The U.S.-China Military Balance in Space

Implications for Future Warfare in the Pacific

Zachary Burdette

How will the U.S. military's growing use of space to support its operations and the growing counterspace capabilities available to its competitors shape the balance of power? These two trends have contributed to a meteoric rise in concern that the United States would struggle to defend its allies and partners if adversaries attacked U.S. military satellites during a war. Since China's landmark test of a direct-ascent anti-satellite (ASAT) weapon in 2007, U.S. defense analysts have cautioned that satellites are "as vulnerable as they are essential,"[1] and that space has become "the American military's Achilles heel."[2] Government officials have also issued dire warnings, such as invoking the possibility of a "space Pearl Harbor" that would leave the U.S. military "deaf, dumb, blind, and impotent."[3] This pessimistic rhetoric is often vague and unsubstantiated by technical assessments that could enable a more rigorous public debate about the scale and character of the problem.[4] This article contributes to this

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1. Michael Krepon et al., "China's Military Space Strategy: An Exchange," *Survival*, Vol. 50, No. 1 (2008), pp. 160–161, https://doi.org/10.1080/00396330801899512.
2. Paul Scharre, "The U.S. Military Should Not Be Doubling Down on Space," *Defense One*, August 1, 2018, https://www.defenseone.com/ideas/2018/08/us-military-should-not-be-doubling-down-space/150194/.
3. Jim Cooper, "Foreword," in Todd Harrison, Kaitlyn Johnson, and Thomas Roberts, *Space Threat Assessment 2019* (Washington, DC: Center for Strategic and International Studies, 2019), https://www.csis.org/analysis/space-threat-assessment-2019.
4. For outstanding exceptions, see: Eric Heginbotham et al., *The U.S.-China Military Scorecard: Forces, Geography, and the Evolving Balance of Power, 1996–2017* (Santa Monica, CA: RAND, 2015), https://www.rand.org/pubs/research_reports/RR392.html; Brian Weeden and Victoria Samson, eds., *Global Counterspace Capabilities: An Open Source Assessment* (Washington, DC: Secure World Foundation, 2024), https://swfound.org/media/207827/swf_global_counterspace_capabilities_2024_en_es.pdf; Harrison, Johnson, and Roberts, *Space Threat Assessment 2019*; Jaganath

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debate by developing a framework to assess the U.S.-China military balance in space and applying that framework to a Taiwan scenario.[5]

The article's framework distinguishes between dependence and resilience as two key concepts for understanding the military balance in space. Dependence captures how much the United States relies on satellites to support the military operations required to defend Taiwan. The U.S. military would need to conduct certain missions to defeat a Chinese invasion, such as attacking Chinese warships and troop transports, defending airspace from Chinese fighters, and potentially striking military targets (e.g., ports and logistics hubs) on mainland China. Dependence represents the extent to which the U.S. military's ability to satisfy the operational requirements of those specific missions would decline because of degraded or denied access to space. Because satellites are not the only way to provide enabling capabilities such as communications, intelligence collection, and precision guidance, measuring dependence requires assessing how effectively terrestrial alternatives could substitute for satellites. This assessment provides a performance baseline for gauging how much degraded access to space would affect the U.S. military's ability to conduct the missions required to defend Taiwan.

Resilience captures how effectively U.S. satellite constellations can withstand Chinese counterspace attacks and still provide useful support to U.S. forces. The conventional wisdom is that the offense has overwhelming advan-

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Sankaran, "Limits of the Chinese Antisatellite Threat to the United States," *Strategic Studies Quarterly*, Vol. 8, No. 4 (Winter 2014), pp. 19–46, https://www.airuniversity.af.edu/Portals/10/SSQ/documents/Volume-08_Issue-4/Sankaran.pdf; Ivan Oelrich, Paul van Hooft, and Stephen Biddle, "Anti-Satellite Warfare, Proliferated Satellites, and the Future of Space-Based Military Surveillance," *Journal of Strategic Studies*, Vol. 47, No. 6–7 (2024), pp. 1–24, https://doi.org/10.1080/01402390.2024.2379398; James M. Acton, "Escalation Through Entanglement: How the Vulnerability of Command-and-Control Systems Raises the Risks of an Inadvertent Nuclear War," *International Security*, Vol. 43, No. 1 (Summer 2018), pp. 56–99, https://doi.org/10.1162/isec_a_00320.

5. Michael O'Hanlon, "Why China Cannot Conquer Taiwan," *International Security*, Vol. 25, No. 2 (Fall 2000), pp. 51–86, https://doi.org/10.1162/016228800560453; David A. Shlapak et al., *A Question of Balance: Political Context and Military Aspects of the China-Taiwan Dispute* (Santa Monica, CA: RAND, 2009), https://www.rand.org/pubs/monographs/MG888.html; Stephen Biddle and Ivan Oelrich, "Future Warfare in the Western Pacific: Chinese Antiaccess/Area Denial, U.S. AirSea Battle, and Command of the Commons in East Asia," *International Security*, Vol. 41, No. 1 (Summer 2016), pp. 7–48, https://doi.org/10.1162/ISEC_a_00249; Michael Beckley, "The Emerging Military Balance in East Asia: How China's Neighbors Can Check Chinese Naval Expansion," *International Security*, Vol. 42, No. 2 (Fall 2017), pp. 78–119, https://doi.org/10.1162/ISEC_a_00294; Mark F. Cancian, Matthew Cancian, and Eric Heginbotham, *The First Battle of the Next War: Wargaming a Chinese Invasion of Taiwan* (Washington, DC: Center for Strategic and International Studies, 2023), https://www.csis.org/analysis/first-battle-next-war-wargaming-chinese-invasion-taiwan; Bleddyn E. Bowen, *War in Space: Strategy, Spacepower, Geopolitics* (Edinburgh: Edinburgh University Press, 2020), chap. 6.

tages over the defense in space, so much so that the "defense is impractical in the long term" against sophisticated military competitors like China.[6] These claims tend to focus on the tactical-level survivability of individual satellites, but the more important question is the operational-level resilience of satellite constellations. Although defending any one satellite might be difficult, what ultimately matters is the resilience of networks of satellites in terms of their ability to keep providing support even as they lose individual nodes. Most satellites are just nodes in larger networks, and the importance of any one node depends on a network's characteristics. Measuring resilience requires assessing how the attributes of different satellite constellations make them more or less robust to different counterspace threats. Analysts sometimes discuss counterspace capabilities as having almost mystical or omnipotent qualities, but like any other weapon they have strengths and weaknesses rooted in the laws of physics.[7]

Applying this framework to a Taiwan invasion scenario shows some of the growing challenges that the U.S. military faces, but it also supports qualified optimism about the future. Over much of the past two decades since China's direct-ascent ASAT test in 2007, the direction of trends for U.S. dependence and resilience has been negative because China has rapidly modernized and expanded its military.[8] The United States has developed some dependencies on space to maximize the effectiveness of its operations to defend Taiwan, and China has made impressive advances in its counterspace capabilities. But the magnitude of the challenge remains more manageable than many analysts fear.[9] The United States' dependence on space is not so brittle that degraded access would necessarily hamstring its operations to defend Taiwan, and the

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6. Biddle and Oelrich, "Future Warfare in the Western Pacific," p. 25. See also Avery Goldstein, "First Things First: The Pressing Danger of Crisis Instability in U.S.-China Relations," *International Security*, Vol. 37, No. 4 (Spring 2013), p. 67, https://doi.org/10.1162/ISEC_a_00114.
7. For excellent overviews, see: Todd Harrison, Kaitlyn Johnson, and Makena Young, *Defense Against the Dark Arts in Space: Protecting Space Systems from Counterspace Weapons* (Washington, DC: Center for Strategic and International Studies, 2021), https://www.csis.org/analysis/defense-against-dark-arts-space-protecting-space-systems-counterspace-weapons; David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security: A Reference Manual* (Cambridge, MA: American Academy of Arts and Sciences, 2005), https://www.amacad.org/publication/physics-space-security-reference-manual.
8. David A. Ochmanek et al., *Inflection Point: How to Reverse the Erosion of U.S. and Allied Military Power and Influence* (Santa Monica, CA: RAND, 2023), https://www.rand.org/pubs/research_reports/RRA2555-1.html.
9. For an overview of alarmist predictions, see, especially, Brandon Davenport and Rich Ganske, "'Recalculating Route': A Realistic Risk Assessment for GPS," *War on the Rocks*, March 11, 2019, https://warontherocks.com/2019/03/recalculating-route-a-realistic-risk-assessment-for-gps/.

Chinese counterspace threat is not so severe that China could quickly and easily deny the United States access to space. Additionally, U.S. space architectures are already becoming more resilient, reversing the direction of this previously negative trend. The shift toward "proliferated" constellations that have hundreds or thousands of small satellites along with the explosive growth of the United States' commercial space sector have been key drivers of this positive trend. The United States also has the potential to reduce its dependence on space through investments in promising new capabilities and operational concepts, though progress has not been as striking as it has with resilience.

There are two key qualifications to these findings. First, this article's qualified optimism about the future assumes that the United States continues to invest in more resilient space systems and more robust terrestrial alternatives. This article provides a more realistic and precise threat assessment, but it is not a call for complacency. Even if China's counterspace capabilities are not decisive wonder weapons, they still contribute to eroding the advantages that the United States enjoyed when it had command of the space commons.[10] The return of a contested military balance across all domains reflects a return to historical normalcy in many ways.[11] But a smaller margin of advantage is still cause for concern because it increases the risk of deterrence failures and the costs required for victory if deterrence fails.

The second qualification to these findings is that the growth of China's satellite capabilities to enable its own operations is becoming increasingly central to the U.S.-China military balance. Some of the article's findings about the practical difficulties of counterspace campaigns that are good news for U.S. resilience against Chinese attacks are also bad news for the United States' ability to deny the military benefits of space to China. Contrary to the influential prediction that offensive advantages in space will limit the effective reach of China's precision strike networks beyond 400–600 kilometers from the mainland, China's nascent long-range kill chains will become a serious and enduring challenge.[12]

10. Barry R. Posen, "Command of the Commons: The Military Foundation of U.S. Hegemony," *International Security*, Vol. 28, No. 1 (Summer 2003), pp. 5–46, https://doi.org/10.1162/016228803322427965.
11. For a canonical Cold War assessment, see Ashton B. Carter, "Satellites and Anti-Satellites: The Limits of the Possible," *International Security*, Vol. 10, No. 4 (Spring 1986), pp. 52–55, https://doi.org/10.2307/2538950.
12. Biddle and Oelrich, "Future Warfare in the Western Pacific," pp. 13, 25.

The article proceeds as follows. The first section develops an analytic framework that focuses on dependence and resilience. The second section implements this framework by assessing the extent of U.S. dependence on space to defeat a Chinese invasion of Taiwan. The third section evaluates the extent of U.S. resilience to a Chinese counterspace campaign. The conclusion considers how the Chinese military's growing dependence on space could reshape the military balance going forward.

A Framework for Assessing the Military Balance in Space

The framework focuses on dependence and resilience because they capture the two pillars behind the prevailing pessimism. If the U.S. military did not depend on satellites for anything, or if its satellites were immune to attack, then there would be no cause for concern. Fears about dependence and resilience have deep roots in the U.S. defense community, as then–National Security Advisor Brent Scowcroft previewed in 1976: "We are very dependent on a relatively small number of low altitude satellite missions and have done very little to protect them from Soviet attack."[13] Now that space is again contested, it is worth reassessing these concerns.

The military use of space matters because it can enable forces on Earth to fight more effectively, which makes countries more likely to achieve their political objectives. Given that space operations are a means to an end, analysts should base their judgments about dependence and resilience on the specific military campaigns and political objectives that policymakers ultimately care about supporting.[14] A U.S.-China war over Taiwan is a valuable campaign to analyze for that purpose because the U.S. military considers China its "pacing challenge" and Taiwan its "pacing scenario."[15] In other words, China is its most capable competitor and Taiwan is its key priority.

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13. "Memorandum from the President's Assistant for National Security Affairs (Scowcroft) to President Ford," Washington, DC, April 26, 1976, *Foreign Relations of the United States (FRUS), 1969–1976*, Vol. E–3, *Documents on Global Issues, 1973–1976*, ed. William B. McAllister (Washington, DC: Government Printing Office, 2009), doc. 126, https://history.state.gov/historicaldocuments/frus1969-76ve03/d126.
14. Rachel Tecott Metz and Andrew Halterman, "The Case for Campaign Analysis: A Method for Studying Military Operations," *International Security*, Vol. 45, No. 4 (Spring 2021), pp. 44–83, https://doi.org/10.1162/isec_a_00408.
15. Terri Moon Cronk, "Testimony: DOD Is Laser Focused on China Pacing Challenge, Meeting Our Commitments Under the Taiwan Relations Act," *DOD News*, U.S. Department of Defense, December 8, 2021, https://www.defense.gov/News/News-Stories/Article/Article/2867003/testimony-dod-is-laser-focused-on-china-pacing-challenge-meeting-our-commitment/.

DEPENDENCE

The U.S. military's dependence on space is a function of how effectively it can operate without support from satellites. The three most important enabling capabilities that satellites provide to U.S. forces are intelligence, surveillance, and reconnaissance (ISR); positioning, navigation, and timing (PNT); and satellite communications (SATCOM).[16] Satellites are not the only way to collect intelligence, navigate, and communicate. Looking at how effectively alternatives to satellites can satisfy requirements helps establish a baseline to gauge dependence on space. The key quantity of interest for dependence is how much an incremental decrease in U.S. operational effectiveness would increase either the risk of losing the war or the costs required for victory.

For example, U.S. military forces have alternatives to satellites for communications. Nearly all global communications flow through fiber-optic cables, not satellites.[17] When U.S. forces, such as aircraft, are within line of sight of one another, they also generally use tactical data links rather than satellites for wireless communications. Evaluating the extent of U.S. dependence on space requires understanding the specific importance of wireless beyond-line-of-sight (BLOS) communications for different missions. This approach is more useful than citing how much the United States uses space (e.g., how much SATCOM bandwidth it consumes) as an indicator of dependence.[18] The U.S. military uses space heavily because satellites are efficient for certain purposes. But base-rate usage reveals little about what contributions from satellites are truly mission-critical to operational success. Base-rate usage also does not indicate how effective terrestrial backups to satellites would be if an adversary degraded or denied the U.S. military's access to space.

Because different kinds of military operations have different requirements, assessing U.S. dependence requires looking at the component parts of a potential campaign to defend Taiwan. Identifying variation in dependence across these missions highlights key areas of concern for important missions to de-

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16. Satellites support other important functions, such as missile warning, that are beyond this article's scope.
17. Bryan Clark, "Undersea Cables and the Future of Submarine Competition," *Bulletin of the Atomic Scientists*, Vol. 72, No. 4 (2014), pp. 234–237, https://doi.org/10.1080/00963402.2016.1195636.
18. For an example of Chinese analysts basing their appraisals of U.S. dependence on how much SATCOM bandwidth the United States uses, see Kevin Pollpeter, "Space, the New Domain: Space Operations and Chinese Military Reforms," *Journal of Strategic Studies*, Vol. 39, No. 5–6 (2016), p. 717, https://doi.org/10.1080/01402390.2016.1219946.

fend Taiwan that are also highly dependent on space. It is also useful to know which operations are more robust to degraded access to space.

RESILIENCE

The U.S. military's resilience in space is a function of how effectively its space systems can withstand attacks and continue to support U.S. forces. In some cases, constellations can degrade gracefully and still meet key performance requirements even as they lose nodes. Their ability to do so depends on a constellation's attributes and how demanding the performance requirements are to support terrestrial operations. Because multiple constellations support ISR and SATCOM, the resilience of some networks can also partially offset the fragility of others. The key quantity of interest for resilience is how robust the overall U.S. space architecture is in its ability to satisfy the requirements of U.S. forces, even if individual satellites come under attack.

Shifting from the tactical to operational levels highlights different analytic benchmarks. As a terrestrial analog, there are debates about the Iranian military's ability to disrupt oil supply chains.[19] Focusing on the survivability of individual satellites is equivalent to assessing the survivability of individual oil tankers and refineries without examining the broader economic effects of losing them. Identifying the vulnerabilities of tankers and refineries to attack does not in itself reveal how much of an impact losing these nodes would have on larger oil supply chains, or how much economic harm would result from supply chain disruptions. Attacks on tankers and satellites are means to more ambitious ends, so tactical-level vulnerabilities are not inherently meaningful without knowing about the resilience of the networks that they support.

The opportunities and constraints that characterize individual counterspace attacks are different from counterspace campaigns. Campaigns must account for certain capabilities working well against some kinds of targets but not others, the capacity of the attacker's inventories to strike many individual targets at scale, and the speed at which the attacker can achieve its objectives by accumulating individual attacks within an operationally relevant timeframe. Space has some features that favor the offense at the tactical level, such as satellites traveling in predictable orbits. But for tactical-level advantages to contribute to operational and strategic results, the attacker must orchestrate

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19. Joshua R. Itzkowitz Shifrinson and Miranda Priebe, "A Crude Threat: The Limits of an Iranian Missile Campaign Against Saudi Arabian Oil," *International Security*, Vol. 36, No. 1 (Summer 2011), pp. 167–201, https://doi.org/10.1162/ISEC_a_00048.

a campaign that can address challenges related to capability, capacity, and speed. The connection between the tactical, operational, and strategic levels is often vague when analysts discuss threats in space. This article aims to make such assessments more explicit.

U.S. Dependence on Space

How dependent is the United States on access to space to defend Taiwan? This section identifies the missions that the U.S. military might conduct during a war to defeat a Chinese invasion of Taiwan and assesses how much degraded access to space would impede the United States' ability to execute them.

The U.S. military's strategy in a war over Taiwan would determine the missions that it conducts and therefore the kinds of operations that U.S. satellites would support. If the U.S. strategy has a denial "theory of victory," then the goal would be to persuade Beijing that it should end the war rather than continue the fighting because China lacks a viable military pathway to achieve its political goal of controlling Taiwan.[20] Defeating China's invasion forces would be a key operational goal to support this theory of victory. If the United States wants to persuade Beijing that its bid to control Taiwan has failed and that protracted fighting would not help China achieve its war aims, then the United States needs to prevent China from seizing Taiwan in the first place.

This U.S. strategy would prioritize three missions to defend Taiwan. The first and most important would be the *anti-surface warfare mission* targeting China's ships, especially its amphibious transports. The operational center of gravity in an invasion scenario would be interdicting the transports that China needs to deliver many thousands of soldiers to Taiwan and to sustain them with supplies and reinforcements. Two critical breaking points for China's invasion would be if it failed to either land enough troops to overcome Taiwan's military or supply them with enough food, fuel, and ammunition to remain combat effective for weeks to months.[21] Targeting these transports would be the best way to defeat the invasion. Military history suggests that China

20. Jacob L. Heim, Zachary Burdette, and Nathan Beauchamp-Mustafaga, *U.S. Military Theories of Victory for a War with the People's Republic of China* (Santa Monica, CA: RAND, 2024), https://www.rand.org/pubs/perspectives/PEA1743-1.html.
21. Elbridge A. Colby, *The Strategy of Denial: American Defense in an Age of Great Power Conflict* (New Haven, CT: Yale University Press, 2021), pp. 153–170.

would need to establish air and naval superiority around Taiwan to protect its troop transports.[22]

The second priority is the *counter-air mission* targeting Chinese aircraft during the war. The United States would want to deny China air superiority for several reasons. Doing so would create safer windows of opportunity for U.S. aircraft to strike Chinese amphibious transports and Chinese forces on Taiwan. The United States would also want its fighters to attack Chinese aircraft, such as China's transport aircraft and attack aircraft targeting Taiwanese ground forces. In the airspace farther from Taiwan, the United States would want to protect areas in the Pacific where U.S. forces might operate.

Finally, as a supporting mission, the United States might *strike select military targets on the mainland* that enhance China's ability to project power. While the United States would prefer to destroy Chinese transports only in the seas and skies around Taiwan to reduce escalation risks, it might conclude that defeating the invasion could be difficult without some attacks on targets such as China's ports, logistics hubs, airfields, and over-the-horizon radars.[23]

INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE

ANTI-SURFACE WARFARE. To execute the anti-surface warfare mission, the U.S. military would first need to find Chinese ships. Satellites are one element within a larger ecosystem of sensors that the United States and Taiwan could use. Other parts of that sensing ecosystem could include aircraft, fast patrol boats, submarines, undersea sensors, sonobuoys, and Taiwanese forces acting as spotters.[24] Once a platform locates a Chinese ship, it can either attack the target if the platform is both a "sensor" and a "shooter," or it can cue other strike platforms that are shooters.[25] Examples of potential strike platforms include Taiwanese ground forces with anti-ship cruise missiles, U.S. fighters and bombers with cruise missiles or glide bombs, U.S. submarines with torpedoes in the Taiwan Strait, U.S. submarines or surface ships with cruise missiles in the Philippine Sea east of Taiwan, and U.S. forces with ground-launched mis-

22. O'Hanlon, "Why China Cannot Conquer Taiwan," p. 55.
23. Caitlin Talmadge, "Would China Go Nuclear? Assessing the Risk of Chinese Nuclear Escalation in a Conventional War with the United States," *International Security*, Vol. 41, No. 4 (Spring 2017), pp. 50–92, https://doi.org/10.1162/ISEC_a_00274.
24. David A. Ochmanek, *Determining the Military Capabilities Most Needed to Counter China and Russia* (Santa Monica, CA: RAND, 2022), https://www.rand.org/pubs/perspectives/PEA1984-1.html.
25. Andrew Krepenivich, *Origins of Victory* (New Haven, CT: Yale University Press, 2023).

siles in Japan or the Philippines.[26] Taken together, the battle networks that support anti-surface warfare include a mix of sensors to find Chinese ships and shooters to strike them.

Satellites play a valuable role in this sensing ecosystem because they can observe Chinese ships beyond the sensor range of U.S. aircraft, ships, and submarines. The range of sensors is usually limited by their line of sight to the horizon, so placing sensors at higher altitudes can increase their range.[27] There are three main ways to find ships from space. First, electronic intelligence (ELINT) satellites have passive sensors that listen for electronic emissions like radar and radio communications. ELINT constellations can geolocate those emissions using time-difference-of-arrival techniques, whereby a distributed network of sensors tracks when the same signal arrives at multiple locations.[28] ELINT constellations provide wide-area surveillance to establish the general location of ships; they can then cue other sensing systems to generate more precise targeting coordinates and confirm the type of target.[29] Second, optical imaging satellites can find ships with electro-optical sensors that provide traditional photoreconnaissance, sometimes paired with infrared sensors that detect heat signatures. Imaging satellites can generate precise targeting coordinates, but optical sensors need to focus on a much narrower area, so they are ideal for follow-on imagery but inefficient for wide-area searches without receiving a cue from other platforms (e.g., ELINT satellites or aircraft) for where to look. Third, radar satellites use synthetic aperture radar techniques to image targets by illuminating them with radio waves and listening for returns. Radar imaging is especially valuable because it can find targets at night and in bad weather, both of which can obscure optical imagery.

The key question for assessing U.S. dependence on ISR satellites for anti-surface warfare is how well the sensing ecosystem could operate with degraded or denied access to space. Degraded here means the United States still has some access to space, but the quality is reduced, potentially because of jamming or because China destroyed some satellites in a constellation. Degra-

26. Shlapak et al., *A Question of Balance*, p. 113; Heginbotham et al., *The U.S.-China Military Scorecard*, pp. 219–221.
27. Biddle and Oelrich, "Future Warfare in the Western Pacific," p. 23.
28. Owen R. Cote Jr., *Assessing the Undersea Balance Between the U.S. and China*, SSP Working Paper (Annapolis: U.S. Naval Institute, 2011), p. 26, https://www.usni.org/sites/default/files/inline-files/Undersea%20Balance%20WP11-1.pdf.
29. For reference, China's ELINT constellations have an estimated accuracy within "tens of kilometers," which is useful for finding ships but requires cueing additional sensors for precise targeting coordinates. Heginbotham et al., *The U.S.-China Military Scorecard*, pp. 157–159, 253.

dation exists on a spectrum, with potential disruptions ranging from minor to severe. Denied means that U.S. forces do not have access to space at all for a given enabling function.

U.S. dependence on space for long-range ISR has grown over the past two decades because China's military modernization has made it harder for U.S. aircraft and ships to operate close to mainland China, and Taiwan is close to the mainland.[30] Two decades ago, the United States had powerful military advantages that could likely have enabled it to establish air superiority and persistently generate sorties of ISR aircraft around Taiwan. In 2025, China's increasingly modern fighter force would make it difficult for the United States to establish air superiority around Taiwan.[31] The United States had 24 times more fourth-generation fighters than China in 2004 but only 1.5 times more than China in 2024.[32] The United States also lost its monopoly on fifth-generation fighters during this timeframe. By 2024, China had about 200 of its own fifth-generation aircraft (though U.S. fifth-generation inventories were still four times larger than China's and likely had qualitative advantages).[33] Additionally, China's ability to strike U.S. air bases in the Pacific with larger numbers of more accurate ballistic and cruise missiles could further strain the availability of U.S. aircraft.[34] The United States could still intermittently push forward fighters and reconnaissance aircraft to collect intelligence, but the shift from persistence to intermittence represents a decline in its ability to rely on terrestrial alternatives to satellites. China's growing anti-ship missile capabilities, coupled with a dramatic naval buildup that has more than doubled the size of China's fleet, would also make it risky for U.S. surface ships to approach Taiwan early in the war.[35] As China's ability to threaten U.S. ships and aircraft operating close to Taiwan grows, this places additional pressure on satellites to provide long-range targeting intelligence.

Despite this decline, the United States would still have some advantages in its ability to find Chinese transports. One advantage is that the invasion would require amphibious transports to operate in a predictable area—that is, the United States would not need to search the open Pacific Ocean to find them.

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30. Ibid., pp. 94, 199.
31. Cancian, Cancian, and Heginbotham, *The First Battle of the Next War*, p. 86.
32. Christopher Langton, ed., *The Military Balance* (London: International Institute for Strategic Studies, 2004); Robert Wall, ed., *The Military Balance* (London: International Institute for Strategic Studies, 2024).
33. Ibid.; Cancian, Cancian, and Heginbotham, *The First Battle of the Next War*, pp. 77–78.
34. Cancian, Cancian, and Heginbotham, *The First Battle of the Next War*, p. 112.
35. Ibid., p. 8.

The three opportunities to find and target the transports are when they are at port in China, underway across the Taiwan Strait, or unloading forces and supplies near Taiwan. First, transports at port would be fixed targets at well-known Chinese naval bases. The transports would likely need to return to Chinese ports for at least twelve hours between each transit to Taiwan to reload and undergo maintenance.[36] Second, while traversing the strait, transports would be vulnerable to U.S. submarines, which provide "self-contained" kill chains that can find ships with sonar or periscopes and attack them with torpedoes.[37] China's transports would also likely transit undersea minefields, which are another self-contained kill chain. Third, when unloading forces, Chinese transports would have no choice but to come close to Taiwan, which could act as an allied sensing hub. Taiwan's geography makes it difficult to invade. It has only about a dozen beaches suitable for amphibious landings, some of which are clustered together.[38] Once China established a lodgment, its transports would be tethered to sustain that beachhead, further reducing the search area for U.S. and Taiwanese sensors. Military history suggests that beaches can easily become congested and clogged, potentially forcing transports to sit for hours or days waiting to unload follow-on forces and supplies, raising the risk that at least one sensor cues a strike platform.[39]

If China managed to degrade but not deny U.S. access to ISR satellites, the United States would opportunistically use this intermittent intelligence to support its sensing ecosystem. Even if China destroyed half the United States' imaging satellites, the remaining systems would still regularly pass overhead to provide imagery. Given the finding from recent wargames that the United States could quickly deplete its long-range missiles in a war over Taiwan, the limiting factor in this scenario might be the United States' ability to strike Chinese ships rather than to find them.[40] Satellites cannot solve this problem.

To be clear, the United States would not face a transparent battlefield where it had perfect situational awareness and a constant track on Chinese transports in a Taiwan scenario. China would do everything it could to prevent the United States from finding and striking its amphibious transports, including deploying large numbers of decoys to confuse and deceive U.S. terrestrial and

36. Heginbotham et al., *The U.S.-China Military Scorecard*, p. 205.
37. Ibid., p. 210.
38. Ian Easton, *The Chinese Invasion Threat: Taiwan's Defense and American Strategy in Asia* (Arlington, VA: Project 2049 Institute, 2017), p. 43.
39. Shlapak et al., *A Question of Balance*, pp. 111–113n35.
40. Cancian, Cancian, and Heginbotham, *The First Battle of the Next War*, pp. 88–89.

satellite sensors.[41] The United States might also have general awareness of where Chinese ships are but lack precise targeting coordinates to attack them. Satellites would help to address these challenges, but the United States still has a range of options to collect intelligence without having to rely on satellites alone.

Investments in new capabilities and concepts can potentially strengthen terrestrial alternatives to satellites, slowing or even reversing the increase in U.S. dependence on space for long-range reconnaissance. The U.S. military is developing a "sensing grid," which would reportedly fuse and process targeting data from distributed sensors across multiple domains.[42] This could make terrestrial alternatives to satellites more effective by networking them together more seamlessly. For example, a U.S. military task force in the Middle East has been experimenting with a "Digital Ocean" concept to monitor Iranian naval activity by fusing data from myriad unmanned platforms, including surface vessels, submarines, buoys, undersea sensors, and aircraft.[43]

Because sensing grids are only as good as the sensors on them, the United States needs to invest in more survivable sensing systems in order to build more robust terrestrial sensing networks. U.S. defense analysts have proposed investing in large numbers of runway-independent unmanned aircraft to field a "targeting mesh" around Taiwan.[44] Mesh networks are comprised of multiple nodes that can communicate directly with one another, which provides a resilient way to disseminate targeting intelligence. Fielding large numbers of drones could make it difficult for Chinese air defenses to dismantle the network, and making those drones runway-independent could avoid relying on vulnerable U.S. air bases. There are promising signs that the United States is beginning to invest more heavily in unmanned systems. For example, the U.S. military announced the "Replicator initiative" in 2023, which is on track to field "multiple thousands of attritable, autonomous systems in multiple domains" to the Pacific by July 2025.[45]

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41. Ochmanek et al., *Inflection Point*, p. 14.
42. Laura Heckmann, "Just In: Air Force Updating, Clarifying ISR Vision, Official Says," *National Defense*, May 17, 2023, https://www.nationaldefensemagazine.org/articles/2023/5/17/air-force-working-on-updated-isr-vision-official-says.
43. Emma Helfrich, "Navy's Task Force 59 to Keep Tabs on Iran with Armada of Drones," *War Zone*, January 12, 2023, https://www.thedrive.com/the-war-zone/navys-task-force-59-to-keep-tabs-on-iran-with-armada-of-drones.
44. Thomas Hamilton and David Ochmanek, *Operating Low-Cost, Reusable Unmanned Aerial Vehicles in Contested Environments* (Santa Monica, CA: RAND, 2020), https://www.rand.org/pubs/research_reports/RR4407.html.
45. "Attritable" systems are designed to be reusable but also cheap enough that it is possible to

COUNTER-AIR OPERATIONS. U.S. dependence on ISR satellites for counter-air operations is relatively low. The U.S. military has had a long-standing interest in using satellites to track enemy aircraft, but it reports that this capability is unlikely to become operational until the 2030s.[46] In the interim, U.S. fighters will continue to rely primarily on their own sensors as well as those of Airborne Early Warning and Control aircraft. Imaging satellites could also monitor activity on Chinese air bases. Even though U.S. fighters are qualitatively superior to Chinese aircraft, one concern is that China might surge forward many aircraft at once to overwhelm U.S. fighters.[47] Having some early warning of surges could help the United States respond more dynamically, which would be a useful but not mission-critical contribution.

MAINLAND STRIKES. The United States is highly dependent on ISR satellites for pursuing mobile targets and less so for pursuing fixed targets. The United States can locate fixed targets during peacetime through satellite imagery or other means, and the targeting coordinates would remain accurate even if China destroys the satellite. Satellite reconnaissance would still be useful for observing activity around important fixed targets like ports and logistics hubs, as well as for battle damage assessments after strikes. But significant intelligence collection on these targets would occur before the war. By contrast, mobile targets (e.g., China's road-mobile missile launchers) can relocate, which would require the United States to track or refind these targets during the war itself. This is a much greater challenge, and the United States would rely on space for tracking or refinding mobile ground targets more than for any other tasks.

The United States is especially reliant on ISR satellites to pursue mobile ground targets because the main alternative is aircraft, which would face exceptionally high risks from operating over mainland China for long periods. China has developed one of the best integrated air defense systems in the world, featuring an extensive network of early-warning radars, modern fighter aircraft, and a large inventory of long-range surface-to-air missile bat-

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amass and operate them in ways that accept higher levels of risk and attrition. Ted Harshberger, *Consider This Air Force Replicator Concept for All the Right Reasons* (Santa Monica, CA: RAND, 2024), p. 5; John A. Tirpak, "Replicator 'on Track' to Field Thousands of Cheap Drones Within Months," *Air & Space Forces*, December 12, 2024, https://www.airandspaceforces.com/replicator-on-track-cheap-drones/.
46. Courtney Albon, "Space Force to Field Sensors for Tracking Air, Ground Targets in 2030s," *DefenseNews*, September 4, 2024, https://www.defensenews.com/space/2024/09/04/space-force-to-field-sensors-for-tracking-air-ground-targets-in-2030s/.
47. Heginbotham et al., *The U.S.-China Military Scorecard*, p. 73.

teries.[48] The United Sates could try to use stealthy aircraft to avoid Chinese air defenses, but stealth attributes cannot make aircraft undetectable, even if they make detection harder.[49] Aircraft would also face a trade-off: They either emit radar signals to find a target quickly but reveal their location in the process, or they rely on passive electro-optical/infrared targeting pods, which could force them to stay in Chinese airspace for significantly longer to find the target.[50] Instead, the United States could try to suppress or destroy Chinese air defenses so that it could search for targets more freely. Given the quality and quantity of China's air defense capabilities, the United States would need to dedicate large numbers of aircraft to target them.[51] Doing so would reduce the number of U.S. aircraft available for more important missions, such as searching for and attacking China's amphibious transports.

Despite extremely high U.S. dependence on space for pursuing mobile ground targets, the United States could still defend Taiwan effectively without large-scale operations against these targets. The U.S. military might want to pursue launchers because they threaten air bases and carriers, but it has other countermeasures, such as air base dispersal, hardening, rapid repair, missile defenses, runway-independent drones, decoys, and other deceptive tactics.[52] Even with access to space, a campaign to hunt mobile missiles would require tremendous resources. China has hundreds of missile launchers that could operate across wide areas and hide in complex terrain like cities and forests.[53] China would likely further complicate U.S. efforts by deploying physical and electronic decoys and by making some launchers look like decoys. The history of overcoming these countermeasures is grim. For example, the United States failed to achieve a single confirmed kill against Iraqi Scud launchers in the Gulf War.[54] The United States should instead prioritize using its scarce sensing

48. Office of the Secretary of Defense, *Military and Security Developments Involving the People's Republic of China 2023* (Washington, DC: Department of Defense, 2023), pp. 64, 89.
49. Biddle and Oelrich, "Future Warfare in the Western Pacific," pp. 33–36.
50. According to some estimates, electro-optical/infrared targeting pods could take more than six times longer than radar to find targets. Jeff Hagen et al., *Needs, Effectiveness, and Gap Assessment for Key A-10C Missions* (Santa Monica, CA: RAND, 2016), p. 11, https://www.rand.org/pubs/research_reports/RR1724z1.html.
51. Colby, *The Strategy of Denial*, pp. 148–149.
52. Christopher Lynch et al., *Operational Imperative: Investing Wisely to Bolster U.S. Air Bases Against Chinese and Russian Attacks* (Santa Monica, CA: RAND, 2023), https://www.rand.org/pubs/perspectives/PEA1996-1.html.
53. For an overview of the challenges, see Thomas MacDonald, "Hide and Seek: Remote Sensing and Strategic Stability" (PhD dissertation, Massachusetts Institute of Technology, 2021), pp. 127–129, chap. 6, https://hdl.handle.net/1721.1/139559.
54. Alan J. Vick et al., *Aerospace Operations Against Elusive Ground Targets* (Santa Monica, CA: RAND, 2001), p. 65n8, https://www.rand.org/pubs/monograph_reports/MR1398.html.

and strike assets against China's amphibious transports and the key fixed targets that those transports need to be effective, especially ports and logistics hubs. In sum, satellites are more important for hunting mobile ground targets than for any other mission, but the United States would ultimately be better off not pursuing this category of targets.

POSITIONING, NAVIGATION, AND TIMING

ANTI-SURFACE WARFARE. When U.S. sensors find a target and cue a shooter, closing that kill chain requires firing a weapon that can precisely hit the target. For example, if a U.S. bomber fired a long-range anti-ship missile from outside the perimeter of China's air defenses, that missile would need to navigate accurately over long distances before it reached the targeted Chinese ship.[55] The U.S. network of Global Positioning System (GPS) satellites helps support requirements for precision guidance, general navigation, and synchronized timing.

The U.S. military already uses a range of alternatives as backups to GPS, but they are not as precise. Most importantly, it pairs GPS receivers with inertial navigation systems (INS) that estimate the position of a platform or a weapon by using gyroscopes and accelerometers to track its movement. The key limitation is that INS "drifts" over time as small measurement errors gradually accumulate. The size of the errors depends on factors like time, movement, and system quality. There is wide variation in INS quality, and high-performance options rapidly increase system costs.[56] One way to correct the accumulated INS drift is if GPS signals became available again after temporary disruptions.

Another alternative to GPS is celestial navigation. Long before the advent of GPS, U.S. Navy sailors used sextants to find a ship's position within a few kilometers. The celestial navigation aids that sailors use today are largely automated, such as STELLA (System to Estimate Latitude and Longitude Astronomically). Newer celestial systems use infrared sensors—which are reportedly accurate up to 50 meters—to track the stars during the day and through light cloud cover.[57] Celestial navigation can also correct INS drift if the

55. Cancian, Cancian, and Heginbotham, *The First Battle of the Next War*, pp. 88–89.
56. Naser El-Sheimy and Ahmed Youssef, "Inertial Sensors Technologies for Navigation Applications: State of the Art and Future Trends," *Satellite Navigation*, Vol. 1, No. 2 (2020), p. 3, https://doi.org/10.1186/s43020-019-0001-5.
57. Brian Bothwell and Jon Ludwigson, *GPS Alternatives: DOD Is Developing Navigation Systems but Is Not Measuring Overall Progress* (Washington, DC: Government Accountability Office, 2022), p. 8, https://www.gao.gov/assets/730/722071.pdf.

systems are integrated. The U.S. Air Force has an automated astroinertial navigation system called "R2-D2," which sits behind pilots on strategic aircraft.[58] As an additional navigational reference, some aircraft and missiles use terrain features, which are reportedly accurate at about 10 meters.[59] But using terrain features to achieve this accuracy requires clear landmarks and does not work well over flat terrain, including oceans.

Assessing the impact of degraded PNT depends on the quality of these backups to GPS and the operational requirements. For general navigation—that is, moving ships and aircraft from point A to point B—pilots and sailors are trained to adapt to errors like a ship straying a few dozen kilometers off course. But for weapons guidance, being off by even a few dozen meters could significantly lower the probability of hitting targets.

The impact of precision guidance depends on multiple factors, including how long the weapon traveled, how long the weapon lacked access to GPS, and the quality of the backups. Figure 1 shows the impact of degraded precision on the probability of directly striking a target. The underlying model uses a weapon's circular error probable (CEP) to measure its accuracy.[60] The model assumes that drift would effectively increase the CEP and therefore reduce the weapon's accuracy. As a point of reference, the U.S. government reports that one of its cruise missiles has a "less than" 13-meter CEP using only GPS-INS (before accounting for the missile's terminal seekers that search for targets after arriving at the initial aim point).[61] Without GPS, INS drift would add to this baseline.

The model's findings suggest that degraded weapons guidance is a problem of high uncertainty and high risk. Against large targets, degraded precision is less problematic because the target is simply harder to miss. Figure 1 uses a target with a 50-meter radius as an example, which could be a large hangar on

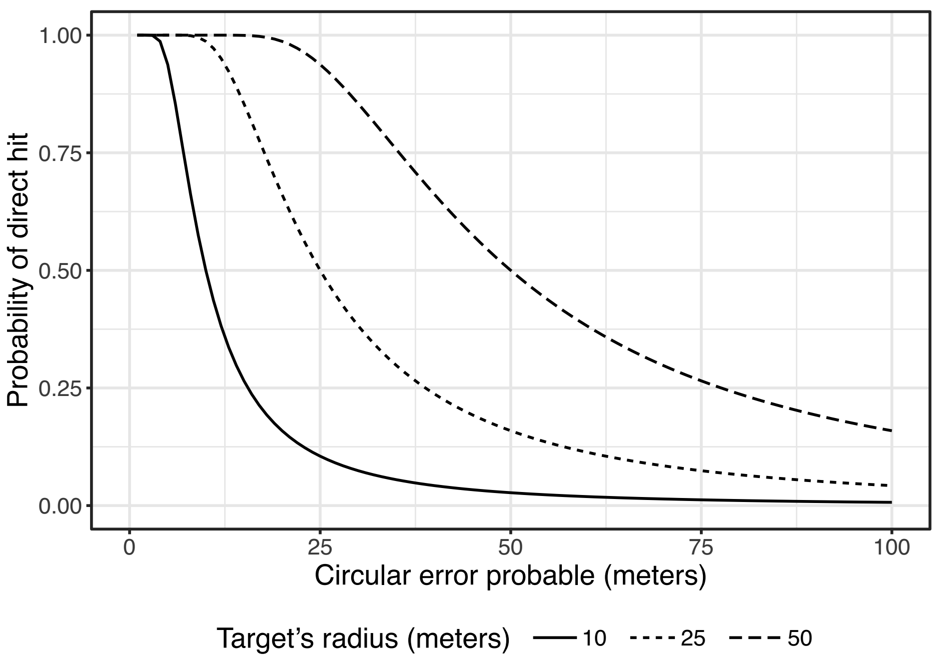
58. Tyler Rogoway, "SR-71's 'R2-D2' Could Be the Key to Winning Future Fights in GPS Denied Environments," *War Zone*, accessed January 2, 2018, updated April 16, 2019, https://www.thedrive.com/the-war-zone/17207/sr-71s-r2-d2-could-be-the-key-to-winning-future-fights-in-gps-denied-environments.

59. Bothwell and Ludwigson, *GPS Alternatives*, p. 8.

60. Circular error probable is the radius of a circle around an aim point within which 50 percent of weapons would land. See the online appendix for model details: https://doi.org/10.7910/DVN/LF5HCY.

61. Defense Acquisition Management Information Retrieval, *Joint Air-to-Surface Standoff Missile (JASSM)* (Washington, DC: U.S. Department of Defense, 2019), p. 7, https://www.esd.whs.mil/Portals/54/Documents/FOID/Reading%20Room/Selected_Acquisition_Reports/FY_2019_SARS/20-F-0568_DOC_46_JASSM_SAR_Dec_2019_Full.pdf.

Figure 1. Degraded Precision Reduces the Probability of Hitting Targets

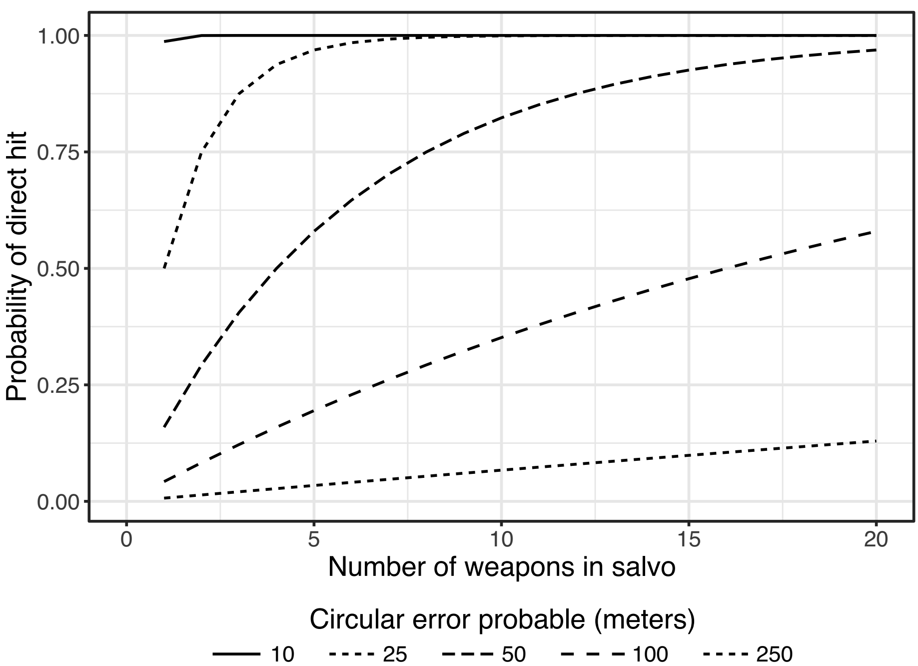


SOURCE: Shifrinson and Priebe, "A Crude Threat," p. 187n90.
NOTE: See the online appendix for model details: https://doi.org/10.7910/DVN/LF5HCY.

an air base.[62] Against smaller targets, modest drift starts to have a larger impact. If targets are mobile (e.g., Chinese ships), errors in the estimated location of the target add to degradation from guidance errors. There is limited public information about the quality of INS systems that the U.S. military uses for different weapons, which is why there is particularly high uncertainty for this assessment. Another source of uncertainty is that terminal seekers can search for targets if the weapon arrives close enough that the target is within the seeker's field of view (the weapon's "basket"), meaning that INS or other guidance

62. Jacob L. Heim, "The Iranian Missile Threat to Air Bases: A Distant Second to China's Conventional Deterrent," *Air & Space Power Journal*, Vol. 29, No. 4 (July/August 2015), p. 33, https://www.airuniversity.af.edu/Portals/10/ASPJ/journals/Volume-29_Issue-4/F-Heim.pdf.

Figure 2. Degraded Precision Increases the Number of Weapons Required to Hit Targets



SOURCE: Heim, "The Iranian Missile Threat to Air Bases," p. 33.
NOTE: See the online appendix for model details. The model assumes a target with a 25-meter radius.

methods only need to get the weapon close enough for its terminal sensors to see the target.[63] But, as with INS, there is limited public information about the in-flight search and targeting capabilities of U.S. weapons.

Degraded weapons accuracy would deplete U.S. inventories of weapons more quickly. The United States would need to either accept a lower probability of hitting targets or fire more weapons at each target to increase the probability of at least one hit. Figure 2 illustrates this dynamic against a target with a 25-meter radius.[64] The United States could strain its limited inventories of long-range weapons if it fired more missiles at each target. The result is an op-

63. Heginbotham et al., *The U.S.-China Military Scorecard*, p. 166.
64. Heim, "The Iranian Missile Threat to Air Bases," p. 33.

erational dilemma: either accept greater risks that the target survives or attack fewer targets. In either case, the Chinese military benefits.

If China only succeeded in degrading but not denying U.S. access to GPS, the impact would be more moderate. For example, U.S. missiles might still have access to GPS signals until they came close to jammers defending targets. If China destroyed only some GPS satellites, the constellation would degrade gracefully, resulting in temporary windows of disruption rather than an immediate breakdown in services.[65] If China destroyed the entire GPS constellation, doing so would likely severely degrade the United States' ability to strike targets accurately at long ranges. This would likely require U.S. forces to conduct strikes at shorter ranges, increasing the risk to U.S. aircraft and ships, or to rely more on anti-ship weapons that do not depend on GPS, such as torpedoes and mines.

In the future, technological advances could reduce U.S. dependence on GPS. For example, advances in quantum sensors could dramatically reduce INS drift rates.[66] There have also been advances in "signals of opportunity," which use signatures like magnetic fields and communications signals for PNT. Using communications signals from SpaceX's Starlink satellites as a signal of opportunity has provided a location fix accurate to 8 meters.[67] Achieving that accuracy likely requires the receiver to remain stationary, but innovation could change that limitation.

COUNTER-AIR OPERATIONS. U.S. fighters conducting counter-air operations would benefit from the precision timing that GPS provides. GPS satellites use atomic clocks to broadcast a shared reference time. That level of precision is not always necessary for operations, but it is important for electronic networks, such as the tactical data links that U.S. aircraft use for tactical communications and coordination with one another.[68]

The impact of losing GPS timing would depend on the quality of "holdover" clocks and alternative methods to share an updated reference time.[69] Hold-

65. Sankaran, "Limits of the Chinese Antisatellite Threat," pp. 28–33.
66. Patrick Tucker, "Quantum Sensor Breakthrough Paves Way for GPS-Free Navigation," *Defense One*, November 2, 2021, https://www.defenseone.com/technology/2021/11/quantum-sensor-breakthrough-paves-way-gps-free-navigation/186578/.
67. Jon Brodkin, "Researchers Use Starlink Satellites to Pinpoint Location, Similar to GPS," *Ars Technica*, September 27, 2021, https://arstechnica.com/information-technology/2021/09/researchers-use-starlink-satellites-to-pinpoint-location-similar-to-gps/.
68. Ronald Davies et al., *AU-18 Space Primer* (Maxwell Air Force Base, AL: Air University Press, 2023), chap. 16, p. 71.
69. Richard Mason et al., *Analyzing a More Resilient National Positioning, Navigation, and Timing Capability* (Santa Monica, CA: RAND, 2021), https://www.rand.org/pubs/research_reports/RR2970.html.

over clocks are the onboard backup clocks that U.S. forces could use if GPS timing signals were unavailable, similar to how INS provides a backup for navigation. The quality of U.S. holdover clocks likely varies for different platforms. Chip-scale atomic clocks have been commercially available and relatively cheap for over a decade, so some platforms could have them. While the quality does not match that of larger atomic clocks, two U.S. Army engineers report that the accuracy is "acceptable, making it a trusted source of time" if "GPS is degraded or disrupted" temporarily.[70] As with INS drift, addressing time drift requires either using larger and better holdover clocks or receiving an external update from other sources, such as aircraft or ships with high-quality atomic clocks, signals from communications satellites, or fiber-optic cables on bases.[71] The quality of these backups to GPS for precision timing will improve in the future. For example, the Defense Advanced Research Projects Agency (DARPA) is developing new miniaturized clocks that are a hundred times more accurate and can retain nanosecond-level precision for a month.[72]

MAINLAND STRIKES. The quality of precision guidance would have a significant impact on U.S. strikes against targets on the Chinese mainland. Because China's air defenses have become so capable, the United States faces growing pressure to launch strikes from greater distances.[73] That approach puts a premium on the ability of long-range weapons to navigate accurately over significant distances. As with the anti-surface warfare mission, there is notable uncertainty about the quality of INS and other navigational backups to GPS on different U.S. weapons. But the central risk is the same. If weapons experienced meaningful levels of degraded accuracy, that would increase the number of U.S. weapons required to hit the same number of Chinese targets.

COMMUNICATIONS

ANTI-SURFACE WARFARE. When U.S. sensors find a target, they want to be able to cue shooters even if they are far apart. For example, if a U.S. aircraft near Taiwan locates a group of Chinese transports, it would want to quickly com-

70. John Delcolliano and Paul Olson, "It's About Time—All of It," *Army ALT Magazine*, July 18, 2016, https://asc.army.mil/web/news-its-about-time-all-of-it/.
71. Son Dinh and Ilya Stevens, "Precise Time Transfer Concepts," in *Military Capabilities Enabled by Advances in Navigation Sensors*, Meeting Proceedings RTO-MP-SET-104, Paper 15 (Neuilly-sur-Seine, France: Research and Technology Organisation, NATO, 2020), pp. 15-1–15-14.
72. "Providing GPS-Quality Timing Accuracy Without GPS," Defense Advanced Research Projects Agency, January 20, 2022, https://www.darpa.mil/news-events/2022-01-20.
73. Cancian, Cancian, and Heginbotham, *The First Battle of the Next War*, pp. 128–129.

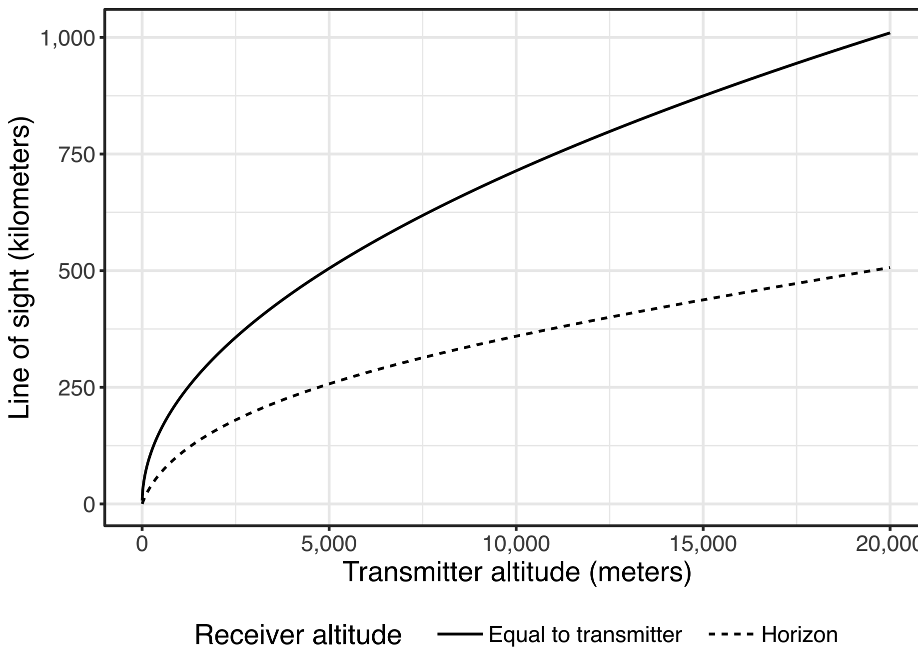
municate that targeting intelligence to many different strike platforms. Closing kill chains at long ranges therefore requires the ability to communicate over the horizon, which SATCOM provides. A degraded ability to pass information quickly between sensors and shooters creates inefficiencies that make kill chains less lethal, such as receiving outdated information on an enemy ship's location. The ideal case for the United States is that it could seamlessly share information with forces distributed widely throughout the Pacific, including ships at sea, aircraft at dispersed operating locations, and ground units with missile batteries on isolated islands.[74] Delays in sharing information could make it harder to have shooters in the right place at the right time to exploit time-sensitive opportunities to target Chinese ships.

The United States has strong alternatives to satellites for short-range communications. Tactical data links are the bread and butter of short-range communications when U.S. forces are within line of sight. Tactical data links do not work well for long-range communications because they use a part of the radio spectrum that passes through the atmosphere, so their range is limited to the horizon.[75] Using high-frequency signals is one option to communicate over the horizon because such signals reflect off the ionosphere, but this process lowers bandwidth and reliability. Very low frequency (VLF) signals and extremely low frequency (ELF) signals also propagate over the horizon, but they provide more reliability in exchange for much less bandwidth. They also require very large transmitters, making them primarily useful for one-way communications. SATCOM provides reliable, high-bandwidth, BLOS communications to bridge these gaps.[76] Relying exclusively on tactical data links to share targeting information on Chinese transports would require U.S. forces to operate closer to Taiwan, which would put them at greater risk because of China's air and naval capabilities close to the mainland.

The United States could use aircraft as communications relays to extend the range of tactical data links. A high-altitude aircraft operating at 20,000 meters would have about a 500-kilometer line of sight to the horizon or a 1,000-kilometer line of sight to another aircraft at the same altitude (figure 3).[77] Large

74. Miranda Priebe et al., *Distributed Operations in a Contested Environment: Implications for USAF Force Presentation* (Santa Monica, CA: RAND, 2019), https://www.rand.org/pubs/research_reports/RR2959.html.
75. Carter, "Satellites and Anti-Satellites," pp. 52–55.
76. Norman Friedman, *Seapower and Space: From the Dawn of the Missile Age to Net-Centric Warfare* (Annapolis: Naval Institute Press, 2000), pp. 62–66.
77. Line of sight to the horizon is not always the same as the effective communications range.

Figure 3. High-Altitude Aircraft Could Extend the Range of Tactical Data Links



NOTE: See the online appendix for model details.

mesh networks of airborne communications relays could provide a more resilient way for the United States to share targeting intelligence over wide areas in the Pacific by dynamically rerouting communications through whatever nodes in the network were available. Implementing this concept at scale would likely require the United States to procure new unmanned systems.[78] Another short-term challenge is that not all data links in the U.S. military are interoperable. The different services have historically had separate data link ecosystems, and the United States is still working to make them interoperable through the Combined Joint All-Domain Command and Control (CJADC2) strategy.[79] In the future, the United States could leverage pockets of decentralized commu-

78. Some unmanned systems historically required humans to operate them via SATCOM links, but advances in autonomy are making drones more capable and resilient to disruptions.
79. Joseph Clark, "Hicks Announces Delivery of Initial CJADC2 Capability," *DOD News*, February 21, 2024, https://www.defense.gov/News/News-Stories/Article/Article/3683482/hicks-announces-delivery-of-initial-cjadc2-capability/.

nications networks that flexibly share information through available communications nodes and frequencies.[80]

If China only managed to degrade but not deny the U.S. military's access to SATCOM, doing so would moderate the impact on U.S. operational effectiveness. Attacks on communications satellites would reduce the overall bandwidth available, so the United States would need to set priorities for how to use what remained. As with any scarce commodity, conservation and rationing can help allocate bandwidth for vital needs. Managing SATCOM bandwidth would require the United States to prioritize and limit bandwidth-intensive practices, such as transmitting raw video feeds.

COUNTER-AIR OPERATIONS. The United States would benefit from SATCOM to coordinate its air operations, but it could mitigate the impact through decentralized approaches. The U.S. military's doctrine champions decentralization in theory, but in practice it has become accustomed to highly centralized command and control after operating in permissive environments in the Middle East.[81] The principle of mission command—centralized decision-making with decentralized execution—gives U.S. military personnel flexibility to adapt and manage ambiguities that arise during denied communications. Personnel can operate with a shared understanding of objectives and priorities. Instead of orchestrating one master plan from Hawaii, future air operations may resemble a mosaic of local air tasking orders.[82] This decentralized approach is less efficient but more resilient. U.S. fighter aircraft in a combat air patrol also do not necessarily need uninterrupted long-range communications, even if they would benefit from them. After two decades of centralization, reorienting the "software" of organizational practices to embrace distributed operations may be just as difficult as updating the "hardware" for new data links and data management systems.

Additionally, while fiber-optic cables are not a solution for tactical communications, undersea cable networks could preserve long-haul communications into and out of the theater. Fixed cables do not work for wireless communication with mobile forces, but they could help connect fixed facilities like air

80. Chris Dougherty, "Confronting Chaos: A New Concept for Information Advantage," *War on the Rocks*, September 9, 2021, https://warontherocks.com/2021/09/confronting-chaos-a-new-concept-for-information-advantage/.
81. Priebe et al., *Distributed Operations in a Contested Environment*, p. 48.
82. Rachel Coates, "Mosaic Tiger 24-1 Demonstrates Mission Command Concepts," *U.S. Air Force*, November 21, 2023, https://www.moody.af.mil/News/Article-Display/Article/3595859/mosaic-tiger-24-1-demonstrates-mission-command-concepts/.

bases. U.S. aircraft serving as communications relays could potentially connect tactical data links with ground stations in friendly countries like Japan and the Philippines, bridging data links and cable networks.[83] China might sever some undersea cables, especially those to Taiwan, but it would likely struggle to dismantle the entire undersea network in the Pacific.

MAINLAND STRIKES. The United States would have significant dependencies on SATCOM to pursue mobile targets on the Chinese mainland. Because having high-quality intelligence on these targets may be especially rare, and because the targets can relocate, it would be particularly important to rapidly disseminate that information to available shooters. This dependency is lower for fixed targets. There may sometimes be time-sensitive information about specific targets of opportunity at locations like ports or air bases, but there is not the same fundamental level of uncertainty as with mobile targets about whether targets of any value will still be there.

ASSESSMENT

The extent of U.S. dependence on space varies across the three missions. The United States has the lowest dependence on space for counter-air operations, which benefit from GPS precision timing for data links, SATCOM to coordinate operations, and ISR satellites to monitor Chinese air bases. The United States has an intermediate level of dependence on space for anti-surface warfare, which would benefit from ISR satellites to find Chinese ships, SATCOM to network together distributed sensors and shooters, and GPS to strike targets precisely at long ranges. The United States has the highest dependence on space to strike mobile ground targets on mainland China, which would likely depend almost entirely on ISR satellites to find targets, SATCOM to cue shooters, and GPS to guide weapons. But this target set is the least important, and the United States is better off forgoing it.

Examining the operational requirements of a Taiwan scenario can help assess how much degradation to its access to space the United States could afford. For China to seize Taiwan, it must be able to land and sustain enough forces on the island. Doing so makes China's amphibious transports the operational center of gravity in an invasion scenario, so anti-surface warfare is the most important U.S. mission. There are two potential metrics to assess U.S. requirements for anti-surface warfare to defeat the invasion. One potential metric is for the United States to destroy a significant share of China's amphibious

83. Cote, *Assessing the Undersea Balance Between the U.S. and China*, p. 26.

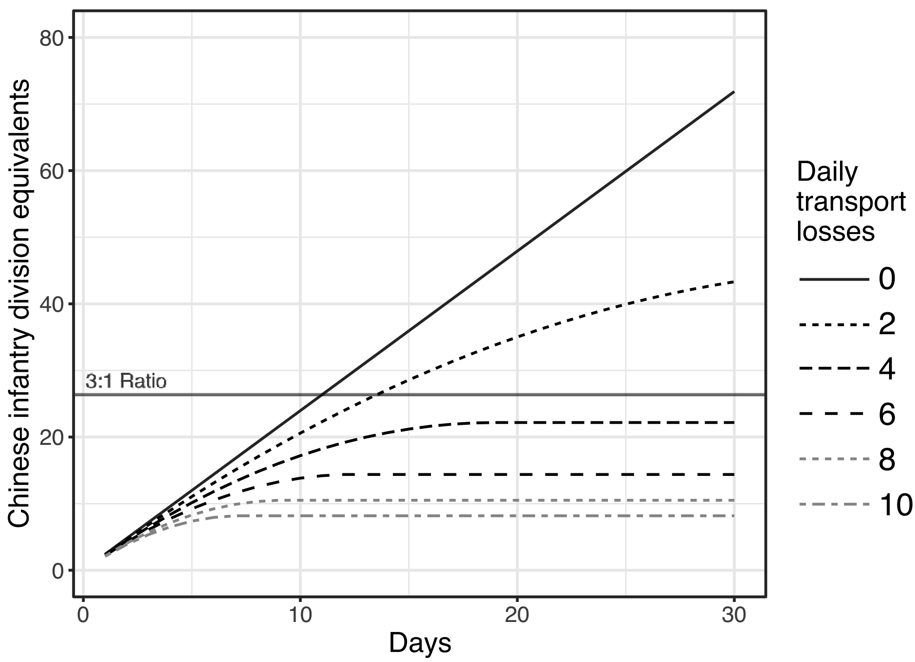
lift capacity, such as 50–75 percent of China's 78 military transports, or roughly 39–59 military transports.[84] These numbers exclude China's civilian lift capacity, which would supplement but not substitute for purpose-built military transports.[85] China could significantly increase its transport capacity if it were to either capture a port that Taiwan failed to sabotage (e.g., by sinking blocking ships at choke points) or use capabilities to bypass ports (e.g., by erecting floating piers).[86]

A second metric is how many forces China would need to transport to Taiwan to seize control. A classic rule of thumb is that the attacker wants a 3:1 advantage over the defender, which is an imperfect but useful heuristic for illustrative purposes here.[87] According to this defense planning principle, China would need about 270,000 troops to overcome Taiwan's active duty ground forces (before considering Taiwan's reservists).[88] Figure 4 shows how different loss rates to China's transports would affect this second metric.[89]

How could the United States satisfy the operational requirements for these two metrics with degraded or denied access to space? Ideally, it could rely on kill chains that depend less on space, such as short-range kill chains in which U.S. forces use their own sensors to find ships and their own tactical data links to communicate. Attack submarines are especially useful because they are a self-contained kill chain, and the United States has an enduring advantage over China in undersea warfare.[90] In 2017, RAND estimated that two attack submarine patrols in the Taiwan Strait could destroy an average of five transports a day.[91] Doing so would cause China to lose 50 percent of its military amphibious fleet in just eight days and 75 percent in twelve days, which would prevent China from achieving a 3:1 advantage over Taiwan. Other short-range kill chains with low dependence on space include undersea mines, Taiwanese anti-ship missile batteries, and stealthy strike fighters or bombers that ap-

84. See the online appendix for details. Wall, *The Military Balance*, pp. 240–241.
85. Conor M. Kennedy, "Getting There: Chinese Military and Civilian Sealift in a Cross-Strait Invasion" in *Crossing the Strait: China's Military Prepares for War with Taiwan*, in Joel Wuthnow et al., ed., (Washington, DC: National Defense University, 2022), pp. 223–252, https://ndupress.ndu.edu/Portals/68/Documents/Books/crossing-the-strait/crossing-the-strait.pdf.
86. Heginbotham et al., *The U.S.-China Military Scorecard*, p. 204n9.
87. Shlapak et al., *A Question of Balance*, p. 110. On the 3:1 rule and its limitations, see, especially, Paul Davis, *Aggregation, Disaggregation, and the 3:1 Rules in Ground Combat* (Santa Monica, CA: RAND, 1995).
88. Office of the Secretary of Defense, *Military and Security Developments*, p. 185.
89. See the online appendix for model details.
90. Cote, *Assessing the Undersea Balance Between the U.S. and China*, p. 6.
91. Heginbotham et al., *The U.S.-China Military Scorecard*, p. 211.

Figure 4. China's Military Capacity to Sealift Forces to Taiwan



SOURCE: Heginbotham et al., *The U.S.-China Military Scorecard*, p. 205.
NOTE: The y-axis represents how many "infantry division equivalents" China successfully transports to Taiwan (each contains 10,000 troops and their associated vehicles). Each line in the figure represents a different attrition rate (0–10 daily transport losses) for China's amphibious transports during the war's first month. For example, the United States fails to sink or disable any Chinese transports at baseline. See the online appendix for model details.

proach Taiwan. The Chinese military has improved significantly since 2017, however, raising uncertainty about the sufficiency of these methods and the risks to U.S. forces from operating so close to China.[92]

The United States could supplement these approaches with longer-range kill chains, but they would depend more on space to see and communicate over the horizon. For example, U.S. submarines, bombers, ships, or ground-based

92. Cancian, Cancian, and Heginbotham, *The First Battle of the Next War*, p. 89.

missile batteries could fire missiles while remaining over the horizon at a safer distance from China's naval and air forces.[93] But they would depend more on satellites to relay targeting information because they would not be close enough to find Chinese ships themselves. Depending on modeling assumptions, a salvo of fifty U.S. long-range cruise missiles might interdict about eleven ships at once without requiring the shooters to approach Chinese defenses.[94] The trade-off for adding such valuable lethality and safety to U.S. operations is that they would depend more on space. Degraded intelligence collection and SATCOM bandwidth would create inefficiencies that would make these kill chains less effective, but they would not entirely prevent long-range strikes. The biggest risk is denied access to GPS, which could prevent long-range weapons from hitting targets even if sensors and shooters found them. Additionally, given that a Chinese counterspace campaign would take time to significantly degrade U.S. space systems, there would be windows of opportunity early in the fighting to use capabilities that depend more on space.

In the long term, the United States has promising opportunities to reduce its dependence on space. For ISR, it can field a resilient terrestrial targeting mesh around Taiwan. For PNT, it can invest in backups to GPS for navigation and timing, including next-generation inertial sensors and atomic clocks. For SATCOM, it can procure drone relays for communications mesh networks, train for distributed operations, and secure fiber-optic cable networks. It can also strengthen self-contained kill chains with new unmanned submarines, smart mines, and mesh networks of runway-independent drones armed with anti-ship weapons. Bolstering Taiwan's own coastal defenses, such as helping it field more resilient sensing systems and more anti-ship cruise missile batteries, can also make allied kill chains more robust to degraded access to space. There is no structural reason that kill chains must be space-*dependent*, even if they remain space-*enabled* in the future.

In the short term, however, the extent to which China degrades or denies the United States' access to space would have a significant impact on the U.S. margin of advantage over China, even if alarmist predictions that U.S. forces would become completely ineffective are wrong. Critically, the United States

93. Ibid., p. 4; Shlapak et al., *A Question of Balance*, pp. 113–117.
94. This is the result from a notional RAND model. Shlapak et al., *A Question of Balance*, pp. 115–116n40. See the online appendix for model details.

depends much more on having *some* access to space than on having *uncontested* access. If the United States completely lost access to every space system, this worst-case scenario would raise the costs of fighting and increase the risks of defeat much more significantly than degraded access. The next section explains why extreme fears about decisive Chinese counterspace attacks are also overstated.

U.S. Resilience in Space

How resilient are U.S. satellite constellations against a Chinese counterspace campaign? This section highlights trends that are increasing the resilience of U.S. satellite architectures and analyzes underappreciated limitations of China's counterspace capabilities. The analysis focuses on five types of counterspace capabilities: direct-ascent ASATs, co-orbitals, jamming, directed-energy, and cyberattacks. Taking an operational-level perspective, the analysis highlights variation in (1) a Chinese counterspace campaign's *capability* to attack satellites in different orbits; (2) its *capacity* to attack large numbers of satellites; and (3) its *tempo*—that is, whether Chinese attacks could generate significant effects within an operationally relevant timeframe.

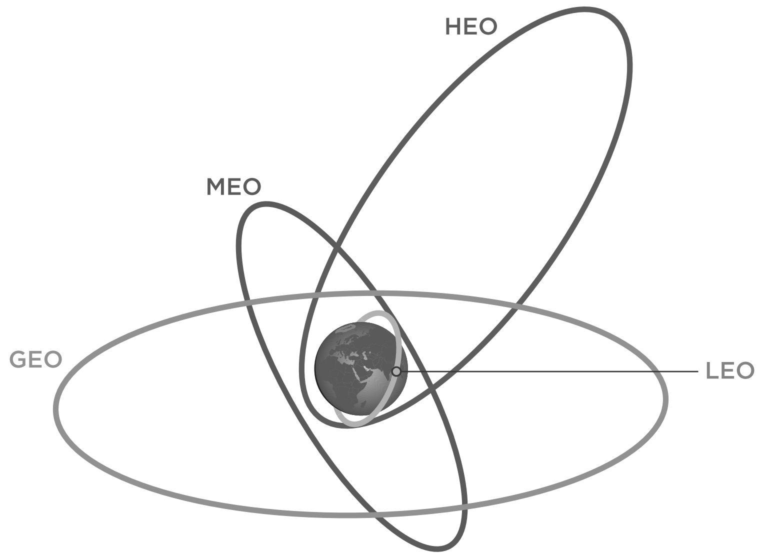
DIRECT-ASCENT ASATS

CAPABILITY. Direct-ascent ASATs are missiles that use interceptors to destroy satellites. The U.S. government reports that China has an operational direct-ascent ASAT system capable of striking satellites in Low Earth Orbit (LEO) and "likely intends to field" another system that can reach Geostationary Orbit (GEO) in the future.[95] China has demonstrated its ability to target satellites in LEO with repeated testing. The U.S. government cites one suspected 2013 test as evidence that China "may already have a basic ASAT capability against higher orbits."[96] But open-source experts describe China's capability against higher orbits as "likely still in the experimental or development phase"—that is, it will not be operational without additional testing.[97]

This distinction in China's mature capability to strike satellites in LEO but

95. "Space Threat Fact Sheet" (Washington, DC: Headquarters Space Force Intelligence, April 29, 2024), p. 1.
96. Ibid.
97. Weeden and Samson, *Global Counterspace Capabilities*, chap. 3, p. 11.

Figure 5. Satellite Orbits



SOURCE: *Challenges to Security in Space* (Washington, DC: Defense Intelligence Agency, 2019), p. 12.
NOTE: The image shows four satellite orbits: GEO (Geostationary Orbit); HEO (Highly Elliptical Orbit); LEO (Low Earth Orbit); and MEO (Medium Earth Orbit).

not in higher orbits is significant because these orbits have different physical characteristics and host different kinds of space systems.[98] Figure 5 visualizes the four key orbits. LEO has an altitude up to 2,000 kilometers, and each orbit takes about 90 minutes (the "orbital period"). Imaging satellites generally operate in LEO because resolution decreases over distance, but the trade-off for doing so is that they observe only a small portion of the Earth at any given moment. Satellites in LEO therefore need to operate as part of a constellation to provide persistent coverage over a specific area; the time between satellites passing over an area decreases as the number of satellites in the constellation increases. Because signal strength also decreases over distance, there are incentives to operate some ELINT and SATCOM systems in LEO.[99] Satellites in GEO operate at an altitude of 35,786 kilometers, which puts about 70 percent of a

98. This paragraph draws on the first principles descriptions in: Carter, "Satellites and Anti-Satellites," pp. 48–52; Wright, Grego, and Gronlund, *The Physics of Space Security*, pp. 19–48.
99. This logic also applies to using Low Earth Orbit (LEO) for positioning, navigation, and timing (PNT), given a large enough constellation for coverage.

given hemisphere within their field of view. At zero degrees of inclination and eccentricity, the orbit's speed matches the Earth's rotation, creating a 24-hour orbital period that allows satellites to loiter persistently over a spot on the equator. This combination of range and persistence makes GEO ideal for communications and early warning. The two other orbits are Medium Earth Orbit (MEO), which includes a series of orbital bands up to 35,000 kilometers that countries primarily use for PNT satellites, and Highly Elliptical Orbit (HEO), which is a sparsely populated orbit with a roughly 40,000-kilometer apogee and a roughly 500-kilometer perigee. HEO is useful for surveillance and communication over the north and south poles.

China's direct-ascent ASATs pose a major challenge to individual satellites in LEO. Defending any one satellite in LEO from a direct-ascent weapon is structurally challenging. The flight time is only 5–15 minutes, which leaves little time for the satellite to maneuver to avoid interception, especially because many satellites are not designed to maneuver rapidly.[100] Attacking the ASAT launchers themselves would be difficult because they are likely mobile.[101] Attacking the Chinese space domain awareness capabilities guiding these weapons would likely be more effective, but the large phased-array radars that reportedly guided China's 2007 ASAT test are also part of its nuclear early-warning system, so escalation concerns could deter U.S. attacks.[102] Given these limitations, it is difficult to make individual satellites in LEO resilient.

China's direct-ascent ASATs do not yet pose a major challenge to satellites in higher orbits. China cannot simply use the same direct-ascent ASAT against targets in LEO and MEO or GEO because reaching higher orbits requires more capable missiles, just like a short-range ballistic missile cannot hit the same targets as an intercontinental ballistic missile.[103] Additionally, the flight time to GEO takes several hours, creating greater opportunities for defensive maneuvers and countermeasures, if defenders have invested in them.[104] Because GPS is in MEO and some military SATCOM constellations are in GEO, those systems are currently under comparatively low threat from direct-ascent attacks. In the long term, the United States cannot count on diversified orbits alone because China can field longer-range ASATs.

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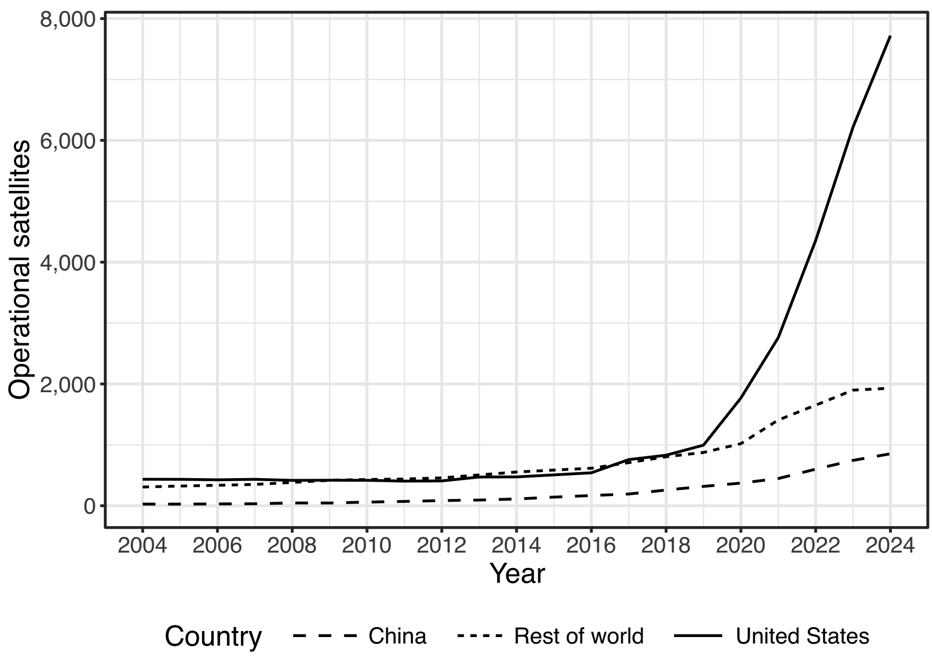
100. Weeden and Samson, *Global Counterspace Capabilities*, chap. 3, p. 16.
101. Ibid.; Ochmanek et al., *Inflection Point*, p. 23.
102. Brian Garino and Jane Gibson, "Space System Threats," in Brian C. Tichenor, coord., *AU-18 Space Primer* (Maxwell Air Force Base, AL: Air University Press, 2009), chap. 21, p. 277.
103. Sankaran, "Limits of the Chinese Antisatellite Threat to the United States," p. 24.
104. Harrison, Johnson, and Young, *Defense Against the Dark Arts in Space*, pp. 17–18.

Figure 6. The Growth of Satellites in Orbit



SOURCE: Todd Harrison, "Operational Satellites," in Space Data Navigator, American Enterprise Institute, 2025, https://spacedata.aei.org.

CAPACITY. The rapidly growing number of satellites in orbit is creating new challenges for China's capacity for direct-ascent attacks. Defense analysts have had long-standing fears that the U.S. military's small constellations of extremely capable satellites, often referred to as "exquisite" systems, concentrated too much value into too few potential targets. In 2017, then–Commander of Strategic Command John Hyten referred to exquisite satellites as "big, fat, juicy targets."[105] Technological innovation has started to address this problem. Advances in miniaturizing satellites and reducing launch costs are bringing about a revolution in space architectures—new proliferated constellations in LEO have hundreds or thousands of smaller and cheaper satellites rather than a handful or a dozen of exquisite satellites. Figure 6 visualizes the rising number of satellites in orbit.

105. Sandra Erwin, "STRATCOM Chief Hyten: 'I Will Not Support Buying Big Satellites That Make Juicy Targets,'" *SpaceNews*, November 19, 2017, https://spacenews.com/stratcom-chief-hyten-i-will-not-support-buying-big-satellites-that-make-juicy-targets/.

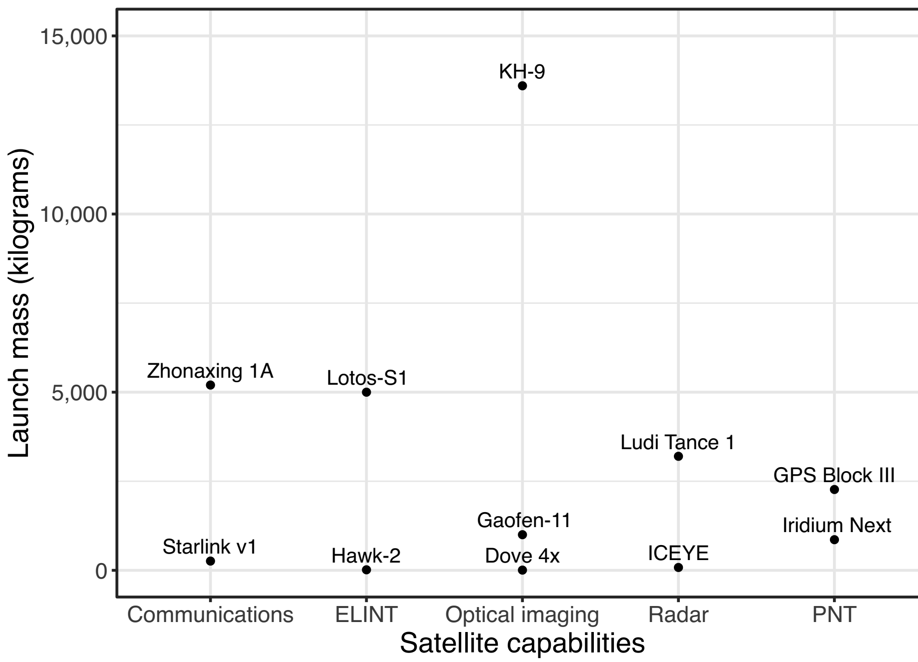
Proliferated constellations with larger numbers of smaller and cheaper satellites will make U.S. space architectures more resilient. At the operational level, proliferated constellations distribute vulnerability over more nodes, which compensates for the loss of any one satellite. Presenting so many targets can strain the attacker's finite inventory of ASATs. It is unclear how many direct-ascent ASATs China has in its inventory, but the overall size of China's missile forces suggests in principle that it could build many ASATs if it chose to do so. In the short term, it is unlikely that China's inventories have kept pace with the exponential increase of targets.

In the long term, why could China not easily solve this capacity problem by building proportionately larger inventories of direct-ascent ASATs? Doing so would likely not be a cost-effective solution to the challenge that proliferated constellations create. At the tactical level, small satellites and lower launch costs are reducing the long-standing cost advantages that ASATs have had over satellites. ASATs historically had these extremely large cost advantages because their interceptors were much lighter than satellites and because lofting objects through orbit requires less energy than accelerating them into orbit.[106] The U.S. government's declassified KH-9 Hexagon imaging satellite from the Cold War reportedly weighed 13,600 kilograms.[107] By contrast, an ASAT interceptor might weigh as few as a dozen kilograms (though it could be significantly heavier depending on design factors such as maneuverability).[108] Figure 7 visualizes how satellite miniaturization has reduced asymmetries in mass between ASATs and their targets. The U.S. company Planet Labs has a 5-kilogram "Dove" optical imaging satellite—2,226 times smaller than the KH-9—that provides about 3-to-5-meter resolution imagery.[109]

Small satellites will rarely match the capabilities of exquisite satellites, but this is not necessary to support military operations. Design features like smaller antennae and smaller power sources necessarily constrain performance attributes like resolution and signal strength.[110] Small satellites generally operate in LEO, however, and that closer proximity to Earth can help partially counterbalance these limitations. Small satellites will never match the resolution of the bus-sized, billion-dollar imaging satellites that supported

106. Biddle and Oelrich, "Future Warfare in the Western Pacific," p. 25.
107. Dwayne A. Day, "The HEXAGON and the Space Shuttle," *Space Review*, October 31, 2011, https://www.thespacereview.com/article/1960/1.
108. Oelrich, van Hooft, and Biddle, "Anti-Satellite Warfare, Proliferated Satellites," pp. 3–4.
109. Saadia M. Pekkanen, Setsuko Aoki, and John Mittleman, "Small Satellites, Big Data: Uncovering the Invisible in Maritime Security," *International Security*, Vol. 47, No. 2 (Fall 2022), pp. 177–216, https://doi.org/10.1162/isec_a_00445.
110. Oelrich, van Hooft, and Biddle, "Anti-Satellite Warfare, Proliferated Satellites," p. 5.

Figure 7. Comparing the Mass of Exquisite and Small Satellites



SOURCES: "Satellite Database," Union of Concerned Scientists, 2023, https://www.ucs.org/resources/satellite-database; "Global Positioning System," *U.S. Space Force Fact Sheets*, 2020, https://www.spaceforce.mil/About-Us/Fact-Sheets/Article/2197765/global-positioning-systems; Dwayne A. Day, "The HEXAGON and the Space Shuttle," *Space Review*, October 31, 2011, https://www.thespacereview.com/article/1960/1.

NOTE: Iridium is a communications constellation that also provides PNT services (after acquiring Satelles in 2024). Small satellite alternatives to GPS lag behind those for ISR and SATCOM. The Zhonaxing 1A, Gaofen-11, and Ludi Tance 1 satellites are modern Chinese military satellites. The Lotos-S1 is a Russian military satellite.

missions like arms control verification in the Cold War. But they do not always need the best possible resolution. Detecting and identifying Chinese warships is reportedly possible with 5-meter resolution imagery.[111] Small satellites are so valuable not because they offer exquisite performance, but because the United States could afford to field them at an exponentially larger scale while retaining sufficient performance for many tasks.

Beyond satellite size, changes in satellite launch costs also benefit the de-

111. Heginbotham et al., *The U.S.-China Military Scorecard*, p. 161n33.

fender. Launch costs have fallen roughly by a factor of ten over the past decade because of advances in launch technologies and greater competition in the commercial launch market.[112] Some satellites still weigh more than interceptors, but small satellites have an additional cost advantage in that many are now placed in orbit through ride-sharing on partially reusable launch vehicles. Accounting for the reduced unit costs of putting many satellites into orbit at once, this is likely cheaper than the expendable ballistic missiles used for direct-ascent ASATs. To launch one 50- or 500-kilogram satellite to LEO, SpaceX charged $330,000 or $3.25 million, respectively.[113] Factoring in the cost of the satellite itself, a Starlink satellite might cost around $2.02 million (260 kilograms) or $5.55 million (730 kilograms).[114] The unit cost of China's direct-ascent ASAT is unknown, but it might be around $5–11 million per missile based on similar Chinese ballistic missiles.[115] The tactical-level cost advantages of direct-ascent ASATs are therefore diminishing and may even become negative for some but not all satellites. The challenge for the attacker becomes even more significant at the operational level. From a force structure perspective, marginal tactical-level cost advantages matter less if the target set is large enough that the attacker must procure many more missiles (e.g., 500 rather than just 50) to generate large operational effects.

A caveat to the promise of proliferated constellations is that the U.S. military is still in the process of fielding its own proliferated architecture. Table 1 breaks down U.S. satellites in orbit by user, showing that the commercial sector is driving recent growth. Table 2 summarizes the U.S. military's announced plans to launch new proliferated constellations. The U.S. intelligence community has its own proliferated architecture, and it reports that it launched about one hundred new imaging satellites from 2023 to 2024 alone.[116] The U.S. mili-

112. Oelrich, van Hooft, and Biddle, "Anti-Satellite Warfare, Proliferated Satellites," p. 5.
113. "Smallsat Rideshare Program," SpaceX, accessed January 14, 2025, https://www.spacex.com/rideshare/.
114. These estimates assume that SpaceX did not give itself a discount. Sandra Erwin, "Starlink Soars: SpaceX's Satellite Internet Surprises Analysts with $6.6 Billion Revenue Projection," *SpaceNews*, May 9, 2024, https://spacenews.com/starlink-soars-spacexs-satellite-internet-surprises-analysts-with-6-6-billion-revenue-projection/.
115. China's main direct-ascent anti-satellite (ASAT) weapon is reportedly based on the DF-21 family of missiles. The DF-21D are estimated to cost $5–11 million. Weeden and Samson, *Global Counterspace Capabilities*, chap. 3, p. 11; Henry Hendrix, *At What Cost a Carrier?* (Washington, DC: Center for a New American Security, 2013), p. 8, https://www.cnas.org/publications/reports/at-what-cost-a-carrier.
116. Audrey Decker, "'You Can't Hide': Spy Agency Will Have 100 New Sats on Orbit by Year's End," *Defense One*, October 3, 2024, https://www.defenseone.com/threats/2024/10/you-cant-hide-spy-agency-will-have-100-new-sats-orbit-years-end/400047/.

Table 1. U.S. Satellites in Orbit, 2024

	Civil	Commercial	Military
Intelligence, surveillance, and reconnaissance	5	208	160
Communications	9	7,111	78
Positioning, navigation, and timing	—	1	32
Missile warning	—	4	25
Weather	11	3	4
Space surveillance	—	—	8
Scientific	25	30	28
Total	50	7,357	335

SOURCE: Harrison, "Operational Satellites."
NOTE: SpaceX accounted for most of the U.S. commercial communications satellites (6,866).

tary's greater reliance on commercial providers while its own constellations take shape raises questions about the effectiveness of commercial satellites and the U.S. military's ability to use them.

First, can commercial providers offer the capabilities that U.S. forces need? A key feature of the emerging environment in space is that the gap in capabilities between civilian and military systems has shrunk. The war in Ukraine has demonstrated the growing military value of commercial SATCOM and ISR. For example, Starlink has become central to Ukrainian military communications, and the company HawkEye 360's small ELINT satellites have mapped Russian GPS jamming so that Ukrainian drones can adjust their flight paths.[117] Yet commercial PNT is an important exception that lags behind ISR and SATCOM. This disparity is partly because the U.S. government's free provision of GPS reduces market incentives for private alternatives.

Second, can the U.S. military effectively integrate commercial capabilities into its battle networks? Integrating these commercial capabilities poses a greater challenge because the United State would need to ensure that terrestrial users have the right equipment to interface with commercial satellites.[118] It also needs agreements with companies to ensure continued access to com-

117. Warren P. Strobel and Robert Wall, "Ukraine War Puts Spy Satellites for Hire in the Spotlight," *Wall Street Journal*, May 1, 2022, https://www.wsj.com/articles/ukraine-war-puts-spy-satellites-for-hire-in-the-spotlight-11651410002.
118. Jonathan P. Wong et al., *Leveraging Commercial Space Services* (Santa Monica, CA: RAND, 2023), pp. 9–11, https://www.rand.org/pubs/research_reports/RRA1724-1.html.

Table 2. U.S. Military's Announced Plans for Proliferated Constellations

Tranche	Fiscal year	Type	Number
0	2022	Communications	20
		Missile tracking	8
1	2024+	Communications	126
		Missile tracking	35
		Experimentation	12
2	2026	Communications	~216
		Missile tracking	~52
		Experimentation	~20
3	2028	Communications	Unknown
		Missile tracking	Unknown
		GPS-independent PNT	Unknown
4	2030	Unknown	Unknown
Total			~489+

SOURCES: Rachel Zisk, "The Proliferated Warfighter Space Architecture (PWSA), *Payload*, December 5, 2022, https://payloadspace.com/ndsa-explainer/; Greg Hadley, "SDA Awards $1.5 Billion for 72 New 'Transport' Satellites to Lockheed and Northrop," *Air & Space Forces Magazine*, August 21, 2023, https://www.airandspaceforces.com/sda-72-new-satellites-2026/; David Vergun, "Space Development Agency Will Soon Deliver Capability to Warfighters," *DOD News*, September 5, 2024, https://www.defense.gov/News/News-Stories/Article/Article/3896274/space-development-agency-will-soon-deliver-capability-to-warfighters/.

NOTE: In 2024, the Space Development Agency announced some delays of Tranche 1 beyond the originally stated Fiscal Year 2024 timeframe (Vergun 2024).

mercial systems during a war. The U.S. military has extensive experience and contracts with commercial space providers, and it has started to field new equipment, such as Starlink terminals.[119] But it will take time to more fully integrate commercial and military capabilities. The Space Force has announced that accelerating this integration is a top priority, and successfully doing so is critical to strengthening short-term resilience.[120] There are similar opportuni-

119. The U.S. military has a long history of using commercial satellite communications (SATCOM), which provided around 80 percent of SATCOM bandwidth in Iraq and Afghanistan. Bryan Eberhardt, Kenneth Kemmerly, and Paul Konyha III, "Satellite Communications," in Tichenor, *AU-18 Space Primer*, chap. 14, p. 183; Joseph Trevithick, "Starlink Now Being Deployed on U.S. Navy Warships," *War Zone*, August 22, 2024, https://www.twz.com/sea/starlink-now-being-deployed-on-u-s-navy-warships.

120. *U.S. Space Force Commercial Integration Strategy* (Washington, DC: Space Force, 2024), https://www.spaceforce.mil/Portals/2/Documents/Space%20Policy/USSF_Commercial_Space_Strategy.pdf.

ties and constraints to the United States leveraging the space capabilities of its allies and partners. Allied integration would provide another way to bolster U.S. resilience in space, but the United States would need to ensure interoperability, and it would face potential concerns about the reliability of access to systems that the U.S. government does not directly control.[121]

TEMPO. China faces a limitation in its ability to generate large effects within an operationally relevant timeframe. Even if direct-ascent ASATs retain tactical-level cost advantages against some satellites, at the operational level it will still take time before the attacker can destroy enough satellites to significantly degrade the defender's systems, especially against proliferated constellations. If it takes China three months to dismantle U.S. proliferated constellations, for example, the United States will have a significant window to use capabilities that depend heavily on space. During the Cold War, the U.S. military's goal was a modest "6–10 intercepts in a week" against Soviet satellites.[122] If China were to complete ten intercepts a day, it would take almost two years to destroy just SpaceX's satellites (before considering the massive debris that doing so would create).[123]

The United States could create additional tempo challenges by reconstituting lost satellites to further slow China's progress. Reconstitution has historically been slow, but the record time between receiving orders and launching a satellite decreased from twenty-one days in 2021 to twenty-seven hours in 2023.[124] SpaceX has launched 143 satellites at once, which raises the possibility that intermittent launches could restore temporary windows of access to space that take time to close again.[125]

Given these constraints, China's best options against proliferated constellations will be either to settle for non-kinetic alternatives like jamming or to use indiscriminate attacks that destroy many satellites at once. The U.S. gov-

121. Bruce McClintock et al., *Allied by Design: Defining a Path to Thoughtful Allied Space Power* (Santa Monica, CA: RAND, 2024), https://www.rand.org/pubs/research_reports/RRA1739-1.html.
122. "Memorandum from the Deputy Chief of the Office of Assistant Director (Smith) to the President's Assistant for National Security Affairs (Scowcroft)," Washington, DC, November 3, 1976, *FRUS, 1969–1976*, Vol. E–3, doc. 137, p. 3, https://history.state.gov/historicaldocuments/frus1969-76ve03/d137.
123. Harrison, "Operational Satellites."
124. Eric Lipton, "Intelligence About Russia Puts Focus on New U.S. Satellite Push," *New York Times*, February 15, 2024, https://www.nytimes.com/2024/02/15/us/politics/satellites-russia-us-intelligence.html.
125. Jackie Wattles, "SpaceX Launches 143 Satellites on One Rocket in Record-Setting Mission," *CNN*, January 25, 2021, https://www.cnn.com/2021/01/24/tech/spacex-rideshare-transporter-mission-scn/index.html.

ernment claims that Russia is considering this indiscriminate approach with an ASAT capability to detonate a nuclear weapon in space.[126] Nuclear use could create havoc in orbit, but it would also require China to start a nuclear war. This would involve tremendous escalation risks, and there is little evidence that China is seriously considering doing so. Research on Chinese doctrine actually points in the opposite direction—China appears to have a growing preference for discriminate and calibrated counter-space attacks.[127]

Another major consideration is that direct-ascent attacks create orbital debris, which could damage or destroy other satellites. There are concerns about triggering a tipping point in LEO called the "Kessler syndrome," whereby spiraling debris cascades make the orbit unusable.[128] China's own growing dependence on space has made it increasingly worried about debris, including "fratricide" concerns that debris created by a direct-ascent attack could end up destroying its own satellites.[129] Similar concerns apply to fears of escalation and triggering U.S. retaliation against its satellites. Combined with the practical difficulties of destroying proliferated constellations, China might rely primarily on non-debris producing capabilities, such as jamming communications signals and dazzling the sensors on reconnaissance satellites, while only using direct-ascent ASATs against certain exquisite military satellites.

In the long term, China could develop more cost-effective direct-ascent ASATs. For example, it might develop the capability to launch large salvos of cheaper interceptors from high-altitude aircraft, which might replace the use of expensive ballistic missiles.[130] If China succeeded, concerns about debris and escalation would become particularly important in deterring these mass attacks.

126. "Space Threat Fact Sheet," p. 1.
127. Jonas Vidhammer Berge and Henrik Stålhane Hiim, "Killing Them Softly: China's Counterspace Developments and Force Posture in Space," *Journal of Strategic Studies*, Vol. 47, No. 6–7 (2024), pp. 940–963, https://doi.org/10.1080/01402390.2024.2388658; Fiona S. Cunningham, *Under the Nuclear Shadow: China's Information-Age Weapons in International Security* (Princeton, NJ: Princeton University Press, 2025).
128. Brendan Rittenhouse Green and Caitlin Talmadge, "Then What? Assessing the Military Implications of Chinese Control of Taiwan," *International Security*, Vol. 47, No. 1 (Summer 2022), pp. 7–45, https://doi.org/10.1162/isec_a_00437.
129. Vidhammer Berge and Hiim, "Killing Them Softly"; Fiona Cunningham, "Maximizing Leverage: Explaining China's Strategic Force Postures in Limited Wars" (PhD dissertation, Massachusetts Institute of Technology, 2018), pp. 333, 349–350, https://dspace.mit.edu/handle/1721.1/121602?show=full.
130. Oelrich, van Hooft, and Biddle, "Anti-Satellite Warfare, Proliferated Satellites," pp. 6–7.

CO-ORBITALS

CAPABILITY. Co-orbital ASATs are satellites or space planes that operate in orbit and can attack satellites using capabilities like mechanical arms or jammers. The main advantage of co-orbital ASATs is that they strengthen China's capability to attack satellites in higher orbits. Whereas ground-based ASATs are the most threatening against targets in LEO, space-based ASATs are better at reaching targets in higher orbits. China has conducted dual-use technology demonstrations like debris removal that demonstrate its ability to develop co-orbital ASATs.[131] From December 2021 to January 2022, China's SJ-21 tug satellite rendezvoused with a broken BeiDou satellite in GEO and took 4–6 days to move it into a graveyard orbit.[132] China could use this kind of capability to move U.S. satellites as well. To defend against these kinds of attacks, the United States would need to use defensive satellite maneuvers, deploy its own co-orbital systems as "bodyguard" satellites, or rely on architectural defenses such as having large constellations that are diversified across multiple orbits.[133]

CAPACITY. China's capacity to use co-orbital ASATs at scale likely remains limited. Open-source experts have tracked Chinese tests of co-orbital space systems, and fewer than a dozen satellites have demonstrated the kind of maneuvers that would best support co-orbital attacks.[134] There is also uncertainty about how many of China's co-orbital systems are designed to collect intelligence on satellites rather than to attack them directly.[135] In the long term, though, China could field more co-orbital ASATs to threaten satellites in higher orbits at scale.

TEMPO. A major limitation of co-orbital attacks is that they can be slow. As the SJ-21 demonstrated, maneuvering into position for an attack in GEO can take several days unless the attacker has already pre-propositioned its co-orbital ASATs close to their targets.[136] The tempo challenges may become

131. *Annual Threat Assessment of the U.S. Intelligence Community* (Washington, DC: Office of the Director of National Intelligence, February 5, 2024), p. 11, https://www.dni.gov/files/ODNI/documents/assessments/ATA-2024-Unclassified-Report.pdf.
132. Weeden and Samson, *Global Counterspace Capabilities*, chap. 3, p. 8.
133. Kaitlyn Johnson, Thomas G. Roberts, and Brian Weeden, "Mitigating Noncooperative RPOs in Geosynchronous Orbit," *ÆTHER*, Vol. 1, No. 4 (Winter 2022), pp. 79–94, https://www.airuniversity.af.edu/Portals/10/AEtherJournal/Journals/Volume-1_Number-4/Weeden_Mitigating_Noncooperative_RPOs_.pdf.
134. China has also tested three robotic space planes. Weeden and Samson, *Global Counterspace Capabilities*, chap. 3, pp. 5–11.
135. Ibid., chap. 3, p. 10.
136. Ibid., chap. 3, p. 11.

even larger if the defender is maneuvering to avoid attack. Repositioning co-orbital ASATs after each attack could therefore slow down the tempo of a Chinese campaign.

JAMMING

CAPABILITY. Jamming targets the electronic links between satellites and their users. The main advantage of jamming is that China can degrade U.S. space capabilities without the debris and escalation risks of destroying satellites. "Uplink jamming" targets satellites to drown out their ability to receive signals from terrestrial forces.[137] "Downlink jamming" targets terrestrial forces to drown out their ability to receive signals from satellites, such as jamming a GPS receiver on a missile or aircraft. China's military doctrine and exercises heavily emphasize jamming, including targeting communications satellites, radar imaging satellites, and GPS.[138] Ukraine has demonstrated the serious threat that jamming can pose to communications and GPS signals for both unprotected commercial systems and some military systems.[139]

Jamming also has limitations rooted in the laws of physics that defenders can exploit. Jammers need to operate within line of sight of the satellite or ground receiver, which limits their range. For downlink jamming, Chinese jammers would need to be close to U.S. weapons or platforms to prevent them from receiving signals, so the risks decrease with distance from the mainland.[140] The biggest advantage that downlink jammers have is that signal strength degrades over distance, and jammers broadcast much closer to targets than do satellites. The defender has a variety of technical countermeasures to help offset this asymmetry, such as quickly hopping across unjammed parts of the spectrum and using jam-resistant equipment like directional antennae that listen for signals only from certain areas and "null" out unwanted interference.[141] These types of countermeasures do not eliminate the challenge that jamming poses, but they do moderate the problem.

Proliferated constellations in LEO will improve resilience against uplink

137. This section draws on the first principles discussion in: Wright, Grego, and Gronlund, *The Physics of Space Security*, p. 166.
138. "Space Threat Fact Sheet," p. 1.
139. Thomas Gibbons-Neff and Yurii Shyvala, "How Electronic Warfare Is Reshaping Ukraine's Battlefields," *New York Times*, March 12, 2024, https://www.nytimes.com/2024/03/12/world/europe/ukraine-drone-russia-jamming.html.
140. Wright, Grego, and Gronlund, *The Physics of Space Security*, p. 166.
141. Davenport and Ganske, "'Recalculating Route'"; Harrison, Johnson, and Young, *Defense Against the Dark Arts in Space*, p. 15.

jamming. Whereas uplink jammers can attack GEO satellites from wide areas because the satellites have a large footprint and effectively loiter in one spot, having a line of sight to satellites in LEO requires jammers to attack from within a much smaller, constantly shifting footprint. The farther away Chinese uplink jammers are from U.S. forces, the longer the "jam-free" communications window becomes when a satellite in LEO is within line of sight of U.S. forces but not yet high enough on the horizon for the jammer to see it.[142] Additionally, because jammers must emit powerful signals close to their targets, they are also susceptible to geolocation and counterattack.

CAPACITY. China's strong doctrinal commitment to jamming and its decades-long development program suggests in principle that it may have a large number of jammers.[143] Jammers are also reusable, unlike direct-ascent ASATs that attackers can only use once. But proliferated constellations in LEO could still create capacity challenges. China would need multiple uplink jammers in a given area to dynamically track and target the multiple satellites that could be overhead at once. For example, there are about eleven Starlink satellites within view of Taiwan at any given moment.[144] China would also need to field multiple jammers in all areas where it wanted to degrade U.S. communications.

TEMPO. If jammers are within line of sight of a satellite or a terrestrial receiver, they can quickly emit signals. But jammers still need to be in the right place at the right time, which narrows the windows during which they can generate effects. They also need to repeatedly jam targets to keep them suppressed over time, whereas destructive attacks offer permanent effects.

DIRECTED-ENERGY

CAPABILITY. Directed-energy weapons interfere with imaging satellites by temporarily dazzling or permanently blinding their sensors. The main advantage of directed-energy weapons is that they provide a reusable way for China to degrade U.S. satellite imagery without generating debris. China has "multiple ground-based laser weapons" designed to target satellite sensors.[145] In the "mid-to-late 2020s," China reportedly might finish developing higher-power

142. Timothy M. Bonds et al., *Employing Commercial Satellite Communications* (Santa Monica, CA: RAND, 2000), p. 77.
143. Heginbotham et al., *The U.S.-China Military Scorecard*, pp. 249–251.
144. Timothy M. Bonds, *Keeping the World Close: How Taiwan Can Maintain Contact with Allies, Supporters, and Its Own People If Attacked* (Santa Monica, CA: RAND, 2023), pp. 14–15, https://www.rand.org/pubs/perspectives/PEA2557-1.html.
145. "Space Threat Fact Sheet," p. 1.

weapons that can damage other satellite structures besides sensors, which could threaten a broader range of targets beyond imaging satellites.[146]

As with other counterspace capabilities, directed-energy weapons have limitations. First, it is easier to dazzle satellites than to blind them, but doing so requires attacking satellites each time they pass overhead.[147] Second, like jammers, directed-energy weapons need a direct line of sight to the satellite. This requires weapons to be close to what they are trying to hide because they need to attack from within the satellite's field of view. Third, there are a range of technical countermeasures available to the defender. These include using filters or shutters to protect sensors, using optical designs that manage stray light and thereby limit how many pixels in an image dazzling obscures, and shielding other satellite components against high-powered attacks.

CAPACITY. China's capacity to use directed-energy weapons likely remains limited. The U.S. government has described China's lasers as providing only a "limited capability."[148] Researchers have identified five Chinese facilities suspected of having directed-energy weapons, but they note uncertainty about China's overall capacity.[149] Proliferated constellations could create capacity challenges for small numbers of directed-energy systems. Directed-energy weapons can only attack one target at a time, but proliferated constellations can have multiple satellites overhead at once. China would therefore need to distribute multiple weapons across every area that it wants to hide. In the long term, however, China could field large numbers of mobile systems to help offset U.S. progress with proliferated imaging constellations.

TEMPO. Like jammers, directed-energy weapons have tempo limitations in that they need to be in the right place at the right time. The attacker must wait for targets in LEO to pass overhead, limiting the pace at which it can suppress or damage the defender's satellites. For dazzling attacks, the weapon must repeatedly target the same satellite to keep it suppressed.

CYBERATTACKS

CAPABILITY. Cyberattacks could target the computer networks that militaries use to operate satellites rather than the satellites themselves, potentially cor-

146. "Space Threat Fact Sheet," p. 1.
147. This section draws on the first principles discussion in: Wright, Grego, and Gronlund, *The Physics of Space Security*, pp. 123–135.
148. *Challenges to Security in Space* (Washington, DC: Defense Intelligence Agency, 2022), p. 17, https://www.dia.mil/Portals/110/Documents/News/Military_Power_Publications/Challenges_Security_Space_2022.pdf.
149. Weeden and Samson, *Global Counterspace Capabilities*, chap. 3, p. 19; Kristin Burke,

rupting data or interfering with the ability to operate satellites. The main advantage of cyberattacks is that successful attacks could degrade or disable proliferated constellations en masse without having to target satellites one at a time. Chinese cyberattacks have targeted U.S. space infrastructure in the past, such as a 2014 attack on a government computer system that managed data for nonmilitary weather satellites.[150]

Although cyberattacks are a serious concern, breaching well-resourced and properly defended computer networks is much more difficult than many often assume.[151] Because private companies sometimes underinvest in cybersecurity to cut costs, the risk of cyberattacks against commercial space providers requires sustained attention.[152] There will likely be variation in cybersecurity across different commercial providers. For example, Russia conducted a successful cyberattack in 2022 against the SATCOM company Viasat, but cyberattacks against other companies, such as SpaceX, have accomplished little since.[153]

CAPACITY. There are two important capacity limitations for cyberattacks. First, cyberattacks do not necessarily become more difficult as the number of satellites in a constellation increases, but they do become more difficult as the number of computer networks in the target set increases. If multiplier commercial providers or allies support a mission area, China would need to orchestrate successful cyberattacks across multiple different networks.[154] Second, skilled personnel are critical to successful attacks against hardened networks.[155] China devotes significant resources to cyber operations, but its finite number of skilled personnel would still face competing demands on their attention to space systems versus other targets.[156]

TEMPO. The main tempo limitation for cyberattacks is that finding and exploiting cyber vulnerabilities can take significant time.[157] If the attacker has

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"Where Are the PLA's Other Laser Dazzling Facilities?," (Maxwell Air Force Base, AL: China Aerospace Studies Institute, 2023), https://www.govinfo.gov/content/pkg/GOVPUB-D301-PURL-gpo215 076/pdf/GOVPUB-D301-PURL-gpo215076.pdf.

150. Weeden and Samson, *Global Counterspace Capabilities*, chap. 14, p. 5.

151. Rebecca Slayton, "What Is the Cyber Offense-Defense Balance? Conceptions, Causes, and Assessment," *International Security*, Vol. 41, No. 3 (Winter 2016/17), pp. 72–109, https://doi.org/10.1162/ISEC_a_00267.

152. Ibid, p. 81.

153. Weeden and Samson, *Global Counterspace Capabilities*, chap. 14, p. 6.

154. Wong et al., *Leveraging Commercial Space Services*, p. 16.

155. Slayton, "What Is the Cyber Offense-Defense Balance?," p. 85.

156. Heginbotham et al., *The U.S.-China Military Scorecard*, pp. 260–277.

157. Slayton, "What Is the Cyber Offense-Defense Balance?," p. 83.

already developed exploits before the war starts, it might be able to use them quickly. Otherwise, developing entirely new exploits might be a slow-moving process.

ASSESSMENT

Resilience in space varies significantly depending on the characteristics of the defender's satellite constellations and the attacker's counterspace capabilities. A Chinese counterspace campaign would face practical limitations related to capability, capacity, and tempo. Given these limitations, China could likely degrade but not deny U.S. access to space in any given mission area.

In the short term, China's capabilities pose the greatest challenge to small constellations of exquisite satellites in LEO. The U.S. military is still in the process of fielding its own proliferated architectures in LEO, but it can leverage commercial providers as a bridge to greater resilience for ISR and SATCOM. Satellites in higher orbits, such as GPS and some SATCOM systems, face threats from jamming and potentially co-orbital attacks on a limited scale. But China lacks a robust direct-ascent ASAT capability against them.

In the long term, trend lines are positive for the United States because it is investing in more resilient space systems and architectures. Proliferated constellations offer resilience for several reasons: They can degrade more gracefully as they lose nodes; they create capacity challenges and cost inefficiencies for direct-ascent ASATs; and they might deter China from widespread destructive attacks because of concerns about debris and escalation. China's direct-ascent ASATs are still a concern, though, because China could use them to attack exquisite satellites while relying on jamming and dazzling against small satellites with less capable countermeasures. Fielding large numbers of directed-energy weapons, jammers, and decoys, along with other deceptive tactics, will preserve China's ability to degrade and counter U.S. space systems, even if complete denial remains out of reach.[158] If China fields direct-ascent ASATs that can reach MEO and GEO, this capability will also put GPS and other SATCOM systems under greater threat. But SATCOM already has proliferated constellations in LEO as a backup, and the U.S. government has announced plans to field a new PNT architecture as a backup to GPS (see table 2). The new PNT architecture will be particularly important to reinforcing U.S. resilience because commercial alternatives to GPS lag behind other areas.

158. Oelrich, van Hooft, and Biddle, "Anti-Satellite Warfare, Proliferated Satellites."

The findings suggest that the offense-defense balance in space is less offense-dominant than it once was. At the tactical level, the cost-effectiveness of using direct-ascent ASAT attacks is declining. At the operational level, obstacles related to the speed and scale of counterspace campaigns will increase as proliferated constellations become common. Small satellites and proliferated constellations are not panaceas, but they are significant advantages for defenders. Quick and easy counterspace campaigns are increasingly unlikely. Even if the long-term equilibrium of a protracted conflict is that the attacker denies the defender access to space, it will take time to reach that equilibrium. During that transition period, which could take months, the defender will continue to benefit from space to support its operations.

Conclusion

Space has become central to how modern militaries operate, but discussions about how space and counterspace capabilities will shape the future of war often remain vague and alarmist. This article has developed a framework for assessing the military balance in space and applied that framework to a U.S.-China conflict over Taiwan. The findings highlight variation in the extent of U.S. dependence on space and the resilience of U.S. space systems. Past trends for both dependence and resilience have generally been negative for two reasons: (1) China's military modernization and expansion have put pressure on U.S. forces to depend more on satellites for long-range operations; and (2) China has fielded an array of new counterspace capabilities to target U.S. satellites. These negative trends are concerning, but there is a risk to overstating the magnitude of the challenge. Degraded access to space would decrease the margin of the U.S. military's advantage over China, but the United States has meaningful countermeasures and backups to moderate the extent of the impact. China has significant counterspace capabilities, but a Chinese counterspace campaign would face practical limitations that make worst-case scenarios unlikely.

The direction of these trends is changing. The resilience of U.S. space systems is increasing as proliferated constellations start to supplement exquisite architectures. The U.S. military has opportunities to leverage the growth of the commercial U.S. space sector while it fields its own proliferated architectures. The United States also has promising opportunities to reduce its dependence on space. Some solutions involve emerging technologies, ranging from autonomous drones for resilient targeting and communications mesh networks to quantum sensors for GPS-free navigation and timing. Other solutions require embracing new operational concepts or organizational adaptation rather than new technologies. These include training for decentralized operations in low-bandwidth environments and fixing bureaucratic problems to field new capabilities quicker.

China's improved counterspace capabilities will reduce U.S. operational effectiveness, even if they are not wonder weapons that will generate decisive strategic effects. The U.S. military's approach to force planning has focused on maintaining a qualitative edge at the expense of quantity, but degraded access to space would make the fighting in a U.S.-China war more attritional. For example, degraded overhead reconnaissance would incentivize the United States to push more aircraft closer to the forward edge of the battle. Degraded accuracy would also incentivize the United States to expend more munitions to hit the same number of targets. This kind of fighting could increase U.S. wartime losses and potentially strain the United States' force structure. As the United States considers how to rebalance quantity versus quality in its force structure, this article's findings caution against overcorrecting. For example, investing in more expensive but better long-range missiles that can operate effectively without GPS would be more cost-effective than building a massive number of cheap munitions that cannot reliably hit targets in jammed environments. By forcing the United States to invest in more robust terrestrial backups and new space architectures, China's counterspace program will still impose a peacetime cost on the United States even if a war over Taiwan never occurs.

China's dependence on space is an increasingly key part of the military balance. Defense analysts in the post–Cold War era have viewed one of space's defining features as a striking asymmetry, in which the United States enjoyed a quasi-monopoly over the military use of space while its competitors viewed space only through the lens of how to deny the United States those advantages.[159] That dynamic is over. China has been investing in not only counterspace capabilities but also new satellite capabilities to enable its own military operations. China's orbital presence grew from 36 satellites in 2010 to over 1,000 satellites in 2024.[160] This includes almost 500 ISR satellites that the U.S. government reports can "enable long-range precision strikes against

159. Krepon et al., "China's Military Space Strategy."
160. Theresa Hitchens, "China's Space Moves: Highly Mobile Satellites Stalking GEO Spook Space Force," *Breaking Defense*, December 10, 2024, https://breakingdefense.com/2024/12/chinas-space-moves-highly-mobile-satellites-stalking-geo-spook-space-force/.

U.S. and allied forces."[161] As China's dependence on space increases, concerns about debris and retaliation may incentivize Beijing to restrain the scope of its counterspace attacks to limited options like jamming, dazzling, and cyberattacks.

Many of the same challenges and trade-offs that apply to Chinese counterspace campaigns would also apply to a U.S. campaign against China. How should the United States balance the desire to limit China's access to space while managing escalation and debris? How can it cost-effectively degrade proliferated constellations at the necessary scale? To sharpen the United States' offensive capabilities, the article's findings suggest that investments in jamming and directed-energy weapons will be more cost-effective for countering China's proliferated constellations, though kinetic attacks may still have a role against exquisite systems. Investing in large numbers of advanced decoys will also be critical. Confusing and polluting China's overhead sensing networks may be a more promising approach than destroying the sensors themselves. Countermeasures like dispersion, deception, and concealment can help mitigate the impact of China's space-based sensing, though these adaptations can make U.S. operations less effective and involve trade-offs of their own.

Finally, there is still a concern that China could miscalculate about what it can accomplish by attacking U.S. space systems. While the Chinese military has reportedly become less optimistic about the extent of the effects that counterspace attacks would generate, some elements may still "regard space as a great vulnerability that if denied, can so debilitate an enemy that victory can be achieved."[162] As in 1941, a space Pearl Harbor today would not be the knock-out blow that the attacker envisioned. But the analogy could still prove to be accurate. Misperceptions could encourage China to attack U.S. space systems that are not actually an Achilles' heel but are alluring enough to invite escalation and a costly conflict.

161. "Space Threat Fact Sheet," p. 1.
162. Pollpeter, "Space, the New Domain," p. 714. On recent trends, see Cunningham, *Under the Nuclear Shadow*.