race-to-develop-AI-enabled-weapons. Accessed on June 28, 2018.
67. Brown and Singh, n.65.

in Artificial Intelligence (AI), Internet of Things (IoT), Analysis of Things (AoT), Virtual Reality (VR), Augmented Reality (AR) and UAV swarms. As part of the Chinese industry's capability development endeavours, Baidu, the Chinese search giant, established the Deep Learning Lab in the US in 2014. This lab is headed by Andrew Ng, adjunct professor of Stanford University and an expert on machine learning and deep learning. This lab is actively pursuing the development of autonomous vehicles.[68] China has been making an all-out effort through its companies to woo Chinese expatriates as well as other experts to exploit their potential for developing futuristic technologies. Baidu, in one such manoeuvre, appointed Qi Lu, a former vice president of Microsoft, as chief operations officer of its newly established laboratory on Augmented Reality (AR) in Beijing in January 2017. Dr Lu was important for China's ambition to enhance the automation of UAVs and for building UAV swarms.[69]

**A scrutiny of China's progress in aviation indicates that China made concerted endeavours in establishing a robust aviation eco-system since 1949, which laid the foundation for its indigenous development programmes. In the beginning, it established aviation research and development centres, production factories, aerospace universities, provided funding and government support for indigenous manufacturing.**

## CONCLUSION

China's success in demonstrating the largest UAV swarms ahead of many other aviation leaders indicates its leap in cutting-edge technologies. UAV swarm development is significant for China to establish itself as an

68. Phoenix Kwong, "Alphabet Soup is the Top Draw on China's 2017 Technology Menu, AI, IoT, AoT, AR and VR are the Must-Haves in China's 2017 Technology Portfolio," *South China Morning Post*, January 06, 2017, http://www.scmp.com/business/china-business/article/2059661/alphabet-soup-top-draw-chinas-2017-technology-menu?utm_source=MIT+TR+Newsletters&utm_campaign=cf4628adc3-The_Download&utm_medium=email&utm_term=0_997ed6f472-cf4628adc3-153925993. Accessed on March 15, 2018.
69. Jamie Condliffe, "In 2017, China is Doubling Down on AI", *MIT Technology Review*, January 17, 2017, https://www.technologyreview.com/s/603378/in-2017-china-is-doubling-down-on-ai/. Accessed on March 15, 2018.

innovator of cutting-edge technologies. This is also significant because it was viewed as a country which was manufacturing aviation platforms through reverse engineering or from clandestinely acquired technologies. A scrutiny of China's progress in aviation indicates that China made concerted endeavours in establishing a robust aviation eco-system since 1949, which laid the foundation for its indigenous development programmes. In the beginning, it established aviation research and development centres, production factories, aerospace universities, provided funding and government support for indigenous manufacturing; however, its isolation from the global community restricted its progress in aviation technologies. The easing of relations with the US enabled China to collaborate with global civil aviation manufacturers since the 1980s, which helped it in filling the technology and manufacturing quality gaps and consolidate its aviation eco-system. Another factor contributing to China's progress in aeronautics manufacturing is the staunch support of its leadership and consistent policy on indigenous development. The policy interventions by Deng Xiaoping in 1978, Jiang Zemin in 2000 and Xi Jinping in 2015 provided the necessary impetus for transforming China's aviation manufacturing industry into a modern industry. As a result, it started exploring innovative and futuristic designs and the development of the largest UAV swarm is a result of one such endeavour. On the other hand, the absence of a Chinese programme to develop an operational UAV swarm on the lines of the Gremlins programme of the US indicates its challenges in operationalising the UAV swarm. The launching of the Swarm Challenge by the PLAAF in late 2017 is an endeavour to bridge the technology gaps to develop operational UAV swarms.

The study of Chinese investments in the US indicates a new trend in the Chinese approach to technology acquisition in which Chinese venture capital companies funded high technology start-ups and defence manufacturing companies of the US to acquire IPRs of emerging technologies and innovations. China also explored other legal means for acquiring cutting-edge technology by recruiting the best talent and taking over promising start-ups in the US by exploiting loopholes in the US trade and investment policies. In its journey

for capability development in aviation, clandestine operations, cyber attacks and espionage were never a taboo for China. The acquisition of technology through venture capital funds and other investments has added a new dimension to its multifaceted approach to technology acquisition. China has also ensured systematic and persistent strengthening of its eco-system, which enabled it to achieve significant progress in manned platforms, AI, autonomous UAVs and UAV swarms. Therefore, there is a need to examine China's technology development initiatives in the correct perspective, by taking into account its policies, its establishment of an aviation eco-system, aviation development programmes, investments in science and technology, the role of key stakeholders, the strategy of leveraging trade relations and exploiting gaps in the economic and investment policies of other nations to bridge technology gaps.

The development of UAV swarms is an indicator of the gradual transformation of the Chinese industry in general and defence aviation industry in particular from the "reverse engineering approach" to "leading the innovation and development of cutting-edge defence technologies". China is expected to strive hard to transform its initial gains in the fixed-wing and multi-rotor UAV swarms into operationally deployable combat products in the coming decades. The reorientation of the Chinese defence industry from imitation and technology absorption to leading the cutting edge technology development through disruptive innovations is going to be the new norm and the US and other global powers are becoming increasingly aware, as well as concerned, about this change. China, on its part, is working hard to ensure that UAV swarms are operationalised at the earliest to demonstrate its ability to develop innovative and cutting-edge futuristic civil-military technologies, an essential ingredient for realising its long-term goal of establishing itself as the global leader in innovation by 2049.