THE HISTORY AND FUTURE OF US–CHINA COMPETITION AND COOPERATION IN SPACE

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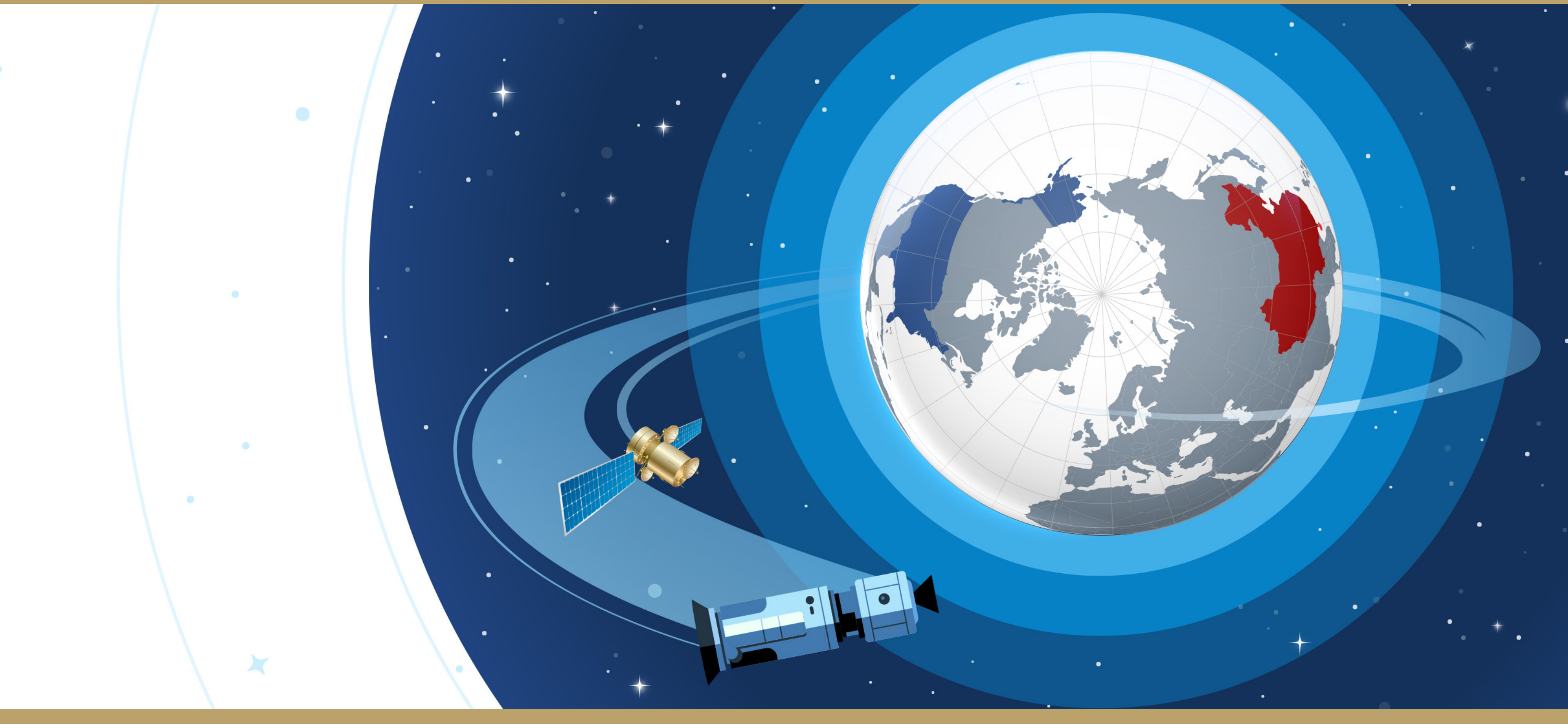

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Foreword

This paper is part of the "Measure Twice, Cut Once: Assessing Some China–US Technology Connections" research series sponsored by the Johns Hopkins University Applied Physics Laboratory.

As competition has intensified between the United States and China, actions to disengage their technology establishments from one another have also intensified. The two countries' systems for research and development, production, and sale of cutting-edge technologies have been substantially, though by no means uniformly, commingled. More recently, there have been concerted efforts by both nations' governments to reverse some or all of that commingling. Policymakers' priorities include perceived risks to national security, worry about economic disadvantage from proliferation, and concern about uses of technologies that intentionally or indifferently may harm civil liberties or the environment.

To explore the advisability and potential consequences of decoupling, the Johns Hopkins University Applied Physics Laboratory commissioned papers from experts in specific technology areas. In each of these areas, the authors have explored the feasibility and desirability of increased technological separation and offered their thoughts on a possible path forward. Other papers in this series include:

- *Two Worlds, Two Bioeconomies: The Impacts of Decoupling US–China Trade and Technology Transfer* by Rob Carlson and Rik Wehbring
- *Symbiosis and Strife: Where Is the Sino–American Relationship Bound? An Introduction to the APL Series "Measure Twice, Cut Once: Assessing Some China–US Technology Connections"* by Richard Danzig and Lorand Laskai
- *An Entwined AI Future: Resistance Is Futile* by Christine Fox
- *Cutting off Our Nose to Spite Our Face: US Policy toward Huawei and China in Key Semiconductor Industry Inputs, Capital Equipment, and Electronic Design Automation Tools* by Douglas B. Fuller
- *The Telecommunications Industry in US–China Context: Evolving toward Near-Complete Bifurcation* by Paul Triolo
- *Addressing the China Challenge for American Universities* by Rory Truex
- *US–China STEM Talent "Decoupling": Background, Policy, and Impact* by Remco Zwetsloot

Summary

This paper observes that American and Chinese space programs have been sharply disconnected for the last two decades and remain so today. Both programs lead the world, but between the two countries, America has greater strengths and is likely to maintain its advantages in the decades ahead. Notwithstanding this, this paper observes that our present policies may have long-term costs that exceed their benefits to America. Principally, this is because constraints on interaction continue to increase the cost of engaging our own allies and partners, are unlikely to significantly hobble the Chinese program, and are likely to impose added challenges on our own programs. These costs are mostly in consequences to America's commercial space industry, to our ability to draw partner nations closer to our space program, and to our ability to understand (and therefore to better compete with) Chinese government space programs. Accordingly, while endorsing the thrust of our present policies toward disconnection, this discussion advises framing next steps with a greater focus on effects on the US space industry and especially clarity about US strategic objectives in space. A focus on US space primacy suggests continued separation is the best path; a greater focus on the United States playing an international ordering role and managing risks of conflict in space suggests some narrow relaxation of these policies, mostly in civil space activities.

US and Chinese space activities today are highly separated, largely as a result of US policies. The roots of China's space program, however, are partly in the United States, also as a result of US policies. One of the founders of China's space program, Tsien Hsue-shen (sometimes written Qian Xuesen), returned to China in 1955 because the United States compelled him to do so. At the height of McCarthyism, Tsien, who had come to the United States to study at MIT twenty years earlier, was deported. Over those two decades, he had worked at Caltech,[1] participated with the founders of the Jet Propulsion Laboratory on World War II rocketry and explosives experiments, and served on a US mission after the war to survey Nazi V-2 facilities in Germany (Figure 1)—the counterpart project to Operation Paperclip, which brought Wernher von Braun and other German rocket scientists to the United States. In 1955, he was driven from the United States by a years-long series of accusations of Communist Party membership. Navy Secretary Dan Kimball much later remarked, "It was the stupidest thing this country ever did. He was no more a Communist than I was, and we forced him to go."[2] Back in China, Tsien was one of the early leaders to spearhead that nation's space and rocketry programs, helping to develop China's first ballistic missiles, first satellite, and first antiship missile system.[3]

As of 2020, the United States and China now possess the world's leading space programs. There are more countries operating in space than ever before. The United States, China, Europe (collectively), and Russia are widely seen as the world's leading space powers, and many other nations are active.[4] Across these global space activities, however, the United States and China are the clear front-runners, even while China still lags in niche technologies. Europe has a smaller span of military space activities than the other three, while Russia lacks a robust commercial space industry and has growing challenges in its government programs. By contrast, the governments of the United States and China plan to undertake highly visible and politically significant human spaceflight programs to the moon, lead international partners in Earth orbit, expand their commercial space ecosystems, and make major military space investments (directed especially at each other).

US export controls have blocked space technology exchanges with China for more than two decades. China's destructive antisatellite test in 2007 alarmed Western national security analysts in particular and contributed to the maintenance of controls. Subsequent US policy has aimed to prevent nearly all civil space engagement with China.

In terms of civil and economic policies, outside of military programs, where do we go from here? This paper analyzes this question in three parts: first, it contrasts the US and Chinese approaches to research, development, and operations in space; second, it describes initiatives the United States might undertake if it were to desire to expand or narrow the current US–China division in space technology ecosystems; and third, it considers the likely costs and benefits to both the US and China sides if separation is maintained or expanded.

The United States should give greatest priority to building on its own strengths in space. There are

1 Caltech Department of Aerospace, "Legends of GALCIT."

2 Chang, *Thread of the Silkworm*.

3 Wines, "Qian Xuesen."

4 Beyond those, Japan, France, and India have extensive and growing national space capabilities; Germany, Italy, Canada, and Israel have technical capabilities similar to the leading space powers but have smaller space sectors in total. The United Kingdom, South Korea, New Zealand, and Luxembourg have even more narrow and specialized space sectors but also host leading-edge space organizations; Iran and North Korea continue to have limited space launch capabilities; and many niche actors and new entrants, spanning the United Arab Emirates, Argentina, and Sweden, have noteworthy modern space activities.

Tsien (right) is pictured in a US Army uniform while on a US mission to Germany in 1945. With Tsien are (from left) Hugh L. Dryden, Ludwig Prandtl, and Theodore von Karman. Image courtesy of the California Institute of Technology Archives.

Figure 1. Tsien Hsue-shen, One of the Fathers of the Chinese Space Program

many reasons for this,[5] the greatest being the fact that the variable we control most is our own activities—our ability to shape Chinese space capabilities will always be indirect and uncertain at best. Beyond this maxim, US choices will require having greater clarity about our strategic objectives in space.

Strategic Context: A Period of Change for Both the United States and China

Having seen the emergence of new commercial space capabilities in the 2010s, the United States is now, at the start of the 2020s, experiencing some of the largest changes in the space security environment in thirty to forty years. If even one space internet constellation is fully deployed in the 2020s, as seems likely, the population of operational satellites in Earth orbit will probably double or triple relative to 2020. In addition, US–China military space competition has continued to intensify since China conducted its 2007 antisatellite test and General Secretary Xi took power,[6] and as China and Russia deploy advanced hypersonic missiles, the United States will face a choice about whether to pursue new midcourse tracking or defense. This choice will have significant space implications. Finally, a public Defense Intelligence Agency report indicates that "China and Russia, in particular, have taken steps to challenge the United States . . . both states are developing jamming and cyberspace capabilities, directed energy weapons, on-orbit capabilities, and

[5] See, for example, the framework of Danzig et al. in *Preface to Strategy*.

[6] See, for example, Bahney and Pearl, "Why Creating a Space Force Changes Nothing."

In the 2020s, China's national space capabilities will emerge in a much more globally visible way.

ground-based antisatellite missiles that can achieve a range of reversible to nonreversible effects."[7]

Changes to the US civil space environment will be no smaller: the International Space Station (ISS), after twenty years of operation under the leadership of the United States along with fourteen international partners, is expected to end operations sometime in the 2020s; the United States is starting to build a new generation of international space agreements with its allies and partners; US domestic capability to launch astronauts into orbit is regrowing for the first time since the Space Shuttle retired a decade ago; and NASA plans to return astronauts to the moon for the first time since 1972.

In the 2020s, China's national space capabilities will emerge in a much more globally visible way: a new Chinese space station will begin operations in orbit, probably with international partners contributing under Chinese leadership; the Beidou system, China's version of GPS, is now globally operational; Chinese space companies may increasingly compete for global launch, satellite, and data contracts (having been grown and fueled by Chinese domestic markets[8]); and Chinese military space capabilities will presumably reach significant levels of maturity.[9]

Beyond a recognition that we appear to be in one of those occasional "hinge periods" in history, there is limited agreement on an organizing framework that can be used to understand the United States' current strategic situation, especially in space. In the absence of such a framework, this paper uses three assumptions about the larger US–China context:

(1) The United States and China will compete for power in military, economic, and diplomatic spheres, even while the economies of both countries remain intertwined.

(2) Absent other large changes, US–China military space competition will intensify in the 2020s. Even while the probability of full-scale war remains low, military crisis and conflict in space will be a growing risk.

(3) Space activities, especially human spaceflight, will continue to have special political significance for each country. National space programs, including civil programs, will continue to be used as a measure of each side's broader military and technological capabilities, as they have since the Cold War.

The Separation of US and Chinese Space Activities

US and Chinese space technologies and activities are substantially separated today: there are almost no direct links between the United States and China with regard to space technology research, development, and operations.

The United States and China both impose relevant barriers, though for the last twenty years the US barriers have been most influential in creating this separation. In particular, US export controls block all economic and many research exchanges involving space technology, and US laws inhibit NASA (and the White House Office of Science and Technology Policy) from bilateral engagement with Chinese counterparts. In military and intelligence space activities, the United States and China increasingly regard each other as competitors—a dynamic that is likely to intensify in the 2020s.

It is useful to understand the current separation of US and Chinese space technologies in two parts:

7 Defense Intelligence Agency, "Challenges to Security in Space."

8 Liu et al., *China's Commercial Space Sector*.

9 See, for example, Bahney and Pearl, "Why Creating a Space Force Changes Nothing."

(1) by tracing the different paths that US and Chinese space activities have followed from their origins to reach the 2020s and (2) by examining the US policies that have separated US and Chinese space technologies in the last twenty years.

The United States and China Have Followed Different Paths to Modern Space Capabilities

China's space history can be divided into the periods before and after the year 2000. Before 2000, compared with the United States, Europe, and Russia, China's progress in satellite and launch vehicle technology was generally uneven and slow. The largest exception to this was in ballistic missile technologies, where China made steady progress.[10] China's space activities were especially limited in the 1960s and 1970s: this was the result of small government budgets and of the destruction of a generation of scientific and technical talent during the Cultural Revolution.[11] State-sponsored violence during the Chinese Cultural Revolution led to the deaths and torture of many leading scientists and scholars, a legacy the Chinese Academy of Sciences still continues to navigate.[12] In the 1990s, as Deng Xiaoping's reforms of the 1980s bore fruit and the Chinese government accessed more money, China's investment in both space capabilities and the People's Liberation Army (PLA) grew steadily.[13] Growing budgets in the 1990s laid the foundation for more explosive growth in space after 2000.

The year 2000 provides a convenient benchmark for the inflection point in China's space activities. Since the years around 2000, Chinese space activities have advanced steadily and rapidly. The first launch of a Chinese astronaut ("taikonaut") occurred in 2003, and China began to present its space activities more internationally in the 2000s. In the years around 2010, China's annual orbital launch rate nearly doubled,[14] especially accelerating the growth and diversification of Chinese space activities in the 2010s.

The most rapid period of Chinese space development has therefore taken place in the age of the internet and during an era of diminished nuclear strategic concerns.

Expansion of China's commercial space sector began to accelerate notably around 2014. "Commercial" has particular meaning in this case: most Chinese space activities are still implemented through large state-owned enterprises (SOEs); Chinese SOEs also continue to make international sales. Only more recently have space companies emerged that demonstrate some independence from SOEs, private risk taking, and selling or planning to sell to customers other than the Chinese government.[15] A change in Chinese government policy was at least partially responsible for this acceleration. In 2014, China's State Council *Document 60* opened China's launch and satellite remote sensing sectors to private investment and private companies.[16] More than half of China's current "commercial" space companies were founded after 2014, and China's entire commercial space sector (outside the older SOEs) focuses on the launch and use of small satellites.[17]

The most rapid period of Chinese space development has therefore taken place in the age of the

[10] Lewis and Di, "China's Ballistic Missile Programs."

[11] Kulacki and Lewis, *Place for One's Mat*.

[12] "The Chinese Academy of Sciences at 70," *Nature*.

[13] For example, Maizland, "China's Modernizing Military"; and Kulacki and Lewis, *Place for One's Mat*.

[14] McDowell, "China Satellite Update."

[15] Liu et al., *China's Commercial Space Sector*.

[16] China State Council, *Document 60*. *Document 60* is also explained effectively in Liu et al., *China's Commercial Space Sector*.

[17] Liu et al., *China's Commercial Space Sector*.

internet and during an era of diminished nuclear strategic concerns. It also occurred after the United States demonstrated space contributions to conventional military operations in the Gulf War[18] and after microelectronics and sensor technologies began to make small satellites globally commercially viable. These conditions are very different from those under which the United States initiated most of its government space programs.

China's push for civil–military fusion, partially motivated by observations of US government interactions with companies like SpaceX, has helped to allow China's first commercial space companies to appear and has created ties between those companies and the Chinese military.

China's defense sector continues to dominate Chinese space activities. Unlike in the United States, civil and military space activities in China are not clearly separable. The majority of China's space development activity is within defense SOEs, and the China National Space Administration (CNSA) reports to the State Administration for Science, Technology and Industry for National Defense (SASTIND). Likewise, China's push for civil–military fusion, partially motivated by observations of US government interactions with companies like SpaceX, has helped to allow China's first commercial space companies to appear and has created ties between those companies and the Chinese military.[19] An important factor in US considerations, therefore, is that it is likely that nearly all Chinese space activities can be quickly applied by the PLA. The Yaogan series of Earth-observing satellites illustrate this dilemma for American decision-makers: the Chinese government claims Yaogan satellites are for civilian purposes only, while independent analysts believe these systems are also operated by the PLA for military purposes.[20]

The United States has followed a very different path in space compared with the People's Republic of China (PRC). For about sixty years, the US government has effectively run three space programs in parallel: a civil program (NASA), a military program (within the Department of the Air Force and recently reorganized into the US Space Force), and an intelligence program (the National Reconnaissance Office, or NRO). The existence of the NRO was declassified in 1992. The origins of all three programs date to the early Cold War, and the existence of NASA has created a consistent separation of military and civil space programs since the early 1960s.[21] Until the early 1990s, the bulk of US space activities occurred through these three government programs.

In the years since the Cold War, the United States has had two waves of commercial space development—first in the 1990s and then in the 2010s. In between, in the years around 2000, global microelectronics, sensor, and satellite technology converged to make small satellites commercially viable.[22] The growth of US commercial space activities in the 2010s has therefore included large constellations of

18 For example, see Maizland, "China's Modernizing Military"; and Hines, "Is China Catching up?"

19 *Hearing on China in Space*, Laskai statement.

20 Nouwens and Legarda, *China's Pursuit*.

21 Pete Hays ("Struggling towards Space Doctrine") describes this history from the military side: "With the loss of JPL and the von Braun team [to NASA], the Army lost the bulk of its space expertise and no longer had the infrastructure or the stomach to pursue a major space program. The decline of the Army space program helped to clear the way for Air Force dominance of military space within DoD. Moreover, the demise of the Army space program along with the rise of NASA marked a fundamental change in the character of the U.S. military space program away from military elements with national or even civil space interests towards a more monolithic focus on military space. . . . the U.S. had somewhat more distinct civil and military space programs moving into the 1960s."

22 Sweeting, "Modern Small Satellites."

microsatellites in addition to the first commercially operated reusable rockets.

The United States retains a lead over China in several areas of space technology, and prospects for the future range from the positive to the uncertain:

- Reusable launch systems created by US companies such as SpaceX and Blue Origin are a generation ahead of those of Chinese competitors—a sustainable lead of probably five to six years for the next decade.[23] Reusability, however, primarily serves to reduce the cost of launch vehicles, and Chinese firms may be able to offer cheap launch vehicles without reusability.
- US current and historic capabilities in reliable heavy launch (systems like the Atlas V and Delta IV Heavy, and more recently the Falcon Heavy) suggest a technological lead over China, which has recently returned its first heavy launch system (the Long March-5) to operation after an eighteen-month hiatus following a launch failure. Future US heavy launch systems from SpaceX (Falcon Heavy and Starship), Blue Origin (New Glenn), and United Launch Alliance (Vulcan) could sustain this US lead for a decade or more.
- Based on publicly available data, US organizations appear to have more advanced capabilities in in-space propulsion and space robotics.[24]
- US satellite manufacturers and satellite remote sensing start-ups have a visible lead over Chinese ones in terms of sophistication of technical capability and the quantity of satellites in orbit,[25] but this lead will probably be narrower and more at risk in the years ahead. China is rapidly growing the capabilities needed to launch and operate small satellites.
- US satellite component manufacturers probably have a lead in technical capabilities over their Chinese counterparts.
- US firms probably have a narrow lead in data processing and analytics, but it is less clear whether the United States has advantages in software and data analysis, which are needed to make this lead sustainable. Software related to space activities will be highly competitive.

As markets for the launch and use of small satellites grow significantly in the 2020s, China's emerging commercial space sector will have particular opportunities to continue growing rapidly.

China's greatest advantages in "catching up" to US space technologies include a relatively mature knowledge of underlying principles for launch vehicles and satellites; the convergence of technologies that made small satellites commercially viable around the year 2000, which helped diffuse advanced satellite capabilities to countries like China; and the opportunity to—leveraging aerospace labor that costs less in China than in the United States—sell competitively priced launch and satellite services in the years ahead. As markets for the launch and use of small satellites grow significantly in the 2020s, China's emerging commercial space sector will have particular opportunities to continue growing rapidly.[26] The United States' greatest advantages for continued leadership in space technologies are also its broader historic strengths: stable rule of law, first-rate

[23] This can be seen in the demonstrated successes of SpaceX and Blue Origin in landing boosters after flight, while there is no public data to suggest that China has successfully demonstrated this capability yet.

[24] For example, see Henry, "Northrop Grumman's MEV-1 Servicer."

[25] For example, companies like Planet deployed constellations in the early 2010s.

[26] Liu et al., *China's Commercial Space Sector*.

human talent, the US economic engine and US companies, a network of international allies and partners, and effective partnerships between US government organizations and US companies.

US Policies to Inhibit US–China Space Technology Exchange

President Reagan created one of the early bridges between the US and Chinese space sectors by allowing US satellites to be launched on Chinese rockets—the first time a non-Western government was allowed to handle a US-made satellite.[27] Two subsequent Chinese rockets carrying US commercial satellites failed during launch in 1995 and 1996; the American satellite manufacturers whose payloads were on the rockets, Hughes and Loral, participated in the Chinese launch failure review. The Congressional Cox Committee later determined that some technical information exchanged during this review involved launch vehicle technology instead of just satellite technology and so was outside the Commerce Department's approval, constituting an export control violation. Both companies were heavily fined.[28]

The US Congress went further, using the 1999 National Defense Authorization Act (NDAA) to impose significant export controls on satellite technology. (Launch technology, given its relevance to the design of missiles, was already protected by additional US export controls.) The act moved satellite technology to the US Munitions List, making it subject to the International Traffic in Arms Regulations (ITAR) process under the jurisdiction of the State Department.

Two important factors quickly became apparent. First, although motivation for the change in export controls focused on China, the new controls applied globally. The change made it much more difficult for US organizations, especially companies selling satellite systems and components, to engage potential partners and customers worldwide.

Second, the designation of satellite technology in the ITAR process did not specify in sufficient detail what constituted "satellite technology," and so enforcement expanded to nearly anything related to space. Absurd situations followed: in one widely quoted case, because the aluminum floor stand for a satellite awaiting launch in Russia, which was "indistinguishable from a common coffee table," was deemed part of the satellite assembly and therefore a controlled item on the US Munitions List, the US company accompanied it with security officers.[29]

The control regime also imposed significant, personal penalties for violations, and violations could consist simply of discussing certain information about a commercial or scientific satellite with anyone who was not a US citizen. University researchers, therefore, were forced to limit collaborations with foreign colleagues on space projects to ensure that details of scientific spacecraft would not be shared.

While the 1999 changes caused the United States to treat many space technologies as munitions, Europe continued to regulate them as dual use largely through the Wassenaar Arrangement. By the early 2000s, foreign customers began turning to non-US companies to avoid the challenges of export control regulations. European programs sought to eliminate dependency on US parts, and Canadian industry sought to use European systems. In 2002, France's Alcatel Space (now Thales Alenia) was developing "ITAR-free" communications satellites. Between 1998 and 2004, the company doubled its

[27] Pine, "China Told It Can Launch." Congress also reduced US export controls on some US satellite technologies in 1992. This took the form of moving some communications satellite technologies from the State Department–managed US Munitions List to the Commerce Department–managed Commerce Control List in 1992.

[28] For example, see Gerth, "2 Companies Pay Penalties."

[29] "Earthbound," *The Economist*.

market share,[30] and in 2005, it launched its first ITAR-free satellite on a Chinese rocket.[31] In the same year, the European Space Agency concluded that ITAR made cooperation on NASA's current Mars rover infeasible.[32] On the US side, American companies appear to have lost significant market share in foreign markets for satellite manufacturing, launched payloads, and launch vehicles.[33]

Other second-order effects were more subtle but nonetheless significant. For example, insurance companies that work with the US space industry became entangled in US export controls. Insurance firms that support the space industry require technical information to decide policy terms and premiums. Most of these firms are based outside the United States, and the technical information they needed had become export controlled.[34]

US satellite technology export controls in this period almost certainly slowed any transfer of space technology from the United States to China. The broader effect, however, of these fifteen years from 1999 to 2014 was to make the European space industry more independent of US technology and ultimately to help deepen space technology cooperation between Europe and China.[35] The effects of this initial period endure, are difficult to reverse, and will erode the effectiveness of future attempts to inhibit the transfer of space technologies to China. Domestically, the effects of export controls on US companies were lost revenue and confusion.[36]

The United States reformed satellite technology export controls largely in response to these issues,

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30 "Earthbound," *The Economist*.

31 Abbey and Lane, *United States Space Policy*.

32 "Earthbound," *The Economist*.

33 For example, a report by the Department of Defense and Department of Commerce (US Air Force, *Defense Industrial Base Assessment*, 15–17) provides the following data:

> Satellite manufacturing is the segment of the space industry that has been most directly affected by changes in U.S. export control policy. Based on Satellite Industry Association reports in 2004 and 2006, the U.S. share of global satellite manufacturing has decreased since the ITAR changes were implemented in 1999.
>
> . . . U.S. market share dropped from 63% in 1996-1998 to 52% in 1999-2001 and 42% in 2002-06. . . .
>
> Global competition significantly increased for several reasons. Some foreign companies entered the market as a response to opportunities created by more stringent U.S. export controls; others due to policies within foreign countries that sought to increase indigenous capabilities. In this competitive environment, changes in U.S. export control policies may provide a more level competitive market for U.S. products. In terms of launched payloads, commercial communications satellites represent a key measure for competitiveness and an indicator of future manufacturing capabilities. For all commercial communications satellites, U.S. market share of launched payloads dropped from 84% in the pre-policy change period to 79% in the transition period, 1999-2001, to 65% in the post-policy change period, 2002-2006. In the same periods, Europe's share grew from 9% to 11%, and finally 23% in 2002-2006. . . .
>
> . . . The long-term trend has been a steady loss in market share for U.S. manufacturers and a steady increase for European competitors.

These numbers (including even the long-term effect of European "ITAR-free" satellites) remain contentious. For example, John Hoffner notes difficulties in measuring changes in the US global market share of satellite manufacturing as a result of changing the export control regulation of commercial satellites. He notes that commonly quoted data on satellite manufacturing revenue often records revenue for individual satellites on their launch year, rather than the year an order might be placed, which makes untangling impacts of export controls more complicated; these data must also be viewed in the context of other factors that drive the US satellite industry's revenue (Hoffner, "The Myth of 'ITAR-Free'"). The overall effect, however, appears clear: increased challenges and costs for US companies and increased market opportunities for European firms.

34 Foust, "One Nation, Over Regulated."

35 As an example of the latter, China appears to have leveraged European technology to accelerate development of Beidou, the Chinese position, navigation, and time satellite system. See Lague, "Special Report."

36 See, for example, US Department of Commerce, *U.S. Space Industry*.

with new rules taking effect in 2014.[37] The reforms reduced controls to many nations, especially allies and partners in Europe. Restrictions on exports to China remained unchanged.[38] US industry generally describes these reforms as a positive step.

Beyond export controls, US civil space exchanges with China were limited starting in 2011. Earlier in the 2000s, the United States and China had held four noteworthy interactions involving NASA and the Chinese National Space Administration (CNSA). In 2004, the head of the CNSA visited NASA for the first time.[39] The next year, CNSA's vice administrator presented China's space plans at the National Space Symposium in Colorado Springs.[40] In 2006, Michael Griffin became the first NASA administrator to visit CNSA in China, though he cut his trip short after learning the Chinese would limit his access to one of its launch centers.[41] In 2010, NASA Administrator Charles Bolden visited China.

In 2011, partly in response to Administrator Bolden's visit to China, Congress passed a law that imposed restrictions on NASA engagement with China. This was spearheaded by Congressman Frank Wolf,[42] and the resulting law is known commonly as the Wolf Amendment:

> None of the funds made available by this Act may be used for the National Aeronautics and Space Administration (NASA) or the Office of Science and Technology Policy (OSTP) to develop, design, plan, promulgate, implement, or execute a bilateral policy, program, order, or contract of any kind to participate, collaborate, or coordinate bilaterally in any way with China or any Chinese-owned company unless such activities are specifically authorized by a law enacted after the date of enactment of this Act.[43]

The Wolf Amendment has been renewed each year since 2011 and has continued to have the effect of preventing nearly all direct bilateral cooperation between US and Chinese civil space activities. Perhaps the largest exception occurred in 2019, when NASA coordinated with the Chinese government (and the US Congress) to have the NASA Lunar Reconnaissance Orbiter image the landing site of China's Chang'e-4 spacecraft on the lunar far side.[44]

Chinese Policies That Would Inhibit US–China Space Technology Exchange

US export controls and restrictions on civil space activities have driven much of the gulf between the United States' and China's space technology research, development, and operations at the start of the 2020s.

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[37] For a relatively clear explanation, see US Department of Commerce, *Introduction to U.S. Export Controls*.

[38] See section 1261, subsection C, of the National Defense Authorization Act for Fiscal Year 2013.

[39] Pollpeter et al., *China Dream, Space Dream*; and Foust, "New Opportunities Emerging."

[40] Ball, "NASA's 'First Date.' "

[41] Pollpeter et al., *China Dream, Space Dream*.

[42] See Wolf, "U.S. Should Not Cooperate" for Representative Wolf's full rationale.

[43] Consolidated and Further Continuing Appropriations Act. Subsections (c) and (d) also provide one exception:

> (c) <<NOTE: Certification.>> The limitations described in subsections (a) and (b) shall not apply to activities which NASA or OSTP have certified pose no risk of resulting in the transfer of technology, data, or other information with national security or economic security implications to China or a Chinese-owned company.
>
> (d) <<NOTE: Deadline.>> Any certification made under subsection (c) shall be submitted to the Committees on Appropriations of the House of Representatives and the Senate no later than 14 days prior to the activity in question and shall include a description of the purpose of the activity, its major participants, and its location and timing.

[44] Foust, "New Opportunities Emerging."

Chinese policies also, however, maintain some separation. These policies were initially informal. A large fraction of activities for China's space program are contracted to two SOEs, the China Aerospace Science and Technology Corporation (CASC) and China Aerospace Science and Industry Corporation (CASIC). Close coordination between Chinese government officials and leaders of these SOEs made formal regulatory controls unnecessary.[45]

Maintaining the current separation can be achieved primarily by maintaining export controls on US space technology to China and the current limitations on US civil space bilateral engagement with China.

Policies defining controls on space technology became more concrete as commercial Chinese firms emerged in the 2010s: enterprises involved in defense work, and at least some launch companies, are subject to secrecy rules and limitations on the involvement of foreign nationals; enterprises are forbidden from transferring launch vehicle technology without approval from SASTIND; and all enterprises working in space-related technologies, including universities and research institutes, are restricted from exporting most space technologies without approval from China's National Export Control Department.[46]

These restrictions have not prevented Chinese space enterprises from collaborating with European space organizations and companies. Despite the restrictions, China has regularly sought partnerships with outside organizations, particularly those in Europe, with the goal of obtaining new technologies.

To What Degree Can the Current Separation Be Maintained or Modified?

US and Chinese space technologies and activities are largely separated today. If at least the United States is committed to this course, maintaining the current degree of separation appears highly achievable in the 2020s. What is required to maintain the status quo, or even widen the current separation slightly, can be summarized relatively succinctly and is described first. (The effects of this separation on the United States and China may be changing, however, and this is discussed in the next section.) Alternatively, lessening the separation is also possible but would represent a change in direction by US leaders—such a scenario necessitates more discussion and is described second.

Maintaining or Extending the Current Separation in US and Chinese Space Technology

Maintaining the current separation can be achieved primarily by maintaining export controls on US space technology to China and the current limitations on US civil space bilateral engagement with China.

Although the US and Chinese space technology sectors are now very substantially separated, options—and some would argue imperatives—exist to expand this separation in places where this remains possible. These options aim primarily to curtail remaining Chinese direct investment in US firms, further limit domestic leakage of US aerospace knowledge, and reduce technology leakage through Europe. There are multiple ways to pursue these aims. Examples include the following:

[45] Lorand Laskai, "Chinese Space Controls," individual memorandum, March 2020.

[46] Lorand Laskai, "Chinese Space Controls," individual memorandum, March 2020.

- Further barriers to the transfer of US commercial space technologies: deepening Committee on Foreign Investment in the United States involvement in Chinese investment in US companies relevant to the US space industry and increasing restrictions on the sale of commercial satellite imagery, communications services, and other data to Chinese organizations.
- Seeking reductions in digital intellectual property theft by further increasing counterintelligence and cyber-penetration warnings for US companies focused on space technology.
- Further limits on US civil space engagement and coordination: further restricting NASA and Department of Defense provision of data to the Chinese government on flight safety and operational issues and restraining NASA engagement with China in multilateral fora.
- Diplomatic pressure on third parties who work with both the United States and China: seeking to persuade European countries and Russia to limit further space technology exchanges and collaboration with China. This would probably require both diplomatic pressure and increased NASA engagement with these countries to reduce the appeal of engaging with China.
- Visa restrictions: limiting study and research in the United States for Chinese students and scholars seeking to study aerospace fields.

The Other Direction: Ways to Reduce Restrictions

Reducing the separation between US and Chinese space technology sectors would be a large break from the status quo. Such a course change would also be more complicated than policies to maintain the current separation—both because a wide spectrum of approaches is possible and because near-term uncertainties matter much more substantially.

Although simple in theory, this change in export controls appears politically implausible at best.

Reducing space technology export controls to China would require an act of Congress but is the most conceptually straightforward option: the simplest approach would be to make the 2014 space technology export control reforms apply also to exports to the PRC.[47] This would have the immediate effect of making it easier for companies to sell certain commercial satellite technology to China and purchase launches from China; it would also make it easier for American researchers to collaborate on space technology projects with Chinese entities.[48] Restrictions on the transfer of technology associated with US launch vehicles and classified satellite systems to China would remain in effect. Three examples illustrate what would be permissible after such a change: an American satellite remote sensing start-up could buy a launch to orbit on a Chinese rocket, as such a company currently can to orbit on an Indian or Russian rocket, as long as the start-up meets the broader post-2014 export control restrictions;[49] an American satellite manufacturer could sell a commercial communications satellite to a UK fleet operator, which in turn could buy a launch to orbit on a Chinese rocket; and American universities could collaborate with Chinese universities on joint small satellite projects. Although simple in theory,

[47] This would consist of revising section 1261, subsection C, of the National Defense Authorization Act for Fiscal Year 2013.

[48] Roughly, this would include communications satellites that do not contain classified components or capability; remote sensing satellites with performance parameters below certain thresholds; and systems, subsystems parts, and components associated with these satellites and with performance parameters below a certain threshold. See, for example, MIT Office of the Vice President for Research, "Is My Satellite ITAR or EAR?"

[49] See, for example, MIT Office of the Vice President for Research, "Is My Satellite ITAR or EAR?"

this change in export controls appears politically implausible at best.

With or without modifying export controls, US leaders might offer greater civil space engagement with China through NASA. For small or moderate engagement, a US president could direct NASA to engage China on particular issues, subject to satisfying requirements in the Wolf Amendment.[50] For more substantive engagement, Congress would need to reduce or remove the Wolf Amendment restrictions.

If US leaders chose to offer some degree of civil space engagement, two immediate uncertainties would arise next: first, would China be interested in civil space engagement, and if so, would it be interested in the same areas as US leaders? Second, and most importantly, would China follow through on commitments involving data sharing and transparency during any such engagement with the United States? Two NASA administrators have been frustrated by China's lack of openness during early attempts at engagement, and China does not appear to have provided meaningful transparency to Europe during China–European engagements. Based on this history, there is substantial reason for US leaders to be skeptical of the degree to which Chinese government organizations will provide transparency and reciprocity in information exchanges.

The most common place where US leaders continue to look for lessons about this kind of engagement is the US decision to work with the Soviet Union on the 1975 Apollo-Soyuz Test Project. In Cold War engagement with the USSR, the United States learned mostly about differences in how the two countries approached human spaceflight.[51] Within human spaceflight, most of the learning focused on the organizational processes and culture of the other side's government space organizations. This has some relevance today: the United States and China have asymmetrical organizational structures, management systems, and technical approaches to government space programs. Information about these differences is not evenly distributed: NASA is relatively transparent, and so the character of US civil space activities is visible to China. Chinese "civil" space programs are, however, ultimately shaped by the PLA—and so the United States today does not have equivalent access to insights about Chinese space programs and their future directions. Further, because China blends civil–military programs, insights about China's civil space activities may offer some insights into the intent and management of Chinese military space programs. None of this, however, offers insight into the plausibility of Chinese willingness to share meaningful information; it only adds weight to the basic idea that if China *is* willing share information, civil space engagement could provide a mechanism for US-side learning.

For US–China civil space engagement, there is a wide and finely delineated spectrum between nothing and broad collaboration. Table 1 lists several examples in order of roughly increasing

[50] Consolidated and Further Continuing Appropriations Act:

> (c) <<NOTE: Certification.>> The limitations described in subsections (a) and (b) shall not apply to activities which NASA or OSTP have certified pose no risk of resulting in the transfer of technology, data, or other information with national security or economic security implications to China or a Chinese-owned company.
>
> (d) <<NOTE: Deadline.>> Any certification made under subsection (c) shall be submitted to the Committees on Appropriations of the House of Representatives and the Senate no later than 14 days prior to the activity in question and shall include a description of the purpose of the activity, its major participants, and its location and timing.

[51] For example, the Soviets preferred testing systems by flying them without crew in orbit, whereas the United States has a tendency to build complex test facilities on the ground. Neither approach was obviously better in absolute terms, and each side preferred to retain the approach to which it was accustomed. NASA staff saw this adherence to prior, particular technical approaches as ultimately the best reason to believe that risks of technological transfer to the USSR were manageable. See Ezell and Ezell, *The Partnership*, 354–355.

depth of associated technical exchange. Rows in the table are not mutually exclusive, and the table is far from exhaustive.

Engagement through civil space programs both affects the specific area of collaboration (such as mutually improved orbit tracking data for select objects) and, independently of the topic, generally necessitates a communications channel on space operations between the two governments.

Costs and Benefits of Separation to the United States and China

What are the likely costs and benefits to the United States and China if separation is maintained or deepened?

Likely Effects of Continued Separation

All costs and benefits are summarized in Table 2 and described below.

Export controls and restrictions on civil space engagement have partially overlapping effects. It helps to discuss them separately, however, because they constitute policies that can be modified somewhat independently.

If satellite technology export controls to China are maintained, the largest benefit to the United States would be continued limitation of the transfer of technology relevant to Chinese military space activities. For the decade ahead, the benefit of full limitation may actually be much smaller than in the past: the most plausible export controls that might be relaxed (such as with the 2014 export control reforms) would be those on commercial remote sensing and communications satellites. The US technical lead in these areas is narrowing as China fields increasingly sophisticated indigenous space systems, especially their growing indigenous capabilities for the launch and operation of small satellites. Other benefits of fully maintaining export controls might include, more speculatively, some near-term bolstering of American and allied "new space" launch companies such as SpaceX, Blue Origin, Virgin Galactic, Rocket Lab, and Astra. This is because current export controls block US-made satellites from launching on Chinese rockets, forcing US companies to buy launches from the rest of the world, including American companies.

Table 1. Potential US–China Civil Space Engagement

Intensiveness of Technical Exchange	Potential Activity
Least ↓	Visits to each other's space centers for civil space program leaders
	Exchanges of space situational awareness and orbit tracking data
	Coordination of major scientific objectives and missions
	Exchanges of raw scientific data
	Hosted payloads on each other's spacecraft
	Taikonaut visit to the ISS
	Space agency personnel exchanges
	Joint robotic space missions
	Astronaut/taikonaut handshake on orbital vehicles independent of ISS
Most	Joint human spaceflight laboratories and programs

The largest cost to the United States of export controls on China is their risk of eventually contributing to growth of indigenous supply chains and markets in China for China's own space technologies. This outcome may, in turn, eventually translate into an economic cost for American companies, which may face stronger Chinese competitors for global launch, satellite, and data service markets in the longer term. Export controls generally also carry an opportunity cost for engaging our own allies and partners, as they increase regulation and limits on technical collaboration for US companies

Table 2. Costs and Benefits of Maintaining Separation in Space Technology

Separation Type	Country	Benefits of Separation	Costs of Separation
Separation of commercial and nongovernmental activities (primarily by space technology export controls)	United States	• Limit transfer of space technology useful to PRC military space programs • Support US commercial space launch businesses	• Possible long-term economic costs to US companies • Some increased costs to engaging US allies and partners • Decreased access to launch supply for US companies and start-ups • Limits on research collaboration
	China	• Incentives for long-term self-sufficiency in space technology • Gain opportunity for launch sales to Europe	• Reduced access to advanced space technology from the United States • Limits on academic and research collaboration
Separation of civil space programs (primarily by limiting civil space program engagement)	United States	• Limit transfer of space technology and operational knowledge useful to PRC military space programs • Limit Chinese military knowledge about operation of US systems • Limit risk of "validating" current Chinese domestic and military policies through new cooperation • Reduce cybersecurity risk to US systems • Avoid risk of unbalanced engagement, in which China does not meaningfully share data or provide transparency	• Reduced opportunity to acquire information about organization, decision-making, and intentions of PRC space programs • Risk of ceding US international leadership opportunities by enabling greater Chinese independence in building international coalitions • Reduced opportunity for scientific, operational, and flight safety coordination and collaboration • Reduced channel for communication on space operations • Potentially increased probability of China–Russia condominium in space activities • Reduced experience base for longer-term future interactions or collaborations
	China	• Potentially increased long-term opportunities for international leadership in space activities	• Lost opportunity to signal to Chinese citizens that the Chinese Communist Party is dominant and making China a world leader by working with leading institutions (in this case, NASA) • Reduced information about US management and operational techniques for space programs • Reduced opportunity for scientific, operational, and flight safety coordination and collaboration • Reduced opportunity to manage global spaceflight issues

and research institutions. In theory, a third cost is the restriction of US access to Chinese talent. Under current export controls, US space organizations generally cannot hire foreign nationals. One of the United States' historic strengths has been the ability to draw the world's best talent—this strength is limited by export controls on space technologies.

For China, the largest long-term benefit of these export controls will probably be the continued incentivization for Chinese organizations to become self-sufficient in space technologies, drawing on indigenous development and technology transfers from Europe and Russia. The largest cost for China remains simply reduced access to space technology from the United States—most of all, reduced access to US commercial communications and remote sensing satellite technology (assuming US launch technology continues to be more highly controlled). Because China has been relatively successful at accessing European technologies and is reaching advanced indigenous capabilities, this cost for China is shrinking.

If restrictions on civil space engagement with China are maintained, the largest benefits to the

United States are again limitations on the transfer of space technology to China. Other US benefits, however, include limiting the transfer of operational knowledge about US space programs to the PLA; avoiding the appearance of condoning Chinese human rights, military, and foreign policies by collaborating on space exploration; and, to some degree, avoiding additional cybersecurity risks to US systems created by technical and personnel exchanges involving US space programs. Finally, the United States may also benefit by avoiding the risk of failed civil space engagement caused by Chinese unwillingness to share data and meet transparency thresholds.

The potential costs to the United States of continued civil space separation span more diverse areas. From having the most to least strategic impact to the United States in the 2020s, these costs include:

- Lost opportunity to obtain strategic information about the organization, decision-making, and intentions of Chinese space activities, assuming China would be willing to share such information as part of civil space engagement, which remains highly uncertain. The structure of US space programs gives the United States a disproportionate opportunity to learn in successful exchanges: because the United States is an open society, China knows a great deal about US civil programs (but not military and intelligence programs), while the United States lacks equivalent knowledge about Chinese ones. Further, the structure of US space programs, which separates civil programs at NASA from military and intelligence programs of the US Space Force and NRO, gives NASA an ability to engage with lower risk of transferring information about military and intelligence programs.
- Increased risk of ceding international leadership opportunities. Continued separation may give China more opportunity to build alternative international coalitions. Without engagement from the United States, it will be easier for China to draw Europe and Russia into coalitions that it leads while later obstructing membership of the United States. For example, China is likely to be fielding a space station in low Earth orbit just as the ISS is ending its life and may draw partnerships from European and Russian space agencies. (In this way, isolating China to prevent technology flow may also ultimately increase the probability of further Chinese access to European and Russian technologies.)
- Reduced opportunities for deconfliction. Without civil space engagement, the United States does not have the opportunity to develop professional and technical lines of communication between space agencies—akin to military–military links, these lines of communication can be used to reduce uncertainty about particular behaviors and events, address operational safety issues, and manage crises.
- More speculatively, increased risk of China–Russia condominium in space activities, which could serve as a pathfinder for larger alignment in military activities. (For example, Russia may already be considering a shift in emphasis in civil space cooperation to China from the United States.[52])
- Reduced opportunity for scientific, operational, and flight safety coordination and collaboration. A finite quantity of mass is launched into orbit each year globally: without the opportunity to collaborate, the United States has less access to knowledge from scientific exploration and absorbs more risk in all its programs.
- Loss of a foundation for more complex collaboration in the future. Near-term engagement creates optionality for longer-term future collaboration, if future leaders on both sides choose it. For example: if both the United States

[52] Zak, "Russia's Space Agency."

and China operate lunar surface stations by the 2030s, both may seek, at a minimum, protocols and capabilities for each side to provide assistance in emergencies; such capabilities would require previous technical experience operating together.

The largest likely benefit to China of continued separation in civil space programs is a larger opportunity to lead international space initiatives, with concomitant soft power opportunities. Many of the costs to China of continued separation parallel the US ones, with the largest exception being internal signaling—a lost opportunity to use engagement with NASA as a signal to Chinese citizens that the Chinese Communist Party is making China a "world leader" in key technologies.

Conclusion

The story of Tsien Hsue-shen encapsulates two of the themes that reoccur in America and China's intertwined space history: larger political forces play a substantial role in shaping space technology development, and US desire to shape a competitor's access to space technology can have substantial unintended and undesired consequences.

US and Chinese research, development, and operation of space technology is largely separated today: little direct, substantive interaction occurs between the countries' commercial and government space activities. US and Chinese policy both currently maintain this separation, but US policy has driven the separation for the last twenty years. Since 1999, US export controls have inhibited most commercial, academic, and government exchanges on space technology;[53] and since 2011, US law has further inhibited bilateral interactions between NASA and the Chinese government on civil and scientific topics.

If at least the United States proves committed to this course, extending the current separation is achievable throughout the 2020s. Continued application of export controls to China will limit the transfer of US satellite and rocket technologies, and restrictions on civil space engagement will limit the exchange of managerial, operational, and technical knowledge associated with national space programs. New policies could wisely attempt to reduce technology leakage through Europe.

If we widen or preserve the current separation, what future world might we expect? Predicting any distance into the future is fraught, especially on the scale of a decade or more. Here only directed guesses are possible. First, we should not expect China to have qualitatively inferior space technology as a result of this separation in a decade. America has greater strengths and is likely to maintain many specific advantages in space activities; but in total, we should also not expect China to lack major space technology capabilities that the United States possesses. Chinese space capabilities will have different strengths and weaknesses than those of the United States, reflecting larger asymmetries in our histories, policies, government organizations, economies, and international partners. These asymmetries should form the basis of US competitive strategies in the years ahead; better understanding these asymmetries will be a key near-term task for leaders of American space programs.

Shaping our relative strengths and weaknesses will be an important longer-term factor for US decision-makers. In the 1990s, US decisions about space technology export controls on China could have an enormous impact on Chinese industry. This is not true to the same degree today. Preserving the current US–China separation in space may have multiple benefits, but the analysis above suggests there is particular uncertainty about this separation's ability to prolong Chinese space technology weaknesses. The current separation will probably continue to slow China in the near

[53] The earlier 1996 Loral and Hughes case resulted from controversy over the exchange of launch vehicle technology, which was already restricted before 1999.

A good maxim, in this light, is to focus on building on our own strengths. The most enduring US strengths generally include being free, open, and a place of opportunity—we should play to these strengths.

term; this effect will diminish, however, and it may help grow indigenous supply chains and markets in China, incentivizing a stronger Chinese space technology ecosystem in the longer term. The net results for China remain uncertain.

A good maxim, in this light, is to focus on building on our own strengths. The most enduring US strengths generally include being free, open, and a place of opportunity[54]—we should play to these strengths. Given where we stand today, one starting place for considering broad space technology separation might then be simply to examine in more detail what course would be best for the long-term growth of the US space industry. If we start with an emphasis on launch industry that provides access to space, then continued separation is probably the better path at least initially.

For US government programs, if principles of transparency, reciprocity, and mutual benefit can be met, opportunity should exist for cooperative scientific space research and coordination on basic orbital safety issues. Beyond that, especially for any substantial choices regarding civil space engagement, the answer will depend on having clarity about US strategic objectives in space. If space primacy is the foremost US goal, then continued separation from China is probably the better path. If US leaders want to place more weight on playing an international ordering role and managing risks of conflict in space, then less separation than the status quo may be a better path.

[54] Danzig et al., *Preface to Strategy*.

Bibliography

Abbey, George, and Neal Francis Lane. *United States Space Policy: Challenges and Opportunities Gone Astray*. Cambridge, MA: American Academy of Arts and Sciences, 2009. https://www.amacad.org/sites/default/files/publication/downloads/spaceUS.pdf.

Bahney, Benjamin, and Jonathan Pearl. "Why Creating a Space Force Changes Nothing: Space Has Been Militarized from the Start." *Foreign Affairs,* March 26, 2019.

Ball, Philip. "NASA's 'First Date' with China." *Nature*, September 26, 2006. https://www.nature.com/news/2006/060925/full/060925-3.html.

Caltech Department of Aerospace. "Legends of GALCIT: Qian Xuesen (Tsien Hsue-Shen)." http://galcit.caltech.edu/about/qian.

Chang, Iris. *Thread of the Silkworm.* New York: BasicBooks, 1995.

China State Council. *Document 60: Guiding Opinions of the State Council on Innovation of Investment and Financing Mechanisms in Key Fields to Encourage Social Investment*. China State Council, November 16, 2014. English translation available at http://en.pkulaw.cn/display.aspx?cgid=ff6edea03b103284bdfb&lib=law.

"The Chinese Academy of Sciences at 70." Editorial. *Nature* 574 (October 1, 2019): 5. https://www.nature.com/articles/d41586-019-02950-5.

Consolidated and Further Continuing Appropriations Act, 2012. Pub. L. No. 112-55, 125 Stat. 552. 2012. https://www.govinfo.gov/content/pkg/PLAW-112publ55/html/PLAW-112publ55.htm.

Danzig, Richard, John Allen, Phil DePoy, Lisa Disbrow, James Gosler, Avril Haines, Samuel Locklear III, James Miller, James Stavridis, Paul Stockton, and Robert Work. *A Preface to Strategy: The Foundations of American National Security.* National Security Perspective NSAD-R-18-038. Laurel, MD: Johns Hopkins University Applied Physics Laboratory, 2018. https://www.jhuapl.edu/Content/documents/PrefaceToStrategy.pdf.

Defense Intelligence Agency. "Challenges to Security in Space." US Department of Defense, January 2019. https://www.dia.mil/Portals/27/Documents/News/Military%20Power%20Publications/Space_Threat_V14_020119_sm.pdf.

"Earthbound." Briefing. *The Economist*, August 23, 2008. https://www.economist.com/briefing/2008/08/21/earthbound.

Ezell, Edward, and Linda Ezell. *The Partnership: A History of the Apollo-Soyuz Test Project*. Mineola, NY: Dover Publications, 2010. First published 1978 in the NASA History Series as NASA SP-4209 (Washington, DC).

Foust, Jeff. "New Opportunities Emerging for U.S.-China Space Cooperation." *Space News*, April 8, 2019. https://spacenews.com/new-opportunities-emerging-for-u-s-china-space-cooperation/.

———. “One Nation, Over Regulated: Is ITAR Stalling the New Space Race?” *Ad Astra*, Winter 2005.

Gerth, Jeff. “2 Companies Pay Penalties for Improving China Rockets.” *New York Times*, March 6, 2003. https://www.nytimes.com/2003/03/06/world/2-companies-pay-penalties-for-improving-china-rockets.html.

Hays, Peter. “Struggling towards Space Doctrine: U.S. Military Space Plans, Programs, and Perspectives during the Cold War.” PhD diss., Tufts University, 1994.

Hearing on China in Space: A Strategic Competition? *Testimony before the U.S.-China Economic and Security Review Commission*. 116th Cong. 2019. Statement of Lorand Laskai, visiting researcher, Georgetown Center for Security and Emerging Technology. https://www.uscc.gov/sites/default/files/Lorand%20Laskai%20USCC%2025%20April.pdf.

Henry, Caleb. “Northrop Grumman’s MEV-1 Servicer Docks with Intelsat Satellite.” *Space News*, February 26, 2020. https://spacenews.com/northrop-grummans-mev-1-servicer-docks-with-intelsat-satellite/.

Hines, R. Lincoln. “Is China Catching up to the United States in Space?” *Washington Post*, April 24, 2019. https://www.washingtonpost.com/politics/2019/04/24/is-china-catching-up-united-states-space/.

Hoffner, John. “The Myth of ‘ITAR-Free.’ ” CSIS Aerospace Security Project, May 15, 2020. https://aerospace.csis.org/the-myth-of-itar-free/.

Kulacki, Gregory, and Jeffrey Lewis. *A Place for One’s Mat: China’s Space Program, 1956–2003*. Cambridge, MA: American Academy of Arts and Sciences, 2009. https://www.amacad.org/sites/default/files/publication/downloads/spaceChina.pdf.

Lague, David. “Special Report: In Satellite Tech Race, China Hitched a Ride from Europe.” Reuters, December 22, 2013. https://www.reuters.com/article/breakout-beidou/special-report-in-satellite-tech-race-china-hitched-a-ride-from-europe-idUSL4N0JJ0J320131222.

Lewis, John Wilson, and Hua Di. “China’s Ballistic Missile Programs: Technologies, Strategies, Goals.” *International Security* 17, no. 2 (1992): 5–40.

Liu, Irina, Evan Linck, Bhavya Lal, Keith Crane, Xueying Han, and Thomas Colvin. *Evaluation of China’s Commercial Space Sector*. IDA Document D-10873. Washington, DC: IDA Science and Technology Policy Institute, September 2019.

Maizland, Lindsay. “China’s Modernizing Military.” Council on Foreign Relations, February 5, 2020. https://www.cfr.org/backgrounder/chinas-modernizing-military.

McDowell, Jonathan. “China Satellite Update – 2014.” https://www.planet4589.org/space/papers/china2014.pdf.

MIT Office of the Vice President for Research. “Is My Satellite ITAR or EAR?” https://research.mit.edu/integrity-and-compliance/export-control/guidance-documents/my-satellite-itar-or-ear.

National Defense Authorization Act for Fiscal Year 2013. Pub. L. No. 112–239, 126 Stat. 1632. 2013. https://www.congress.gov/112/plaws/publ239/PLAW-112publ239.pdf.

Nouwens, Meia, and Helena Legarda. *China's Pursuit of Advanced Dual-Use Technologies*. International Institute for Strategic Studies, December 18, 2018. https://www.iiss.org/blogs/research-paper/2018/12/emerging-technology-dominance.

Pine, Art. "China Told It Can Launch U.S.-Made Satellite in 1989." *Los Angeles Times*, September 10, 1988. https://www.latimes.com/archives/la-xpm-1988-09-10-fi-1546-story.html.

Pollpeter, Kevin, Eric Anderson, Jordan Wilson, and Fan Yang. *China Dream, Space Dream: China's Progress in Space Technologies and Implications for the United States*. US-China Economic and Security Review Commission, 2015. https://www.uscc.gov/sites/default/files/Research/China%20Dream%20Space%20Dream_Report.pdf.

Sweeting, Martin. "Modern Small Satellites – Changing the Economics of Space." *Proceedings of the IEEE* 106, no. 3 (March 2018).

US Air Force. *Defense Industrial Base Assessment: U.S. Space Industry*. August 31, 2007. https://www.space.commerce.gov/defense-industrial-base-assessment-of-the-u-s-space-industry/.

US Department of Commerce, Bureau of Industry and Security, Office of Technology Evaluation. *U.S. Space Industry "Deep Dive" Assessment: Impact of U.S. Export Controls on the Space Industrial Base*. February 2014. https://www.bis.doc.gov/index.php/documents/technology-evaluation/898-space-export-control-report/file.

US Department of Commerce, Office of Space Commerce and the Federal Aviation Administration's Office of Commercial Space Transportation. *Introduction to U.S. Export Controls for the Commercial Space Industry*. 2nd ed. November 2017. https://www.space.commerce.gov/wp-content/uploads/2017-export-controls-guidebook.pdf.

Wines, Michael. "Qian Xuesen, Father of China's Space Program, Dies at 98." *New York Times*, November 3, 2009.

Wolf, Frank. "U.S. Should Not Cooperate with People's Liberation Army to Help Develop China's Space Program." Press release, November 2, 2011. http://www.spaceref.com/news/viewpr.html?pid=35130.

Zak, Anatoly. "Russia's Space Agency Might Break up with the U.S. to Get with China." *Popular Mechanics*, March 7, 2018.

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