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Special Issue
International Space Policy

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FROM THE EDITOR

Dear Reader,

This year, the most comprehensive and widely approved treaty applicable to the space domain, the 1967 Outer Space Treaty, turns 56. A new UN working group on "reducing space threats through norms, rules, and principles of responsible behaviours," established in November 2021, met twice last year and will meet twice this year.[1] At the conclusion of the first session, the representatives from the Canadian government summarized the findings. All countries (1) desired to preserve "the use of space for peaceful purposes, and for it to remain a domain free from conflict"; (2) recognize[d] the need for accessibility to space; (3) agreed "with the principle of due regard," and (4) desired "to prevent an arms race in space."[2]

As international military and commercial use of Earth and Moon orbits and deeper space exploration expand, the global need to address the space commons grows increasingly urgent. In recognition of this critical time in history, our Winter 2022 issue is devoted entirely to the subject of international space policy with a focus on military activities. The two fora in the issue reflect the focus of our *Æther: a Journal of Strategic Airpower & Spacepower* and *Air & Space Operations Review* (*ASOR*) unified flagship Department of the Air Force journal effort—one strategic and one operational.

Certain themes emerge throughout the issue. States recognize the importance of being active civil and military participants in space, out of necessity and out of national pride. The complexity of national goals make the roles of adversaries and allies more opaque than headlines would otherwise conclude or alliances would suggest, yet the need for formal Alliances and partnerships in space activities is clear. The reassuring global commitment, at some level, to adhere to and desire clarity in international space law rests somewhat uneasily against states' national security requirements and historical state practice in space. Throughout, there is a recognition that the higher ground of space—the leading frontier for science and human exploration—is held by competing national, civil, and commercial interests.

1. UN Office for Disarmament Affairs (UNODA), "Open-Ended Working Group on Reducing Space Threats," UNODA (website), 2022, https://meetings.unoda.org/.

2. Government of Canada, "Canadian Statement," (delivered at the open-ended working group on reducing space threats, first session, Geneva, Switzerland, May 13, 2022), 2, https://documents.unoda.org/.

The International Space Strategy forum leads with an article by Jiemin Hou that discusses the probability of the People's Liberation Army taking preemptive deterrent actions against US assets in space in the event of a Taiwan invasion. The author recommends denying military benefits to the PLA and raising Beijing's strategic costs in an effort toward deterrence. In our second article in the forum, Michael Listner takes us to a broader view of international space law and considers the history of national security space activities in light of over 65 years of the Outer Space Treaty, specifically two legal rights and one legal duty under Article IX of that treaty.

Our third article in the forum by John Burton, Domenic Thompson, Alessandro Papa, and Arthur Wong discusses NATO's recently adopted Overarching Space Policy and its effort to establish international norms of space behavior. The forum closes with an article by Mohammad Ali Zafar and Ayesha Zafar reviewing the over 60-year history of Pakistan's space program. They conclude it is in Pakistan's best interest to establish a national space policy.

In the first article of our Space Operations forum, Adam Wilmer and Robert Bettinger provide an update to their summer 2022 *ASOR* article discussing a new taxonomy for Earth-Moon system orbits that includes emerging space law considerations. The second article, by Kaitlyn Johnson, Thomas Roberts, and Brian Weedon, discusses noncooperative rendezvous proximity operations and offers four policy options for mitigating these potentially escalatory activities, namely improved space situational awareness, pattern of life information sharing, keep-out zones, and guardian satellites.

In our third article in the forum, Alexander Jehle and Alexander Gentzel propose an international, civilian-led, in-space logistics infrastructure to conserve propellant and promote exploration and reliable use of space and its resources, modeled in part on terrestrial global petroleum distribution architecture. Our final article of the forum and the issue, by Liberty Shockley, discusses the operational aspects and international law compliance of the nascent Lawn Dart Program, an unattended ground sensor system deployed to the lunar surface that would provide security assets for lunar exploration and space missions. **Æ**

–The Editor

OFFENSIVE DEFENSE

PEOPLE'S LIBERATION ARMY LOGIC OF PREEMPTION IN SPACE

Jiemin Hou

The People's Liberation Army has incentives to strike preemptively against US space assets in a Taiwan invasion scenario. Doing so would cripple the US Joint Force's ability to project power into the theater before the fight. Denying and degrading US military space capabilities increases the probability of victory and lowers the costs of war for the Chinese Communist Party. But the military advantage gained by striking first does not necessarily translate into a strategic advantage for the Party. This analysis examines the costs and benefits calculi at the operational and strategic levels to understand China's preemption motives. It also evaluates three alternative options to preemption in space to derive a US deterrence strategy. Denying a military benefit while raising the strategic cost to China provides a basic guiding principle to deter and hedge against Beijing's potential decision to preempt in space.

According to a Chinese 2019 defense white paper, achieving complete reunification with Taiwan is in "the fundamental interests of the Chinese nation and essential to realizing national rejuvenation."[1] Chinese Communist Party (CCP) leader Xi Jinping stated in his 20th Party Congress speech that the "wheels of history are rolling on toward China's reunification and the rejuvenation of the Chinese nation. Complete reunification of our country must be realized, and it can, without doubt, be realized!"[2] As an instrument of CCP policy, the People's Liberation Army (PLA) will be tasked to reunify Taiwan if and when necessary.

The PLA will increase its chance of success if it prevents the United States from intervening. Due to the US military dependence on space, the PLA is developing and fielding a full spectrum of counterspace capabilities designed to exploit US vulnerabilities.[3] The common perception suggests space is an offense-dominant domain, which

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1. People's Republic of China (PRC) Ministry of National Defense (MoD), "China's National Defense in the New Era," 2019 White Paper (Beijing: PRC MoD, 2019), http://eng.mod.gov.cn/.
2. Low De Wei, "Full Text of Xi Jinping's Speech at China's Party Congress," Bloomberg, October 18, 2022, https://www.bloomberg.com/.
3. Office of the Secretary of Defense (OSD), *Defense Space Strategy Summary* (Washington, DC: Department of Defense (DoD), June 2020), 3, https://media.defense.gov.

increases the incentive for the PLA to attack in space preemptively.[4] Preemptive attacks against US space capabilities could potentially paralyze the US miliary in coming to Taiwan's aid.

Without the US mounting an effective intervention, the PLA increases its probability of victory in reunifying the island and lowers the costs of war for Beijing. But the operational advantages of preemption in space do not necessarily translate into strategic gains. Examining the costs and benefits calculi at the operational and strategic levels will clarify reasons behind a future decision by China to act preemptively in space.

This article makes two assumptions to reduce the number of variables influencing China's decisions. 1) The PLA will be militarily ready or highly confident in its ability to forcefully reunify Taiwan if and when given the order to execute; and 2) China will have unambiguous indications and warnings of the United States committing to intervention before China decides to strike preemptively in space.

Although a US military intervention is contingent on clear CCP intention to reunify Taiwan by force, the United States has reasons to develop and maintain an ongoing capability to intervene due to the critical factor of time. When Washington discovers the true intentions of the Chinese Communist Party, it may be too late to deny the PLA from landing on Taiwan and establishing a foothold.

Conversely, it would also be wise for PLA planners to assume the United States will intervene because failing to account for such a scenario could jeopardize its chance of success.[5] These assumptions thus remove PLA readiness and the uncertainty of US intervention from the CCP decision calculus. This article analyzes the remaining key variables and examines how they contribute to preemption motives.

Why Preempt?

When an adversary attack is imminent, striking first is preferable to absorbing the first blow. Preemption can make the subsequent conflict less damaging and may lead to a quick victory by shifting the balance of force in favor of the attacker.[6] In some cases, it can be the difference between victory and defeat.[7] Preemption can be

4. China Aerospace Studies Institute (CASI), "Webinar for ACC on PRC Counter Space 2020 08 11," Youtube, video, 1:26:29, https://www.youtube.com/; Brad Townsend, "Strategic Choice and the Orbital Security Dilemma," *Strategic Studies Quarterly* 14, no. 1 (Spring 2020): 64, https://www.airuniversity.af.edu/; and M. V. Smith, "Spacepower and the Strategist," in *Strategy: Context and Adaption from Archidamus to Airpower*, ed. Richard J. Bailey Jr., James W. Forsyth Jr., and Mark O. Yeisley (Annapolis, MD: Naval Institute Press, 2016), 171.

5. M. Taylor Fravel and Christopher P. Twomey, "Projecting Strategy: The Myth of Chinese Counter-intervention," *Washington Quarterly* 37, no. 4 (Winter 2015): 182, https://www.taylorfravel.com/.

6. Williamson Murray, "Preemptive Strike or Preventive War?," Strategika, August 29, 2017, https://www.hoover.org/.

7. Karl P. Mueller et al., *Striking First: Preemptive and Preventive Attack in U.S. National Security Policy* (Arlington, VA: RAND Corporation, 2006), xi–xii.

justified as self-defense, and it is accepted as a legitimate use of force when the threat is imminent.[8]

In addition to a greater chance of victory, preemption allows the attacker to seize the initiative in choosing the time, place, and scope of the attack. Nevertheless, preemption bears significant strategic costs. Striking the first blow can damage a nation's reputation in the international community, especially when the imminence of the threat is dubious or there are other options to neutralize the threat without using force. In these instances, the attacker incurs global political costs.[9]

Attacking preemptively may also weaken international norms and set a precedent that may come back to haunt the attacker; for example, the aggressor may become the victim of preemption in the future. Furthermore, preemption may deepen the victim's enmity toward the attacker, resulting in a more bloody and protracted conflict. Given these disadvantages, operational successes from preemption can translate into a strategic disaster.

Two variables contribute to the preemptive decision: the degree of certainty of the threat and the first-strike advantage.[10] Greater certainty of the imminent threat and first-strike advantage make preemptive attacks more attractive. The assumption of China having unambiguous indications and warnings regarding a US intervention removes one of these two variables from consideration. The first-strike advantage becomes the dominant contributing factor, one that depends on the net changes in the probability of victory and the costs of war. Preemption is appealing when it increases the probability of victory, reduces war costs, or both.

Preemption motives can also emerge from the prevailing conditions, particularly when the state of military affairs and technology favor the offense.[11] Offense is dominant when it is easier to attack than to defend or when it is more costly to defend than to attack. Preemptive attacks are less costly to execute in an offense-dominant environment. Nevertheless, the decision to strike first depends not on the actual but the perceived offense dominance, first-strike advantage, and reduction in the costs of war. Understanding the value of space to the Party and the People's Liberation Army capabilities provides key insights to China's perceptions.

Space and PLA Capabilities

Space is key to developing China's comprehensive national power. The Chinese dream of national rejuvenation envisions China becoming a global leader with

8. Matthew J. Flynn, *First Strike: Preemptive War in Modern History* (New York: Routledge, 2008), 1–2.
9. Alan M. Dershowitz, *Preemption: A Knife That Cuts Both Ways* (New York: W. W. Norton & Co., 2006), chap. 3; and Mueller, *Striking First*, xiii, 42.
10. Mueller, *Striking First*, xiii.
11. Mueller, 27.

national strength by 2049.[12] China competes for space resources for economic development by focusing on Moon mining, space-based solar power, and asteroid mining.[13]

Space also serves as a platform for China to pursue technological innovations. Over the past two decades, China's space programs grew rapidly, and it became one of the most capable spacefaring nations. China has built constellations of communication, remote-sensing, and navigation satellites. China now operates five spaceports and launch sites with various launch vehicles to access space. China is also constructing a manned space laboratory and engaging in lunar, Mars, and deep-space explorations. Furthermore, space allows China to gain national prestige and international influence as a leading actor in charting the international governance for space.[14] In short, space is essential to national rejuvenation in making China "rich, strong, and proud."[15]

China develops its counterspace capabilities to protect its own interests in space and to win wars against the United States. China sees space as critical for its national and social development in strategic competition.[16] China also understands the military advantage of space from observing how the US military wages war. The 2020 *Science of Military Strategy* argues "Western countries headed by the United States have clearly gained unprecedented war advantages from space."[17] To achieve space dominance, the PLA has developed a wide variety of kinetic and nonkinetic counterspace capabilities.

The PLA puts antisatellite weapons in three broad categories: kinetic, directed energy, and electronic warfare. These weapons can produce permanent nonreversible "hard kills" or temporary reversible "soft kills."[18] Space weapons can be co-orbital or terrestrial-based (air, land, and sea). The PLA is developing space weapons across

12. Xi Jinping, "Secure a Decisive Victory in Building a Moderately Prosperous Society in All Respects and Strive for the Great Success of Socialism with Chinese Characteristics for a New Era" (address, 19th Communist Party Congress, Beijing China, October 18, 2017), 5–6.

13. Kevin Pollpeter et al., *China's Space Narrative: Examining the Portrayal of the US-China Space Relationship in Chinese Sources and Its Implications for the United States* (Maxwell AFB, AL: China Aerospace Studies Institute, 2020), 48; and Namrata Goswami and Peter A. Garretson, *Scramble for the Skies: The Great Power Competition to Control the Resources of Outer Space* (New York: Lexington Books, 2020), 21–22.

14. State Council of the People's Republic of China (PRC), "China's Space Program: A 2021 Perspective," State Council 2021 Space White Paper, accessed October 21, 2022, http://english.www.gov.cn/; and Defense Intelligence Agency (DIA), *2022 Challenges to Security in Space: Space Reliance in an Era of Competition and Expansion* (Washington, DC: DIA, March 2022), 8–18.

15. Pollpeter et al., *China's Space Narrative*, 8.

16. PRC MoD, 2019 White Paper.

17. PLA Academy of Military Science, *In Their Own Words: Science of Military Strategy 2020* (Maxwell AFB, AL: China Aerospace Studies Institute, January 2022), 145, https://www.airuniversity.af.edu/.

18. PLA Academy of Military Science, *In Their Own Words: Lectures on the Science of Space Operations, Foreign Military Thought* [2012](Maxwell AFB, AL: China Aerospace Studies Institute, August 12, 2022), 137–38, https://www.airuniversity.af.edu/.

these categories.[19] For instance, China demonstrated its direct-ascent antisatellite capability by destroying satellites in low Earth orbit (LEO) in January 2007. This test created more than 3,000 pieces of space debris.[20]

China is also developing an array of ground-based, directed-energy and electronic warfare weapons that can produce both destructive and reversible effects on satellites ranging from temporary blinding to physical destruction. The PLA possesses sophisticated jammers and routinely exercises jamming against communication and Global Positioning System (GPS) signals.[21]

Furthermore, China is actively testing co-orbital technology that can translate into antisatellite capabilities. In January 2022, China tested the Shijian-21 satellite in maneuvering and conducting a rendezvous and proximity operation and tugged a Compass G2 satellite into the geosynchronous graveyard orbit. Another Shijian satellite, the SJ-17, is reported to have a robotic arm capable of grabbing another satellite.[22]

These capabilities can be used for satellite inspection and maintenance missions, but they can also perform antisatellite missions because the technology and knowledge are transferrable. In 2021, the annual US Department of Defense report to Congress on China's military and security highlighted Beijing's continuing intent to develop antisatellite weapons capable of destroying satellites up to geosynchronous orbit.[23] If the United States does not match this full spectrum of counterspace capabilities, China will likely have escalation dominance in space.

PLA Perceptions

Active Defense

Attacking first in space is consistent with PLA's Active Defense strategy. At its core, active defense is offensive defense and decisive defense, "combining offense with defense, insisting on the unity of strategic defense and offensive in battle."[24] In other words, operational and tactical offensives, such as preemption in space, can be justified and considered as strategic defense.[25]

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19. DIA, *Security in Space*; Todd Harrison et al., *Space Threat Assessment 2022* (Washington, DC: Center for International & Strategic Studies, April 2022), 8–10, https://csis-website-prod.s3.amazonaws.com/; and Brian Weeden and Victoria Samson, *Global Counterspace Capabilities: An Open Source Assessment* (Washington, DC: Secure World Foundation, April 2022), 03-01–03-24.

20. Weeden and Samson, *Global Counterspace Capabilities*, 03-15.

21. DIA, *Security in Space*, 17.

22. Harrison et al., *Space Threat Assessment*, 24, 28.

23. OSD, Military and Security Developments involving the People's Republic of China, 2021 (Washington, DC: DoD, November 2021), 85–86, https://media.defense.gov/.

24. PLA, *Military Strategy 2020*, 31; and M. Taylor Fravel, *Active Defense: China's Military Strategy since 1949* (Princeton, NJ: Princeton University Press, 2019), 61.

25. Joe McReynolds, ed., *China's Evolving Military Strategy* (Washington DC: Brookings Institute Press, 2016), 21, https://www.jstor.org/.

The 2013 *Science of Military Strategy* links active defense to the space domain. It states China "pursues a defensive national defense policy and a military strategy of active defense, advocates peaceful use of outer space, and persists in holding that each nation has an equal right to open-up develop and exploit outer space."[26] The 2012 *Lectures on the Science of Space Operations* states this linkage more explicitly by stating that space operations in wars should follow the guiding thought of "active defense, full-spectrum integration, and a focus on control of space."[27] In sum, under the framework of Active Defense, the CCP will most likely justify a preemption in space as strategic self-defense.

Winning Informatized Local War

PLA strategy also centers around winning informatized local war as directed by the 2015 Chinese Communist Party strategic guideline to the People's Liberation Army.[28] The PLA sees information capabilities such as cyber warfare and psychological operations as important factors in influencing the outcome of war. The targets for these capabilities are the adversary's "information detection sources, information channels, and information processing and decision-making centers."[29] War will manifest in a systems-versus-systems confrontation across multiple domains.

Another key tenet of winning informatized local war is building capabilities that deny the ability of a powerful state to gain and maintain access to operating areas that hold Chinese interests at risk.[30] As China's most capable adversary, the threat posed by the US military inevitably drives PLA resource allocation and organizational structures.

In late 2015, the PLA began implementing major reforms to promote joint effectiveness in winning informatized local wars. The PLA consolidated seven military regions into five theater commands, each consisting of ground, naval, air, and missile forces.[31] Additionally, the Strategic Support Force (SSF) was established to support the theater commands. The SSF consolidated PLA's intelligence, space, cyber, and electronic warfare capabilities under one organization.[32]

The Strategic Support Force's responsibilities include managing PLA space assets for intelligence, global positioning, and defense against electronic warfare and other hostile activities.[33] The SSF is an operational force and an essential component in securing China's access to space and contributing to the overall anti-access capabilities.

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26. PLA Academy of Military Science, *In Their Own Words: Foreign Military Thought, Science of Military Strategy (2013)* (Maxwell AFB, AL: China Aerospace Studies Institute, 2021), 232, https://www.airuniversity.af.edu/.

27. PLA, *Lectures*, 50.

28. Andrew Scobell et al., *China's Grand Strategy: Trends, Trajectories, and Long-Term Competition* (Arlington, VA: RAND Corporation, 2020), 74; and PLA, *Military Strategy 2020*, 109–10, 182.

29. PLA, *Military Strategy 2020*, 183.

30. Scobell et al., *China's Grand Strategy*, 77.

31. Scobell et al., 84; and PRC MoD, 2019 White Paper.

32. Scobell et al., 88; and PRC MoD 2019 White Paper.

33. Scobell et al., 95.

Military Value of Space

The PLA likely perceives space as an offense-dominant domain with significant first-strike advantage. Consequently, it is making substantial investments in a variety of offensive capabilities to contest the command of space.[34] The PLA recognizes space as an independent domain with strategic values as the "commanding height" in influencing the outcome of the war.[35]

First, space contributes to strategic deterrence.[36] Due to the US reliance on space for warfighting, PLA counterspace capabilities act as a part of an overall strategic deterrence to prevent the United States from interfering with its "peaceful rise."[37] Second, space is essential for the PLA to develop a modern fighting force to defend China's expanding global interests around the world. These capabilities include space-based intelligence to support long-range precision strikes. Finally, the PLA recognizes the strategic value of space to warfighting, as discussed above.[38]

The 2013 *Science of Military Strategy* assesses outer space as an essential element of modern war and that "future wars may begin in outer space and cyberspace."[39] Therefore, the PLA must develop space offensive and defensive capabilities for these reasons.[40] By building strong military capabilities in space, the PLA possesses the ability to hold any nation with space dependence at risk.

The importance of space to military operations is again emphasized in the 2020 *Science of Military Strategy*. "The dominance of space has been inseparable from the outcome of the war, which determines that the military conflict in space will revolve around the dominance of the space [domain]."[41] To achieve space dominance, the PLA is developing and fielding a multitude of electronic warfare, directed-energy weapons, and terrestrial-based and orbital antisatellite capabilities.[42] These capabilities also allow the PLA to exercise deterrence by controlling the escalation dominance in the domain.

Escalation in space may result in the Kessler Syndrome rendering space unusable for all, which also harms Chinese interests. China is becoming increasingly dependent on space to advance its political, economic, military, and technological goals. Yet there are three asymmetries favoring China.

The first asymmetry comes from America's economic reliance on space. For example, GPS enables a wide variety of economic activities from finance and logistics to farming. Furthermore, US companies such as SpaceX and Blue Origin are forming an

34. OSD, *Space Strategy Summary*, 3.
35. McReynolds, *Military Strategy*, 265; and PLA, *Military Strategy (2013)*, 226.
36. PLA, 234–35.
37. PLA, 139, 200, 234–35.
38. McReynolds, *Military Strategy*, 266; and PLA, *Military Strategy (2013)*, 226, 229.
39. McReynolds, 285; and PLA, 118.
40. PLA, 229.
41. PLA, *Military Strategy (2020)*, 145.
42. DIA, *Security in Space*, 17–18.

innovative space industry—a distinct US competitive advantage over China. The second asymmetry is the US military's dependence on space, discussed further in the next section. The third asymmetry is America's network of alliances and partners. The most advanced spacefaring nations, including Britain, Japan, Australia, France, and India, are US Allies or partners. Escalation in space disproportionally and negatively impacts the US alliance network and partnership compared to China.

Due to these asymmetries, the comparative cost-benefits analysis of space becoming unusable likely favors China—it ultimately impacts China less negatively due to their relative level of investment in space compared to the United States, its Allies, and its partners. Therefore, the PLA can achieve escalation dominance by exploiting these asymmetries and the resulting advantages by possessing a full spectrum of counterspace capabilities. People's Liberation Army military writings and the manifested counterspace capabilities suggest the PLA perceives an offense dominance and significant first-strike advantage in space. The PLA has the incentives and capability to conduct preemptive attacks against the United States in space.

Operational Alternatives to Preemption in Space

Preemption in space is attractive because it degrades the US ability to project power to interfere with the armed reunification with Taiwan. Without a credible US intervention, the PLA has a higher probability of victory in occupying Taiwan by force. It also renders the US military less effective in inflicting damages on the PLA, thus lowering the costs of war. For this discussion, PLA preemptive attacks in space involve destroying or degrading US space-based capabilities resulting in the US military being unable to intervene in an invasion of Taiwan.

The intended effects on US assets would be nonreversible through the use of kinetic or nonkinetic weapons. The GPS constellation is an obvious choice for preemptive attacks, but such an attack would result in wide-ranging impacts and unintended consequences because of the global economic and civil dependence on GPS.

US military communications satellites on geosynchronous and geostationary orbits are better targets for preemptive attacks. These satellites enable tactical force employment and command and control functions. They are few in number and with fixed coverage over a specific region of the globe. The PLA only needs to target a few to degrade the US military communication networks in the Pacific region. China's Shijian satellites may able to perform the targeting function. With its robotic arms, the Shijian satellites can produce a range of damaging effects such as destroying key components or sending a satellite tumbling.

Another set of potential targets are communications and intelligence, surveillance, and reconnaissance (ISR) satellites in low Earth orbit. The PLA has multiple options for targeting them such as high-power lasers that can damage the sensors and direct-ascent antisatellite to destroy the spacecraft.

A decision matrix helps visualize the preemptive attack option and potential outcomes for the PLA. Taking US intervention into account, the following decision matrix looks at two alternative options for the PLA: preempt in space or not preempt. The aim of preemption in space is to render the US military ineffective in threatening PLA military objectives and inflicting costs. The PLA would expect the following outcomes:

1. If the United States is willing and able to intervene, preemption will degrade or deny US intervention. Preemption increases PLA's probability of victory while reducing its costs of war. The expected outcome is an increased likelihood the PLA will take Taiwan.
2. If the United States is unwilling to intervene, preemption will provoke an undesirable US retaliatory response. But the United States will be unable to intervene in a consequential way, thus increasing the probability of victory and reducing the costs of war for the PLA. The expected outcome is an increased likelihood the PLA will take Taiwan.
3. If the United States is willing and able to intervene, not preempting will not hinder the US intervention. So, the PLA is uncertain about its probability of victory and expects high costs of war. The prospect of the PLA taking Taiwan becomes questionable.
4. If the United States is unwilling to intervene, not preempting will not provoke a US response. The PLA expects a high probability of victory with low costs of war. The expected outcome is an increased likelihood the PLA will take Taiwan.

Table 1. Operational alternatives for preemption in space

	US willing and able to intervene	US unwilling to intervene
Preempt	Outcome 1 Degrade or deny US intervention Increases probability of victory Reduces costs of war PLA likely takes Taiwan	Outcome 2 Provokes a US response Increases probability of victory Reduces costs of war PLA likely takes Taiwan
Not preempt	Outcome 3 US intervenes Uncertain probability of victory Expects high costs of war PLA takes Taiwan questionable	Outcome 4 No US response–lacks political will High probability of victory Expects low costs of war PLA likely takes Taiwan

The PLA would rank these outcomes in the following order from most preferred to least preferred: Outcome 4 > Outcome 2 > Outcome 1 > Outcome 3. With the assumption China will have reliable intelligence regarding the US commitment to intervention, the PLA is left with a choice between Outcome 1 and Outcome 3. The perception of offense dominance in space and first-strike advantage would increase the preference for a preemptive attack.

Even without taking US intervention as a given, the PLA has several reasons and the capability to degrade US space capabilities before a conflict. First, the US military relies on space to project power. Space assets enable military command and control, ISR, precision weapons employment, navigation, missile warning, and weather forecast. These capabilities have given the US military an asymmetric advantage in war. Moreover, they allow the United States to project power globally and will remain a critical dependence moving forward.

Indeed, space is indispensable to Joint all-domain command and control by connecting sensors and operators across multiple domains over vast distances.[43] When space-based capabilities are degraded or denied, the US military will be a less effective fighting force. On the other hand, the PLA enjoys the homefield advantage with less reliance on space-based capabilities to project military power. Once US intention is known, the PLA has the incentives to strike first according to the preemption logic discussed above.

Second, assessing the US willingness to intervene is difficult. Judging the adversary's intentions is challenging; the opponent has the incentive to mislead, and one can never be certain of what the opponent thinks.[44] Intentions may be clarified through communication. But these messages may not be believed. Intentions can also change. It is easier and more practical for the PLA to focus on the US military's ability rather than intention to intervene.

With evidence of US mobilizations and force flow into the Pacific, the PLA will likely interpret these actions as signals of "imminent" threat, and it then becomes "necessary" to strike first to avoid the expected harm. Thus, the PLA will likely justify preemptive attacks in space as anticipatory self-defense.[45] The PLA would focus on Outcome 1 and Outcome 3, with preemption as the more preferable option.

Third, Xi's pessimistic worldview of the United States likely permeates the PLA. Xi sees US actions in Asia as aimed at containing China.[46] Several US behaviors reinforce this perception including alliances with Japan and South Korea and the provision of defensive arms to Taiwan. Additionally, Beijing perceives the Australia, United Kingdom, and United States (AUKUS) security pact and the Quadrilateral Security Dialogue (Quad) as attempts to contain China and interfere with its rise.

The alignment between India and the United States is particularly concerning to Beijing.[47] China's Foreign Minister Wang Yi said in a press conference that "Anyone attempting to isolate China with some framework will only isolate themselves."[48] China's

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43. Tim Ryan, "The Indispensable Domain: The Critical Role of Space in JADC2," Policy Paper Vol. 39 (Arlington, VA: Mitchell Institute, October 2022): 2; and Amy Walker, "Space Provides Key to Joint All Domain Command and Control," Army Public Affairs, June 14, 2022, https://www.army.mil/.

44. James D. Fearon, "Rationalist Explanations for War," *International Organization* 49, no. 3 (Summer 1995): 381.

45. Flynn, *First Strike*, 2.

46. Jude Blanchette, "Xi Jinping's Faltering Foreign Policy: The War in Ukraine and the Perils of Strongman Rule," *Foreign Affairs*, March 16, 2022, https://www.foreignaffairs.com/.

47. C. Raja Mohan, "Why China Is Paranoid about the Quad," *Foreign Policy*, May 17, 2022, https://foreignpolicy.com/.

48. Wang Yi 王毅, "Yaodui Meiguo 'Yintai jingji kuangjia' huayige dadade wenhao 要对美国的"印太经济框架"划一个大大的问号" [There is a big question mark on the US "Indo-Pacific economic framework"], PRC Ministry of Foreign Affairs, accessed October 21, 2022, https://www.mfa.gov.cn/.

Ministry of National Defense accused the United States of "clinging to the Cold War mentality" and the Quad as a mechanism targeted at China.[49] These negative views could lead to the assumption of hostile US intentions toward China. Thus, the PLA judges a US intervention in an armed conflict with Taiwan is more likely.

Finally, the PLA likely holds the advantage in dominating escalation in space. The PLA possesses and is developing more nonkinetic and kinetic counterspace options. If the United States cannot match the escalating actions with proportional responses in the space domain, the PLA can escalate vertically without worrying about the United States responding in kind. Cross-domain responses from the US military are possible options to keep vertical escalation in check. But they would inevitably escalate the conflict horizontally and less credibly without the enabling space capabilities.

There is also a danger of escalating to the use of nuclear weapons. Nevertheless, it will be difficult for the United States to justify using nuclear weapons in responding to a PLA preemptive attack in space because preemption could be justified as a legitimate use of force for self-defense.[50]

A positive trend in favor of the United States is the proliferation of small satellites and cubesats replacing the larger expensive overhead assets. This trend makes it harder for the PLA to gain a decisive outcome in a preemptive attack in space by shifting the offense-defense balance toward the defense because it becomes more costly to target multiple redundant space assets. Even so, underlying asymmetries of economic reliance, military dependence, and maintaining US alliances remain. Overall, escalation dominance in space lowers the PLA's risks of taking aggressive actions in the domain.

Strategic Calculus

Given the operational advantages, it is more rational for the PLA to preempt in space to achieve its object of taking Taiwan. The analysis above suggests the PLA will preemptively attack US space capabilities in the armed reunification with Taiwan. Yet a preemption against the United States in space is not a foregone conclusion.

Preemption is a rational choice at the operational level, but it can also be strategically costly. Strategic costs are higher when preemption faces severe international uproar or jeopardizes China's grand strategic goals of national rejuvenation. Preemptive attacks in space set the precedent for a terrestrial conflict extending into space and could cause wide condemnation. Therefore, China would suffer political costs and detract from its progress in making China a preeminent global power. Furthermore, debris-generating attacks can catalyze the Kessler Syndrome and threaten China's development goals in space, hindering its economic activities in exploiting natural space resources. Therefore, an effective deterrence strategy against the CCP should focus on cost imposition at the strategic level.

49. Senior Colonel Tan Kefei, "Regular Press Conference of the Ministry of National Defense on June 30, 2022," PRC Ministry of National Defense, accessed October 21, 2022, http://eng.mod.gov.cn/.

50. Flynn, *First Strike*, 1–2.

Strategic Alternatives to Preemptions in Space

A decision matrix again helps to illustrate the CCP's strategic options. A key factor influencing the decision outcome is the level of international opposition to conflicts in space. Each outcome in the matrix also assesses the impact of preemption on the military object, political costs, and costs to the CCP's grand strategy.

Table 2. CCP strategic alternative decision matrix

	Strong international opposition to conflicts in space	**Weak international opposition to conflicts in space**
Preempt	Outcome A Higher chance of victory: PLA likely takes Taiwan Incurs higher political cost for preempting More harms to national rejuvenation (political costs + economic costs)	Outcome B Higher chance of victory: PLA likely takes Taiwan Incurs lower political cost for preempting Some harms to national rejuvenation (economic costs)
Not preempt	Outcome C Lower chance of victory: PLA takes Taiwan questionable Incurs little political cost from not preempting Suffers little setback to national rejuvenation	Outcome D Lower chance of victory: PLA takes Taiwan questionable Incurs little political cost from not preempting Suffers little setback to national rejuvenation

The decision matrix above provides four outcomes with the assumption of US intervention. The CCP's preference ordering depends on whether reunifying Taiwan is more strategically important than national rejuvenation. If Taiwan is more important, then Outcome B > Outcome A > Outcome C = Outcome D. This preference order would also apply to the situation when the CCP sees reunification as an inseparable and necessary component in achieving national rejuvenation. Therefore, it is willing to suffer economic and political costs for strategic territorial gain.

On the other hand, if national rejuvenation is more important, then Outcome C = Outcome D > Outcome B > Outcome A. This situational preference ordering presents some opportunities for the United States to influence the CCP calculus.

First, the United States could shape an international norm that strongly opposes military conflicts in space. This approach attempts to make Outcome B and Outcome D inaccessible to the CCP. Second, the United States could render a successful invasion of Taiwan by China questionable even with a PLA preemption in space, thus denying the operational benefits. Doing so would deter the PLA from attacking preemptively, which restricts the CCP's option to Outcome C.

With the US denying PLA military benefits and raising strategic costs, attacking preemptively in space would result in a lose-lose scenario for the Chinese Communist Party. It is a lose-lose option because attacking preemptively in space does not produce operational benefits, incurs strategic costs, and calls into question the prospect of a successful armed reunification. This strategy has the best chance of preserving the current status quo across the Taiwan Strait and preventing conflict from starting or extending to outer space. Combining the two opportunities forms the basis of a "denial of military benefits of preemption in space, impose strategic costs" strategy for the United States.

Options to Maneuver Out of a Lose-Lose Situation

The CCP has options to think outside of the decision matrices presented here. Three possible scenarios will be discussed—two operational and one strategic. These scenarios reduce the need for the PLA to conduct preemptive strikes in space because they either increase the probability of victory or reduce the costs of war. Nevertheless, they have their own benefits and disadvantages.

The first option, at the operational level of war, primarily focuses on increasing the probability of victory. The PLA may delay, degrade, or deny US intervention using other ways and means. In addition to counterspace capabilities, the PLA has other offensive and defensive means to increase the costs of intervention for the United States. In a full-scale armed reunification scenario, the PLA will likely conduct a joint firepower strike campaign with missiles and long-range artillery strikes to soften Taiwan's defenses preceding the Joint Island Landing Campaign.[51]

To deal with or resist US intervention in a Taiwan invasion scenario, the PLA could extend its targeting to strike key US military bases and naval assets in the region. The PLA has a broad range of offensive capabilities, including ballistic missiles, antiship cruise missiles, fighters, and long-range bombers. These actions will inflict costs on intervention, thus possibly compelling the United States to stand down. But striking the US military bases and killing American troops could produce the opposite result—strengthening US resolve and making the conflict more intense, protracted, and costly for the PLA.

A second alternative option is taking a more defensive approach. The PLA's counter intervention capabilities could also delay American responses when the United States is committed to coming to Taiwan's aid. The US military would need to roll back PLA anti-access and area-denial capabilities. Therefore, the PLA could go hard and fast to achieve its objectives before the United States and its Allies and partners could mount an effective intervention.[52]

Slowing down the US military with a counterintervention campaign would increase the PLA's probability of success, creating a fait accompli. It would be more difficult and costly for the US military to reverse PLA gains and restore the status quo. Yet accomplishing a fait accompli is also a function of Taiwan's ability to resist until the United States joins the fight.

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51. Phillip C. Saunders, "Crossing the Strait? PLA Modernization and Taiwan," (address, Hoover Institution, Stanford, CA, April 6, 2022), https://www.hoover.org/.

52. Brad Roberts, "On Theories of Victory, Red and Blue," Livermore Papers on Global Security no. 7 (Livermore, CA: Lawrence Livermore National Laboratory Center for Global Security Research, June 2020): 42–43, https://cgsr.llnl.gov/.

The February 2022 Russian invasion of Ukraine demonstrates another model of US intervention. The United States could provide weapons, training, and intelligence to Taiwan instead of direct military involvement. Going hard and fast does not guarantee success, especially when facing a determined defender, as the Russian invasion of Ukraine has shown. The PLA will undoubtedly study the implications of the Russian invasion of Ukraine.

In additional to the US military, commercial space actors can also play an important role. For example, SpaceX donated close to 2,000 Starlink units to Kiev, providing a vital communication capability to the Ukrainian military. But SpaceX is now saying that it can no longer pay the bill.[53] Another downside to relying on commercial space is that companies are susceptible to economic and physical coercion through various means, including cyberattacks and physical threats to their assets in space. Without a security guarantee and revenue stream, it is difficult for companies to sustain support to military operations.

Nevertheless, implications from Russia's invasion of Ukraine could potentially change the CCP calculus. Beijing will no doubt investigate the effectiveness of an indirect US intervention in Taiwan and the roles of commercial space to derive applicable lessons on how best to increase the PLA's probability of military success and lower strategic costs.

Third, at the strategic level of war, the Chinese Communist Party could modify its political objective and extend the time horizon to reap a long-term strategic benefit. Even with a comprehensive joint island landing campaign, complete reunification with Taiwan does not have to be the overarching political object of the CCP.

The CCP could use a short and intense armed invasion to "teach Taiwan a lesson" and show the United States to be an unreliable or incapable partner. The intent would not be to capture the island by force but to extinguish Taiwan's hope of an external actor coming to its aid. Beijing will likely seize a window of opportunity when American political will is low or the US military is least ready to intervene. With US acquiescence, the CCP diminishes American influence in the region and shapes a more favorable environment toward eventual reunification. A seemingly short-term, lose-lose outcome (not being able to take Taiwan and suffering political costs in international opposition) can still translate into a long-term strategic win for the CCP.

Toward an Effective US Strategy

The multitude of options available to the Chinese Communist Party highlights the complexity of trying to understand the CCP and PLA's decision calculi. Many variables and possible scenarios are at play, and the strategic context also matters a great deal. Nevertheless, having an organizing principle will guide the United States in making strategic choices.

53. Alex Marquardt, "Musk's SpaceX Says It Can No Longer Pay for Critical Satellite Services in Ukraine, Asks Pentagon to Pick Up the Tab," CNN, October 14, 2022, https://www.cnn.com/.

Denial of the military benefits of preemption in space and imposing strategic costs provide a good chance for success. Denying the PLA military benefits means the CCP does not increase its probability of victory in reunifying Taiwan by force even with a preemptive attack against US space assets. Accomplishing a denial of benefits strategy not only requires the United States to build a more resilient space architecture, but also addresses the US asymmetric dependence on space.

As mentioned previously, the proliferation of smaller satellites and a more resilient architecture are shifting the offense-defense balance toward the defense, but they do not address the underlying asymmetries favoring China. Addressing these asymmetries, along with matching China's ability to escalate, will reduce China's escalation dominance in space. The US military should also work to reduce the first-strike advantage in space by reducing the probability of a PLA victory in taking Taiwan in a degraded space environment.

Another key component of the costs and benefits equation is imposing strategic costs on the Party. The United States should shape a strategic environment in which preemption in space will have severe negative impacts on the CCP's goals of technological advancement, economic development, and international influence.

The CCP must understand that preemptive attacks in space harm their interests focused on national rejuvenation. Therefore, the United States should strengthen international norms of freedom of access and peaceful use of space, making it more costly for Beijing to initiate a conflict in the domain. Additionally, the potential strategic costs have to be clearly communicated to the CCP. Strategic cost imposition exerts a deterrent force on the Party, but it is the denial-of-benefit side of the ledger that makes deterrence more credible and renders it less damaging to the United States when deterrence fails.

Conclusion

The People's Liberation Army has the incentives and capabilities to conduct preemptive attacks against US space assets. In doing so, the PLA expects significant first-strike advantage due to asymmetric reliance of the United States on space. Without space-based capabilities, the US military will be less effective in reducing the PLA's chance of success in capturing Taiwan.

A less capable US military will be less able to inflict damage on the PLA, thus reducing the CCP's costs of war. The perception of first-strike advantage, in combination with offense dominance and the latitude to escalate, will incentivize preemption. Moreover, the CCP will most likely justify a preemptive attack in space as self-defense. An effective US deterrence strategy should deny PLA military benefits of preemption in space while imposing strategic costs on Beijing.

The logic of denial of military benefits and imposing strategic costs is simple. Simplicity makes it easier to translate the strategy into concrete actions. These approaches are applicable to China when it thinks strategically and rationally. A dual-track strategy allows the United States to hedge against uncertain CCP decisions at both the operational and strategic levels of war.

Denying military benefits and imposing strategic costs of preemption in space can force China into a lose-lose situation. If the PLA preemptively attacks the United States in space, this action could potentially derail the CCP's grand strategy of national rejuvenation. But without preemptive attacks against US space assets, the PLA could fail to unify Taiwan. The United States could, however, create the conditions where a preemptive PLA attack in space does not increase a CCP victory and causes Beijing to incur strategic costs. To accomplish this, the United States needs to address asymmetries between US and Chinese dependence on space, shifting the offense-defense balance in favor of defense while reducing the PLA's escalation dominance in the space domain. **Æ**

THE PARADOX OF ARTICLE IX AND NATIONAL SECURITY SPACE ACTIVITIES

Michael J. Listner

Article IX of the Outer Space Treaty has stood as one of the more controversial provisions of the accord. In the almost 56 years since it was signed and entered into force, one of the legal duties and a legal right within Article IX that directly implicates national security space activities has elicited debate as to what it means and how it should be applied. Certainly, the expanse of national security space activities during the Cold War and to the present would have called for Article I to have seen significant state practice. Remarkably, there has been no apparent indication of such, unless the lack of clear state practice may be indicative of a more subtle state practice that interprets the obligations and rights of Article IX.

Article IX is one of the more contentious provisions of the Outer Space Treaty as it relates to its application to outer space activities. The terms "due regard" and "harmful interference" found within Article IX elicit debate about their meaning and whether they require a legal definition. Beyond this rudimentary debate, however, the most provocative question relates to the role Article IX plays in national security space activities given the importance of these activities to spacefaring states during the Cold War and to the present day. Yet for the duration of the Outer Space Treaty's existence, the pertinent provisions of Article IX that would arguably apply to these activities have not been utilized.

This raises the question whether Article IX applies to national security activities, or has a conscious state practice created an exception to or modification of the Outer Space Treaty that excludes national security activities from its requirements? This article will examine the roots of Article IX, discuss its duties and rights, and examine how a deliberate state practice may have created a national security carve-out for Article IX.

Seeds of Article IX

The focus of discussion of Article IX is most often the elusive meaning of "due regard" and "harmful interference." But frequently overlooked is the fact that Article IX finds its roots in the scientific community and the preservation of the outer space environment for scientific research, specifically the Air Force Project West Ford.

Project West Ford attempted to create an artificial ionosphere by dispersing 75–110 lbs of copper dipoles in low-Earth orbit that would be 30 miles in diameter and would

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reflect high-frequency radio signals.[1] The proposed disbursement raised concerns in the optical and radio astronomy community, which led to the appointment of a special committee to thoroughly evaluate the project before it was launched.[2] The committee deemed the concerns of the astronomical community unsubstantiated, but the government decided no further launches would be made until after the results of the first test had been evaluated, including comments from astronomers.[3]

The Kennedy administration followed up with a compromise policy on August 8, 1961 that would suspend further operations until the West Ford experiment was analyzed and evaluated. Operations would only resume contingent on the results of the evaluation and the employment of any required safeguards. A panel on Project West Ford convened and presented its results in a report on October 3, 1961. The report was made public the following day.[4] The first launch occurred on October 21, 1961 with a payload of about 75 pounds of the needles. But the payload did not disperse as planned, leaving some of the dipoles in clumps.

In 1961, the International Council of Scientific Unions instructed the Committee on Space Research (COSPAR) to consider the issue of contamination of outer space and specifically to address Project West Ford. The committee established the Consultative Group of Potentially Harmful Effects of Space Experiments in May 1962. This group demanded the United States consult with it before the next launch.[5]

That, combined with diplomatic pressure from the Soviet Union in the United Nations, convinced the United States to suspend further experiments of this type until the results of the first deployment were fully analyzed and the results of the analysis could be shared with the scientific community. The United States also agreed to make prior consultations before performing similar experiments in the future and further consented to give advance warning of the launching of these types of experiments.

The second launch occurred on May 9, 1963. The dipoles deployed as planned and radio transmissions were made using the ring. On July 29, 1963, the United States furnished information about this launch to conform with Resolution 1721 B XVI, noting that an Atlas-Agena (1963 14A) carried about 50 pounds of copper dipoles that would have a similar orbital parameter as 1963 14A.[6] Eight weeks after the launch, it was determined the experiment did not harm radio or optical astronomy observations. Still, even though Project West Ford ultimately had no adverse effects on science, this

1. Delbert E. Terrill Jr., *The Air Force Role in Developing International Space Law* (Maxwell AFB, AL: Air University Press, 1999), 58.

2. Terrill, *International Space Law*, 59.

3. Terrill, 59–60.

4. Report of the Panel of Project West Ford, October 3, 1961, John F. Kennedy Presidential Library and Museum, Folder Title: President's Science Advisory Committee (PSAC), 1961: May–December, Digital Folder JFKPOF-086a-003-p0072-0074, https://www.jfklibrary.org/3.

5. Terrill, *International Space Law*, 66.

6. UN General Assembly, Resolution 1721 (XVI), International Co-Operation in the Peaceful Uses of Outer Space, A/4987 (December 20, 1961), https://www.unoosa.org/.

national security activity became the unintentional impetus for the duty to consult and the right to consultation in Article IX.[7]

Duty of Care and State Practice

Given the context of Project West Ford and the inadvertent creation of an international consultation requirement by a national security activity, it is critical to understand Article IX is fundamentally about preserving the outer space environment for scientific research. Consider Article I of the Outer Space Treaty: "There shall be freedom of scientific investigation in outer space, including the moon and other celestial bodies, and States shall facilitate and encourage international co-operation in such investigation."[8]

Article IX "is 'a provision which is designed to protect outer space and the celestial bodies from contamination and pollution and to protect the legitimate programs of States from undue interference.' "[9] Article IX can be broken down into two legal duties and one legal right preceded by a preamble that builds upon Article I and expresses a duty of care.

> In the exploration and use of outer space, including the Moon and other celestial bodies, States Parties to the Treaty shall be guided by the principle of co-operation and mutual assistance and shall conduct all their activities in outer space, including the Moon and other celestial bodies, with due regard to the corresponding interests of all other States Parties to the Treaty.[10]

"Due regard" is not a defined term but instead a duty of care. It is implemented by two legal duties and one legal right in Article IX.[11] But not all space activities are the same, which means what constitutes "due regard" for one activity may not be similar to what "due regard" is for another. This makes a legal definition of "due regard" impracticable given its meaning will depend on the nature of the space activity.

Furthermore, the duty of care will evolve as experience is gained in certain space activities and new activities come to light. Thus, due regard might be expressed as a legal test: "What would a reasonably prudent state actor performing the same or similar space activity do?" In terms of nongovernmental outer space activities, the question might be framed as, "What would a reasonably prudent nongovernmental actor

7. Terrill, *International Space Law*, 61–62.

8. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (Outer Space Treaty), U.S., U.K., U.S.S.R., January 27, 1967, art. i, 18 U.S.T. 2410, https://www.unoosa.org/.

9. Paul G. Dembling and Daniel M. Arons, "The Evolution of the Outer Space Treaty," *Journal of Air Law and Commerce* 33 (1967): 440, https://digitalcommons.unl.edu/.

10. Outer Space Treaty, art. ix.

11. Dembling and Arons, "Outer Space Treaty," 441.

performing the same or similar space activity do? Bear in mind, the state would be responsible for nongovernmental space activities and any harm it might cause."[12]

These two standards are overly simplistic given politics figure into this analysis, and the political aspect of due regard is likely a subjective duty of care as opposed to an objective one. What one state considers reasonable may differ from state to state, especially in the context of great power competition. From this perspective, the two legal duties and one legal right of Article IX will be examined.

Duty to Prevent Harmful Contamination

The first legal duty of Article IX is a direct result of COSPAR's efforts to address contamination of outer space for scientific investigation and emphasizes the foundation in science. Article IX points back to Project West Ford:

> States Parties to the Treaty shall pursue studies of outer space, including the moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose.[13]

This legal duty has one purpose: to protect outer space and extraterrestrial environments from contamination that would prevent or hinder scientific investigation and to ensure scientific investigation and other activities do not contaminate the Earth's biosphere. This legal duty is strictly designed with the goal of preserving the outer space environment, including celestial bodies, for scientific research and does not serve an ethical, moral, or environmental purpose.

States realize due regard by taking steps to prevent contamination of outer space, including celestial bodies, to preserve them for science and ensure that space activities do not contaminate the Earth's biosphere. This legal duty of due regard finds state practice in domestic planetary protection guidelines and protocols.

Duty to Consult

The second legal duty ties directly to the controversy created by Project West Ford, the complaints raised by the Soviet Union, and COSPAR's insistence on consultation after the first launch of dipoles by the United States. The legal duty implements due regard by imposing a legal duty upon a party planning a potentially harmful experiment to consult with other parties.[14]

> If a State Party to the Treaty has reason to believe that an activity or experiment planned by it or its nationals in outer space, including the Moon and

12. Outer Space Treaty, arts. vi, vii, viii.
13. Outer Space Treaty, art. ix.
14. Dembling and Arons, "Outer Space Treaty," 441.

> other celestial bodies, would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space, including the Moon and other celestial bodies, it shall undertake appropriate international consultations before proceeding with any such activity or experiment.[15]

Key in this legal duty are the phrases "reason to believe" and cause "potentially harmful interference," where due regard on the part of the state is to consult if it has any reason to believe that a space activity performed under its jurisdiction would hypothetically cause harmful interference with the space activities of another state(s).

The word "potentially" is often excluded when discussing harmful interference, although it is a critical part of due regard. "Potentially" creates a lower standard for triggering the duty to consult as opposed to a duty of care requiring only foreseeable "harmful interference," which would create a high bar to trigger the consultation requirement. Yet, Article IX specifically uses "potentially harmful interference," which lowers the threshold to any hypothetical contingency to trigger the duty to consult. Arguably, this would apply to a multiplicity of space activities that might not even remotely interfere with the space activities of other states.

The line of inquiry when considering the duty to consult can be phrased as follows. "Is there any imaginable scenario where the planned space activity could interfere with or obstruct space activities to the detriment of another State?" The answer to this inquiry is "yes" because there is not going to be 100 percent certainty that a state's space activity will not interfere with another state's space activity.

Consider the usage of potentially and its synonyms in domestic settings. In the context of US environmental regulations, "potentially" triggers an environmental assessment in terms of what constitutes a "major federal action" under regulations promulgated under the National Environmental Protection Act, where even a remote possibility of federal involvement will trigger the act. Title 40 CFR § 1508.18 states, "major Federal action includes actions with effects that may be major and which are *potentially* (emphasis added) subject to Federal control and responsibility."[16] Conversely, "potentially" would not be sufficient to meet the threshold of a motion to stay, pending a court's review of an appeal in US federal courts.[17]

The modifier "potentially," coupled with "harmful interference" creates a hair trigger for the duty to consult, making it arbitrary and unrealistic in practice. Consequently, the term "potentially," and particularly "potentially harmful interference," is subject to interpretation depending on what is considered due regard for a specific space activity. The geopolitical factor is also significant in this evaluation, since competing state interests and great power competition are likely evaluated as factors a state must consider before tripping the duty to consult. This ultimately makes the

15. Outer Space Treaty, art. ix.

16. National Archives Code of Federal Regulations, Title 40 CFR § 1508.18, "Major Federal Action," https://www.ecfr.gov/.

17. Nken v. Holder, 556 U.S. 418, 434–35 (2009).

decision to trip the duty to consult a policy decision and not just a legal question for states.

The method of reporting for the consultation requirement is not spelled out in Article IX; however, it appears to be left to the states to communicate between themselves and not through the secretary-general. This is evident from Outer Space Treaty negotiations, where the Japanese delegation proposed parties required to report under the consultation requirement would do so directly to the secretary-general.[18] The Soviet Union's delegation objected to this proposal noting the required information would be transmitted more quickly if the secretary-general was bypassed and communicated directly to the party potentially affected by the experiment or activity.[19]

The duty to consult has no perceptible state practice, although certain activities like kinetic antisatellite tests and other national security space activities arguably should have been preceded by the Article IX obligation.[20] Interestingly, China claimed it alerted the United States, Japan, and others of the impending ASAT test it performed on January 11, 2007.[21] Yet, even if this proved to be true, China did not formally invoke the duty to consult. Nonetheless, the lack of state practice for the duty to consult may be evidence of a state practice of a different sort.

Right to Consultation

The legal right to request a consultation in Article IX aligns with the duty to consult. The right is created in Article IX.

> A State Party to the Treaty which has reason to believe that an activity or experiment planned by another State Party in outer space, including the moon and other celestial bodies, would cause potentially harmful interference with activities in the peaceful exploration and use of outer space, including the moon and other celestial bodies, may request consultation concerning the activity or experiment.[22]

The legal right to request a consultation theoretically provides a state with a mechanism to prod another state to invoke the duty to consult. This means the right to request a consultation, like the duty to consult, must occur before a state performs the space activity in question. The right to consultation is attached to the low threshold of "potentially harmful interference" and provides a state with a low threshold to compel the duty to consult.

18. Dembling and Arons, "Outer Space and Treaty," 441.

19. Dembling and Arons.

20. Michael G. Mineiro, "FY-1C and USA-193 ASAT Intercepts: An Assessment of Legal Obligations under Article 9 of the Outer Space Treaty," *Journal of Space Law 34* (2009).

21. "China Confirms Anti-Satellite Missile Test," *Guardian*, January 23, 2007, https://www.theguardian.com/.

22. Outer Space Treaty, art. ix.

Japan purportedly invoked the right to request a consultation following China's January 11, 2007 antisatellite test. Japan may have been attempting to invoke the right to consultation following the January 11, 2007 antisatellite test performed by China when it requested confirmation of the test.[23] If Japan's request for confirmation was intended as an Article IX request for consultation, it would not be considered state practice of invoking the right because it was made after the test and not prior to it.

The twist in this event is Western intelligence organizations likely had foreknowledge China was planning an ASAT test, although it is unclear how much detail they knew in advance. Yet despite the low threshold to trigger the right to consultation, no such request was made.

Another more recent event that bears scrutiny is when China mounted a lawfare operation against the United States in the UN. China appears to have done an end-run around the right to consultation when it filed a complaint with the UN Secretary General citing Article V of the Outer Space Treaty on December 6, 2021.[24] The complaint alleged on two occasions Starlink satellites nearly collided with China's space station and called these alleged conjunctions "a danger to the life and health of astronauts."[25] It appears China attempted to conflate the language of Article V with "potentially harmful interference" found in Article IX in an attempt to stir an international incident without creating a state practice for the right to consultation.

Accordingly, the right to consultation creates a conundrum similar to the duty to consult in that there is a lack of state practice to support it. The question is whether the lack of state practice for the right to consultation, like the lack of state practice for the duty to consult may be evidence of state practice of a different sort.

National Security Activities, Norms, and Pandora's Box

The duty to consult and the right to consultation in Article IX is a direct result over concerns for national security activities provoked by the the scientific community and the geopolitical fervor over Project West Ford. Yet neither has been invoked. Dozens if not hundreds of national security space activities were performed by the United States and the Soviet Union, including destructive ASAT tests, in the period between Project West Ford and the enactment of the Outer Space Treaty during the Cold War. Since 1967, other states have become significant players in outer space and have performed national security space activities, including the China and India. Still, not once has the duty to consult or the right to consultation been invoked.

Given the low threshold to trigger the consultation requirement and the right of other states to force the issue, it would seem these two features of Article IX would have seen at least some, if not significant, state practice. The answer to this paradox

23. "Japan Voices Concern over China's Missile Test," Reuters, January 19, 2007, https://www.reuters.com/.

24. Information Furnished in Conformity with the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, A/AC.105/1262 (December 3, 2021), https://www.unoosa.org/.

25. Outer Space Treaty, art.v, para. 3.

may lie in deliberate policy decisions and state practice by both the United States and Soviet Union in the environment of Cold War politics and great power competition, which has led to a silent state practice related to and interpreting both the duty to consult and the right to consultation.

Keeping the Lid Shut

National security activities by their very nature are shrouded in secrecy. Invoking the Article IX duty to consult would shine unwanted light on the true nature of the activity in question or at least give geopolitical adversaries and competitors enough clues to discern vital details. A state like the United States invoking the duty to consult or the right to consultation would arguably create a state practice and by extension could create a legally binding norm for both the requirement and the right that could have unintended consequences.

For example, a rival state could use the right to request a consultation as a lawfare tool to compel the duty to consult and pry into and disrupt an adversary's national security activities, bolster its own soft power, and create a diplomatic nightmare for a geopolitical rival. Conversely, invoking the right to consultation could work against the state employing it by exposing intelligence sources and means, which could also affect a state's national security. This may have been a factor in why the United States may not have disclosed it had prior warning of China's 2007 ASAT test.[26]

Accordingly, triggering the duty to consult or invoking the right to consult may not be in the interest of states as it would open a Pandora's Box and might prove to be a two-edge sword to the detriment of national security activities for all involved. All-in-all, the lack of state practice with respect to the duty to consult and the right to consultation in Article IX is likely the result of deliberate policy decisions that remain classified as opposed to a strict legal analysis. Thus, the lack of state practice for Article IX can be construed as state practice that might form a customary norm that excludes national security activities from the duty to consult and by extension the right to consultation.

A Norm Excepting National Security Activities?

The duty to consult and the right to consultation do not have direct state practice supporting them, which has left these precepts in limbo. As mentioned above, this may be a calculated move to avoid turmoil resulting from the exposure of national security activities as well as other state-sponsored space activities. Indeed, the very lack of state practice of invoking this legal duty and legal right for national security space activities may well be deliberate state practice initiated by the United States and the Soviet Union during the Cold War to create a customary norm that excludes national security activities from the duty to consult and the right to consultation.

26. "SC-19 ASAT," Global Security (website), n.d., accessed December 7, 2022, https://www.globalsecurity.org/.

If such a state practice does exist, it has been adhered to silently and raises the question whether it meets the requirements of customary international law. "Customary international law has long been recognized as one of three primary sources of international law. Article 38(1) of the Statute of the International Court of Justice states that international law derives from international conventions, international custom, and general principles of law."[27]

> Customary international law . . . consists of two components. First, there must be a general and consistent practice of states. This does not mean that the practice must be universally followed; rather it should reflect wide acceptance among the states particularly involved in the relevant activity. . . . Second, there must be a sense of legal obligation, or *opinio juris sive necessitatis*. In other words, a practice that is generally followed but which states feel legally free to disregard does not contribute to customary law; rather, there must be a sense of legal obligation. States must follow the practice because they believe it is required by international law, not merely because that they think it is a good idea, or politically useful, or otherwise desirable.[28]

"Not all states are equal from that perspective. State practice *and opinio juris* of states which occupy a special and outstanding position in the field at issue are of more value than those of other states."[29] In other words, the state practice in question and the sense of legal obligation are weighed against the value the state asserting the practice has in the particular field, which in this case is outer space activities and national security space activities. The greater the value a state has in outer space activities and national security space activities, the more probable the state practice and the *opinio juris* will evolve into customary international law.

The existence of the state practice in question and whether it meets the three prongs of the test for customary international law are discussed below.

1. Is there is a general and consistent practice among states that perform national security space activities that excludes these activities from the legal duty to consult and the right to consultation in Article IX?

Answer: Probably. During the Cold War, the United States and the Soviet Union performed numerous national security space activities, including direct-ascent and co-orbital antisatellite tests. The Soviet tested its Istrebitel Sputnikov ("killer satellite") on numerous occasions and deployed it as a break-out capability. The United States tested the ASM-135 air-launched ASAT that destroyed the Solwind P78-1 on

27. Ronald Alcala, "Opinio Juris and the Essential Role of States," Articles of War, Lieber Institute, February 11, 2022, https://lieber.westpoint.edu/.

28. United States v. Bellaizac-Hurtado, 700 F.3d 1245, 1252 (11th Cir. 2012).

29. Frans G. von der Dunk, "THE DELIMITATION OF OUTER SPACE REVISITED: The Role of National Space Laws in the Delimitation Issue," *Proceedings of the Forty-First Colloquium on the Law of Outer Space* (1998), 254, https://digitalcommons.unl.edu/.

September 13, 1985.[30] These tests arguably would have risen to level of Project West Ford and triggered the low threshold of the duty to consult in Article IX or given a state opportunity to invoke the right to request consultation.

Other examples include China's 2007 ASAT test, the United States' deorbit operation of USA-193 in 2008 during Operation Burnt Frost, and India's 2019 ASAT test in Mission Shakti. Significantly, none of these states invoked the duty to consult before these events nor did any states invoke the right to consultation. Operation Burnt Frost stands out as it was made public well in advance of the first and only attempt, yet no state invoked the right.[31]

This suggests the state practice of not invoking the Article IX duty to consult nor invoking the right to consultation for national security space activities appears to be a consistent state practice that has wide acceptance among states performing outer space and national security space activities and meets the first requirement of customary international law.

2. Do states that follow this practice do so out of a sense of legal obligation?

Answer: Maybe. This is where the analysis gets tricky because even though a state practice appears to exist, states that appear to exercise this practice are silent about its existence, which makes its status as customary international law ambiguous. In other words, the lack of pronouncement of the existence of the state practice makes it difficult to determine whether states believe they are legally obligated to follow this state practice and otherwise feel they are required by international law to do so. "Undoubtedly, state silence regarding customary law can create ambiguity, and that ambiguity can, in turn, invite speculation about the law."[32]

Yet, states likely have an interest in not acknowledging this state practice to allow the penumbra of customary law to grow stealthily and uninterrupted from geopolitical challenge. But the strategy of silence only works until it is openly challenged. Consider this hypothetical.

State A is preparing a national security activity that would likely trigger the duty to consult but does not do so because it believes international law excludes these activities from Article IX. State B becomes aware of the planned activity either through public statements or a breach of security and challenges state A through the right of consultation.

State A has two choices: (1) submit to state B's challenge and comply with the duty to consult, in which case, the *opinio juris sive necessitatis* is quashed or at the very least compromised; or (2) challenge state B's use of the right of consultation and assert the

30. Ronald Reagan, *The U.S. Anti-Satellite (ASAT) Program: A Key Element in the National Strategy of Deterrence*, Collection Green, Max: Files 1985-1988, Folder Title: Anti-Satellite Program, Box: 03 (Simi Valley, CA: Ronald Reagan Presidential Library, 1987), https://www.reaganlibrary.gov/.

31. Laura Grego, *The Anti-Satellite Capability of The Phased Adaptive Approach Missile Defense System*, Public Interest Report (Washington, DC: Federation of American Scientists, 2011), https://pubs.fas.org/.

32. Alcala, "Opinio Juris."

state practice of excluding national security space activities from the Article IX duty to consult invalidates state B's challenge.

If state A chooses the former, legitimacy for the state practice being customary international law is destroyed or at least crippled. If state A chooses the latter, then it will reveal the state practice to the international community but also give state A the opportunity to strengthen the practice as customary international law and gain support among other states that may or may not have quietly accepted a similar state practice.

This hypothetical illustrates the risk associated with state silence, but that does not mean it is unwise for a state to openly acknowledge a state practice it regards as a customary international law. Regardless, the existence of and the *opinio juris sive necessitatis* of this suspected state practice as customary international law may have been validated, and the existence of the state practice itself may have been acknowledged by a recent event.

On November 15, 2021, the Russian Federation launched a direct-ascent, antisatellite weapon from its A-235 PL-19 Nudol system and destroyed a defunct SIGINT intelligence satellite, Cosmos 1408 (COSPAR ID: 1982-092A). The Russian Federation initially denied the intentional destruction of its satellite but freely admitted to the incident 24 hours later and justified the destruction of Cosmos 1408 while downplaying international condemnation of the resulting orbital space debris. The Russian Federation weathered the resulting criticism from the international community and boasted about the capability and capacity it demonstrated.[33]

Retired Major General Vladimir Dvorkin, who is the former head of the 4th Central Research Institute (TsNII) of the Russian Defense Ministry, may have supported the existence of a state practice that Article IX is not applicable to national security activities during an interview with a Russian state media news outlet.

> He said Russia sends warnings to the US when it test-fires ICBMs. According to him, this does not apply to the testing of missiles of the anti-missile defense system (ABM). . . . 'Russia has not violated international agreements by testing anti-satellite weapons. . . . There is no direct violation of any international agreements. And we should not warn anyone when we test our systems—anti-missile or anti-satellite. We are not obliged to warn anyone about this, there is nothing like that.'[34]

Dvorkin may have revealed the state practice toward Article IX and national security space activities and validated the *opinio juris sive necessitatis*, which would satisfy the two prongs of customary international law. His statements should be considered

33. Tracy Cozzens, "Russia Issues Threat to GPS Satellites," *GPS World*, November 29, 2021, https://www.gpsworld.com/.

34. "The Former Head of the Research Institute of the Ministry of Defense Did Not See Violations of the Law in the Test of an Anti-Satellite Missile," *Interfax* (Moscow), November 6, 2021, https://www-interfax-ru.translate.goog/.

cautiously as he is supposed to be retired, and it is uncertain whether he was speaking or has ever spoken for the government of the Russian Federation.

If Dvorkin's statements accurately represent the official position of the Russian government, then it can be inferred that not only does a state practice toward Article IX and national security space activities exist, but it also meets the test of customary international law, especially since the Russian Federation (and the Soviet Union) occupies a special and outstanding position in the field of outer space activities, including national security space activities. This gives weight to the state practice and *opinio juris* in question and argues in favor of meeting the prerequisites of customary international law.[35]

What happens if there is a challenge to the state practice? Suppose in the prior hypothetical where state B asserts the right to consultation, state A responds and asserts the right to consultation does not apply to national security space activities. State B replies that no such rule of international law exists. Who would prevail presuming state B is a state party to the Outer Space Treaty but has limited experience and value in performing outer space activities, much less national security space activities, and state A has decades of experience in outer space activities and national space security space activities? Would state B's assertion have sufficient weight to dislodge state A's position and force state A to comply with the consultation requirement?

It could be argued state B's petition of the right to consultation would provide the necessary state practice to override state A's *opinio juris sive necessitatis*. But the state practice and *opinio juris* of state A, which occupies a special and outstanding position in the field of outer space activities, including national security space activities, has more value than that of state B. Therefore, state A's special and outstanding position would give greater weight to its claim of customary international law and allow it to rebuff the challenge.

Conversely, if several states having value similar to state B were to support state B's position, it could pose a threat to state A's *opinio juris sive necessitatis* regardless of its outstanding position. But other states that may silently support state A's position and have lesser or similar value in outer space activities, including national security space activities, could break their silence and openly support state A's claim and not only override the attempt by state B and its supporters but also bolster the state practice regarding the duty to consult and the right to consultation as it applies to national security space activities thereby increasing its legitimacy as binding international law.

Consequently, it appears not only does a state practice that excludes national security space activities from the Article IX duty to consult and the right of consultation exist, but it is also supported by *opinio juris sive necessitatis* of state actors who have outstanding positions in outer space activities and national security space activities to make it binding as customary international law. *The important takeaway is this customary rule of international law does not abrogate nor exploit a gap in Article IX; instead, it defines the parameters of due regard and delimitates when the duty to consult*

35. von der Dunk, "Delimitation Issue," 254.

and the right to consultation do not need to be invoked and effectively exempts national security space activities from Article IX.

Presuming the state practice at issue is customary international law complementing the Outer Space Treaty and defining the parameters of Article IX in particular, the question is whether the practice of excluding national security space activities from the duty to consult and the right to consultation is a norm of customary international law.

> Treaties may constitute evidence of customary international law but "will only constitute sufficient proof of a norm of customary international law if an overwhelming majority of States have ratified the treaty, and those states uniformly and consistently act in accordance with its principles. . . . Of course, States need not be universally successful in implementing the principle in order for a rule of international law to arise . . . but the principle must be more than merely professed or aspirational.[36]

Most provisions and principals of the Outer Space Treaty can be considered norms as it has been ratified by over a 100 states, and arguably most provisions have state practice from a multiplicity of states with varying degrees of outer space capabilities and achievements. But the only part of Article IX and due regard that has shown any overt state practice is the legal duty related to the protection of the outer space environment and the Earth's biosphere. "A customary international law norm will not form if specially affected States have not consented to its development through state practice consistent with the proposed norm."[37]

In this case, it is not the silence of the states that assert the state practice toward the duty to consult and the right of consultation that prevents the formation of a norm but the silence and failure of states to invoke the right to consultation that permitted the creation of the norm. In other words, silence by states asserting the customary norm for the state practice directed at the duty to consult and the right to consultation has created ambiguity that has allowed customary international law and a norm to grow in the shadows. Moreover, the silence by states that would have opposed the existence of such a norm by failing to timely invoke the right to consultation has permitted the penumbras of customary international law room to grow and with it the formation of a norm.

Conclusion

The existence of a state practice and a norm excluding national security space activities from the Article IX duty to consult and the right to consultation is notional for the time being. It is unlikely states will either confirm or deny the existence of such a

36. Bellaizac-Hurtado, 700 F.3d at 1255 citing Flores v. Southern Peru Copper Corp., 414 F.3d 233, 256 (2d Cir. 2003); and Bellaizac-Hurtado, 700 F.3d at 1255 citing Flores v. Southern Peru Copper Corp., 414 F.3d 233, 248 (2d Cir. 2003).

37. Bellaizac-Hurtado. at 1255 citing North Sea Continental Shelf Cases (Fed. Republic of Ger. v. Den.; Fed. Republic of Ger. v. Neth.), 1969 I.C.J. 3, 43 (Feb. 20).

state practice unless challenged directly by a state invoking the right to consult. That seems unlikely to happen anytime soon. Nongovernmental organizations and academia will continue to hold out Article IX in terms of national security space activities such as ASAT tests, and the terms due regard and harmful interference will continue to be bandied about relating to nongovernmental activities.

But states themselves, while brandishing due regard and harmful interference as political terms, do not appear eager to give these terms authority. Certainly there have been missed opportunities to give legitimacy to Article IX. The Starlink nongeostationary satellite orbit system and other such large-scale systems, for example, have generated concerns among both optical and radio astronomers similar to the concerns raised by Project West Ford.[38] Yet, no state has invoked the right to consult against the United States on this matter.

Perhaps this lack of action on the part of states is due to the recognition the duty to consult and by extension the right to consultation is flawed given the low threshold of "potentially harmful interference" and have decided it is better to leave the lid of Pandora's Box shut. Whatever the reason, the state practice for the exemption of national security space activities from the duty to consult and the right to consultation will likely continue in silence. These two manifestations of due regard may not find legitimacy in practice and remain merely an aspirational part of the Outer Space Treaty. They will certainly continue to be a talking point and generate controversy but will likely find little pragmatic use in the scope of not just national security space activities but outer space activities in general. **Æ**

38. Jeff Foust, "Starlink vs. the Astronomers," Space News, February 4, 2020, https://spacenews.com/.

INTERNATIONAL SPACE COLLABORATION AND SECURITY

A NATO PERSPECTIVE

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NATO's Overarching Space Policy model for international collaboration in space sets a unique security framework in the organization's approach to interoperability, defense planning, and deterrence. The policy represents the singular voice of 30 NATO Allies, and its public release was a significant step toward establishing international norms of space behavior. While not a norm-setting organization like the UN, NATO is positioned to be the center of gravity for evolving standards and improving space security for all.

The operationalization of space presents a unique challenge for NATO to secure the Alliance's access to services and capabilities in an unconventional domain, especially considering the range of complex regional threats and global challenges.[1] NATO meets this unique challenge by growing capacity, coordinating capabilities, and collaborating as an alliance for its defense. Specifically, this article will address, as outlined in the Overarching Space Policy, how NATO (1) approaches interoperability within the Alliance, thereby enhancing space domain awareness; (2) coordinates defense planning and capability development at the political and military level; (3) deters potential adversaries through a deterrence-by-denial posture; and (4) sets the stage for the development of proposals of responsible space behavior.[2]

Introduction

Since 2007, four space powers—China in 2007, the United States in 2008, India in 2019, and Russia in 2021—successfully executed direct-ascent antisatellite missions.

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1. North Atlantic Treaty Organization (NATO), *NATO's Overarching Space Policy* (Brussels, Belgium: NATO, January 2022), https://www.nato.int/.
2. NATO, *Brussels Summit Communiqué* (Brussels, Belgium: NATO, July 1, 2022), https://www.nato.int/.

These missions created an excessive amount of debris in low Earth orbit, putting other space systems and, in some cases, humans at risk. Within the same time frame, the number of space launches and subsequent satellites in orbit have increased dramatically, further crowding the space environment.

As of May 2022, there were over 5,400 active satellites in orbit with exponential growth projected by private industry in the next several years.[3] This increasingly "congested, contested, and competitive" environment has created a myriad of disparate international, national, and private enterprise initiatives around the world dedicated to furthering and securing their interests in space.[4] This growth has also significantly increased global dependence on space data, products, and services, a reality adversarial actors are keen to exploit.[5]

But the myriad of space initiatives exploit gaps in established space governance and cause increased fear of collision and threat of malign activity.[6] These fears are rational. A range of counterspace weapons are being developed, most notably by China. Aside from direct-ascent antisatellite technology, adversaries execute nonkinetic or nonpermanent attacks on US satellites "every single day" through lasers, jammers, and cyberattacks.[7] Perhaps more concerning are potential attacks from co-orbital antisatellite weapons that can be used to stalk critical systems in peacetime, only to neutralize these systems during a crisis.[8]

Clearly, global activity in space warrants globally recognized norms of behavior that actively contribute to the security of each actor's satellites while ensuring the long-term sustainability of the domain. "Conventional thinking about how to deter an enemy from attacking on the ground, by sea or in the air doesn't really apply to space. New doctrines and norms for space need to be established, mostly by diplomats."[9] In this context and in consideration of recent initiatives by the UN to further space

3. Union of Concern Scientists Satellite Database, updated May 1, 2022, https://www.ucsusa.org/; and Michael Sheetz, "The Space Industry Is on Its Way to Reach $1 Trillion in Revenue by 2040, Citi Says," CNBC, May 21, 2022, https://www.cnbc.com/.

4. UN General Assembly, First Committee, Outer Space Increasingly 'Congested, Contested and Competitive,' First Committee Told as Speakers Urge Legally Binding Document to Prevent Its Militarization, GA/DIS/3487 (October 25, 2013), (statement of Jeffrey L. Eberhardt), https://www.un.org/.

5. Jonathan Beale, "Space, the Unseen Frontier in the War in Ukraine," BBC, October 6, 2022, https://www.bbc.com/; and Ashish Dangwal, "Sabotaging Starlink, Russia Is Using EW Complex 'Tirada' to Disrupt SpaceX Satellites Connecting Ukraine – Media," EurAsian Times, October 9, 2022, https://eurasiantimes.com/.

6. Rajeswari Pillai Rajagpalan, "It Is Time for Space Governance Talks," *Diplomat*, May 21, 2020, https://thediplomat.com/.

7. Josh Rogin, "A Shadow War in Space Is Heating Up Fast," *Washington Post*, November 30, 2021, https://www.washingtonpost.com/.

8. Brian G. Chow, "Stalkers in Space: Defeating the Threat," *Strategic Studies Quarterly* 11, no. 2 (Summer 2017), https://www.airuniversity.af.edu/.

9. Rogin, "Shadow War."

governance, NATO's space policy deserves attention, not as much from a legal perspective as from a military perspective.[10]

Among the different governments, companies, and organizations that have given special attention to space, NATO is the largest intergovernmental organization. NATO represents 30 nations and approximately 50 percent of the world's GDP.[11] Unlike the UN, however, NATO has a strategic concept based on collective defense with the three core tasks of deterrence and defense, crisis prevention and management, and cooperative security.[12] Furthermore, the criteria for membership require substantial political, military, and financial obligations.[13] These factors give significant weight to the Overarching Space Policy and how NATO approaches the space domain.

NATO has diplomatic and political intergovernmental functions. The key principles and tenets of the Overarching Space Policy align to ensure "free access" to space for "peaceful purposes" per the Outer Space Treaty of 1967 and other international laws.[14] But the operationalization of space as a contested domain brings new challenges to the international community, even while keeping with the spirit and intent of international law. Unique to NATO as an intergovernmental alliance is its ability to advance international collaboration and security, specifically now concerning outer space.

Interoperability

> *NATO will encourage cooperation between Allies to enhance the compatibility and interoperability of their space capabilities, including through information sharing (e.g., Space Situational Awareness) and coordination, joint development and production, standardization and related doctrinal, legal and procedural work.*
>
> *NATO Overarching Space Policy*

One of NATO's strengths lies in its interoperability, defined as the "ability for Allies to act together coherently, effectively and efficiently to achieve tactical, operational and strategic objectives."[15] In support of these objectives, NATO considers interoperability from technical, procedural, human, and informational dimensions.

10. UN General Assembly, Resolution 76/561, Open-ended Working Group on Reducing Space Threats Through Norms, Rules, and Principles of Responsible Behaviors, A/DEC/76/561, (April 26, 2022), https://digitallibrary.un.org/.

11. "NATO Parliamentary Assembly (PA) Membership," NATO PA (website), https://www.nato-pa.int/; and Jens Stoltenberg (speech, NATO's Outlook Towards 2030 and Beyond, Riga, Latvia, November 30, 2021), https://www.nato.int/.

12. "Strategic Concepts," NATO (website), updated July 18, 2022, https://www.nato.int/.

13. NATO Public Diplomacy Division, "NATO Enlargement & Open Door," Fact Sheet (Brussels, Belgium: NATO, July 2016), https://www.nato.int/; and "NATO's Purpose," NATO (website), updated July 4, 2022, https://www.nato.int/.

14. NATO, *Space Policy.*

15. "Interoperability: Connecting Forces," NATO (website), updated February 22, 2022, https://www.nato.int/.

In this context, the technical dimension includes equipment, hardware, and other systems needed to conduct operations effectively. The procedural dimension looks at doctrines and procedures. The human dimension addresses terminology and training. The information dimension considers how information is shared across the Alliance.[16] As a newly established operational domain, space approaches each dimension differently than the other conventional domains, but these dimensions are all still considered in capacity-growing efforts across the Alliance.

Technical interoperability, which includes space systems and hardware, is conceptualized in modeling tools that contribute to space domain awareness and provide a common space picture for NATO operational commanders. These operations are still in the early stages. Currently, NATO does not own or operate space-based assets. In general, military equipment is owned and deployed to NATO by the member nations. Unlike aircraft or similar capabilities where many Allies may purchase the same platform with inherent technical interoperability, space technology involves a high degree of classification, and satellites have been generally designed to meet national purposes alone.

Traditionally, space capabilities are distributed through data, products, and services by a few contributing nations, usually voluntarily or upon specific request. Technical interoperability may unfairly burden less-developed members, including those facing financial hurdles in capability development while balancing national interests. But NATO's space policy does not seek to apportion requirements unnecessarily.[17] The policy provides an opportunity for creative multinational solutions the Alliance requires for security in this unfamiliar domain.

Multiple NATO entities are developing procedural interoperability, including doctrines, procedures, and best practices. These entities work to align efforts across NATO's two strategic commands to operationalize the new domain. These offices include, among others, the NATO Standardization Office (NSO), Allied Command Transformation; NATO's Warfare Development Centre strategic command located in Norfolk, Virginia; the NATO Space Centre of Excellence, currently being established in Toulouse, France; Allied Command Operations, NATO's other strategic command, located in Supreme Headquarters Allied Powers Europe in Mons, Belgium; and the NATO Space Centre located in Ramstein, Germany at Headquarters Allied Air Command.

These commands already integrate data daily from numerous Allies' space operations centers and space entities. This is a critical and initial step in developing a common space operating picture, and preparing missions, activities, and operations in peace and during crises. Data integration and production must be ready and standardized to meet the commander's intent during any future mission.

16. NATO, "Interoperability."

17. Laetitia Cesari Zarkan, "In Pursuit of the Best Standards: What Material and Legal Interoperability for NATO Forces?," *NATO Legal Gazette* 42 (December 2021), https://www.act.nato.int/.; and NATO, *Space Policy*.

Human interoperability addresses terminology, education, and training, which are critical to clear communication. The human element represents the most important factor in interoperability. Even before NATO recognized space as an operational domain, space cadres were scarce across the Alliance. Despite the space operational interface being inherently digital, this scarcity will only grow more acute as demand for their knowledge increases to meet growing operational requirements. Compounding this, many Allies are trying to increase their own domestic space-domain capabilities while simultaneously supporting NATO's increased needs. Even the United States, with its nascent Space Force, only has a few thousand military space professionals, and there are fewer in other NATO countries.

To grow capacity, NATO coordinates education and training for its personnel and standardizes a common space lexicon and curriculum for the Alliance. NATO has developed space courses to train personnel without prior space education or training, thereby reducing some reliance on spacefaring member nations to provide specialists. These courses provide foundational operational instruction and an in-depth understanding of processes and procedures for disseminating data, products, and services across the NATO command structure for all missions, activities, and operations from peacetime to crisis.

These courses produce professionals the Allies may also use in helping develop space forces in their own countries. The challenge for NATO and its member states moving forward is not only training new specialists to carry out space requirements but also educating the other forces to understand how space enables their own domains. This awareness will affect how NATO addresses future threats.[18]

Information interoperability is a critical cross-functional element and is related to intelligence preparation of the operational environment. NATO is familiar with combined air, maritime, and land intelligence processes as they apply to the Alliance, but the focus on space has added complications.[19] National classification of space data products and services has traditionally been a significant hurdle to interoperability.[20] In this case, the intent of overclassification to protect technology or means of collection may risk the overall goal of international collaboration and deterrence. With increased incentives to share more information, each Ally must negotiate internal national procedures.

The NATO Space Centre, as the operational hub for the organization, has a responsibility to fuse information collected from the different national space operations centers across the Alliance and transform it into viable NATO products that support all operational processes and communities. Currently, products releasable to NATO originate

18. NATO, "Multi-Domain Operations: Enabling NATO to Out-Pace and Out-Think Its Adversaries," NATO Allied Command Transformation (ACT) (website), July 29, 2022, https://www.act.nato.int/.

19. Arndt Freytag von Loringhoven, "A New Era for NATO Intelligence," NATO Review, October 29, 2019, https://www.nato.int/.

20. Christopher Stone, "Over-Classification in Space Programs Presents Too Great a Risk," Breaking Defense, September 2, 2021, https://breakingdefense.com/.

from a small number of Allies that have the capabilities to provide space intelligence, such as space-based missile warning systems.

For proper classification, national standard operating procedures must evolve to immediately consider sharing with the entire Alliance through a NATO-releasable product. A battle rhythm is required to share information regularly, and NATO will benefit from a concerted effort to improve space information sharing. No one nation has the sensor capacity to capture the entirety of space or Earth, however, the consolidation of space information across the Alliance can provide far more enhanced space domain awareness and other space support than currently exists in any one nation.

Ultimately, NATO faces challenges in how it collectively understands and operates as an alliance within space. As NATO aligns procedures across strategic commands to meet requirements, it must also educate new space specialists, coordinate with national initiatives, and share information in a fast-paced environment. Despite these challenges, multinational interoperability in space can be a force multiplier. As the ultimate multidomain enabler, greater interoperability in space has the potential to improve how the Alliance operates in other domains, thereby enhancing cooperative security.

Defense Planning

> *While resilience and survivability of Allies' space systems is a national responsibility, NATO will consider ways to improve space resilience Alliance-wide, including through sharing of best practices, and by exploiting force-multiplying redundancies in space capabilities owned by Allies.*
>
> *NATO Overarching Space Policy*

One of the unique characteristics of NATO is how it plans for the defense of and fosters capability development for the Alliance through the NATO defense planning process (NDPP). The NDPP is used to align national defense planning activities with NATO priorities in providing multinational forces to meet "agreed targets" in the "most effective way."[21] The process allows NATO to take on a "full spectrum of missions" while limiting redundancy and harmonizing efforts across the Alliance without undue impact on national sovereignty.[22] It is the heartbeat of NATO.

As NATO does not aim to become an "autonomous space actor," it apportions requirements to member nations with existing space capabilities or the capability and willingness to develop them.[23] This planning design allows the Alliance to hold each Ally accountable for its requirements, link each Ally to collective defense, and help each Ally foster its national capability. In essence, NATO defense planning contributes to national capability development, limits unnecessary redundancy, and coordinates

21. NATO, "NATO Defence Planning Process," NATO (website), updated March 31, 2022, https://www.nato.int/; and Alan Campbell, *Analytic Implications of the NATO Defence Planning Process*, SAS-081 Specialist Team Summary Report (The Hague, The Netherlands: NATO, April 2010): 9-4, https://apps.dtic.mil/.

22. Campbell, *Analytic Implications*, 9-4.

23. NATO, *Space Policy*.

requirements for the Alliance. For space specifically, NATO optimizes space support, contributes to national space efforts, and enables interoperability.

As a planning methodology for a large alliance, the NDPP is a political process separate from operational planning. The process is an iterative, quadrennial procedure that begins when the Allies issue the political guidance for the overall military aims and objectives of the Alliance, known as the Level of Ambition, which focuses on the medium term—approximately 7 to 19 years into the future.[24] The Level of Ambition is based on various factors including a range of threats, challenges, and opportunities for the Alliance.

The next political guidance, to be released in 2023, will set a tone for planning over the next four years and address NATO's ambition in light of current events in Ukraine. It will also be the first political guidance since NATO formally recognized space as an operational domain in December 2019. As such, it will have a significant influence on how NATO approaches space within defense planning.

Although the upcoming NATO defense planning process cycle is the first where space will be recognized as a separate domain, space requirements have been part of the NDPP since its inception. Several capabilities have been refined over multiple NDPP cycles and currently define space situational awareness; space-based atmospheric monitoring; space-based reconnaissance; positioning, navigation and timing; and satellite communication. For this cycle, the planning staff will integrate key aspects of the Overarching Space Policy into the NDPP.

Some of this integration will be relatively straightforward: the staff will refine existing requirements or they will add new ones to describe such things as the communications infrastructure necessary to share space domain awareness data to enhance "the Alliance's strategic anticipation and resilience."[25] Other integration efforts will be more difficult as the staffs seek to resolve the disconnect between a policy that calls for, among other things, "avoiding unnecessary duplication of effort" while simultaneously relying on the Allies for voluntary contributions to the domain.[26]

The NATO defense planning staffs face a unique challenge to further integrate space into the Alliance's decision-making processes and operations. One of the fundamental tenets of the space policy is that NATO does not intend to "become an autonomous space actor." This posture leaves capability acquisition to the member nations. This could hinder the inclusion of some command and control functions in NATO but also provides opportunities for interoperability by design or cooperative multinational solutions.[27]

Another dynamic to space can be challenging for defense planners. When capabilities are apportioned to the Allies as part of the NDPP, they are classified as quantitative

24. NATO, "Defence Planning Process."

25. NATO, *Space Policy*.

26. NATO.

27. NATO News, "NATO and Luxembourg Boost Alliance Space Situational Awareness," NATO (website)," updated June 15, 2021, https://www.nato.int/.

or qualitative. Most capabilities are quantitative, such as airborne air surveillance or a heavy infantry brigade, which means the owner of that apportioned capability is accountable for providing it when called upon. To measure their effect, these types of capabilities are easier to quantify in terms of units, which is useful for apportioning them to the Allies.

Qualitative capabilities are more difficult to define, measure, or apportion properly, such as command and control or position, navigation, and timing. The inability to properly quantify space capabilities or effects is also a challenge for defense planners when it comes to scenario planning and building an effective multidomain force model commensurate with the Allies' Level of Ambition. Furthermore, while NATO's space policy states that all space assets will be provided to the Alliance voluntarily, all space capabilities currently fall into the qualitative category. A refined policy may be required to guarantee the Alliance has space resources available in anticipation of situations in which national and NATO mission priorities may not be aligned.

This policy may also need to address the proper coordination and deconfliction of services provided by multiple sources to align and reduce redundant efforts. As it stands, NATO's current role has the potential to hinder overall operational support. For example, when more than one NATO country has agreed to provide satellite communications, intelligence, surveillance, and reconnaissance services, or space situational awareness capabilities, NATO should be able to properly coordinate the required capabilities from the Allies according to demand. This requires a higher level of coordination with national operation centers to prioritize resources and deconflict coverage properly.

Despite these challenges in integrating space into defense plans, the NATO defense planning process contributes to space capability development and overall NATO resiliency. In the NDPP, after the capabilities are agreed upon, planners apply apportionment methodologies to ensure fair burden-sharing, and reasonable challenges are weighed appropriately for each Ally.[28] In the context of space capabilities, fair burden sharing and reasonable challenges mean that NATO cannot continue to rely on a single or few nations to provide a specific capability. This methodology, linked to the latest NATO strategic concepts and initiatives that focus on emerging technology development, can help distribute expertise and competitive advantage to more suppliers of space capabilities than NATO currently has.[29]

NATO's Allied Command Transformation has the expertise to encourage developments that meet NATO's military needs and comply with NATO policy. Allied Command Transformation works with the Allies to share developments and fund some of

28. Campbell, *Analytic Implications*, 9-5.

29. "Emerging Disruptive Technologies," NATO (website), updated October 17, 2022, https://www.nato.int/; and NATO News, "NATO-Private Sector Dialogues Focus on NATO 2030 Initiative," NATO (website), updated June 2, 2021, https://www.nato.int/.

their research.[30] In the case of space, NATO military and legal professionals will ensure that all developments comply with the Overarching Space Policy, NATO's principle to act as a defensive alliance, and applicable international laws and treaties.[31]

Another way defense planners can seek to incorporate the policy into the NATO defense planning process is to integrate standards for interoperability into capability requirements. While operational planners write the standards, NATO defense planners can incorporate these standards into capability requirements themselves. This improves Allies' requirements over time and helps address the call to "improve space resilience Alliance-wide."[32]

In the long term, the defense planning staff must counter misconceptions about the space domain to encourage further integration of space into NATO defense planning. These misconceptions focus on the belief that space domain operations are always expensive and challenging. While not every nation will be able to fund relatively expensive or exquisite satellite constellations, there are plenty of other options for all Allies to participate in NATO's newest operational domain.

With the general decline of space technology costs, the Allies could contribute to NATO's space domain awareness through the procurement of low-cost sensors, services, and data from the commercial sector.[33] If NATO policy changes in the future, adopting quantitative space requirements through lower-cost capabilities could be accomplished without overly impacting the Allies' defense budgets. Overall apportionment is a zero-sum game, therefore, without a further increase in spending, the Alliance will have to decide which current requirements would need to be decreased or eliminated.

NATO defense planning is an uncommon process, one that aims to iteratively improve the collective security of the Alliance. Space presents a new challenge and opportunity for creative solutions in how to approach the development of capabilities fit for purpose. Furthermore, how NATO approaches its methodology for apportionment, scenario planning, and quantitative measurement of space capabilities will affect how capabilities are developed as an alliance and how successful the Alliance will be at maintaining a safe and secure domain.

Deterrence

Considering that Allies have recognised that space is essential to the Alliance's deterrence and defence, and to a coherent Alliance posture, the Alliance will consider a range of potential options, for Council approval, across the conflict spectrum to

30. "Allied Command Transformation," NATO (website), updated September 23, 2021, https://www.nato.int/.

31. NATO, "NATO's New Space Policy Launches Activity for Allied Command Transformation," NATO ACT (website), updated February 8, 2022, https://act.nato.int/.

32. NATO, *Space Policy*.

33. Eric Tegler, "The Commercial Satellite Industry Is Increasing Awareness in Space But It's Not Changing Behavior Yet," *Forbes*, December 17, 2021, https://www.forbes.com/.

> *deter and defend against threats to or attacks on Allies' space systems, as appropriate and in line with the principles and tenets outlined in this policy.*
>
> *NATO Overarching Space Policy*

Deterrence is at the heart of NATO's mission of collective defense. By incorporating space as one of its operational domains, NATO has considerably increased the complexity of its deterrence mission. But NATO's strength in deterrence lies not solely in its military ability to defend against a threat but also in denying the adversary any advantage of attacking in the first place. In this context, the collective space capabilities of the Allies contribute to NATO's deterrence strategy. Space certainly augments the Alliance's standing concept of deterrence, but the operationalization of space now adds a level of resiliency to NATO's mission. Furthermore, the space policy sets the stage for consultation and supports the concept of behavioral norms, which adds an additional layer of deterrence for the space domain and NATO.

Traditional Deterrence

NATO's traditional deterrence posture was the ability to present a force against which a rational adversary would be compelled to reconsider action as the cost of such an action would exceed the gain. At NATO's conception in 1949, US Senator Arthur Vandenberg hailed the Alliance as "the greatest war deterrent ever devised."[34] Drawing upon Article 51 of the United Nations Charter, NATO claims the right to collective self-defense.[35] In Article 5 of the North Atlantic Treaty, the Alliance declares its willingness to respond accordingly to "armed attacks" with the military might of all of the Allies if necessary to "restore and maintain the security of the North Atlantic area."[36] This is undoubtedly a formidable deterrent. This declaration has been tested over the past 73 years, but NATO has only invoked Article 5 once; in response to the September 11, 2001 terrorist attacks on the United States.

At the Brussels Summit in June 2021, NATO member state leaders declared that "attacks to, from, or within space . . . could lead to the invocation of Article 5."[37] This presents a level of complexity to NATO's deterrence posture as the definition of attacks may be left up to interpretation considering the myriad of kinetic, nonkinetic, and potentially reversible space threats that exist today. This addendum deserves much attention as NATO will need to consider strategic messaging and preconceived responses to attacks on critical national space assets that may lead to severe ramifications and possible escalation in a fragile domain. NATO did clarify the invocation would be considered "on a case-by-case basis."[38]

34. Benn Steil, *The Marshall Plan: Dawn of the Cold War* (New York: Simon and Shuster, 2018), 319.
35. The North Atlantic Treaty, April 4, 1949, art. V, https://www.nato.int/.
36. North Atlantic Treaty, art. V.
37. NATO, *Brussels Summit Communiqué*.
38. NATO, *Space Policy*.

Deterrence by Denial

Space adds complexity to NATO's traditional posture. It also contributes to a deterrence-by-denial posture by adding a layer of resilience to NATO's defenses. The concept aims to deny the adversary any "confidence in attaining its objective."[39] While NATO may be highly capable of deterring an adversary from engaging in hostile behavior, deterrence by denial requires the development of specific capabilities to persuade an opponent that a particular attack on NATO's space assets would be too difficult or less fruitful.

Today, NATO maintains a strategy of deterrence and defense that draws on all the resources at its disposal to give the Alliance a wide variety of options for responding to threats from any direction. NATO's "Concept for the Deterrence and Defense of the Euro-Atlantic Area" has been characterized as a "reimagine[d] deterrence by denial" concept that does not rely entirely on the depth or weight of the Alliance's force employment but is intended to be more agile and robust.[40]

In *NATO 2030: Towards a New Strategic Concept and Beyond*, Kaitlyn Johnson articulates in the chapter "NATO in Space" how a deterrence-by-denial concept should apply to space. The concept includes a range of passive- and active-defense methods. The passive methods describe a division of labor among a proliferated and robust constellation, controlled by agile operators, that may be replenished as needed but where there is no single point of failure.[41]

This does not translate perfectly for NATO as it does not operate its own satellites, however, through defense planning and capability development, the Alliance can address technical interoperability standards for member states' satellites to incorporate robust hardware and software measures to shield or protect satellite sensors. NATO may also be able to address the management of requirements to disaggregate and distribute capabilities appropriately. Active defenses such as jamming, spoofing, dazzling, and lazing may provide effective deterrence, but their dual capability makes them politically challenging to adopt from a NATO perspective.[42]

Deterrence by denial can also be supported by the commercial space sector as it provides critical mission assurance and resiliency.[43] Another unique aspect of NATO membership is articulated in Article 3 of the North Atlantic Treaty. It calls on mem-

39. Michael J. Mazarr, "Understanding Deterrence," Perspectives (Santa Monica, CA: RAND Corporation, 2018), https://www.rand.org/.

40. Julian Lindley-French, "The NATO Strategic Integrated Operating Concept," Alphen Group (blog), October 16, 2020, https://thealphengroup.home.blog/.

41. Kaitlyn Johnson, "NATO in Space," in *NATO 2030: Towards a New Strategic Concept and Beyond*, ed. Jason Blessing, Katherine Kjellström Elgin, and Nele Marianne Ewers-Peters (Washington, DC: Foreign Policy Institute/Henry A. Kissinger Center for Global Affairs, Johns Hopkins University SAIS, 2021), 246–48, https://sais.jhu.edu/.

42. Johnson, "NATO in Space," 248–49.

43. John J. Klein, *The Influence of Commercial Space Capabilities on Deterrence* (Washington, DC: Center for a New American Security, March 25, 2019), https://www.cnas.org/.

bers to individually and collectively grow the capacity to defend against an armed attack.[44]

This capacity development relies on the interdependency between government and commercial sectors.[45] NATO's deterrence and defense task must consider the services of the commercial space industry. The growing commercial space industry provides options to NATO. Commercial open-source data, low-cost space launches, and other satellite services can help governments meet NATO requirements. The percentage of government- or military-owned satellites worldwide is smaller than commercially owned satellites, and that gap is increasing.

These commercial systems provide an additional layer of defense and deterrence that NATO needs to consider in application. For example, the commercial space industry provides resilience in its ability to improve communications, surveillance, launch, and space situational awareness. Commercial satellites provide a layer of resilience if another commercial or military satellite is damaged or degraded during a conflict. If satellite communications are jammed or damaged, a commercial service provider can route communications through its networks or potentially through the networks of another provider, also using different frequencies.

Commercially owned, proliferated Earth observation satellite constellations can also provide surveillance imagery that can augment or corroborate other sources. These commercial services have proven extremely effective in supplementing communications and providing valuable surveillance in the war in Ukraine.[46]

Responsive airborne launch is another example where commercial services can provide resilience to NATO. Should an asset be disabled or denied its utility, Allies should be able to rely on agile companies with a disaggregated global launch capability to rapidly respond to a critical gap in space.[47]

The commercial space sector can also play a part in deterrence by increasing space situational awareness and space forensics. Through its growing network of space situational awareness ground telescopes and other terrestrial tracking systems, the commercial industry may be able to assist in the attribution process following a hostile or criminal act in space.[48] Although the commercial space sector will not be considered to perform any active defensive or offensive action, commercial partners may be able to assist traditional military space systems in gathering information that may be used to identify those responsible and facilitate any subsequent response. These commer-

44. "Resilience, Civil Preparedness and Article 3," North Atlantic Treaty Organization (website), updated September 20, 2022, https://www.nato.int/.

45. "Resilience," NATO (website).

46. Beale, "Unseen Frontier."

47. Bret Perry and John Fuller, "Developing an Operational Framework to Enable Interoperable Allied NATO Responsive Space Activities" in *Air and Space Power Conference 2022: Enhancing NATO Air and Space Power in and Age of Global Competition*, 11–13 October 2022 Read Ahead (Kalkar, Germany: Joint Air Power Competence Center, June 2022), https://www.japcc.org/.

48. Theresa Hitchens, "China's SJ-21 'Tugs' Dead Satellite out of GEO Belt: Trackers," Breaking Defense, January 26, 2022, https://breakingdefense.com/.

cial capabilities are not accounted for in traditional defense planning, but NATO's ability to leverage the range of commercial space capabilities will dramatically improve its deterrence posture.

Responsible Space Behavior

Another aspect of deterrence is developing a shared understanding of concepts such as the role of space in a crisis or conflict or supporting international efforts to establish norms, rules, and principles of responsible space behaviors. One way to develop this shared understanding while maintaining the competitive advantage is through collective legal diplomacy. While NATO does not plan to change the international legal framework for space activities, it can serve as a venue for discussing and supporting norms to eliminate gaps in interpreting and implementing international law in space.[49]

An excellent example of collective legal diplomacy was the NATO-sponsored multiyear cybersecurity study that resulted in the internationally appreciated publication of the *Tallinn Manuals*, which includes the rules of international law governing cyber incidents that states encounter daily.[50] Other similar manuals or studies have been published specifically discussing military operations in space but were not associated with NATO.[51]

One of NATO's key roles is to serve "as a forum for political-military consultations," including "the development of legal and behavioral norms."[52] This applies to space and other arms control conventions and treaties. This is realized through NATO's Arms Control, Disarmament, and Weapons of Mass Destruction Non-Proliferation Centre that oversees different internal committees that address arms control and disarmament issues. The centre actively contributes to efforts among NATO's 30 members, its dozens of partners, and other countries to further international security obligations.[53] Space deserves the same level of attention afforded to arms control and weapons of mass destruction.

It is not the role of NATO to make international law; that legislation falls to nation-states. But while discussions continue globally that affect space security, NATO, as the world's largest political-military organization, should take the initiative to develop responsible military space behavior. This initiative will help shape an environment that is resilient in the face of actions that have the potential to invoke retaliation.[54]

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49. Karl-Heinz Brunner, *Space and Security – NATO's Role*: *Preliminary Draft Special Report* (Brussels, Belgium: Science and Technology Committee, NATO Parliamentary Assembly, 2021), https://www.nato-pa.int/.

50. Michael N. Schmitt, ed., *Tallinn Manual 2.0 on the International Law Applicable to Cyber Operations* (Cambridge, UK: Cambridge University Press, 2017), https://www.cambridge.org/.

51. Robert Gray 'Butch' Bracknell, "Introduction," *NATO Legal Gazette* 42 (December 2021), https://www.act.nato.int/.

52. NATO, *Space Policy.*

53. "Arms Control, Disarmament and Non-Proliferation in NATO," NATO (website), updated August 2, 2022, https://www.nato.int/; and "Partners," NATO (website), updated March 27, 2020, https://www.nato.int/.

54. Mary Ann Hurtado, "UN Panel Approves Working Group on Space," *Arms Control Today* 51 (December 2021), https://www.armscontrol.org/.

Conclusion

Space security is an international affair, and the framework for such achievement lies with NATO. Space security strategist James Clay Moltz once concluded "global institutionalism" is a less risky approach to achieving sustained security in space than any alternative.[55] Moltz argued unilateral "military-led security in space" as opposed to "transnational partnerships" may harm existing norms of behavior.[56] Moltz did not account for an intergovernmental, military-led alliance whose interest is security in space.

In any discussion of a global military space policy, NATO's Overarching Space Policy should be seriously considered. The policy is significant for a number of reasons. It outlines 30 countries' singular view of the importance of space and their collective approach to improving its security. Significantly, the policy itself highlights NATO's value as a dynamic alliance.

There are significant hurdles in their approach, such as overclassification, a lack of general knowledge of the domain, and an increasing requirement for trained and experienced personnel. Other issues require creative solutions such as capability development and proper accounting of space capability contributions from the Allies, as these pertain to defense planning. But NATO's organizational ability to improve interoperability, plan for its current and future defense, and build deterrence should be viewed as a model for collaboration and security, especially as it applies to space.

NATO will continue to adapt to emerging threats and disruptive technology. Future iterations of political guidance and strategic concepts will continue to drive how NATO approaches modern-day and future crises and will inevitably shape how the Alliance incorporates lessons learned into future capabilities and deterrence postures. Ultimately, current and future trends of space activity will demand measurable stability through international space collaboration, security efforts, and responsible space behavior, which NATO is in a unique position to influence. **Æ**

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55. James Clay Moltz, *The Politics of Space Security*, 3rd ed. (Stanford: Stanford University Press, 2019), 361–62.

56. Moltz, *Space Security,* 361–62.

DEVISING NATIONAL SPACE POLICY IN PAKISTAN

Mohammad Ali Zafar

Ayesha Zafar

In 1962, Pakistan initiated a satellite research program—the first South Asian country to do so. Since then, Pakistan's space program has been subject to emerging security threats, abrogation and then restoration of the Constitution, a shift toward military use of space technology, and confusion over the structure of the national space program. In addition to these internal factors, there is a rising concern about the Indian quest for space technology. The growing diplomatic clout of India's space program and its dual use of space technology leading toward the development of an antisatellite weapon (ASAT) capability raises challenges for Pakistan. Accordingly, Pakistan's policymakers need to analyze the growing developments in the Indian space program that act as a rationale for Pakistan to devise a national space policy. The current structure of the space program in Pakistan and challenges posed by the Indian space program require Pakistan to recalibrate its space program by devising a national space policy.

Pakistan's progress in the area of space research has remained quite stagnant. From the day of its independence on August 14, 1947, several issues including the leadership crisis, resource constraints, constitutional problems, and an indecisive government, have caught the state in a tightening rope. Likewise, emerging national security threats and political instability have affected space program development. Although the initial space program in 1962 was designed to satisfy domestic needs and intended to conduct scientific space research, three martial law rules in Pakistan have shifted the focus of the space program from civil and commercial purposes toward maintaining strategic military orientation. Even so, today, Pakistan is focusing on the socioeconomic advantages of space utilization and set a budget of Rs 7.36 billion for the Space & Upper Atmosphere Research Commission (SUPARCO) for fiscal year 2022.[1] SUPARCO is the executive and national space agency of Pakistan.

Compared to Pakistan, India has made colossal progress in space research. Six decades of research have provided New Delhi with a key edge over Islamabad. India's space program includes historical, cost-effective programs such as Chandrayaan-2

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1. "Development in Focus as PTI Unveils Rs8.5 Trillion FY22 Budget," *Dawn,* June 12, 2021, https://www.dawn.com/.

and myriad active satellites and commercial satellites of several countries. India's space program dates back to 1963 when India's launched its first rocket, the US-supplied Nike Apache. Since its inception, scientific research has been at the core of India's program because of a belief that it could resolve many problems for the newly created state.[2]

In 2004 during the inauguration of the satellite-linked Village Resource Centres, Prime Minister Manmohan Singh stated, "More than any other institution, the Indian space program has brought great prestige to India, especially among the spacefaring nations."[3] The credibility of India's space program is evident by its strong position in space research, where it is ranked among the top spacefaring nations and was the first Asian country to reach the orbit of Mars.

Most research on Pakistan's space program focuses on the need for legislation. Scholars have discussed the need for Pakistan to enter "into all the five space treaties" and formulate space legislation.[4] While Pakistan must introduce space legislation that accounts for regional space programs and international commitments like any spacefaring nation, legislation is not the primary need of the country. For instance India, with its leading space program, also lacks national space legislation.

Therefore, introducing legislative reforms is not the answer. Such reforms entail a lengthy process, especially considering the historical development of SUPARCO, situated under the National Command Authority (NCA), and the fact that the word "space" is not even included in the Federal legislative list of Pakistan. These factors create hurdles for national space legislation in Pakistan.

Scholars do understand the need for space development in Pakistan, however, the real challenge is to understand why and how Pakistan needs to recalibrate its approach toward space research.[5] The answer is based on Pakistan and India's historical asymmetry in the conventional domain. To maintain the balance of power in South Asia, Pakistan needs to understand the threat that exists from the militarization of space by India and the diplomatic isolation of Pakistan in space research. Then Pakistan must determine a way forward. This effort remains a challenge for Pakistan, which has already spent a decade working to transition from a conventional to a counterinsurgency army. Solutions require a deeper assessment of the threat posed by the Indian space program, which include reassessing the decades-long air-, sea-, and land-centric approach toward military technology.

Pakistan's security policy has focused primarily on the threat from its eastern neighbor, India. This has been the case since its inception. Moreover, four major wars, numerous border skirmishes, oppositional narratives, and diplomatic tussles at global

2. Michael Sheehan, *The International Politics of Space*, 1st ed. (London: Routledge, 2007), 142–50.

3. Sheehan, *Politics of Space*, 142–50.

4. Murat Cancan et al., "National Space Legislation: A Dire Need for Pakistan," *Journal of Statistics and Management Systems* 24, no. 4 (2021), https://www.tandfonline.com/.

5. Miqdad Mehdi and Jinyuan Su, "Pakistan Space Programme and International Cooperation: History and Prospects," *Space Policy* 47 (February 2019), https://www.sciencedirect.com/.

platforms demonstrate their mutual hostility. Additionally, when Pakistan tested its first nuclear weapon at Chagai in 1998, it claimed India's hostile posturing had forced it to acquire a nuclear weapon of its own.[6]

Therefore, history reflects that for Pakistan to devise a policy with a security orientation, it acknowledges the existence of an Indian threat to its regional interests. This is why an understanding of the Indian space program, especially the development of antisatellite weapons, is the most compelling reason for Pakistan to devise a national space policy.

Both states have the capability to deter each other in the traditional arms race, but in space research, Pakistan needs to make gains. It can do this by devising a comprehensive space policy. To analyze this, the article examines the beginning of Pakistan's space program, taking into account the tempestuous history, a major shift in Pakistan's space research, and SUPARCO's structure.

The article then discusses India's space program and its recent developments, especially the development of antisatellite technology (ASAT) and that country's rising diplomatic clout, which could pose challenges for Pakistan in the future especially considering no state except China questioned India's testing of ASAT capability. The article concludes with a few recommendations for Pakistan's space program development using the Indian space program as a benchmark.

Pakistan's National Space Program

Pakistan's space program was initiated in 1961 during the days of political instability. Military dictator and Pakistani President General Ayub Khan's decision to join the US bloc during the Cold War led to the foundation of Pakistan as a "security state." At that time, Ayub accepted the proposal of Nobel Prize winner Abdus Salam for the establishment of a space research program.[7] Hence, Pakistan's first-ever space agency, known as the Space and Upper Atmosphere Research Committee (SUPARCO), was established on September 16, 1961.

In the early years of the Space Age in the late 1950s, the US National Aeronautics and Space Administration (NASA) offered to establish rocket ranges in all countries on the Indian coastline.[8] Pakistan accepted the offer and, together with other developing countries, became the first to carry out an experimental rocketry program.

In 1962 in collaboration with NASA, SUPARCO worked on a two-stage sounding rocket, the Nike-Cajun, which was used to initiate a sodium-vapor payload from

6. "Hostile Posturing by India Forced Nuclear Testing in 1998, Says Pakistan," NDTV, May 28, 2018, https://www.ndtv.com/.

7. Mian Zahid Hussain and Raja Qaiser Ahmed, "Space Programs of India and Pakistan: Military and Strategic Installations in Outer Space and Precarious Regional Strategic Stability," *Space Policy Journal* 47 (2019), https://www.sciencedirect.com/.

8. NASA, "SP-4401 - NASA SOUNDING ROCKETS, 1958-1968: A Historical Summary," "VII: Sounding Rockets during the Heyday of Scientific Satellites: NASA's International Programs," n.d., accessed December 12, 2020, https://history.nasa.gov/.

Sonmiani Beach, Pakistan.[9] Salam made a significant contribution to this effort by creating a team of nuclear engineers and scientists. Within two years of its establishment, SUPARCO sent a two-stage, solid-fuel sounding rocket with an 80 pound sodium payload, Rahbar-1, 130 km into the atmosphere. With the assistance of NASA, this test made Pakistan the third state in Asia and the 10th in the world to initiate its first-ever rocket.[10]

Pakistan and NASA also cooperated on the testing of two hypersonic sounding rockets named Shahpar and Rukhnum. Shahpar was a 7-meter solid-fuel, two-stage rocket that carried a 70 kg (154-pound) payload up to 950 km, and Rukhnum was a liquid-fuel three-stage rocket that reached 1,000 km in the atmosphere.[11] This was a big achievement for Pakistan and further opened windows of opportunity by providing scientists with a chance to explore space beyond the atmosphere and study cloud formation, cyclones, and weather patterns over the Arabian Sea. During this time, Pakistan's cooperation with the United States in space exploration played a significant role in Pakistan's space program. Pakistan made these major achievements in the first phase of its space program.

Similarly, new developments resulted during the second phase of Pakistan's space program under General Zia ul Haq, who came to power by imposing martial law in 1977. When Zia took charge, it was opined that SUPARCO would no longer be able to accomplish its original goals. Yet as a result of India's successful launch of its Aryabhatta satellite on April 19, 1975, Pakistan's leaders were motivated to consider devising something similar to counter it. Accordingly, SUPARCO was rejuvenated in 1979, and it began working on a new satellite named PAKSAT.

When Zia visited SUPARCO in the subsequent year, all ongoing projects were terminated due to the lack of funding. But one year later in 1981, through a presidential ordinance, he ordered the reestablishment of SUPARCO, but this time its focus shifted toward military use of space technology.

Pakistan encountered a major hurdle to its space program when the United States imposed sanctions following its first nuclear test conducted on May 28,1998 in Chagai.[12] Because of Pakistan's focus on developing the atomic bomb and its changing political landscape, the country's space program moved away from the United States and shifted more toward China.

During the time of the sanctions (1998–99), China extended strong support to Pakistan, which included support for its space program. This led to the launch of Pakistan's first-ever digital communication satellite, Badr-1, in the 1990s. Relatedly but

9. Hasan Murtaza and Ahmad Khan, "Pakistan Space Activities," in *Handbook of Space Security: Policies, Applications, and Programs*, ed. Kai-Uwe Schrogl (Cham, Switzerland: Springer Nature, 2020).

10. "Pakistan Space & Upper Atmosphere Research Commission, History," SUPARCO (website), n.d., accessed December 12, 2022, https://suparco.gov.pk/.

11. NASA, "NASA SOUNDING ROCKETS."

12. (Name Redacted) Legislative Attorney, American Law Division, *Nuclear Sanctions: Section 102(b) of the Arms Export Control Act and Its Application to India and Pakistan*, R98-486A (Washington, DC: Congressional Research Service, October 5, 2001), https://www.everycrsreport.com/.

much later, in 2014, Pakistan became the first state to deploy China's BeiDou GPS network.[13] In 1991, SUPARCO and the Chinese Ministry of Aerospace Industry signed an agreement to strengthen space cooperation, yet it didn't gain much attention and was limited to personal training and infrastructure development.

Apart from this, the 2005 launch of the Asia-Pacific Space Cooperation Organization with Pakistan, Bangladesh, Iran, Peru, Mongolia, and China was intended to promote space programs developed together with the member states for peaceful purposes. In 2011, Pakistan and China achieved another milestone of cooperation when they launched a Chinese-manufactured communication satellite known as Paksat-1R, which provides broadband internet and tele-education services to South and Central Asia, Eastern Europe, East Africa, and East Asia. In 2019, the states signed a space agreement which facilities Chinese training of Pakistani astronauts and the establishment of a Sino-Pakistan space committee.[14] Overall, cooperation with China will enhance Pakistan's capability in space research and boost cordial bilateral relations.

Structure of National Space Activities

When General Pervez Musharraf took power in 1999, he laid the foundations of the National Security Council (NSC) and approved the creation of the National Command Authority. Consequently, SUPARCO Amendment Ordinance-2002 gave the federal government control over the commission through the NCA.[15] Before the implementation of the ordinance in September 2000, SUPARCO had operated under the Cabinet Division for almost 20 years.

The other related wings, the Space Research Council and Executive Committee of the Space Research Council, were dissolved and replaced by NCA's Development Control Committee. The NCA was given complete authority to control and command all space- and nuclear-related activities.[16] This power also includes supervision, management, coordination, and control of the budget, programs, and projects of the "strategic organizations."[17]

Similarly, SUPARCO, which, per the 2010 NCA, was given the title of a strategic organization, has the authority to look after special scientific and technological work. Maintenance of security matters and defense of Pakistan also come under the responsibility of the NCA. But following the 1973 constitution and the NCA Act of 2010, the

13. "Pakistan Becomes First Country to Deploy China's BeiDou GPS Network," *Tribune*, May, 2014, https://tribune.com.pk/.

14. "Pakistan Signs Space Cooperation Agreement with China to Enable First Pakistani Astronaut," Spacewatch Asia Pacific, n.d., accessed December 12, 2022, https://spacewatch.global/.

15. SUPARCO Amendment Ordinance (No. CXXVII of 2002); and The National Command Authority Act 2010 (Islamabad: the Gazette of Pakistan, Senate Secretariat, March, 2010), http://www.na.gov.pk/.

16. "National Security Council of Pakistan (NSC)," Nuclear Threat Initiative (NTI), last updated December 17, 2021, https://www.nti.org/.

17. Naeem Salik, ed., *Nuclear Pakistan Seeking Security & Stability*, Center for International Strategic Studies Security Series (Lahore, Pakistan: University of Lahore, 2018), 87–89, https://ciss.org.pk/.

prime minister is the chairman of the NCA. On paper, then, the command seems to be under the prime minister, but in practice, the whole structure is under military control. Moreover, considering the persistent political turmoil—no prime minister has completed a full term in office—it is clear the military has been managing the NCA and space program in Pakistan.

Apart from this, all space-related regulations are the responsibility of SUPARCO, which coordinates the policies and programs of the federal government. The research related to space and space development activities, except for launch and services, come under the authority of SUPARCO. Additionally, the committee has been instructed to (1) plan, manage, and direct all industrial or scientific space research programs and projects; (2) work to endorse the transmission of space technology; and (3) promote the exploitation of space technology, capabilities, and facilities for commercial purposes. In this way, the National Command Authority, after receiving reports from SUPARCO, directly reports to the prime minister of Pakistan.

Clearly, the structure of Pakistan's space activities experienced a shift in approach when the military dictatorship of Musharraf implemented structural changes in the governance structure of SUPARCO, emphasizing the military domain and using resources for programs such as the Rehbar spaceflight program, the Haft program, Shaheen 3, and many other localized military-centric space programs. Despite this shift of focus to the military, Pakistan has undertaken some important bilateral initiatives to advance its space program.

Space Vision-2047

In recent years, Pakistan has started giving more attention to space research. In July 2014 during the nineteenth meeting of the NCA, former Prime Minister Nawaz Sharif approved Pakistan's National Space Program 2040 with the objective of bringing the benefits of space technology to the Pakistani public.[18]

This space program was later renamed Space Vision-2047 to mark the anniversary of Pakistan's independence. A few important achievements of the space program include the launch of solid-fuel rockets, geostationary orbit communication satellites, remote sensing, low-Earth orbit experimental satellites, space study, and applications in Pakistan. Moreover, the space program undertook projects related to agriculture, disaster management, water resource management, mapping, environmental monitoring, and others.[19] This is an important development because Pakistan is vulnerable to climate change, especially in terms of droughts, famine, and cloud bursts. It needs a remote sensing satellite to monitor weather events and coordinate effective response strategies.

Pakistan imposed a national emergency as a result of locusts in January 2020. SUPARCO and the Space Application Centre for Response in Emergency and Disasters,

18. "NCA Okays Nuclear Power Prog 2050, Space Prog 2040," Geo News, July 14, 2011, https://www.geo.tv/.
19. Murtaza and Khan, "Pakistan Space Activities."

together with the UN-SPIDER Regional Support Office, used space-based information to identify desert locust habitats based on vegetation, soil type, and other factors.[20]

Pakistan is also facing multiple water scarcity issues. Pakistan's Council of Research in Water Resources has already generated a warning that the country will become water-scarce by 2025. Regionally, Pakistan is predicted to become the most water-stressed country in 2040.[21] Likewise, floods, droughts, and changing climate patterns have already created significant problems not only for the water sector but also for agriculture. Hence, Pakistan's commercial satellite PAKSAT MMI-38, which is expected to be placed in orbit in the year 2024, will aid in mitigating these threats.[22]

But a major challenge is Pakistan's dependence on China for space technology. As a 2020 report noted, presently, Pakistan's total communication satellite capacity usage is approximately 2,200MHz; Pakistani satellites supply 21 percent of this capacity and foreign satellites supply the rest. This means Pakistan spends a minimum of $35-45 million annually on access to these foreign satellites.[23] Therefore, in Pakistan, there is a greater need to invest more in domestic space research to close this loophole.

Rationalizing National Space Policy in Pakistan

Pakistan, like other states, is compelled to regulate space activities for specific national reasons. Initiating a national space policy would address key national security concerns. The first concern is the growing diplomatic clout of India's space program. The second is India's shift toward the dual use of space technology, leading to the development of India's ASAT capability. The third concern is the growing angst over the state's international responsibility for national activities in outer space.

Indian Space Program

The Indian space program is one of the most proficient in the world. India has been able to strengthen these proficiencies in space exploration due to investments worth billions of dollars.[24] The Indian Space Research Organization laid the foundations for their diverse space program. Despite initially pursuing commercial competencies, India's space program has evolved, and the country is now using space programs for constructive space diplomacy, socioeconomic applications, and most recently, a far-reaching shift from peaceful use to the militarization of space.

New Delhi has undertaken a multifaceted approach to expand its position in space research. International cooperation in this arena is key to India's surge as a space

20. "SUPARCO Maps Potential Desert Locust Habitats in Pakistan, United Nations," Office for Outer Space Affairs, UN-SPIDER Knowledge Portal, 2020, http://www.un-spider.org/.

21. "Water crisis: Why Is Pakistan Running Dry?," *News*, June 8, 2018, https://www.thenews.com.pk/.

22. "PakSAT-MM1R," SUPARCO (website), n.d., accessed December 12, 2022, https://suparco.gov.pk/.

23. Khalid Mustafa, "Govt to Raise $700m for National Space Programme," *News*, June 24, 2020, https://www.thenews.com.pk/.

24. "Global Space Economy Grows in 2019, to $423.8 Billion, the Space Report 2020 Q2 Analysis Shows," Space Foundation, July 30, 2020, https://www.spacefoundation.org/.

power. This has not only bolstered space experience, but it has allowed India to emerge as the sixth most effective space exploring nation. It has 226 space cooperation agreements with different states focused on capacity building; exploration; telemetry, tracking, and command; satellite navigation; satellite communication; remote sensing; and space laws.[25]

In India, space cooperation with Russia includes the Thumba Equatorial Rocket Launching Station; a joint venture on Aryabhata, in 1975; cooperation on Chandrayaan 1 and 2; deployment of the first Indian in space, and many other projects including a remote sensing satellite (IRS)-1A, Youthsat, GLONASS, and GLONASS-K.[26] All this expanded Indo-Russia space cooperation at the same time, increasing Russian interest in the Indian market. Such actions allow India to improve its unilateral space research capability while expanding prestige-related space activities for spaceflight programs.

In partnership with the United States, India launched the American Nike Apache from Thumba, a venture for the Satellite Instructional Television Experiment in 1976, and INSAT-1A, 1B, and 1D between 1982 and 1990 to support broadcast, meteorology, and remote sensing experiments.[27] Along with this, NASA and the India Space Research Organization have launched joint initiatives including working groups to explore the potential use of NASA-owned laser retroreflector arrays in Chandrayaan-2 to make precise measurements of the Moon's distance, and NASA-India Space Research Organization Synthetic Aperture Radar to obtain fine-resolution images of Earth. This collaboration has diversified Indian space cooperation.[28]

In such efforts, India has taken a central role on the regional stage in space research. India's regional hegemonic designs include space supremacy. At the 18th South Asian Association for Regional Cooperation (SAARC) summit in 2014, India announced South Asia would have a SAARC satellite. Bangladesh, Bhutan, Afghanistan, Maldives, Sri Lanka, and Nepal signed the agreement.[29] Despite Pakistan's opposition, the project was launched in 2017 and the name was changed to South Asia Satellite.[30] This development poses challenges for Pakistan since space surveillance is a national security concern, consequently raising policy questions about how to

25. Charlotte Mathieu, "Assessing Russia's Space Cooperation with China and India: Opportunities and Challenges for Europe," European Space Policy Institute, June 12, 2008, https://www.files.ethz.ch/.

26. Mathieu, "Russia's Space"; "Indian to Fly on Russian Spaceship?," *Times of India*, March 28, 2008, https://timesofindia.indiatimes.com/; Indian Space Research Organisation, *Annual Report* (Bengaluru: Official Printers, 2007), https://www.isro.gov.in/; and Sergey Revnivykh, "GLONASS: Status and Perspectives," Civil GPS Service Interface Committee, March 14 2005.

27. "Nike-Apache," Fandom, NASA wiki, n.d., accessed December 13, 2022, https://nasa.fandom.com/; and Kenneth I. Juster, "Unleashing the Potential of U.S.-India Civil Space Cooperation," address to India-United States Conference on Space Science, Applications and Commerce, Bangalore, India, on June 22, 2004, https://2001-2009.state.gov/.

28. "NASA-ISRO SAR Mission (NISAR)," NASA (website), n.d., accessed December 13, 2022, https://nisar.jpl.nasa.gov/.

29. "Prime Minister's speech at the 18th SAARC Summit," Ministry of External Affairs (MEA), Government of India (GOI) (website), November 26, 2014, https://www.mea.gov.in/.

30. "India Launches 'Invaluable' South Asia Satellite," BBC, May 5, 2017, https://www.bbc.com/.

counter India, which is taking an official lead in space research with the agreement of regional players.

Moreover, India has partnered with the European Space Agency and signed an agreement leading toward the launch of Europe's Ariane 3 rocket into space with India's first geostationary satellite, Apple.[31] The agency's support for India's lunar mission has allowed both to cooperate—a key to their space strategies. Further cooperation includes space programs for communication, navigation, and earth observation.[32]

India's major EU space cooperation effort is with France. The two nations have worked on Megha-Tropiques to study climate-related aspects, launched SARAL in 2013, and undertaken TRISHNA, a joint Franco-Indian mission to monitor the water status of Continential ecosystems.[33] Despite nascent cooperation with the EU vis à vis Germany, India's efforts illustrate its desire to widen its joint role in space research.

Similarly, India is now a space service provider. The Association of South East Asian Nations (ASEAN) is a case in point. India has provided Indian remote sensing data via a framework agreement with Vietnam in 2016, and it has established stations in Ho Chi Minh City. Additionally, China trains ASEAN members in satellite engineering.[34]

Scholars have discussed the diversity of India's space cooperation with other states, analyzing the country's evolution, challenges, and accomplishments in international space cooperation including bilateral and multilateral efforts.[35] All of this highlights New Delhi's intent to continue expanding its global ambitions: currently India has space cooperation operational agreements with multiple states and international organizations, including the United States, the European Space Agency, France, Canada, Israel, Brazil, Venezuela, Indonesia, Maldives, and Mongolia.[36]

India's increasing diplomatic clout means fewer states question India's militarization of space. In fact, Pakistan and China were the only two nations that raised their voices against New Delhi's 2019 ASAT capability test.[37] Moreover, India's strong relations with several spacefaring nations complicates Pakistan's efforts to forge ties with them in the space domain, especially when India builds threat hysteria regarding Pak-

31. "India – Europe cooperation," The European Space Agency (website), October 20, 2008, https://www.esa.int/.

32. Isabelle Sourbès-Verger, "EU-India Cooperation on Space and Security," working papers 16, no. 38 (Rome, Italy: Istituto Affari Internazionali, December 2016), https://www.gatewayhouse.in/.

33. "SARAL," India Space Research Organisation (ISRO) (website), 2013 https://www.isro.gov.in/.

34. "ASEAN-India Relations," MEA (website), n.d., accessed December 13, 2022, https://mea.gov.in/.

35. B. R. Guruprasad, "Understanding India's International Space Cooperation Endeavour: Evolution, Challenges and Accomplishments," *India Quarterly* 74, no. 4 (2018), https://www.jstor.org/.

36. "International Cooperation," ISRO (website), n.d., accessed December 13, 2022, https://www.isro.gov.in/.

37. Malcolm Davis, "Will India's Anti-Satellite Weapon Test Spark an Arms Race in Space? The Strategist, March 29, 2019, https://www.aspistrategist.org.au/.

istan's military arsenals and fosters misperceptions through disinformation regarding Pakistan's regional ambitions.[38]

Moreover, India's former national security advisor Ajit Doval's doctrine provides further justification of how India aims to use its defensive-offense mode, which includes the aim to internationally isolate Pakistan.[39] The doctrine promotes the use of diplomacy and military power to negotiate from a position of strength.

In addition to the increasing diplomatic clout of India in space research, other rationales exist for Pakistan to devise a national space policy, including the commercialization of the Indian space program. In 2014, India introduced attractive policies for high-technology innovation for the private sector, leading to the Make in India approach, which opened the door to a strong space-technology investment component for the space program.[40] This initiative offered 100 percent foreign direct investment for satellite construction and operations.[41]

The private sector backing of businesses in spacefaring countries, particularly Australia, New Zealand, Luxembourg, and the United Arab Emirates, demonstrates the democratization and privatization of space activities in India.[42] These activities increase India's relationships with international vendor suppliers, which will eventually allow India to improve and expand its domestic space research capabilities, thus raising potential challenges for the rise of new spacefaring nations, especially Pakistan.

As a result of 2020 space reforms, India established a new facilitating agency, the Indian National Space Promotion and Authorization Centre (IN-SPACe), to develop private-sector-friendly regulations.[43] To promulgate industrial policies that promote innovation and support using ISRO space infrastructure, the organization has initiated the Space Entrepreneurship & Enterprise Development project to support new space-related start-ups.[44] This will increase start-ups and technology companies' accrued investments and increase India's share in the space market beyond the current 2 percent.[45]

38. Mahnoor Saleem, "Indian Disinformation Operations against Pakistan and Its Implications," Centre for Strategic and Contemporary Research (website), December 29, 2021, https://cscr.pk/.

39. Abdul Rasool Syed, "Doval Doctrine & Covert Operations," Daily Times, March 18, 2019, https://dailytimes.com.pk/.

40. Narendra Modi, *Strategy for New India @ 75*, (New Delhi, India: NITI Aayog, November 2018), https://niti.gov.in/.

41. "Space," Make in India (website), n.d., accessed December 13, 2022, https://www.makeinindia.com/.

42. Chaitanya Giri, "A Space Exploration Industry Agenda for India" paper 23 (New Delhi, India: Gateway House: Indian Council for Global Relations, May 2020), https://www.gatewayhouse.in/.

43. Press Information Bureau (PIB), "Cabinet: Historic Reforms Initiated in the Space Sector: Private Sector Participation in Space Activities Approved," PIB – GOI (website), June 24, 2020, https://pib.gov.in/.

44. "Empowering India's Startups to Transform Space Sector with ISRO and AIM," ISRO, September 9, 2020, https://www.isro.gov.in/.

45. Antrix Corporation and PricewaterhouseCoopers India, *Preparing to Scale New Heights: Enhancing Private Participation in India's Commercial Space Sector* (New Delhi: Antrix Corporation and PricewaterhouseCoopers India, January 2020), 15, https://www.pwc.in/.

Military Use of Indian Space Activities

India's offensive military capabilities are alarming for Pakistan. Due to a lack of policy and technological development in space research, Pakistan has been unable to counter India's development of dual-use technology and protect its very few satellites. So far, Pakistan's only hope against the Indian belligerent approach is China, who is willing to protect Pakistan's satellites with its massively advanced space program.

Numerous Indian satellites in geosynchronous orbit and low-Earth orbit are used for technological and improved science support as well in support of the Indian armed forces. Currently through the collaboration of ISRO and the Defence Research and Development Organization, 15 satellites are designated for use by the armed forces .[46] Similarly, the Indian Army uses the SAT-2, RISAT-1, and SAT series-GSAT-9 and GSAT-7A-for border defense security, naval navigation services by the Indian Navy, and advanced military communications by the Indian Air Force.[47] Similarly, India has designated the Cartosat series as being used solely against Pakistan to monitor China Pakistan Economic Corridor developments.[48]

India's military use of space capabilities is also evident in its ASAT weapon development. On March 27, 2019, India's mission Shakti tested a kinetic kill antisatellite weapon and successfully achieved ASAT capability.[49] Antisatellite weapons allow India to attack enemy satellites, which would disrupt communication and blind the adversary. India had a policy of not engaging in the weaponization of outer space. Yet in early 2017, the Defence Research and Development Organization initiated the ASAT project and, in a span of two years, India successfully conducted an antisatellite test.[50] India's official stance behind conducting this test is to protect its assets in space against any foreign attack by maintaining credible deterrence.[51]

India has been working on ballistic missile defence since the 2000s, which made it possible for India to achieve ASAT capability in such a short time period. India's ASAT test is likely to initiate an arms race between its rivals, which would contribute to the weaponization of space. Moreover, India's ASAT test produced 400 pieces of debris that damaged the space environment. India's ASAT test is likely to encourage debris-causing tests by other states exacerbating harm to the space environment.[52]

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46. Neelam Mathews, "India Ramps Up Military Satellite Plans," Shephard Media, May 31, 2021, https://www.shephardmedia.com/.

47. Mian Zahid and Raja Qaiser, "Space Programs of India and Pakistan: Military and Strategic Installations in Outer Space and Precarious Regional Strategic Stability," *Space Policy* 47 (February 2019), https://doi.org/; and V. Siddhartha, "Military Dimensions in the Future of the Indian Presence in Space," (powerpoint presentation to CAPS, September 17, 2010), https://www.academia.edu/.

48. Siddhartha, "Military Dimensions."

49. Ashley J. Tellis, "India's ASAT Test: An Incomplete Success," Carnegie Endowment for International Peace (website), April 28, 2021, https://carnegieendowment.org/.

50. India Ministry of Defence, *Anti-Satellite Missile* (New Delhi: Official Printers, 2020), 25.

51. "India Celebrates as Country's Newest Space Weapon Passes 'Hit-to-Kill' Test," ABC News, March 28, 2019, https://www.abc.net.au/

52. Tellis, "India's ASAT Test."

The international community was mixed in its response to the test. The United States did not condemn it, while hours after India's ASAT test, China and Pakistan issued statements that emphasized preventing the militarization of outer space.[53] Pakistan's view that other states must condemn Indian actions will remain unsupported by others in the international community due to India's strong diplomatic clout among spacefaring nations. Yet India's ASAT test is proof it aims to remove an adversary's orbiting remote sensing satellites if such an adversary attempted to offset India's space exploration.

Although Pakistan's strong ties with China indicate China's comparatively overwhelming satellite technology would come to its aid, Pakistan needs to build its defense in this regard. The increasing threat from India's ASAT requires policymakers in Pakistan to recalibrate their orientation towards space research.

International responsibility

The last major rationale for devising a Pakistan space policy is its international responsibility. According to international space law, every state is encouraged to activate outer space through commercialization policies and the formulation of specifics to protect the public interest. To allow private enterprises to invest and add to the space programs of a state, Pakistan needs to have a dedicated policy framework. As a signatory to the Outer Space Treaty, it is the fundamental duty under Article VI for Pakistan to provide for authorization and continuing supervision of private space activities.[54]

At the outset, this requires a transparent, effective, and comprehensive instrument under national space policy for private entities, which is a legal obligation arising from the Outer Space Treaty.[55] Only after the formulation of national space policy can Pakistan move toward an effective mechanism for the national licensing system as per Article VII of the Outer Space Treaty or a national registration for space objects for the monitoring and control of space-related activities.[56]

Recommendations

Pakistan needs a national space policy. The policy should outline the direction and supervision of space activity through a statutory framework. The framework should include comprehensive guidelines for the space sector regarding cooperation with international and regional partners.

Designated national space legislation ensures a comprehensive regulatory framework exists to deal appropriately with legal issues arising from interactions with commercial

53. "Mission Shakti: How China and Pakistan reacted," *Times of India*, March 27, 2019, https://timesofindia.indiatimes.com/.

54. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (Outer Space Treaty), U.S., U.K., U.S.S.R., January 27, 1967, art. VI, 18 U.S.T. 2410, https://www.unoosa.org/.

55. Outer Space Treaty.

56. Outer Space Treaty, art. VII.

space industries. The United States and Russia have introduced a such regulatory framework. Several other states, including Australia, Japan, Canada, France, and the UK, have national space legislation in place. Furthermore, India is nearing the end of the process of developing space laws; it has established a space policy to support its space program, particularly for commercial cooperation.

In the case of Pakistan, it lacks both designated legislation and space policy. As mentioned before, the word "space" is not even included in the Federal legislative list of Pakistan. Therefore, Pakistan must devise a satellite communication policy, a remote sensing data policy, a national telecommunication policy, a space-based communication policy, and others with proper guidelines and procedures for the parties that will be involved.

Pakistan's space cooperation has remained limited to China for the past few decades. It is the right time for Pakistan to diversify its joint ventures in space research to include European states that have much to offer. Such ventures will allow Pakistan to expand bilateral and multilateral space cooperation and establish joint working groups with private space companies. The limited nature of Pakistan's space cooperation and its military-centric view have made it unable to capitalize on several commercial opportunities, which are important for Pakistan to decrease its dependence on China and move toward strong domestic space programs like India's.

Domestically, SUPARCO must collaborate with universities such as Pakistan's Air University and the Institute of Space Technology to raise new start-ups for research and development. For this, Pakistan must establish a facilitating agency to promote space entrepreneurship and enterprises. This agency would provide access to funds for emerging space research.

Start-ups would supply components and subsystems—outsourcing that would reduce the time it takes to develop space projects. With a robust commercial space research sector, Pakistan will be able to expand bilateral and multilateral space activity. But the state needs to provide a policy, a level playing field, and a regulatory environment for the emerging start-ups and private players.

For example, India's ASAT test has created a dilemma for Pakistan, so it should design a roadmap to counter this emerging threat in outer space. This allows Pakistan to protect its satellites from destruction or denial of access by the adversary's use of electromagnetic radiation. As a member of the Outer Space Treaty, Pakistan should highlight the Indian militarization of outer space and how India's aggressive steps could initiate an arms race in this domain.

Raison d'état (national interest) guides a state's actions in any domain. Based on the shallow response of global actors, including the United States, toward India's development of ASAT capability and the threat it posed to global space security, it is important for Pakistan to balance its asymmetric capabilities. Therefore, Pakistan's focus should be on the development of dual-purpose satellites. Developing a kinetic kill ASAT would require decades, so Pakistan should develop a nonkinetic kill ASAT and a defensive weapon to maintain its deterrence equation even in space. Along with this, Pakistan must build its reconnaissance, navigation, surveillance, and communication-related capabilities in space for conventional and strategic weapon platforms.

Conclusion

A national space policy in Pakistan will ensure exclusivity, where private entities will be allowed to cooperate with SUPARCO to build Pakistan's space program. This will provide depth to Pakistan's space research in the future, thus improving Pakistan's position in the international sphere.

This article addressed a pertinent concern for Pakistan that remains undiscussed in policy circles. No doubt Pakistan has several challenges to address including a crippling economy and governance problems, but considering its Indian-centric approach toward national security, it is important for Pakistan to reevaluate what it considers to be a national security concern. If Pakistan is unable to introduce a cohesive and comprehensive national space policy, it will be difficult for the country to match Indian space efforts in South Asia, especially when India, with its hegemonic designs, aims to utilize space as another pawn in the regional gamble for dominance. **Æ**

Space Operations

HOLDING THE HIGH GROUND

OPERATIONAL CONSIDERATIONS FOR THE EARTH-MOON SYSTEM

Adam P. Wilmer

Robert A. Bettinger

Space operations such as space domain awareness and space control can no longer be confined to that which is found in geosynchronous orbit. International activities—commercial and military—and threats to the planet itself exist or are increasing across the entire Earth-Moon system. This reality requires a new Earth-Moon system (EM-Sys) taxonomy to accurately classify missions such as space domain awareness and better apply resources to and development of the same. This work presents such a taxonomy for the classification of space extending from near- Earth orbit to beyond the Earth sphere of influence. The article discusses space law considerations of Earth- Moon system operations with respect to the patentability and property rights of orbits and trajectories that may provide economic and/or space control advantages.

The 2010s witnessed a renewed international interest in space operations extending outside near-Earth space.[1] Invigorated Chinese, Russian, and US lunar mission initiatives, planned commercial lunar projects, and coalescing international efforts to reach Mars encompass the cislunar environment—the spherical volume of space extending from super-synchronous orbit to the Moon's orbit—and beyond. Based on these development initiatives, space beyond geosynchronous orbit will likely become competitive and congested in the coming decades.

Within the context of this increased competition, capabilities that provide distinct advantages emerge. The ability to detect, track, and characterize spacecraft will prove vital for obtaining the competitive edge among space-faring nations. This ability is commonly known in the civilian sector as space situational awareness (SSA) and in the Department of Defense as space domain awareness (SDA). Attaining space-situational and wider space domain awareness will thus require a field of view not limited to the traditional bounds of geosynchronous orbit. This new reality demands a

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novel way of classifying SDA missions that encompass the entire Earth-Moon system, including the spatial expanses in the outside vicinity of Earth's gravitational sphere of influence (SOI).

This article presents a new Earth-Moon System (EM-Sys) taxonomy for the classification of space regions and missions. This work will focus on the modified mission of SDA; however, the EM-Sys taxonomy may be used for both general purposes and specific missions to include logistics, weather, planetary defense, and space control. This taxonomy is set in place to provide a means of characterizing regions near Earth, within cislunar space, and beyond the Earth's gravitational sphere of influence in an effort to better characterize missions and provide adequate terminology for spacecraft within particular regimes.

The new taxonomy will also enable a spatial division of the national orbital mission portfolio, with specific regions corresponding to compounding distances from Earth and multiple SDA mission subsets including space traffic management, space control, lunar and Earth-Moon Lagrange point surveillance, space weather observation, and planetary defense. Inevitably, the EM-Sys taxonomy is set in place to shape US space strategy and how particular regions of space may be viewed to have varying benefits in the context of SDA. Space law considerations must also be mentioned to obtain a sense of international legality with using and possibly saturating these regions of interest. Accordingly, the article includes a discussion on space law, patentability, and property rights of orbits and trajectories.

Background

The US Space Force has declared that space domain awareness "encompasses the effective identification, characterization, and understanding of any factor associated with the space domain that could affect space operations and thereby impact the security, safety, economy, or environment of our Nation."[2] The space domain is becoming increasingly "congested, contested, and competitive" as peer, near-peer, and emerging space powers expand their presence in space.[3] Consequently, SDA will remain a critical mission for securing and advancing the space operations of the United States, its Allies, and partners in the coming decades.[4]

Until the 2010s, SDA missions were nominally restricted to the near-Earth space orbital regime bounded by geosynchronous and super-synchronous orbits due to the volume of space traffic within this region. The late 2010s and early 2020s marked a shift in the space operations paradigm, with renewed international interest in pursu-

2. US Space Force (USSF), *Spacepower: Doctrine for Space Forces*, Space Capstone Publication (SCP) (Peterson Space Force Base [SFB], CO: USSF, June 2020), 38, https://www.spaceforce.mil/.

3. USSF, *Spacepower*, 10.

4. Robert M. Gates and James R. Clapper, *National Security Space Strategy: Unclassified Summary* (Washington DC: Department of Defense and Office of the Director of National Intelligence, January 2011), 1, https://www.hsdl.org/.

ing missions extending into the cislunar environment, to the Moon, and beyond the gravitational influence of the Earth-Moon system.

Domestically, this shift is represented by reinvigorated initiatives to return to the Moon via the National Aeronautics and Space Administration's (NASA) Artemis program and planned commercial space projects. Recent international cislunar activity includes plans to develop a joint Chinese-Russian base at the lunar south pole in the 2036–45 timeframe, China's Chang'e-5 lunar sample-return mission in 2020, Israel's attempted lunar surface mission in 2019, and China's Chang'e-4 far-side lunar mission in 2018.[5]

Of note, China's Queqiao communications relay satellite, which is accompanied by the Chang'e-4 mission, is the first vehicle to orbit the Earth-Moon Lagrange point located on the far side of the Moon.[6] International missions in cislunar space will likely increase throughout the 2020s, with a corresponding increase in the number of spacecraft operating in this region, as scientific exploration expands, space system technology evolves, and the lunar economy emerges and develops.

Undoubtedly, the largest DoD SDA mission will be to protect space lines of commerce. Nations and private companies alike are exponentially building space-based infrastructure to ensure communication, surveillance, and transportation. In doing so, near-Earth space is becoming congested with thousands of active spacecraft, 23,000 debris fragments larger than a softball, and half a million debris fragments larger than a marble, resulting from historical mishaps and breakups.[7]

This congestion, combined with the growing connection of space access to national security and economic growth, has prompted many nations to realize the benefit and prestige of extending space operations into cislunar space. Cislunar space and the outer reaches of the Earth-Moon system are becoming the new high ground for space operations. The SDA mission and focus must expand accordingly to handle this growth of congestion and competition to ensure continued US space dominance.

A key component of a broadened SDA mission is a new multiregion taxonomy that will enable a spatial division of the national SDA mission portfolio. The EM-Sys taxonomy presented in this work includes five constituent regions, which, in total, extend from the planetary surface and low-earth orbit to out beyond Earth's gravitational sphere of influence. The article emphasizes the spatial volume outside of geosynchronous orbit, as four of the five regions exist in cislunar and higher orbital regimes.

5. Eva Dou, "China and Russia to Open Moon Base, Expanding Space Cooperation," *Washington Post*, March 10, 2021, https://www.washingtonpost.com/; Adam Mann, "China's Chang'e-5 Lunar Mission: Sampling the Lunar Surface," Space.com, December 2020, https://www.space.com/; and Maria Temming, "Israel's First Moon Mission Lost Moments before Landing," ScienceNews, April 11, 2019, https://www.science news.org/.

6. Leonard David, "U.S. Military Eyes Strategic Value of Earth-Moon Space," Space.com, August 29, 2019, https://www.space.com/

7. Mark Garcia, "Space Debris and Human Spacecraft," National Aeronautics and Space Administration (NASA) (website), last updated May 27, 2021, https://www.nasa.gov/.

Critically, these five regions host different space missions based on potential orbits including space domain awareness, the focus of this work.

Space Domain Awareness: Structure and Missions

In the wake of World War II, the United States acknowledged the growing importance of the air domain in national security operations by establishing the US Air Force—a service dedicated to attaining and projecting airpower. Similarly the US Space Force has emerged as an independent service due to the need to attain and maintain national power and superiority in space—a domain now irrevocably linked to US sovereignty and economic power.

Until the 2010s, the US military was hesitant to refer to space as a war-fighting domain. The patent realization of space as a congested, contested, and competitive domain has prompted an evolution in how space is viewed and framed from a national security perspective.[8] For almost 50 years following the start of the first Space Age in the mid-twentieth century, space represented a supporting function to wider terrestrial conflict—either on land, at sea, or in the air. Yet as early as 1982, space was described as the "ultimate high ground."[9] Indeed, space operations enabled the introduction of game-changing technologies through persistent overhead surveillance, communication beyond the line of sight, and precision navigation and timing that would spur a revolution in US military strategy and operational art in the later twentieth and early twenty-first centuries.[10]

Against a backdrop of expanding space access and utilization during the first half century of the Space Age, a new mission emerged in the 1960s: early warning and space object tracking and characterization. The protoform of what became known as space situational awareness (SSA) arose due to the need to differentiate between nonhostile resident space objects (i.e., operational satellites and debris) and ballistic missile nuclear payloads.[11]

The SSA mission grew to encompass four functions: search, detect, track, and characterization. Once a space object was characterized and its orbital position and velocity were known for predictive tracking, it was cataloged. At its heart, the SSA mission became one of space traffic management; ground- and space-based sensors constantly

8. Sandra Erwin, "Air Force: SSA is No More; It's 'Space Domain Awareness,' " Spacenews, November 14, 2019, https://spacenews.com/.

9. Benjamin S. Lambeth, *Mastering the Ultimate High Ground: Next Steps in the Military Uses of Space* (Santa Monica, CA: RAND Corporation, 2003), 27, https://www.rand.org/.

10. Lambeth, *Ultimate High Ground*, 27.

11. Brian Weeden, Paul Cefola, and Jaganath Sankaran, "Global Space Situational Awareness Sensors" (lecture, Advanced Maui Optical and Space Surveillance (AMOS) Technologies Conference, Maui, HI, 2010).

updated and refined the space object catalog to deconflict orbits and generate collision-avoidance warnings.[12]

While SSA remains a consistent term in civilian space flight, the general SSA mission has become a subset of a wider mission set for the Department of Defense—space domain awareness. In 2019, then-Major General John E. Shaw, the US Space Command deputy commander, discussed the formal shift from SSA to SDA within the Department of the Air Force. "The implication of space as a warfighting domain demands we shift our focus beyond the Space Situational Awareness mindset of a benign environment to achieve a more effective and comprehensive SDA."[13]

According to Space Force doctrine, SDA "leverages the unique subset of intelligence, surveillance, reconnaissance, environmental monitoring, and data sharing arrangements that provide operators and decision makers with a timely depiction of all factors and actors—including friendly, adversary, and third party—impacting domain operations."[14] Based on the requirements of securing full-domain awareness in near-Earth space and beyond, five distinct missions compose the broader endeavor to attain SDA: 1) space traffic management; 2) space control; 3) lunar and Earth-Moon Lagrange point surveillance; 4) space weather; and 5) planetary defense.

Mission Types

Space Traffic Management

Like air traffic management and—from a localized perspective—sea traffic management, the space traffic management mission promotes safe access to and operations in the space domain. Baseline operations include the SSA function of space catalog maintenance and orbit prediction to avoid collisions between resident space objects such as active and retired satellites, rocket bodies, and space debris.

The space debris population is continuously growing due to decreased launch costs, the expansion of space mission architectures, the increasing reliance on space communication, commerce, and defense, and the emergence of new spacefaring nations. The low-Earth orbital regime, due to ease of access and proximity to terrestrial space users, has become increasingly congested, making space traffic management all the more critical. This congestion will only further and dramatically increase with the expansion of megaconstellations and as new private/commercial and state-affiliated players enter the space operations arena.[15]

12. Mark A. Baird, "Maintaining Space Situational Awareness and Taking it to the Next Level," *Air & Space Power Journal* 27, no. 3 (2013): 60, https://www.airuniversity.af.edu/.

13. Erwin, "SSA is No More."

14. USSF, *Spacepower*, 38.

15. Jonathan C. McDowell, "The Low Earth Orbit Satellite Population and Impacts of the SpaceX Starlink Constellation," *Astrophysical Journal Letters* 892, no. 2 (2020), https://iopscience.iop.org/; and Dan Swinhoe, "China's Moves into Mega Satellite Constellations Could Add to Space Debris Problem," Data Center Dynamics, April 20, 2021, https://www.datacenterdynamics.com/.

Space Control

The United States has a vested interest in securing space superiority to ensure unrestricted access to and the use of space to fulfill national security objectives, support terrestrial military campaigns, and, ultimately, preserve national sovereignty. Space control represents a military-centric mission intended to counter the growing competitive and contested nature of space and is "a mixture of defensive and offensive measures. . . and is particularly important during periods of increased international tensions or hostilities."[16]

One subset of the space control mission will mirror actions performed in the maritime domain: the protection of US economic interests amid the growing competitive nature of the space domain. In July 2020, the commander of the Air Force Research Laboratory Space Vehicles Directorate discussed this subset mission and stated that "our mission in the Space Force will become to protect . . . the 'celestial lines of commerce,' or the space lines of commerce."[17]

Lunar and Earth-Moon Lagrange Point Surveillance

A subset of space traffic management and space control, the lunar and Earth-Moon Lagrange point surveillance mission focuses on the surveillance of lunar orbit, the Earth-Moon corridor comprised of the Moon and the L1 and L2 Lagrange points, and the vicinity of the unstable L3 and stable L4 and L5 Lagrange points. These regions are of particular interest to the international space community due in part to growing international and commercial interest in cislunar and lunar exploration.

In particular, the Lagrange points proffer lucrative positions within the Earth-Moon system for a variety of missions including scientific monitoring of space weather and celestial bodies and intrasystem SSA. Consequently, surveillance satellites operating at the Lagrange points could bolster orbit deconfliction and collision avoidance as a space traffic management function and could track potentially hostile space vehicles under the space control mission.

Space Weather

Space represents a challenging operating domain for both manned and unmanned space vehicles due largely to the natural environmental conditions. The dynamic space weather is primarily a function of solar activity via the generation of thermal radiation, ionizing particles, and plasma. With events such as solar flares and coronal mass ejections, the Sun imperils satellites and their constituent electronic equipment and sensitive payloads with radiation and high-energy particles that may cause temporary

16. Terrence Smith, "Challenges to Future U.S. Space Control," *Army Space Journal* (Summer 2002): 1, https://apps.dtic.mil/.

17. Theresa Hitchens, "DoD Needs Plans to Protect Commercial Space Industry, Says New Study," Breaking Defense, July 28, 2020, https://breakingdefense.com/.

or even permanent damage based on the intensity of the event.[18] Tracking space weather contributes to the general SDA mission and enables operators to forecast potentially harmful or destructive natural environmental events, enhancing the safety posture of space vehicles operating within the Earth-Moon system.

Planetary Defense

Apart from tracking manmade objects, debris, and space weather, another SDA mission involves tracking objects outside of the Earth-Moon system for planetary defense. Asteroids, meteors, and comets orbiting the Sun are classified as near-Earth objects (NEOs) when their orbits bring them within 30 million miles of Earth's orbit. NEOs pose an impact risk to both the Earth and the Moon; searching for and tracking these objects enables the overall planetary defense mission.

Currently, NASA manages this mission by providing early detection, tracking, and characterization of NEOs. Additionally, NASA develops strategies and technologies for mitigating potentially hazardous objects and plays a lead role in coordinating US government planning in response to an actual impact threat.[19]

Constraints and Limitations

As peer and near-peer competitor nations pursue space superiority, the sensors and ground stations that formed the cornerstone of US SDA in previous decades are becoming restrictive in their range and resolution. Previous conceptions of space operations nominally limited to geosynchronous orbit and below are being superseded by a growing necessity to attain situational awareness of resident space objects deep within the cislunar environment.

Current US space sensing assets must be upgraded or replaced to ensure US global superiority. The International Academy of Astronautics assesses "the capacity and accuracy of current space monitoring systems is not sufficient to cover small objects or to provide for orbital avoidance service for all space assets."[20] Ground-based radar and optical systems are the primary methods for characterizing objects in space; however, weather, solar blind spots, and the equipment's terrestrial moorings all cause limitations.[21]

Furthermore, many ground-based systems have significant optical capability gaps. The Ground-Based Electro-Optical Deep Space Surveillance (GEODSS) system is only capable of tracking basketball-sized objects at a distance of 32,187 km (20,000 miles),

18. K. L. Bedingfield and R. D. Leach, and M. B. Alexander, ed., National Aeronautics and Space Administration (NASA) *Spacecraft System Failures and Anomalies Attributed to the Natural Space Environment*, NASA Reference Publication 1390 (Cape Canaveral, FL: NASA, August 1996), https://ntrs.nasa.gov/; and NASA, *Spacecraft Charging*, NASA Reference Publication 1375 (Cape Canaveral, FL: NASA, 1995).

19. "Planetary Defense Coordination Office," NASA (website), last updated March 14, 2019, https://www.nasa.gov/.

20. Corinne Contant-Jorgenson, Petr Lála, and Kai-Uwe Schrogl, eds., *Cosmic Study on Space Traffic Management* (Paris: International Academy of Astronautics, 2006), 11, https://www.black-holes.eu/.

21. Baird, "Space Situational Awareness," 60.

a distance far below that of cislunar space, which is measured in the hundreds of thousands of kilometers.[22]

One primary challenge regarding tracking and orbit determination via optical sensors is the solar exclusion angle—the cone region within which an optical sensor cannot view a given object. In other words, the Sun is too close to the sensor's line of sight for the object to be resolved and distinguished against the celestial background. Cislunar-based sensors offer a solution to these issues in the Earth-Moon system by hosting a wider range of angles from which to view objects compared to ground-based or near-Earth orbital optical sensors.

Of note, Air Force Research Laboratory's Space Vehicles Directorate is beginning to push the bounds of SDA into cislunar space. Once developed and fielded, the Cislunar Highway Patrol System (CHPS) intends to search, detect, track, and characterize missions within cislunar space and the lunar exclusion zone, or a spatial region imperceptible to Earth-based sensors due to lunar albedo, or the reflectivity of the Moon that causes difficulty viewing space objects near the Moon.[23]

Proposed Taxonomy

Currently, the US Space Force uses an orbit taxonomy comprising five altitude-delimited regions: very low-Earth orbit (VLEO), low-Earth orbit (LEO), medium-Earth orbit (MEO), geosynchronous-Earth orbit (GEO), and XGEO.[24] While LEO, MEO, and GEO are all universally standard orbital regions, VLEO is a special LEO case corresponding to the higher-drag environment of the 250-350 km altitude range.[25]

First employed by the Air Force Research Laboratory in 2020, the term XGEO describes distances beyond the GEO belt, with XGEO denoting some multiple "X" of the GEO radial distance.[26] Although the inclusion of XGEO into the current space taxonomy highlights the necessary pivot to focus on the cislunar regime, the existing region-based model is limited and fails to capture the scope of the Earth-Moon system adequately.

The increasing spatial scope of space operations necessitates a general space taxonomy that considers the entire Earth-Moon system rather than the near-Earth space region confined by GEO and geostationary Earth orbits (GSO). The following proposed EM-Sys comprises five distinct, spatially delimited regions radiating outward from Earth (fig. 1).

22. Baird, 58.

23. Joseph J. Roth and Eric J. Felt, "Overcoming Technical Challenges from Low Earth Orbit to Cislunar" (lecture, AMOS Technologies Conference, Maui, HI, 2020).

24. Roth and Felt, "Low Earth Orbit."

25. Eric Kuhu, "Satellite Constellations—2021 Industry Survey and Trends" (lecture, 35th Annual Small Satellite Conference, Logan, UT, 2021).

26. David Buehler et al., "Posturing Space Forces for Operations Beyond GEO," Space Force Journal, January 31, 2021, https://spaceforcejournal.org/.

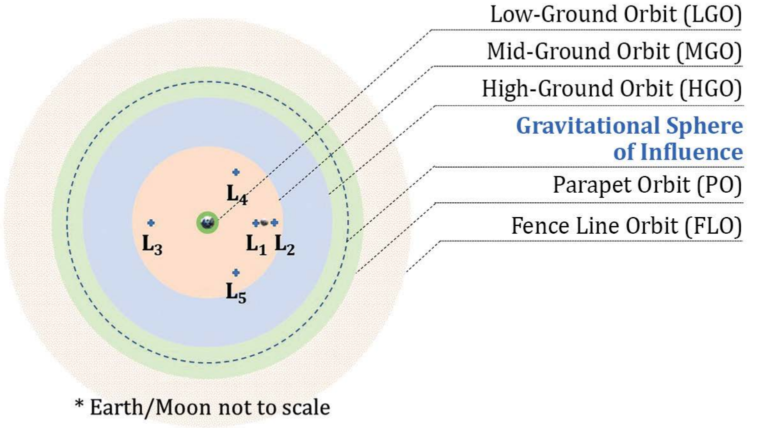

Figure 1. Proposed Earth-Moon system orbit taxonomy (not to scale)

These regions relate to different dynamical zones of operation within the Earth-Moon system. Similar to Air Force Instruction 16-401, *Designating and Naming Defense Military Aerospace Vehicles*, the EM-Sys taxonomy (fig. 1) is capable of suffix additions to denote particular modified missions.[27] Such missions include: SDA, logistics (L), weather (W), and space control (C). For instance, SDA, logistics, weather, and space control missions occurring in LGO would be designated as LG-SDA, LG-L, LG-W, and LG-C, respectively. This is consistent with Wilmer and Bettinger who used the SDA modified mission of the EM-Sys taxonomy.[28] Within the context of the SDA modified mission, each contains different potential SDA missions and space system requirements for access to and operations in these regions.

Some regions present more challenges than others to maintain a specified trajectory due to the chaotic nature of the Earth-Moon system, such as near the Earth SOI, the region around the planet within which the Earth's gravitational influence exceeds the gravitational pull of other celestial bodies. Each proposed region is described below with a corresponding identification of the associated spatial distance as measured radially from the center of the Earth in terms of kilometers and the previously mentioned XGEO. For comparison purposes, other key locations within the Earth-Moon system, such as the Moon and Lagrange points, are also given.[29]

27. Headquarters, Department of the Air Force (DAF), *Designing and Naming Aerospace Vehicles*, Air Force Instruction 16-401 (Washington, DC: Headquarters, DAF, 2020).

28. Adam P. Wilmer and Robert A. Bettinger, "Beyond the High Ground: A Taxonomy for Earth-Moon System Operations," *Air & Space Operations Review* 1, no. 2 (Summer 2022).

29. All values are based on the Earth-Moon non-dimensional mass parameter, μ=0.01215058655.

Low-Ground Orbit

The first three SDA regions contain a similar naming convention exploiting the notion that space is the "ultimate high ground."[30] The first region, low-ground orbit (LGO), encompasses near-Earth space and includes the common orbital regimes of LEO, MEO, and GSO/GEO. Specifically, LGO extends from ~100 km above the surface of the Earth (a region commonly referred to as the Von Karman Line), a nominal delimitation for the start of space, out to a super-synchronous orbit beyond GEO (42,464 km from the center of the Earth), an orbital regime approximately 300 km above GEO typically used for spacecraft disposal at mission end-of-life.[31]

The LGO region contains most current space operations and represents the highest density of resident space objects and debris to search, detect, track, characterize, and catalog for the general ground- and space-based SDA missions. The LGO region extends from the planetary surface to about GEO (1XGEO).

Mid-Ground Orbit

Next, mid-ground orbit (MGO) denotes operations occurring in the region of space commonly referred to as cislunar. The MGO region also contains all five Lagrange points and extends 15,000 km beyond the collinear L2 Lagrange point (~465,000 km). Therefore, MGO encompasses space operations occurring from ~42,500 km to 480,000 km as measured from the Earth's center (between 1–11.4XGEO). Plans for and the development of space-based infrastructure in cislunar space are rapidly growing, thus making MGO an attractive region for performing SDA in the near future.[32]

High-Ground Orbit

High-ground orbit (HGO) is associated with the translunar orbital regime of the Earth-Moon system. The HGO spherical region begins at the outer boundary of the MGO region (480,000 km) and extends to within 25,000 km of the outer bounds of the Earth's SOI, a demarcation occurring at approximately 925,000 km from the Earth (21.9XGEO). At the outermost bounds of the Earth SOI, the effects of solar gravity begin to supersede that of Earth's gravity. Overall, HGO represents SDA operations occurring between 480,000–900,000 km (11.4–21.3XGEO).

Parapet Orbit

Beyond the HGO layer is the parapet orbit (PO) region, a spherical volume containing the demarcation of the Earth-Moon gravitational sphere of influence and extending 25,000 km on either side of said boundary. The gravitational SOI is loosely

30. Lambeth, *Ultimate High Ground*, 27.

31. Nicholas L. Johnson, "A New Look at the GEO and Near-GEO Regimes: Operations, Disposals, and Debris," *Acta Astronautica* 80 (2012): 82–88, https://ntrs.nasa.gov/.

32. James A. Vedda, "Cislunar Development: What to Build—And Why," (Arlington, VA: Aerospace Corporation, Center for Space Policy and Strategy, April 17, 2018), https://csps.aerospace.org/.

analogous to the dynamical wall or fence of the Earth-Moon system and, as a result, the PO region derives its name from a parapet—the protected walkway and/or battlement located on top of a castle wall.[33]

In terms of spatial distance, PO defines operations occurring between 900,000–950,000 km (21.3–22.5XGEO). Orbital trajectories residing exclusively within the PO region are challenging to define and maintain due to the chaotic instabilities of the Earth-Moon gravitational system at these distances. Consequently, space systems seeking to perform a PO mission will likely require orbits that traverse other regions within the Earth-Moon system to deliver the necessary transit times in and around the SOI.

Fence-Line Orbit

The final region within the proposed EM-Sys taxonomy is referred to as fence-line orbit (FLO). Continuing the analogy of the gravitational SOI resembling a pseudo-barrier, FLO embodies the concept of performing surveillance and security operations outside a barrier that may surround a forward operating base in theater or a secure installation. Space system orbits within the FLO region are still influenced by the gravity of the Earth-Moon system; however, the gravitational influences of the Sun have a greater effect on trajectories.

Tertiary bodies to the Earth-Moon system, such as asteroids, also become increasingly relevant at this distance. A given mission such as SDA could extend well beyond the Earth SOI, based on the needs of the mission and the corresponding design of the orbital trajectory. Therefore, an outer boundary for the FLO is only estimated herein. For the purposes of this article, the FLO region starts at 950,000 km from Earth and extends to approximately 2.3 million km (22.5–55XGEO).

Mission Mechanics

Space Domain Awareness Mission Mapping

The efficacy of a new EM-Sys taxonomy depends upon missions allocated to each region and the types of trajectories that can be generated to perform these missions. For the purpose of this article, the SDA modified mission will be considered within the context of this taxonomy. Nominally, the space traffic management mission will reside in the regions closest to Earth and the Moon, specifically LGO and MGO, due to issues related to orbital congestion and collision avoidance between spacecraft and resident space objects (e.g., debris).

The space control mission will reside in regions where space traffic management is a priority due a similar need to monitor spacecraft trajectories. But we suggest including

33. E. Viollet-Le-Duc and Martin MacDermott, *Military Architecture* (Oxford and London: James Parker and Co., 1907), 66, 85.

HGO as a potential region for space control due to the vantage point that translunar space proffers for inward surveillance of the Earth, the Moon, and orbital regimes of interest in the LGO and MGO regions.

Overall, the space weather mission can be performed in any orbital regime within the Earth-Moon system based on specific program needs such as scientific observation or warning. The outer regions of HGO, PO, and FLO are identified as potential areas for space weather missions due to their distance from both the Earth and the Moon, thereby proffering an outward surveillance perspective for pseudo-early warning of space weather events. While the first tier of space weather early warning and monitoring occurs at the Sun-Earth Lagrange points, such as the National Oceanic and Atmospheric Administration's Deep Space Climate Observatory (DSCOVR) at L1, the placement of monitoring spacecraft in trajectories traversing HG-SDA or other outer regions would provide a second tier for warning and solar event observation.[34]

As previously stated, surveillance of the Moon and Earth-Moon Lagrange points is of interest due to the planned infrastructure development at or near these locations in the coming years. Specifically, the collinear L1 and L2 Lagrange points around the Moon have become a focus for mission planners because of their proximity to the Moon. For instance, the Lunar Gateway, a critical component of NASA's Artemis program that will provide "vital support for a long-term human return to the lunar surface [and] a staging point for deep space exploration," is planned to orbit near L2.[35] Therefore, the lunar and Lagrange point surveillance mission will occur in either the MG-SDA or HG-SDA region.

The final mission set, planetary defense, is appropriate for the PO and FLO regions. These regions give the ultimate vantage point for the outward surveillance of NEOs and other transient asteroids and meteoroids that may pass near or traverse the Earth SOI. Early warning is critical to averting and/or preparing for catastrophe arising from an NEO or similar piece of cosmic debris, and the stand-off distance of approximately 21–55 XGEO established by the PO and FLO regions contribute to an early warning posture for planetary defense. In addition to surveillance, the vast spatial volumes of the PO and FLO regions also enable the international space community to field defensive systems that can deflect or destroy potential threats arising from outside the Earth-Moon system.

Orbit Design Considerations

Within the Earth-Moon system, spacecraft can be injected into periodic orbits via direct launch from either the Earth or the Moon. Only a launch from the Earth is currently feasible, but the construction of lunar infrastructure could enable the launch of

34. "Points of Lagrange: A Satellite a Million Miles from Home," National Environmental Satellite, Data, and Information Service, National Oceanic and Atmospheric Administration, October 26, 2015, https://www.nesdis.noaa.gov/.

35. David E. Lee, "Gateway Destination Orbit Model: A Continuous 15 Year NRHO Reference Trajectory," white paper (Houston, TX: NASA Johnson Space Center, August 20, 2019), https://ntrs.nasa.gov/.

spacecraft into periodic orbits that pass near the Moon at relatively low propellant cost—lunar launches will require less propellant than conventional Earth-based launches due to a weaker gravitational field and the absence of virtually any atmosphere.

Regarding orbit maintenance—the expenditure of propellant to maintain a desired orbital geometry—periodic orbits in the Earth-Moon system may remain stable for weeks depending on the selected geometry, particularly depending on how closely a trajectory passes by the Earth, Moon, or the various Lagrange points. We assess orbit maintenance will require a low amount of propellant. This low-order amount of required propellant for orbit maintenance will enhance any SDA mission's lifetime and desirability for implementation.

When designing SDA missions in any of these proposed regions, the duration of a single period will influence the number of spacecraft to perform the mission. Multiple spacecraft will likely be needed to provide a desired level of sensor coverage and revisit time in a particular region, either with a phased operation in the same periodic orbit or with the spacecraft spread over different yet similar periodic orbits. For example, the need for a constellation of SDA spacecraft will likely be important for the planetary defense mission in the FLO region. Due to a single period being on the order of approximately 1–1.5 years, numerous spacecraft—potentially on the megaconstellation scale—may be needed to provide timely and persistent monitoring and defense posture for threats external to the Earth-Moon system.

Space Law Considerations

Space operations have far outpaced and evolved beyond the legal framework initially established in the Outer Space Treaty of 1967, thus creating the need for a new treaty or international code of space conduct that addresses and remedies current legal gaps. Topics of interest that are advocated for inclusion in any new version of the Outer Space Treaty include: property rights and/or sovereignty of lunar territory and Earth-Moon system trajectories, dispute provisions, asteroid and lunar mining law, and the creation of an international space traffic management system.

In the absence of any new or revised international code of space conduct, the continued operation of nations and commercial entities within any of the regions mapped in the proposed EM-Sys taxonomy will likely bring legal and possibly geopolitical friction. Within a competitive environment such as the space domain, questions may arise regarding the patentability and property rights of orbits intended to operate in the regions of the Earth-Moon system beyond GEO.

Patentability of Earth-Moon System Orbits

No known instances of a patent issued for an orbit or outer space trajectory exists. Such an action is in conflict with Article 1 of the Outer Space Treaty, which states, "outer space . . . shall be free for exploration and use by all States."[36] By staking a claim to a particular orbit, a nation is signaling they alone are able to make decisions regarding whom, when, and how a particular orbit can be used. Even so, many interpretations are possible about what is considered "free use," and there is no legal precedent regarding what "free use" means in the context of the Earth-Moon system space.

While a nation or legal entity is unable to patent a particular orbit, a loophole in patent law does exist, however, that enables the patentability of particular technologies and methods required to reach and maintain a desired orbit. For example, United States Patent US10696423B1 by the National Aeronautics and Astronautics Administration (NASA) provides guidelines for a "method for placing a spacecraft into a lunar orbit, either by standard (i.e., impulsive) or ballistic (i.e., non-impulsive) capture, from an Earth orbit that is significantly inclined relative to the lunar orbit plane, with no constraint on the local time of perigee for the starting orbit."[37] Similarly, Chinese Patent CN106660641B provides guidelines for a method for controlling the orbit of a spacecraft in Earth orbit.[38]

While these patents hold merit in their country of origin, history has shown (often in times of war) that they would likely not be honored outside of their respective nation. Similar to the Outer Space Treaty, if a nation or company patents certain technology, there are limited legal avenues and means to prevent another nation from stealing and using that particular technology. Thus the best way for a nation to protect its technology is through preventing the widespread dissemination of said technology—historically, a temporary solution.

Orbital Property Rights

As the cislunar and lunar economies emerge in coming decades, legal disputes will likely arise relating to ownership. If a nation continuously uses a particular transfer trajectory or orbit, does the nation own the trajectory as a fait accompli? The Outer Space Treaty states "outer space is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means."[39] Similar to how an organization within a particular country is able to patent a particular maneuver with no international discussion or agreement, it is possible that other nations may intend to proclaim a particular maneuver or trajectory as its property.

36. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (Outer Space Treaty), U.S., U.K., U.S.S.R., January 27, 1967, art. i, 18 U.S.T. 2410, art. I, https://www.unoosa.org/.

37. A. L. Genova and S. Mitchell, "Method for Transferring a Spacecraft from Geosynchronous Transfer Orbit to Lunar Orbit," US10696423B1, National Aeronautics and Space Administration (NASA), 2017, https://ntts-prod.s3.amazonaws.com/.

38. "Method for Controlling the Orbit of a Satellite in Earth Orbit, Satellite and System for Controlling the Orbit of such a Satellite," CN106660641B, Airbus Defense and Space SAS, 2020.

39. Outer Space Treaty, art. II.

It appears that in the infancy of cislunar infrastructure development, orbital property rights of a given nation may become a function of self-proclamation once they begin using particular trajectories routinely. In this case, it will be a race to find and exploit all of the optimal trajectories between the Earth and Moon, as well as to other points of potential future interest.

History provides many cases of expansionism and territorial aggrandizement by way of fait accompli, with Chinese expansion into the South China Sea via creating artificial islands as a recent example. Although many nations along the East Asian littorals and globally who use the South China Sea for trade and fishing disagree with Chinese expansionism, there are no explicit means short of formal economic sanctions and/or war to curtail or halt the expansion.

A similar situation may occur with Earth-Moon system orbits if they are deemed valuable avenues for cislunar and lunar infrastructure development. Similarly, ownership of desirable orbits and trajectories may be assumed by commercial entities through continued use of and a persistent presence in these orbits. In either case, the Outer Space Treaty stipulates "States…[are responsible] for national activities in outer space… [carried out by either governmental or commercial entities]."[40] Nevertheless, there are no current means to enforce these rules from an international perspective.

Conclusion

In the early years of spaceflight, space operations primarily consisted of near-Earth missions with few spacecraft ever venturing to the Moon. As time progressed, more and more missions began extending beyond geosynchronous orbit. This pattern continues today, with the contemporary space domain facing increasing concerted efforts by commercial and nation-based entities worldwide to reach and operate within the cislunar environment.

This trend will likely continue, with humankind reaching outward to the new high ground. Missions will become increasingly frequent near the Moon, in the high-ground orbit region, and beyond. As such, it is important to develop policy and terminology to address the evolving SDA mission, establishing a paradigm that will come to embrace the entirety of the Earth-Moon system and its celestial environs. At the same time, with the development and growth of the US Space Force, new policies and doctrine intended to secure US space dominance will continue to emerge.

It is likely some of the policies will have no clear guidance within in the context of the Outer Space Treaty due to the novel problems and capabilities faced today that did not exist in 1967 when the treaty was signed. As such, a new international treaty should be drafted that correctly discusses and provides resolutions to the current space landscape. Part of modernizing the current space lexicon includes creating terminology that embodies the entirety of the Earth-Moon system and not just those locations closest to the Earth. The EM-Sys taxonomy presented here is vital to concep-

40. Outer Space Treaty, art. VI.

tualizing space with consideration to key points of interest, gravitational bounds, and areas offering premier coverage of space assets, thus better describing missions such as space domain awareness that ensure the continuous protection of US space assets. **Æ**

MITIGATING NONCOOPERATIVE RPOs IN GEOSYNCHRONOUS ORBIT

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Over the last several years, governments have expressed increasing concerns over foreign satellites making close approaches, known as rendezvous and proximity operations (RPOs), to sensitive national security satellites. These activities have primarily occurred in the geosynchronous Earth orbit (GEO) region where sensitive satellites performing missile warning, secure communications, and intelligence collection missions are located. Rendezvous and proximity operations with another nation's satellite could exacerbate current geopolitical tensions or lead to unwanted escalation. This article provides an overview of the fundamentals of RPOs and other satellite maneuvers in the GEO region. It suggests a taxonomy for categorizing different kinds of RPOs and analyzes four policy options for dealing with them: improved space situational awareness, pattern-of-life information sharing, keep-out zones, and guardian satellites.

A rendezvous and proximity operation (RPO) is defined as an intentional alteration done to a space object's trajectory to bring it close to another object in space. These operations are an emerging national security challenge. Nations and commercial entities have employed RPO technologies since the 1960s, but these efforts have been mostly limited to human spaceflight activities such as docking and assembly of crewed space stations.[1]

Over the last two decades, the emergence of robotic and autonomous or semi-autonomous RPO technologies has led to increased applications for commercial, civil, and national security space activities. For civil and commercial applications, RPO technologies are essential to the emerging sector of in-space servicing, assembly, and manufacturing, which holds significant potential to reimagine space capabilities. For national security, robotic RPO technologies are enabling additional capabilities for collecting intelligence about space objects, collecting signals and electronic intelligence, and conducting both offensive and defensive counterspace operations.[2]

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1. Rebecca Reesman and Andrew Rogers, *Getting in Your Space: Learning from Past Rendezvous and Proximity Operations* (El Segundo, CA: The Aerospace Corporation, May 2018), https://aerospace.org/.
2. Brian Weeden and Victoria Samson, eds., *Global Counterspace Capabilities: An Open Source Assessment* (Washington, DC: Secure World Foundation (SWF), April 2022), chaps. 1-1, 2-1, 3-1, https://swfound.org/.

It is worth noting that close approaches between space objects happen often, particularly within the geosynchronous Earth orbit (GEO) region. In most cases, these close approaches are unplanned and caused by the natural dynamics of the objects' orbits. This phenomenon happens more often in GEO than in lower orbits because most space objects in GEO are in very similar orbits or are collocated at the same longitude in orbit. As a result, it can be difficult to filter out these normal close approaches to find the unexpected yet intentional RPOs.

The increasing planned or deliberate commercial, civil, and national security RPO activities around the world are escalating tensions. This is in part due to the lack of existing norms or international agreements on common standards and practices for conducting RPOs.[3] As a result, governments are concerned about RPOs being conducted in a safe manner, how to distinguish between commercial or civil RPOs and those of a national security nature, and which types of RPOs could be a signal of a potential threat or armed attack.

Two recent examples highlight how RPOs can create geopolitical tensions. The first is an incident that took place between the French-Italian Athena-Fidus satellite (COSPAR ID: 2014-006B) and the Russian Luch (Olymp) satellite (COSPAR ID: 2014-058A) from late 2017 to early 2018.[4] The French government expressed public concern over this event, calling it an "act of espionage," prompting France to issue a new space defense strategy the following year.[5]

The second example is close approaches conducted between 2016 and 2018 by the US Space Force's Geostationary Space Situational Awareness Program (GSSAP) satellites (COSPAR IDs: 2014-043A, 2014-043B, 2016-052A, 2016-052B,) with several non-US satellites. Russian sources reported concern that some of these approaches were conducted in a manner that was difficult to track and distinguish from potential hostile maneuvers.[6]

Misinterpretations of intent from these and other RPO activities are already creating tensions in space. Multiple countries are developing co-orbital antisatellite capabilities that rely on similar RPO technologies and maneuvers in order to reach the intended target.[7] There is a need for better indications and warnings of these activities, including processes to alert others of rendezvous and proximity operations but also processes that track and characterize RPOs as they occur.

This article provides an overview of how RPOs in GEO occur and how this differs from normal station-keeping maneuvers. It then proposes a taxonomy for distinguishing between cooperative and noncooperative RPOs and discusses the pros and cons of

3. Reeseman and Rogers, *Proximity Operations*.

4. Thomas G. Roberts, "Luch(Olymp)/Athena-Fidus," Satellite Dashboard (website), last updated March 18, 2022, https://satellitedashboard.org/.

5. John Leicester and Sylvie Corbert, "France Says Russia Satellite Spied in 'Star Wars' Hostility," Associated Press, September 7, 2018, https://apnews.com/; and Christina Mackenzie, "France Plans to Boost Its Self-Defense Posture in Space," Defense News, July 26, 2019, https://www.defensenews.com/.

6. Weeden and Samson, *Global Counterspace Capabilities*, 3-7.

7. Weeden and Samson, chaps. 1-1, 2-1, 3-1.

specific policy proposals focused on noncooperative RPOs. The space policy community has proposed better quality space situational awareness (SSA) data, developing patterns of behavior or norms for RPOs, keep-out zones, and guardian satellites as potential solutions to this growing problem. The article will examine each of these proposed concepts for both technical and policy implications for policymakers.

Rendezvous Proximity Operations in Geosynchronous Earth Orbit

Although this article briefly defined RPOs earlier, a more detailed technical definition that considers the unique orbital dynamics of the GEO region is useful. In GEO, satellites regularly expend onboard propellant to preserve the orbital characteristic for which the geostationary belt is most coveted: staying near a specific position in the sky over time relative to an observer on the Earth's surface.

Such maneuvers, known as station-keeping, are often categorized by their orientation. North-south and east-west station-keeping refer to maneuvers that correct for deviations from operators' desired positions in geographic latitude or longitude space, respectively. These deviations are caused by natural perturbations that affect GEO satellites' orbits, such as the oblateness of the Earth, the Sun and Moon's gravity, and solar radiation pressure.[8]

Active GEO satellites with chemical propulsion systems typically pursue station-keeping maneuvers several times per month.[9] Less often, operators command GEO satellites to change their position in the geostationary belt more substantially in a phasing or longitudinal-shift maneuver. Such maneuvers shift a satellite's subsatellite point—the point on the Earth's surface directly below a satellite—altering both the region on the Earth's surface the satellite can cover with its services or sensors and its neighbor satellites in the geostationary belt.

When a GEO satellite performs a longitudinal-shift maneuver such that its final position in the geostationary belt is relatively close to another satellite, it may be considered a close-approach maneuver. A satellite that performs a close-approach maneuver typically resumes station-keeping at its final position to maintain a relatively close distance from a nearby satellite.

Longitudinal-shift maneuvers performed in the past often can be plainly seen in the historical records of satellites' longitudinal positions (fig. 1). These maneuvers can thus be calculated from historical orbital elements.[10] The relatively flat portions of the plot in the figure, which last years on end, correspond to periods in which the satellite

8. E. M. Soop, *Handbook of Geostationary Orbits* (Netherlands: Springer Dordrecht, 1994), 68.

9. Jacob Decoto and Patrick Loerch, "Technique for GEO RSO Station Keeping Characterization and Maneuver Detection" (paper presented at the Advanced Maui Optical and Space Surveillance (AMOS) Technologies Conference, Maui, HI, September 2015), https://amostech.com/.

10. T. G. Roberts and Richard Linares, "Geosynchronous Satellite Maneuver Classification via Supervised Machine Learning" (paper presented at the AMOS Technologies Conference, Maui, HI, September 2021).

is consistently performing station-keeping maneuvers to maintain its longitudinal position within the geostationary belt.

Individual station-keeping maneuvers can be observed in the fine wave-like pattern during these periods. The sloped portions of the plot correspond to periods in which the satellite is in eastward or westward drift. Drift periods with positive slopes such as the first, second, and fourth drift periods shown in fig. 1 correspond to eastward drifts. Those with negative slopes such as the third drift period in fig. 1 correspond to westward drifts. The longitudinal position history for a satellite that never pursues a longitudinal-shift maneuver during its operational lifetime—a common pattern of life for a GEO satellite—would appear as a horizontal line, with no longitudinal changes over time.

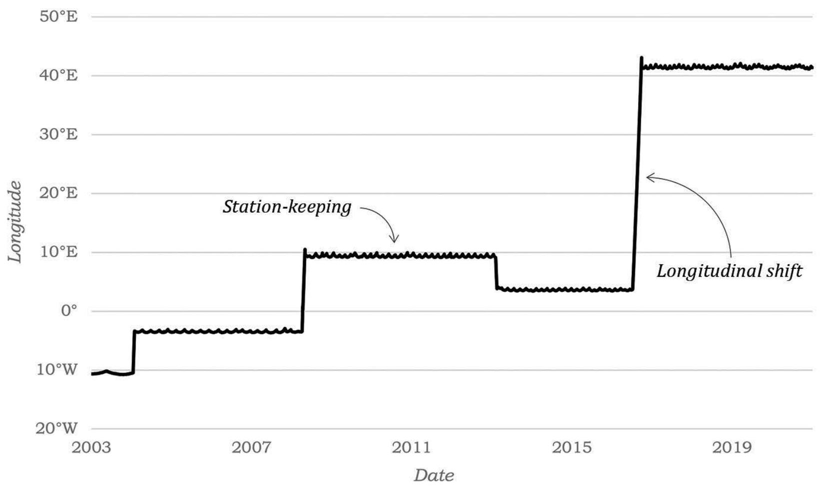

Figure 1: Longitudinal-shift maneuvers shown in a longitudinal position history

Fig. 1 shows the longitudinal position of the European Organization for the Exploitation of Meteorological Satellites' Meteosat 8 (COSPAR ID: 2002-040B) from January 1, 2003, to December 31, 2020. During this time, the satellite pursued four longitudinal-shift maneuvers—three in the eastward direction and one in the westward direction—with a variety of drift periods.[11]

Longitudinal-shift maneuvers are composed of two smaller maneuver components: one to slightly lower or raise the satellite's orbiting altitude and initiate an eastward or westward drift along the geostationary belt, and a second to undo the first orbital adjustment, which ends the drift and reinserts the satellite into its new position. These two maneuvers correspond to the discontinuities visible in fig. 1 when the satellite transitions from a period of station-keeping to a period of natural drift and vice versa.

11. Data source: Space-Track.org.

Fig. 2 describes the orbits associated with eastward and westward two-impulse Hohmann transfers in GEO.[12]

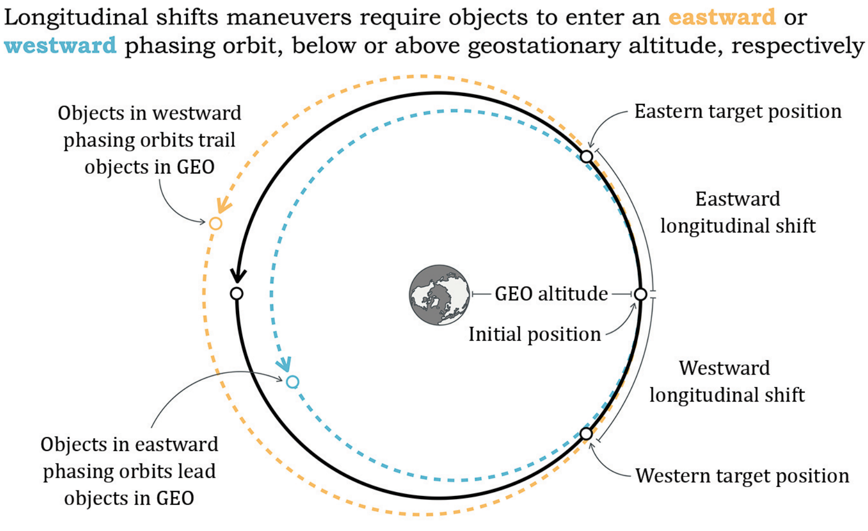

Figure 2: Nominal eastward and westward longitudinal shift maneuver orbits in GEO

As shown in fig. 2, to shift a satellite eastward in the geostationary belt, operators must first place it in an elliptical, lower-altitude orbit such as the one labeled "E" in fig. 2. To shift westward, operators must place it in an elliptical, higher-altitude orbit such as the one labeled "W." (Fig. 2 represents the authors' modification of a Howard Curtis model.)[13]

The first component of a longitudinal-shift maneuver deforms a satellite's orbit from the nearly circular geostationary orbit into a more elliptical one. Once in its new elliptical orbit, known as the transfer orbit, the satellite has some relative motion with respect to other satellites in the geostationary belt. Satellites in eastward drift orbit the Earth faster than their neighbors, passing between them and the Earth during their orbital period with a separation distance that varies based on the satellite's phase within the transfer orbit and the magnitude of the drift rate.

Satellites with a higher drift rate have greater separation distances between them and the satellites they pass in the GEO belt, but that separate distance can vary with the eccentricity of the drift orbit. In general, drifting satellites do not pass close enough to station-keeping satellites to pose a collision risk. Similarly, satellites in westward drift orbit the Earth more slowly than their neighbors, orbiting at a higher altitude

12. Howard Curtis, *Orbital Mechanics for Engineering Students*, 1st ill. repr. ed., Elsevier Aerospace Engineering Series (Oxford: Elsevier Butterworth Heinemann, 2005), 268.

13. Curtis, *Orbital Mechanics*, 72.

than the geostationary belt. After the drift period, the satellite's orbit must be recircularized using a second maneuver to stop the drift and maintain a fixed longitude.

Because of their magnitude, longitudinal-shift maneuvers typically require more onboard propellant than station-keeping maneuvers. A longitudinal-shift maneuver performed at 1.0 degrees per day would require twice the delta-v (Δv*)* as one performed at 0.5 degrees per day. This characteristic of the longitudinal-shift maneuver allows operators to effectively choose how much Δv to spend on their maneuvers: if they perform their maneuvers more slowly, they can save on fuel. By contrast, operators can choose to expend more fuel to drift faster and reach their target longitude more quickly.

Consider the previously mentioned close approach from late 2017 and early 2018 between the Russian Luch and the French-Italian Athena-Fidus satellites (fig. 3). Luch's on-orbit behavior is unlike any other in the US Space Command's space object catalog, clearly performing frequent longitudinal shift maneuvers and occupying more than 20 longitudinal positions since its launch in September 2014.[14] Luch's brief stay near Athena-Fidus occurred in the middle of this long string of maneuvers.

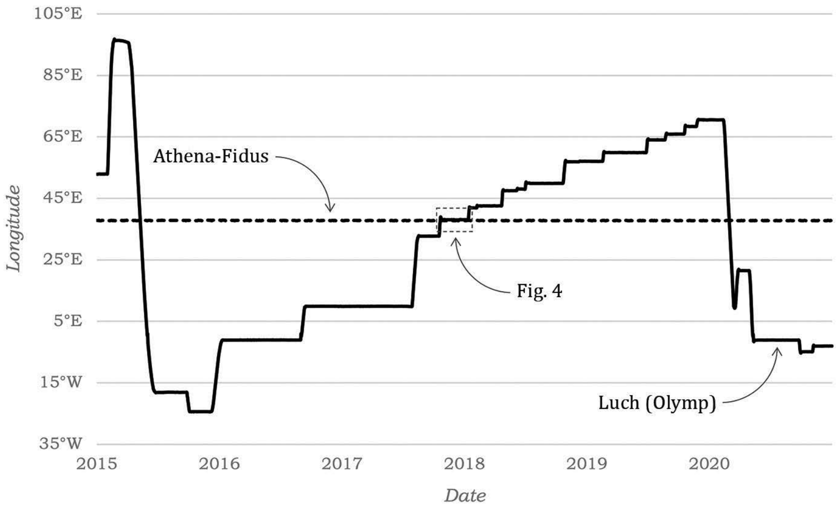

Figure 3: Close approaches revealed by comparison of two satellites' longitudinal position histories

Fig. 3 shows the longitudinal position for Russia's Luch (Satellite ID: 40258) and France and Italy's Athena-Fidus (Satellite ID: 39509) from January 1, 2015, to December 31, 2020.[15]

Fig. 4 offers a closer look at Luch's close approach to Athena-Fidus. On October 17, 2017, when Luch was located at 32.7°E, it initiated an eastward drift at a rate of

14. Thomas G. Roberts and Richard Linares, "A Survey of Longitudinal-Shift Maneuvers Performed by Geosynchronous Satellites from 2010 to 2021," (paper presented at the 73rd Astronautical Congress, Paris, France, September 2022), https://www.researchgate.net/.

15. Data source: Space-Track.org.

approximately 0.9 degrees per day. Less than a week later, Luch terminated its drift and began station-keeping at 38.0°E, near Athena-Fidus, which was stationed at 37.8°E. This maneuver required approximately 5 m/s of Δv. Luch stayed near Athena-Fidus for over two months, getting as close as 12.5 km away on November 27, 2017. Note that during this same time at the end of November 2017, Luch came even closer—within just a few kilometers—of Pakistan's Paksat 1R (COSPAR ID: 2011-042A), which had an operational location at 38.0 degrees.

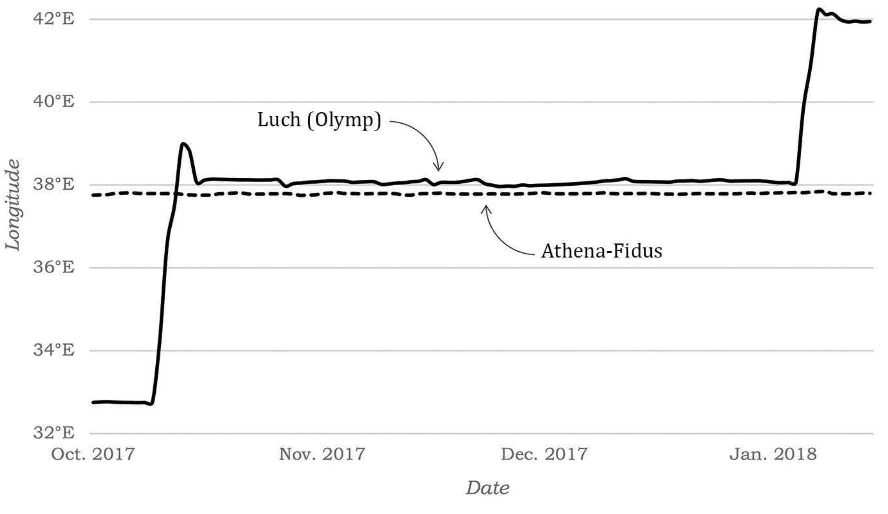

Figure 4: Luch station-keeping near Athena-Fidus in late 2017 and early 2018

Fig. 4 offers a closer look at the longitudinal positions of the two satellites during their time of closest approach.

Cooperative versus Noncooperative Rendezvous Proximity Operations

As previously mentioned, rendezvous proximity operations have been conducted as part of space operations since the 1960s and are becoming an increasingly important part of commercial, civil, and national security space activities. Many of these RPOs will be benign and should not be considered potential threats. Thus, it is important to separate these benign rendezvous proximity operations from the ones that deserve heightened scrutiny. Throughout the remainder of this analysis, this article will categorize RPOs as cooperative or noncooperative.

Cooperative RPOs are generally seen in the civil and commercial sectors and are defined as rendezvous proximity operations where there is a preexisting contract or agreement between the client and the servicer.[16] Either entity may be a private sector entity, such as a company, or a public sector entity, such as a government agency. Details about the RPO may be provided publicly or not. The important point is that the RPO was prearranged between both entities and that it occurred with the consent of both.

An example of a cooperative RPO is the docking of SpaceLogistics' MEV-1 (COSPAR ID: 2019-067B) with Intelsat 901 (COSPAR ID: 2001-024A) in February 2021.[17] The mission was planned for more than a year in advance and included a complex set of discussions and negotiations between the two companies followed by months of technical exchanges and weeks of on-orbit activities. MEV-1 was launched into orbit in October 2019, and in December Intelsat made preparations to move the satellite to a higher orbit for docking. In this case, the fact that a docking was about to occur was public knowledge, but the exact time of the docking was not because it required both companies to be satisfied that the docking would be done safely.

Another example of cooperative RPOs is the activities of China's SJ-17 satellite (COSPAR ID: 2016-065A) in GEO with several other Chinese satellites.[18] SJ-17 was launched into orbit in November 2016 and has since been moving throughout the GEO belt. In July 2018, SJ-17 executed an extensive series of maneuvers to perform an RPO with Chinasat 1C (COSPAR ID: 2015-073A) after the latter likely experienced an anomaly and began drifting out of its normal GEO slot. Chinasat 1C subsequently moved back to its assigned slot and SJ-17 moved away to perform an RPO with another Chinese satellite, Chinasat 6B (COSPAR ID: 2007-031A). These activities suggest SJ-17 was being used to help with anomaly resolution, although these activities have not been publicly confirmed by China.

Noncooperative RPOs are generally associated with national security assets and are defined as RPOs where a preexisting contract or agreement does not exist between the two parties. In many cases, this is because the RPO is part of a military or intelligence mission, and any precoordination could alert the targeted satellite about the nature of the operation. But noncooperative RPOs may also occur because it is impossible to determine which country or entity controls a space object, as in the case of untracked or uncatalogued orbital debris.

The previously mentioned RPO between Luch and Athena-Fidus is a good example of a noncooperative RPO. Notably, the other satellite in the area, Pakistan's Paksat 1R, had been collocated with Athena-Fidus, and the French government did not make the same public complaints about its presence. This is likely because Paksat 1R had been in this location for some time and was assessed by the French and Italian governments

16. "Guiding Principles for Commercial Rendezvous and Proximity Operations (RPO) and On-Orbit Servicing (OOS)" (Summerville, SC: Consortium for Execution of Rendezvous and Servicing Operations (CONFERS), November 7, 2018), https://www.satelliteconfers.org/.

17. Brian Weeden, "MEV-1/Intelsat 901" Satellite Dashboard (website), updated October 31, 2021, https://satellitedashboard.org/.

18. Weeden and Samson, *Global Counterspace Capabilities*, chap. 2-6.

as conducting a nominal communications mission. It is also possible France, Italy, and Pakistan coordinated this collocation.

Within these two major categories, RPOs can be conducted in many ways. In the case of cooperative RPOs, the servicing satellite could have a wide range of sensors on board—including electro-optical, radar, and lidar—for detecting, tracking, and approaching the client satellite. The client satellite could be prepared ahead of time by placing beacons or fiducials onboard to make it easier for the servicing satellite to approach safely, or by including fixtures or plates to enable easier grappling or docking. In most cases, the approach trajectory is designed to be passively safe: if communication with the servicing spacecraft is lost, it will not be on a collision trajectory with the client. While the overall approach is often done autonomously by the spacecraft, there are usually one or more hold points where the process pauses until a human operator signals it is safe to proceed.[19]

Satellites involved in noncooperative RPOs may also have the same wide range of sensors used by the approaching spacecraft, but they may also use passive technologies (such as electro-optical) rather than active technologies (such as radar and lidar) so as to avoid alerting the target spacecraft. Noncooperative RPOs conducted for military purposes might also be done at a higher relative velocity to reduce the time the target has to detect and react. Moreover, these missions may also utilize a trajectory with poor lighting conditions so the target's owner or operator is less likely to accurately detect and track the approaching spacecraft.

Mitigating Noncooperative Rendezvous Proximity Operations

There is a growing need to mitigate the security and stability risks raised by the proliferation of both cooperative and noncooperative RPOs. Several efforts are underway to do this for cooperative RPOs, including the work by the Consortium for Execution of Rendezvous and Servicing Operations to develop principles, recommended practices, and technical standards for RPOs done as part of commercial satellite servicing activities.[20] The remainder of this article will examine four different proposed solutions for mitigating noncooperative RPOs focused on space situational awareness, GEO patterns-of-life information sharing, keep-out zones, and guardian satellites.

Space Situational Awareness

Space situational awareness (SSA), or what the US military now calls space domain awareness (SDA), is knowledge about the space environment and human space activities. While SSA has typically been the responsibility of militaries throughout the Space

19. "CONFERS Recommended Design and Operational Practices" (Summerville, SC: CONFERS, October 1, 2019), https://www.satelliteconfers.org/.

20. "About Us" CONFERS (website), https://www.satelliteconfers.org/.

Age, civil and commercial entities have begun detecting and tracking satellites.[21] There is a growing international awareness that increasing transparency and access to SSA data in the space domain is a fundamental part of creating a sustainable and predictable space domain. The UN-endorsed *Guidelines for the Long-Term Sustainability of Outer Space Activities* includes four voluntary guidelines devoted to improving SSA data and predictability of movement (including RPOs) in orbit:

- "B.1 Provide updated contact information and share information on space objects and orbital events;
- B.2 Improve accuracy of orbital data on space objects and enhance the practice and utility of sharing orbital information on space objects;
- B.3 Promote the collection, sharing and dissemination of space debris monitoring information; and
- B.4 Perform conjunction assessment during all orbital phases of controlled flight." [22]

But current SSA capabilities are not yet sufficient to allow for robust RPO monitoring in the geosynchronous Earth orbit region.[23] Using ground-based telescopes, a rendezvous and proximity operation in the GEO region looks like two objects slowly moving closer to one another until they finally merge and become one. From this vantage point, it can be extremely difficult to distinguish the two objects even while they are still separated by several kilometers in orbit.

Some countries (namely the United States, China, and Russia) have some ability to monitor and detect RPOs from the GEO region, but significant limitations to data sharing exist, given the national security sensitivities of many RPO activities. Improving these national capabilities, including using space-based space situational awareness sensors and leveraging burgeoning commercial SSA capabilities, is critical to better detecting and assessing noncooperative RPOs.

Policy Considerations

The main policy consideration for improved SSA is that it further undermines the ability to keep national security activities and operations in orbit a secret. This trend has been happening for the last two decades as hobbyist satellite trackers and commercial SSA providers have demonstrated that much of what militaries used to be able

21. Brian Weeden, "Space Situational Awareness Fact Sheet" (Washington, DC: SWF, updated May 2017), https://swfound.org/.

22. UN Office for Outer Space Affairs Committee on the Peaceful Uses of Outer Space, *Guidelines for the Long-Term Sustainability of Outer Space Activities of the Committee on the Peaceful Uses of Outer Space* (Vienna: United Nations, January 2021), https://www.unoosa.org/.

23. "2018 AMOS Dialogue Final Report" (Summerville, SC: SWF, 2018), https://swfound.org/; and Brian Weeden, "Insight – Space Situational Awareness and Commercial Rendezvous and Proximity Operations" (Summerville, SC: SWF, November 5, 2018), https://swfound.org/.

to hide in orbit can no longer be hidden. While this will undoubtedly have a significant impact on how military space operations are executed, the focus needs to be on changing the way governments conduct such operations rather than trying to conceal them.[24]

The second policy challenge is how to ensure the appropriate stakeholders have sufficient knowledge about RPOs in the GEO region, including those that do not have their own SSA capabilities. While there are benefits to having such data be public, a partially closed system is likely more politically feasible in the near term. As part of this effort, an international repository or common organization of SSA data could provide a universal understanding of space activities, similar to what already exists in the air and maritime domains. While current US policy requires establishing an open-access data repository for civil SSA data, this does not resolve the international data-sharing question, and there are unanswered questions about data standards, verification, and prioritization of reliable data sources.[25]

Finally, the United States needs to revisit its policy of having the US military be the lead for negotiating SSA data-sharing agreements, as safety and sustainability in space are more than distinct military missions. Due to the US military's lead, most of these agreements have been bilateral. A multilateral approach is necessary to improve equal access to SSA data and must include adversarial nations to establish a sustainable and prosperous space environment. Furthermore, the US government must continue to shift responsibility from the Department of Defense to the Department of Commerce on civil SSA and space traffic management.[26]

GEO Patterns of Life

In GEO, satellites adhere to patterns of life (PoLs) throughout their operational lifetimes. Patterns of life are sequences of both natural and nonnatural behavioral modes, including periods of station-keeping, natural drift, and various maneuvers such as longitudinal shifts or retirement maneuvers.[27] In order to develop norms of behavior for RPOs in GEO—combinations of behavioral modes space actors find agreeable—it is critical to understand the historical PoLs of GEO satellites prior to the development of such norms.

24. Brian Weeden, *Going Blind: Why America Is on the Verge of Losing Its Situational Awareness in Space and What Can Be Done about It* (Summerville, SC: SWF, September 10, 2012), https://swfound.org/.

25. Maui Economic Development Board and Aerospace Corporation, "2018 SSA Data Operators Workshop Meeting Notes" (notes prepared at the AMOS conference, Maui, HI, September 2018), https://amostech.com/.

26. Michael Dominguez et al., *Space Traffic Management: Assessment of the Feasibility, Expected Effectiveness, and Funding Implications of a Transfer of Space Traffic Management Functions* (Washington, DC: National Academy of Public Administration, August 2020), https://napawash.org/.

27. Phil DiBona et al., "Machine Learning for RSO Maneuver Classification and Orbital Pattern Prediction" (paper presented at the AMOS Technologies Conference, Maui, HI, September 2019), https://amostech.com/.

Identifying and quantitatively describing GEO satellite PoLs offer policymakers an opportunity to classify as acceptable or unacceptable historical behavior in the absence of agreed-upon norms of behavior. While no such comprehensive analysis exists, compiling one based on current practices as demonstrated by the historical movements of existing satellites could be a good start. Key elements of GEO satellite PoLs include operators' practices around station-keeping (such as their tolerance for drifting away from their desired position), longitudinal shifts (such as the frequency, drift rate, and drift period of shift maneuvers), and retirement (whether they choose to raise their altitude to enter the GEO belt's graveyard orbit, or not).

Developing a methodology for identifying satellite PoLs would offer insight into operators' adherence to space sustainability practices, compliance with international agreements geared to prevent harmful interference in the radio frequency spectrum, and a willingness to adapt their behavior over time as the GEO region becomes more populated.

Significant advancements have been made—often led by researchers from the machine learning and artificial intelligence communities—to classify satellite PoLs and automatically detect when satellites deviate from them.[28] Such studies often use the term nominal behavior to refer to on-orbit activities that adhere to a satellite's previous PoL and abnormal behavior to refer to activities that defy a satellite's previous PoL.[29] To date, however, specific patterns of life within the space community that have been accepted as the basis for norms of behavior have not been formally codified.

Policy Considerations

Translating PoLs into norms of behavior that will be politically acceptable to the United States and other space actors is a major political undertaking. In 2021, RAND published an assessment that covers the current state of space treaties, behaviors, and barriers to action.[30] The study recommends five key steps forward that while broadly applicable to behavior on orbit, are of particular interest for noncooperative RPOs and are reliant on a keen understanding of PoLs: (1) increase communication and engagement, (2) increase transparency, (3) begin with quickly achievable demonstrations of progress and accountability (quick wins), (4) concentrate on safety before including security considerations, and (5) progress toward security agreements.[31] These can only be achieved with a baseline understanding of how satellites currently and nominally operate in GEO.

As previously mentioned, increasing transparency in the space domain through robust and exquisite SSA data is integral to identifying satellite PoLs with high precision,

28. Charlotte Shabarekh et al., "A Novel Method for Satellite Maneuver Prediction" (paper presented at AMOS Technologies Conference, Maui, HI, September 2016), https://amostech.com/.

29. Roberts and Linares, "Satellite Maneuver Classification."

30. Bruce McClintock et al., *Responsible Space Behavior for the New Space Era: Preserving the Province of Humanity* (Santa Monica, CA: RAND Corporation, 2021), https://www.rand.org/.

31. McClintock et al., *Responsible Space Behavior*.

which will lead to a richer understanding of nominal and anomalous satellite behavior. The international space policy community is responsible for pushing more communication and engagement with policymakers and heads of state, especially when it comes to anomalous on-orbit behavior.

The challenges associated with noncooperative RPOs may be obvious to space experts, but defining PoLs to use for verification of nominal behavior is key to describing what is acceptable versus unacceptable. To build consensus, defining PoLs should be coordinated among nations, nongovernmental organizations, and commercial space companies. Additionally, coordination is necessary to align goals and priorities within UN dialogues and outside in bilateral or multilateral fora among spacefaring nations. This improved record of historical satellite behavior could offer the common ground needed to create international consensus on RPO norms.

Keep-Out Zones

Keep-out zones, or "self-defense zones" have been proposed periodically since the 1980s as a way to better defend satellites against unwanted close approaches.[32] The concept relies on a state declaring, either unilaterally or in agreement with other states, that a satellite entering a certain orbital region or coming within a certain distance of another satellite could be considered a hostile threat and subject to additional scrutiny or self-defensive actions. This is a similar concept to air defense intercept zones in the air domain or naval vessel protection zones at sea.[33]

In the original concept for self-defense zones put forward by Wohlstetter and Chow, the United States and the Soviet Union would agree to divide up the geostationary belt into red and blue zones. An uncoordinated approach of one of their space objects into the other's zone would be subject to additional scrutiny and potentially self-defense measures if it was deemed to be a threat. With the end of the Cold War, this concept is no longer applicable. Today, many countries operate national security assets in GEO, and it is increasingly common for satellites to drift through the GEO region as they relocate to new operating locations. In Chow's updated concept, the zones are placed around specific satellites and not broad regions of orbit but would otherwise function in a similar manner. [34]

Keep-out zones are unlikely to prevent either direct-ascent or co-orbital antisatellite weapons from being used, particularly in the GEO region due to its unique dynamics. Establishing a keep-out zone around a satellite might provide additional

32. Albert Wohlstetter and Brian Chow, *Self-Defense Zones in Space* (Marina del Ray, CA: Pan Heuristics, R & D Associates, June 1986), http://albertwohlstetter.com/; and Brian Chow, "Stalkers in Space: Defeating the Threat," *Strategic Studies Quarterly* 11, no. 2 (Summer 2017), https://www.airuniversity.af.edu/.

33. Zoltán Papp, "Air Defense Identification Zone (ADIZ) in the Light of Public International Law," *Pécs Journal of International and European Law* 28 (2015), https://heinonline.org/; and US Coast Guard (USCG), "Naval Vessel Protection Zone," flyer, USCG (website), September 14, 2001, https://homeport.uscg.mil/.

34. Chow, "Stalkers in Space."

warning time that a hostile approach was underway, but this is unlikely to prevent it from happening. Keep-out zones are also unlikely to prevent co-orbital inspectors from maintaining a persistent stand-off from a protected space asset but could provide increased warning that such an incident is occurring. Additionally, having a publicly declared keep-out zone could be a useful diplomatic tool to generate pressure on another country to move a co-orbital inspector away from a national security space asset.

Policy Considerations

The biggest policy challenge for keep-out zones is that they are not well grounded in the current international space law regime. Article VIII of the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (commonly known as the Outer Space Treaty) asserts a state retains jurisdiction and control over objects they have launched into space.[35]

Article II of the Outer Space Treaty prohibits national appropriation of outer space or celestial bodies by claim of sovereignty, by means of use or occupation, or by any other means. This creates the situation where it is illegal for states to physically interact with another country's satellite but also that states cannot prevent another country from approaching their satellite(s). There is no example of any country claiming a close approach of their satellite was a violation of existing international law, including the rights and obligations for international consultation under Article IX of the Treaty.[36]

Additional policy implications stem from the existing practice that suggests close approaches of another country's satellites are normal or accepted behavior. As outlined earlier in this paper, the United States, Russia, and China have all conducted multiple uncoordinated RPO activities of satellites in the GEO regions that are owned or operated by other countries. And while both the United States and France expressed public concern over some of these RPO activities, neither have publicly expressed an interest in establishing keep-out zones around their satellites.[37]

35. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty), U.S., U.S.S.R., U.K., January 27, 1967, art. VIII, https://www.unoosa.org/.

36. Outer Space Treaty, art. IX.

37. W. J. Hennigan, "Exclusive: Strange Russian Spacecraft Shadowing U.S. Spy Satellite, General Says," *Time*, February 10, 2020, https://time.com/; and John Leicester and Sylvie Corbert, "France Says Russia Satellite Spied in 'Star Wars' Hostility," Associated Press, September 7, 2018, https://apnews.com/.

Guardian Satellites

The concept of guardian satellites has existed for the last decade as one proposed solution to the challenge of uncooperative RPOs.[38] Guardian satellites—or satellite bodyguards—are generally considered to be satellites deliberately placed into a similar orbit as the satellite they are guarding to defend against hostile or unwanted behavior. But in most unclassified discussions of guardian satellites, details on how they would specifically accomplish those objectives are scarce.

Guardian satellites may protect against certain types of attacks, but they have their limitations. There could be a way to add additional defensive or offensive capabilities such as onboard jamming and spoofing, kinetic shoot-back systems, antiradar chaff, and lasers to dazzle or blind an incoming threat.[39] While these capabilities may be able to complicate the targeting solution of an attacking kinetic interceptor, they are unlikely to be able to prevent its success entirely and can likely be overcome by several incoming warheads.

Guardian satellites are likely to be more useful in preventing unwanted RPOs such as foreign satellite inspectors: a guardian satellite could be placed in an orbit inclined to the inspector's own orbit, which would create a natural motion between the two that results in a persistent collision threat if the inspector closes within a certain distance. Guardian satellites could also support defensive operations by providing more information and allow for quicker decision making, including space-based SSA capabilities.

Policy Considerations

The primary policy challenge of employing guardian satellites and on-orbit active defenses in particular is that these systems complicate signaling and may result in inadvertent escalation. Adversaries may not have information on a guardian satellite's capabilities or mission. Many of the previously mentioned capabilities that could defend a valuable asset from an attack (jamming, lasing, etc.) could also be used as a coorbital counterspace weapon. The only difference is the intent of use once on orbit, but even then, a country may simply alter the guardian's satellite mission from defensive to offensive.

Fundamentally, if the purpose is to complicate or confuse an adversary's tracking or targeting, it would be difficult for the defender to know if it was successfully deterring an attack and difficult for the attacker to know that deterrence was the goal. An attacker might assume the guardian was itself an offensive weapon being staged into orbit to be used against the attacker's satellites later. Thus, deploying guardian satellites,

38. Michael Nayak, "Deterring Aggressive Space Actions with Cube Satellite Proximity Operations," *Air & Space Power Journal* 31, no. 4 (Winter 2017), https://www.airuniversity.af.edu/; and Brian Chow, "Space Traffic Management in the New Age," *Strategic Studies Quarterly* 14, no. 4 (Winter 2020), https://www.airuniversity.af.edu/.

39. Todd Harrison, Kaitlyn Johnson, and Makena Young, *Defense Against the Dark Arts in Space* (Washington, DC: Center for Strategic and International Studies, February 2021), 18–26, https://aerospace.csis.org/.

particularly in a covert manner, could increase tensions and have the opposite of the intended effect.

Conclusion

Rendezvous and proximity operations technology is relatively easy to master and provides significant benefits when used in commercial, civil, and national security contexts. By contrast, no single policy option for dealing with RPOs stands out as both easily implementable and likely to yield major benefits that outweigh the drawbacks. Several policy options recommended in this article would require significant changes to the existing international legal or normative regime for space activities, which in turn would require multilateral negotiations and international cooperation.

Despite this, it is still possible to chart a path that mitigates the worst aspects of unrestricted RPOs in GEO by making progress on smaller steps that, if combined, could have major impacts. The first priority is to establish internationally recognized definitions for cooperative versus noncooperative RPOs, which may eventually lead to agreement on international norms of behavior for noncooperative RPOs. This agreement may come in piecemeal puzzle pieces from different organizations like the International Telecommunications Union, the United Nations Committee on the Peaceful Uses of Outer Space, or multilateral or minilateral agreements between groups of willing states.

Incremental progress is the key to success in space governance given the political, security, and cultural barriers to the classification of space assets and the lack of progress to date in existing multilateral fora. Yet, it would still require some degree of coordinated leadership from China, Russia, and the United States, which is challenging in the current geopolitical climate.

Another step is to make progress on the safety aspects of RPOs and space activities in general without directly addressing the national security issues. Safety and security go hand in hand for noncooperative RPOs, especially in valuable and limited orbits like GEO. Focusing on safety-related protocols and norms for cooperative RPOs could be more effective than focusing on security-related protocols for noncooperative RPOs.

Creating standards for commercial and civil RPOs, especially by companies currently pursuing satellite servicing capabilities, is likely to enhance the safety and sustainability of the domain. Common operational and interface standards, like those for aircraft and automobiles, would establish predictability and further understanding of the patterns of life of coordinated RPOs. This data and common understanding would differentiate and distinguish noncooperative RPOs or unusual close approaches.

In time, these steps may lead to progress toward security agreements centered on RPOs. Co-orbital antisatellites or other counterspace technology may rely on RPOs to conduct attacks and establish safe practices and systems to highlight unusual or suspicious behavior that could contribute to a more stable space environment. Actors behaving in good faith and adhering to established norms will always reinforce a secure and peaceful space domain; however, similar to arms control measures in other domains, the recommendations in this article may lessen potential tensions or accidental escalation. ***Æ***

IN-SPACE SUSTAINMENT

AN INTERNATIONAL CIVILIAN-LED LOGISTICS ARCHITECTURE

Alexander Jehle
Alexander Genzel

American policymakers are grappling with ensuring the ability of the US Space Force to project power in space while avoiding either explicitly militarizing space beyond geostationary orbit or by implying the establishment of sovereignty over celestial objects, actions which have the potential to alienate Allies and partners and alarm adversaries. An international civilian-led logistics architecture provides policymakers, military leaders, and proponents of civil exploration an opportunity to cooperatively pool their resources and achieve their objectives. An international civil and military partnership can be used to create shared standards, interfaces, and interoperability procedures to achieve strategic modularity, a fundamental requirement of a sustainment architecture and a paradigm leveraged by the petroleum industry but nearly absent from spacecraft systems engineering.

Allied grand strategy should pursue a future in space that is managed by rule of law (in the Western liberal sense, rather than the Chinese philosophy of legalism), where capitalism flourishes and people can live and work in space. This is the ideal vision of the future outlined by Air Force Space Command in 2019.[1] To achieve this future, the strategy requires a balanced trio of "ends, ways and means." Colin Gray asserts that when preparing for war, economics and logistics—the "means"—underpin strategy. "The economic resources of a polity supply and move a military machine that is directed by a strategy making organization, recruited, armed, and trained by military administration, ordered in accordance with intelligence information, educated and drilled respectively by strategic theory and doctrine."[2]

That is, the intelligence warfighting function informs maneuver, which itself informs the concept of support. Unfortunately, the US Space Force finds itself in an

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1. Air Force Space Command (AFSPC), *The Future of Space 2060 and Implications for U.S. Strategy: Report on the Space Futures Workshop* (Colorado Springs, CO: AFSPC, September 5, 2019), 6–9, https://aerospace.csis.org/; Namrata Goswami, "Explaining China's Space Ambitions and Goals through the Lens of Strategic Culture," Space Review, May 18, 2020, https://www.thespacereview.com/; and Yuri Pines, "Legalism in Chinese Philosophy," in Stanford Encyclopedia of Philosophy, November 16, 2018. https://plato.stanford.edu/.
2. Colin S. Gray, *Modern Strategy* (Oxford: Oxford University Press, 1999), 31.

unprepared theater (logistically speaking) and in an unprepared domain, and has yet to conduct set-the-theater tasks in space. Set-the-theater tasks are a prerequisite for developing a concept of support. Army doctrine defines these tasks as a

> broad range of actions conducted to establish the conditions in an operational area for the execution of strategic plans. . . . Planners leverage whole-of-government initiatives such as bilateral or multilateral diplomatic agreements to allow US forces to have access to ports, terminals, airfields, and bases within the AOR [area of responsibility] to support future military contingency operations.[3]

The envisioned Artemis basecamp on the lunar south pole and the International Space Station are the closest approximation of logistics infrastructure in space. Although the Space Transportation System and its space station was originally envisioned as permanent logistics infrastructure and as the first part of a network enabling access to deep space, the resulting International Space Station became a destination rather than a logistics hub.[4]

The American way of war highly depends upon the use of civilian logistics infrastructure to sustain and project forces.[5] This article discusses some policy, technical, and military considerations needed to establish a reliable network of in-space logistics assets. Gray asserted that "strategy requires the use or development of scarce economic resources."[6] Right now, the US Space Force finds itself contemplating power projection in an unprepared domain: power projection is necessary to maintain security, but power projection is dependent upon the sustainment of its forces.

In a resource-constrained environment, it is necessary to consider utilizing a "live off the land" mentality in space. NASA has researched in-situ resource utilization for decades but for the specific goal of use at the resource extraction location rather than with the intent of storing or further distributing the resources. Fortunately, the basic technology necessary to store and transport propellant has also been researched for decades.[7] The development of the space resources economy and the establishment of an in-space sustainment infrastructure are necessary to achieve Air Force Space Command's vision of the future and prevent the darker futures they envisioned in 2019 from arising.[8]

Challenges to the creation of a space-resources-based sustainment system are primarily bureaucratic or paradigm shifting rather than technical. These challenges

3. Headquarters, Department of the Army (HQDA), *Sustainment*, Army Doctrine Publication (ADP) 4-0 (Washington, DC: HQDA, July 31, 2019), 2-18, https://armypubs.army.mil/.

4. Space Task Group, *The Post-Apollo Space Program: Directions for the Future* (Washington, DC: National Aeronautics and Space Administration (NASA), September 1969), 14–15, https://www.hq.nasa.gov/.

5. Rose Lopez Keravuori, "Lost in Translation: The American Way of War," Small Wars Journal, November 17, 2011, https://smallwarsjournal.com/.

6. Gray, *Modern Strategy*, 31

7. Alexander Jehle and George F. Sowers, "Orbital Sustainment and Space Mobility Logistics Using Space Resources," Space Force Journal 2, no. 4 (June 2021), https://thespaceforcejournal.com/; and George F. Sowers, "The Business Case for Lunar Ice Mining," *New Space* 9, no. 2 (June 2021), https://www.liebertpub.com/.

8. AFSPC, *Space 2060*, 8–9.

include physical, legal, and fiscal constraints surrounding maneuver in space and utilizing space resources; refueling space systems; finding a suitable terrestrial model; and establishing a civilian-led framework.

Ultimately, a propellant-distribution system will be necessary to support the distribution of raw materials and manufactured goods throughout cislunar space. The establishment of a complete sustainment system—not just that of propellant—should be the overarching goal of an in-space logistics commission. Establishing an economy in space gives future US, Ally and partner-nation planners increased means to execute national strategy in space. Recognizing the necessity of utilizing space resources to fulfill strategic and functional objectives, the United States, its Allies, and its partners should create space-resources-based in-space sustainment architecture.

Physical, Legal, and Fiscal Constraints

Operations in the space domain are constrained by physics, national and international law, and fiscal policy. The cislunar operational environment includes the orbits immediately around Earth and extends to the edge of the Earth's gravity well, the area in which Earth's gravitational pull is greater than that of the Sun's. Cislunar key terrain includes the Moon, geostationary orbits, and the five Lagrange points (points of relative stability where the gravitational pull of the Earth, Moon, and Sun balance to create stable orbits relative to the Earth and the Moon orbits).[9]

Physical Constraints

Movement in space is inherent to an orbit—objects are constantly falling towards the central body. But the orbits are predictable. Yet a satellite without the ability to change its orbit may as well be a stationary target, falling prey to electronic or physical fires from an adversary satellite with maneuver capabilities.[10] Moreover, satellites cannot merely move around the battlefield, they need to be moving with a purpose: establish a position of advantage over the adversary, or at a minimum avoid a position of disadvantage by disrupting an adversary's kill chain. Unfortunately, satellites are currently constrained by the amount of propellant they are launched with. Once a satellite runs out of propellant, it can no longer maneuver.

The fundamental argument for in-space refueling is based on the physics of maneuvering in space and can be found in the rocket equation. The rocket equation results in an exponential requirement for propellant as the need for change in velocity (ΔV) increases.

9. M. J. Holzinger, C. C. Chow, and P. Garretson, *A Primer on Cislunar Space*, AFRL 2021-1271 (Wright-Patterson Air Force Base, OH: Air Force Research Laboratory, 2021), https://www.afrl.af.mil/.

10. Emma Helfrich, "Russian Military Satellite Appears To Be Stalking a New U.S. Spy Satellite," The Drive, August 3, 2022, https://www.thedrive.com/; 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, February 25, 2021), https://www.csis.org/; and HQDA, *Operations*, ADP 3-0 (Washington, DC: HQDA, July 2019), https://armypubs.army.mil/.

> This is the reason rockets leaving Earth consist mostly of fuel, and that a rocket going to the Moon and back must be the size of a Saturn V used in Apollo or the SLS currently in development. However, if you can refuel enroute, and reuse the propulsion system through multiple refuelings, you can break the tyranny of the rocket equation. The exponential increase of propellant with ΔV becomes linear.[11]

A reliable network of in-space logistics assets is an enabler for the mobility of all spacecraft, not just military spacecraft. Providing low-cost or nearly free propulsion will enable the transport of other materials and all other warfighting functions in space. Among all spacepower competencies, in-space sustainment holds the greatest potential to link the typically interconnected and international character of military, civil, and commercial space activities. Using space resources for in-space sustainment will facilitate large-scale access to low-cost, sustainable propellant for the space economy.[12]

Legal Constraints

Existing and upcoming human exploration missions to cislunar space and Mars are built on models of international cooperation such as the International Space Station agreement signed by 15 states in 1998.[13] The lunar Gateway is also being planned and executed by an international space agency consortium consisting of NASA, the European Space Agency, JAXA (the Japan Aerospace Exploration Agency), and the Canadian Space Agency with bilateral memoranda of understanding.[14] Such endeavors serve as legal models for an in-space sustainment infrastructure and could also serve as customers who would benefit from the delivery of space-sourced water and its constituent elements (oxygen and hydrogen) for human sustainment, propulsion, or radiation shielding.

The possible interconnections between international space activities and an internationally operated in-space sustainment network are evident in light of a new international civil space exploration agreement. The October 2020 Artemis Accords, with 23 state signatories by December 2022, represents the zeitgeist of international commitment to shape the future of human space exploration and counter adversarial norm-setting in space.[15]

Utilization of space resources is a core aspect of the agreement, which specifies international governance according to standards established in the five major space treaties and monitored by the United Nations Committee for the Peaceful Use of Outer Space (COPUOS). "The Signatories intend to use their experience under the

11. Sowers, "Lunar Ice Mining."

12. Sowers; and Jehle and Sowers, "Orbital Sustainment."

13. International Space Station Intergovernmental Agreement, Can.-European Space Agency member states-Jap.-Rus.-U.S., January 29, 1998, T.I.A.S. 12927 (1998), https://www.state.gov/.

14. Jeff Foust, "NASA and Japan Finalize Gateway Agreement,"Space News, January 13, 2021, https://spacenews.com/.

15. The Artemis Accords: Principles for Cooperation in the Civil Exploration and Use of the Moon, Mars, Comets, and Asteroids, Aus., Can., Jap., Ita., U.S., Lux., U.K., U.A.E., October 13, 2020, https://www.nasa.gov/.

Accords to contribute to multilateral efforts to further develop international practices and rules applicable to the extraction and utilization of space resources, including through ongoing efforts at the COPUOS."[16]

A year prior, on November 12, 2019, The Hague International Space Resources Governance Working Group adopted the *Building Blocks for the Development of an International Framework on Space Resource Activities*.[17] The framework outlines a potential legal framework surrounding property rights, responsibilities, and limitations for governments to coordinate, extract, and use space resources, and it establishes a forum and procedures to prevent and resolve disagreements consistently with existing treaties, including the Moon Agreement.

The Hague *Building Blocks* and multilateral space agreements provide policy and legal examples for establishing and maintaining an international in-space sustainment infrastructure. This spirit of international cooperation can be harnessed for defense-related purposes, but its primary use should be for establishing an in-space sustainment infrastructure and for building the space economy in general. A civilian-led in-space sustainment infrastructure, used by both government and private civil and commercial entities, will support the fulfillment of peaceful international political goals in space.

Moreover, commercial services built on the foundation of the described infrastructures will service military spacecraft but will also generally decrease the costs of spacefaring. This infrastructure will facilitate commercial space activities beyond low-Earth orbit (LEO) for all space players, amplifying digital services, communication, and connectivity on Earth, and ultimately benefiting all consumers of space-based services.[18]

Commercial space activities supported by an in-space sustainment infrastructure provide broad economic benefits to the average person on Earth. They increase the individual consumer's quality of life by reducing the cost of critical services; they lower the cost of doing business for companies operating in space or tangential to the space industry; and they lower the costs to governments that use space capabilities to govern and preserve their defense. An in-space sustainment architecture, then, can serve as a roadmap for Ally and partner governments to invest in this area while adhering to their commitments to international space law. The most prominent treaty, the Outer Space Treaty (1967), emphasizes that space activities "shall be carried out for the benefit and in the interests of all countries . . . and shall be the province of all mankind."[19]

16. The Artemis Accords.

17. The Hague International Space Resources Governance Working Group (HISRGWG), *Building Blocks for the Development of an International Framework on Space Resources Activities* (The Hague: HISRGWG, November 2019), https://www.universiteitleiden.nl/; and Olavo O. Bittencourt Neto et al., eds., *Building Blocks for the Development of an International Framework for the Governance of Space Resource Activities: A Commentary* (The Hague: Eleven International, 2020) 1.

18. HISRGWG, *Building Blocks*.

19. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (Outer Space Treaty), U.S., U.K., U.S.S.R., January 27, 1967, 18 U.S.T. 2410, art. I, https://www.unoosa.org/;

In-space sustainment is a support function with significant dual-use potential that supports ideals reflected in the Outer Space Treaty. Although essential to military operations, it is not inherently aggressive or threatening. It can, however, be an ideal focus point to maintain and promote positive norms and standards for international precedence in the context of the treaty. An opportune moment has now arrived in the light of the international activities of American space policy initiatives. The new space coalition has a common interest in an in-space sustainment infrastructure from strategic and operational perspectives.[20] Accordingly, this is a unique opportunity to spark a demand signal for the space resources industry.

Fiscal Constraints

Military space strategies must be derived from political and economic goals on Earth and in space and are thereby constrained by the economic means available to the planners. Although a consensus on the necessity of international cooperation in space is coming to fruition, not all stakeholders have a long-term strategic mindset. America's Allies and partners must evaluate their interest in participating in international space defense activities from a strategic perspective. Moreover, including these stakeholders from the beginning will allow for the creation of internationally accepted standards, ensuring the willingness of Allies and partners to follow US leadership in space. Civil space exploration programs accompanied by commercial opportunities emphasize international cooperation. In fact, the Artemis Accords explicitly deals with the utilization of space resources.

Several national space strategies must be coordinated into an overall model for international space defense cooperation. Cultural differences regarding the standing of space defense within national priorities, including budgets and the role of military space activities in overall national space activities, should not be underestimated. Unlike the United States, an operational demand for space is still nascent in many nations. Within NATO, space was accredited as an operational domain only in 2019, whereas the United States considered the 1991 Persian Gulf War to be its first space war.[21]

Although states might be relying on large-scale commercial and scientific activities to maintain influence in space, the implications for defense and national security often remain unperceived outside the direct spheres of influence of military institutions.

A low national priority for space results in limited spending. Revenue for military government satellites in Europe amounted to a predicted $12 billion for the two decades from 2008-2017, while North America spent $60 billion.[22] Yet commercial, civil,

20. Rachel S. Cohen, "Building the New Space Coalition," *Air Force Magazine*, March 26, 2021, https://www.airforcemag.com/.

21. NATO, "NATO's Approach to Space," NATO (website), October 6, 2022, https://www.nato.int/; and B. Chance Saltzman, interview by Brookings Institution, "Remembering the First 'Space War,': A Discussion with Lt. Gen. B. Chance Saltzman, March 19, 2021, https://www.brookings.edu/.

22. Euroconsult, *Satellites To Be Built and Launched over the Next Ten Years*, 21st ed. (France: Euroconsult, November 12, 2018), 132, https://www.euroconsult-ec.com/.

and scientific space activities massively outweigh defense applications in most countries. Among Ally nations, only the United States has a significant portion of its space budget dedicated to the defense sector. As one US Space Command official noted, "not all space partnerships are created equal. Where wealthier countries may have more established national security space needs, others may only have the budget or desire to pursue civil and commercial space programs. The United States is learning to meet everyone where they are."[23]

Unlike most other nations, the US Space Force and NASA have broad bipartisan political and economic support and standing that enable US leaders to formulate strategies relevant to national space activities. For many Ally and partner nations, the civil, military, and commercial space sectors do not garner political interest that directly translates into budgets comparable to that of the United States.

In 2018, US government spending on space dominated global government spending ($47.5 of $82.9 billion, or 57 percent of global government spending on space), and over half of that spending was military related (the National Reconnaissance Office, the Missile Defense Agency, and the US Air Force).[24] Yet the commercial satellite industry dominated the space economy ($260 of $344.5 billion, or 75 percent, in global spending), with benefits spread across the world in the form of telecommunications, position, navigation and timing, and weather forecasting. [25] These services support global terrestrial industries including cell phones and internet, transportation, and banking services and are generally outside of direct government control. Consequently the United States and its Allies and partners must collaborate where interests best coincide.

Ultimately, in-space sustainment enhances spacepower with ancillary, dual-use benefits—it develops the space economy while sustaining the principles of free and fair use of all. Additionally, because of its budgetary heft, as compared to its Allies and partners, the United States should encourage adoption of wider cost-sharing opportunities. For example, the US military can develop a space mobility command reminiscent of the Air Mobility Command or the military Surface Deployment and Distribution Command and offer any standards it develops for input and sharing with its Allies and partners.

The Challenge of Refueling

The functional use cases of refueling space vehicles closely mirror space propulsion activities: space launch, rendezvous, and station keeping. These three activities represent the how-to of conducting the movement half of maneuver in space and are a fundamental

23. Cohen, "New Space Coalition."

24. Federal Aviation Administration Office of Commercial Space Transportation (FAA AST), *The Annual Compendium of Commercial Space Transportation: 2018* (Washington, DC: FAA, January 2018), https://www.faa.gov/.

25. FAA AST, *Annual Compendium*.

part of conducting space operations. They are also foundational to sustainment activities necessary to conduct space access mobility and logistics activities.

For each activity, this article considers how refueling expands the space vehicle's mission envelope, the associated cost savings (if known), and resulting new mission opportunities. An overarching theme is that assured propellant resupply enables space vehicles to consume up to all their propellant on a single mission or set of missions without asset loss, that is, without incurring a so-called soft kill. Satellites have traditionally been designed to perform their intended mission until they run out of propellant and are then deorbited or placed in a safe graveyard orbit. Assured propellant resupply in space eliminates the soft-kill outcome, maintaining the space vehicle's design life and expanding its mission profile.

Space Launch

Launch vehicles' upper stages can be refueled in a geostationary transfer orbit or beyond geosynchronous orbits (GEO) to extend their reach and reduce the cost of placing a payload into the destination orbit. Refueling upper stages at geostationary transfer orbit for delivery of payloads to GEO (instead of using GEO satellites propulsion systems) could save up to 20 percent for the launch vehicle. Conceivably, this could eliminate GEO satellites' need for an apogee kick motor and associated propellant mass (~2000 kg, or nearly half the satellite's mass). This could free up mass budgets for other functions.

For missions beyond GEO, potential savings increase. Transportation from Earth to the lunar Gateway would see a 50 percent reduction in cost; transportation to the lunar surface or a Mars mission would cost approximately 66 percent less. A round trip from low Earth orbit to low lunar orbit (LLO) requires approximately 12,000 meters per second (m/s). Without in-space refueling, well over 300,000 kg of propellant would be needed (for a payload constrained by the assumed structure mass fraction of 0.92), sourced from Earth, at the start of the mission in low Earth orbit.[26] With one refueling, this is reduced by nearly an order of magnitude, to 40,000 kg; a 260,000 kg propellant savings.[27]

Upon mission completion, the upper stage is then either disposed of, or in the case of SpaceX's planned Starship, returned to Earth and reused. The upper stage could be refueled in space and repurposed for other missions including cryogenic propellant storage or bulk propellant delivery.[28] The upper stage could also be modified to provide in-space transportation services, including repositioning space vehicles or maneuvering space vehicles from GEO to other destinations within the cislunar

26. Sowers, "Lunar Ice Mining."
27. Jehle and Sowers, "Orbital Sustainment."
28. Jehle and Sowers.

system. This would essentially be a bulked-up version of final-leg delivery services provided by companies such as Bradford Space or Momentus.[29]

The Mars Ascent Vehicle (MAV) will be the first launch vehicle to depart an object in the solar system other than the Earth and the Moon (disregarding Osiris Rex's "Touch and Go" maneuver on the asteroid Bennu).[30] The vehicle was originally envisioned to use Martian in-situ resources to make its own propellant as part of the Martian Sample Return Mission that includes the Perseverance Rover.

The MAV team considered using oxygen sourced from Mars's atmosphere combined with liquid methane brought from Earth. Theoretically, this would have reduced the cost and amount of propellant needed to launch the vehicle from Earth. NASA later decided to use solid propellants while still successfully demonstrating oxygen extraction from Mars's atmosphere with MOXIE, the Mars Oxygen In-Situ Resource Utilization Experiment, one of the Rover's payloads.[31]

The MAV team will still have to contend with ensuring the launch vehicle can survive its entire mission profile: Earth launch, deep-space storage for eight months, Mars landing, and propellant storage on Mars for 2–6 years before a successful launch of the return mission.[32]

Future Mars missions, especially those with human participants, would benefit from local propellant generation and distribution. A round trip from LEO to low Martian orbit costs around 11,000 m/s. This budget compares to the LEO-to-low Lunar orbit mission previously discussed but would not have the benefit of in-space refueling without a dedicated, assured, in-space propellant resupply in the vicinity of Mars. A robotic propellant depot and distribution architecture established for cislunar space would need to be modified to account for the different environment of the Martian or other destination body's orbit, including differences in incident sunlight and latency for remotely controlled operations.[33]

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29. "Logistics Services," Bradford-Space (website), n.d., accessed January 3, 2023, https://www.bradford-space.com/; and Debra Werner, "Momentus Reports Success in Testing Water Plasma Propulsion," Space News, September 25, 2019, https://spacenews.com/.

30. Brittany Enos, NASA's OSIRIS-REx Begins Its Countdown to TAG, NASA (website), September 24, 2020, https://www.nasa.gov/.

31. Stephen Clark, "NASA Narrows Design for Rocket to Launch Samples Off of Mars," Space Flight Now, April 20, 2020, https://spaceflightnow.com/; John Strickland, "Solving the Expendable Lander and MAV Trap," Space Review, October 19, 2015, https://www.thespacereview.com/; Stephen Clark, "Northrop Grumman to Supply Solid Rocket Motors for First Mars Ascent Vehicle," Space Flight Now, March 29, 2021, https://spaceflightnow.com/; and "MOXIE," NASA (website), n.d., accessed January 3, 2023, https://mars.nasa.gov/.

32. "Mars Sample Return Mission," European Space Agency (website), n.d., accessed January 3, 2023, https://www.esa.int/.

33. James R. Wertz, David F. Everett, and Jeffery J. Puschell, *Space Mission Engineering: the New SMAD*, (Torrance, CA: Microcosm Press, 2011), 282.

Rendezvous

Rendezvous missions (1) insert satellites into a specific point in a constellation; (2) inspect operational satellites; (3) service operational satellites; (4) intercept satellites (as a kinetic antisatellite weapon); and (5) avoid collisions. A satellite launched into a geostationary transfer orbit uses its own propulsion system for orbital insertion (utilizing its apogee kick motor). Upon successful insertion, the satellite could be refueled, providing it with an additional 1,700 m/s of delta-V to be used for collision avoidance, repositioning within the GEO belt, or even to fully deorbit rather than enter a graveyard orbit.

Space-based space surveillance missions such as those performed by the Geosynchronous Space Situational Awareness Program (GSSAP) rendezvous with natural motion circumnavigation or forced motion circumnavigation orbits around satellites in the GEO belt to inspect or observe satellites for intelligence purposes. One estimate suggests the GSSAP program could save nearly the entire cost of a replacement satellite—$114 million—by refueling GSSAP assets.[34]

Finally, programs such as the Defense Advanced Research Projects Agency's Robotic Servicing of Geosynchronous Satellites provide rendezvous capabilities with satellites to conduct repairs such as deployment assistance, swap out payloads, inspect environmental damage, and conduct retail-level refueling of satellites' propellant or cryogenic coolants.[35]

Station Keeping

Station-keeping maneuvers are performed to maintain a satellite within its assigned orbital slot. For geosynchronous Earth orbit satellites, this assignment is critical to maintain as the orbital slots are tightly allocated by the International Telecommunications Union to deconflict frequency use and mitigate collisions. The ability to refuel a GEO satellite's station-keeping propellent would enable that satellite to either extend its mission beyond what it was originally fueled for or enable it to launch with a minimal amount of propellant. Savings would be mission dependent, but water extracted from the Moon could cost as little as $1100/kg at Earth-Moon Lagrange Point-1 and only slightly more in GEO: this is a tenfold savings over propellant launched from Earth.[36]

A Terrestrial Petroleum Logistics Model

No single company or government agency including NASA or the US Space Force will be able to independently dictate standards for a widely adopted in-space logistics

34. Jehle and Sowers, "Orbital Sustainment."

35. On-Orbit Servicing, Assembly, and Manufacturing (OSAM) National Initiative, *OSAM State of Play*, 2021 ed. (Washington, DC: NASA, 2021), https://ntrs.nasa.gov/.

36. Sowers, "Lunar Ice Mining"; George Sowers et al., *Thermal Mining of Ices on Cold Solar System Bodies: NIAC Phase I Final Report* (Golden, CO: Colorado School of Mines, February 2020), 78, https://space.mines.edu/.

infrastructure. Instead, the Defense Logistics Agency, as the executive agent for bulk petroleum, manages bulk petroleum distribution to the US Department of Defense. In this capability, it coordinates with combatant commands, industry, and host nations. Additionally, each branch of military service retains its service-specific acquisition and employment strategies to support its environment and mission-unique operational and tactical needs (fig 1.)[37]

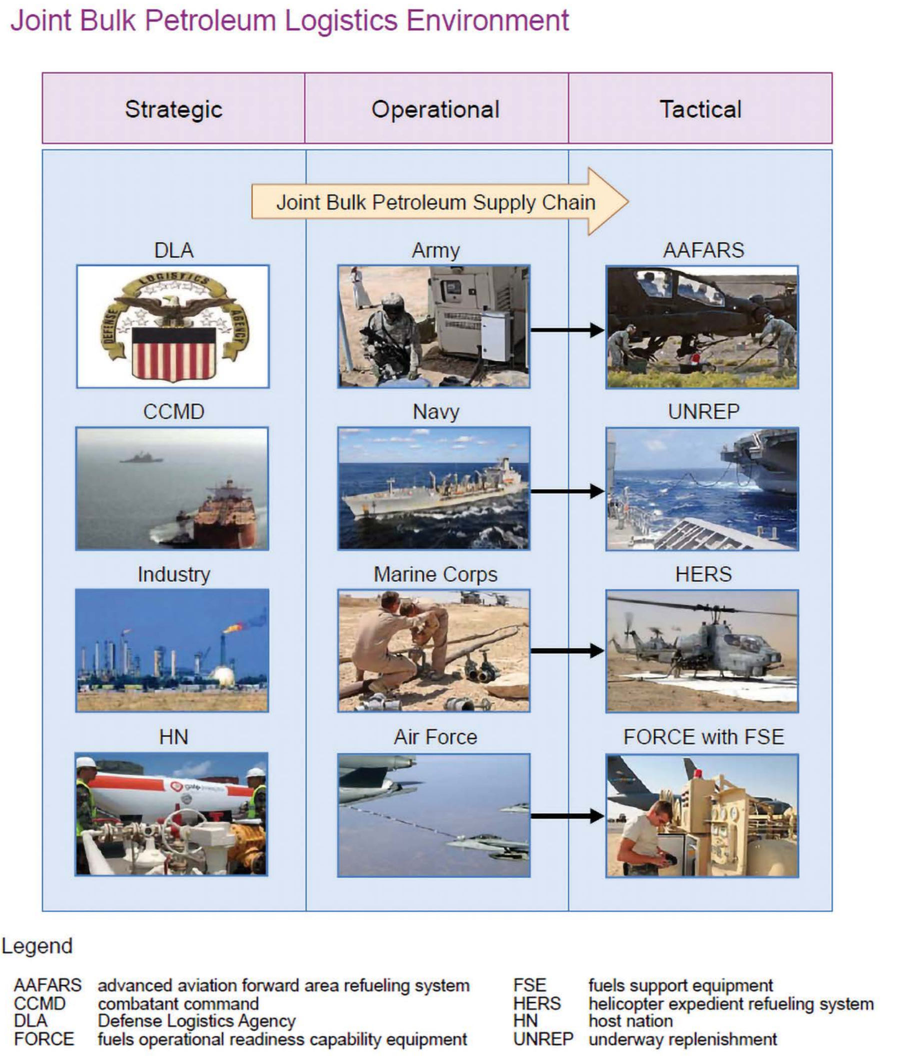

Figure 1. Joint bulk petroleum logistics environment, Joint Publication 4-03

37. Chairman of the Joint Chief of Staff (CJCS), *Joint Bulk Petroleum and Water Doctrine*, Joint Publication 4-03 (Washington, DC: CJCS, November 30, 2017), I-4, https://www.jcs.mil/.

In the petroleum industry, multiple companies are involved in the petroleum value chain, which includes prospecting, extracting, product refinement, bulk distribution, retail distribution, and final delivery to the customer. Gas stations are often privately owned franchises that lease directly from a retail fuel supplier. Those suppliers are subcontracted from bulk distributors that use pipelines or ocean-going vessels and own multiple bulk storage nodes.

A space-resources-based propellant value chain will closely mirror that of the terrestrial petroleum industry, which is global in nature. It, too, will include prospecting, extracting, processing, storage, and delivery nodes. A recent report thoroughly considers the space resources prospecting and extraction portion of the value chain but was intentionally vague about the aggregation, storage, and distribution of propellants.[38] Since that report's release, significant work has gone into prospecting, mining, and extracting water from the Moon and asteroids and transferring cryogenics in space.[39]

Northrop Grumman's Mission Extension Vehicle series has operationalized retail satellite servicing. Additional space resources value chain capability gaps still exist but are being identified and are starting to be filled in by researchers and a robust ecosystem.[40] Yet significant gaps remain including lunar-surface logistics infrastructure and in-situ resource utilization for other lunar and Martian resources.[41] NASA has been taking several steps to close these gaps, launching multiple strategies including public engagement programs like the "Break the Ice Challenge."[42]

Incorporating space resource extraction technologies, the example of DLA's civil-military partnership, and the fact that all active, thrust-producing propulsion systems require propellant, in 2021, researchers proposed a single propellant architecture

38. David Kornuta et al., "Commercial Lunar Propellant Architecture: A Collaborative Study of Lunar Propellant Production," *REACH* 13 (March 2019), https://doi.org/.

39. Justin Cyrus, "Prospecting, Extraction, and Processing of Lunar Resources Utilizing Swarms of Lunar Outpost's Mobile Autonomous Prospecting Platform (MAPP) Rovers" (paper presented at the Space Resources Roundtable, Colorado School of Mines, Golden, CO, June 11–14, 2019); Joel Sercel, "Asteroid Provided In-Situ Supplies (Apis™) Mission Architecture and Progress" (paper presented at the Space Resources Roundtable, Colorado School of Mines, Golden, CO, June 11–14, 2019); Robert Jedicke et al., "Optimized Continuous-Thrust Round-Trip Trajectories to Ultra-Low Δv ISRU Targets," *Planetary and Space Science* 211 (February 2022), https://doi.org/; and Sowers et al., "Thermal Mining."

40. Robert P. Mueller et al., "Lunar Mega Project: Processes, Work Flow, and Terminology of the Terrestrial Construction Industry versus the Space Industry," in *Earth and Space 2021*, Conference Proceedings for the 17th Biennial International Conference on Engineering, Science, Construction, and Operations in Challenging Environments, April 19–23, 2021 (Reston, VA: American Society of Civil Engineers, April 15, 2021), https://ascelibrary.org/.

41. International Space Exploration Coordination Group (ISECG), "In-SITU Resource Utilization Gap Assessment Report," (ISECG, April 21, 2021), https://www.globalspaceexploration.org/.

42. "NASA Break the Ice Lunar Challenge," NASA (website), November 18, 2020 https://www.nasa.gov/; and Molly Porter, "NASA Awards $500,000 in Break the Ice Lunar Challenge," NASA (website), August 18, 2021 https://www.nasa.gov/.

based on water distribution.[43] Nuclear thermal propulsion, an excellent and promising advanced propulsion technology, uses nuclear power to generate electrical or thermal energy to heat and accelerate a propellent—preferably hydrogen.[44] Past research has shown that water ice reserves on the Moon could be sourced and processed into propellant for in-space refueling in a commercially viable way, potentially within 10 years, supporting further space resource extraction and utilization.[45] A corresponding architecture has been proposed to distribute water (fig 2).[46]

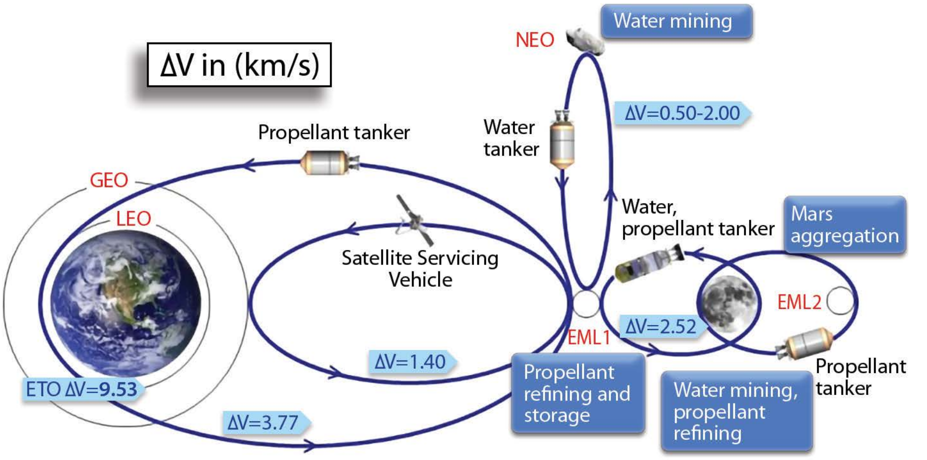

Figure 2. Water and LO2/LH2 propellant logistics architecture in cislunar space[47]

As a system-of-systems engineering problem, interfaces need to be specifically defined and adopted for the environment(s) and position(s) across the value chain in which they connect and serve. Environmentally, this includes the thermal environment for power generation and thermal management, the radiation environment for radiation hardening or to shield components, and day/night cycling for objects orbiting or based on a celestial body, among other considerations.

Value chain considerations include the total volumetric flow rate of the cryogenics being transferred; material selection; mechanical connections considering impact velocities,

43. Matthias Kößling et al., "The Space Drive Project—Thrust Balance Development and New Measurements of the Mach-Effect and EMDrive Thrusters," *Acta Astronautica* 161 (August 2019), https://doi.org/10.1016/; Jehle and Sowers, "Orbital Sustainment"; and Sowers, "Lunar Ice Mining."

44. Alex Gilbert, "Enhancing Military and Commercial Spacepower through Nuclear Thermal Propulsion," Space Force Journal 2 (June 2021).

45. Jehle and Sowers, "Orbital Sustainment"; Sowers, "Lunar Ice Mining"; and Luxembourg Space Agency, *Opportunities for Space Resource Utilization Future Markets and Value Chains: Study Summary* (Luxembourg: Luxembourg Space Agency, December 2018), https://space-agency.public.lu/.

46. Jehle and Sowers, "Orbital Sustainment."

47. Jehle and Sowers.

forces, and vibrations; electrical and data interfaces (both wired and wireless); thermal interfaces,; cycling and aging; weathering; and operational practices and protocols.[48]

Several companies are already developing and promoting their own interfaces in the hopes of achieving early and wide adoption. Some companies are promoting their interfaces as unrestricted (in the case of NovaWurks, both International Traffic in Arms Regulation–and intellectual property-free). Making an interface standard and open does not preclude intellectual property rights. As an example, the computer USB interface is still proprietary, and the owning organization sells licenses for under $10,000 to hardware developers.[49]

Eta Space, Lockheed Martin, SpaceX, and ULA were all awarded tipping point contracts by NASA to demonstrate large-scale, in-space, cryogenic propellant transfer. These demonstrations and the interfaces developed to support them would be critical to upstream propellant transfer—propellant transfer from a wholesale manufacturer to a storage depot or from a storage depot to a bulk transfer vehicle. These transfers are volumetrically high: SpaceX and ULA are specifically planning on demonstrating in-space refueling of launch vehicle upper stages.[50]

NovaWurks, Obruta, OrbitFab, SkyCorp, iBOSS (GmbH), AstroScale, and Northrop Grumman's Space Logistics have independently developed competing interfaces, visions, and standards for conducting satellite servicing. At one end of the spectrum, the Mission Extension Vehicle docks to and remains attached to the serviced satellite for the duration of its services and is relatively interface agnostic, attaching to a satellite's apogee kick motor. At the other end, NovaWurks's Space Lego concept uses its interface to facilitate in-space assembly, including for the exchange of internal propellant tanks between orbits and space systems (in the model of barbecue propane tank exchanges).[51]

Any system actively maneuvering and conducting rendezvous proximity operations and docking must be a fully functioning satellite that can independently maneuver, communicate, and survive in space; while small, the interface is an essential part of both the individual and system-level solutions. In order to achieve strategic modularity, these critical interfaces need to be agreed upon by the relevant stakeholders throughout their international value chain.

A Civilian-Led Framework

A propellant distribution system as outlined above could support the distribution of raw materials and manufactured goods throughout cislunar space. The establish-

48. Alexander Kossiakoff et al., *Systems Engineering Principles and Practice*, 2nd ed. (Hoboken NJ: John Wiley and Sons, 2011), 62.

49. "Getting a Vendor ID," USB (website), https://www.usb.org/.

50. "2020 NASA Tipping Point Selections," NASA (website), October 14, 2020, https://www.nasa.gov/.

51. "Space Logistics," Northrop Grumman (website), https://www.northropgrumman.com/; Sarah Scoles, "Now Entering Orbit: Tiny Lego-like Modular Satellites," December 29, 2019, https://www.wired.com/; and Talbot Jager, founder and CTO of NovaWurks, interview with author, July 29, 2021.

ment of a complete sustainment system—not just that of propellant—should be the overarching goal of an in-space logistics commission. Establishing an economy in space gives future US, Ally, and partner planners increased means to execute national strategies in space. Recognizing the necessity of using space resources to fulfill strategic and functional objectives, the new space coalition should contribute to the creation of a space-resources-based in-space sustainment architecture. The Artemis Accords presents an ideal structure to grow the inevitable military stakeholdership in space resources utilization in adherence to international space law while partnering with civil and commercial stakeholders.

Three areas of technological emphasis will facilitate the development of a space-resources-based sustainment network—strategic modularity, space resources utilization technologies, and orbital servicing and assembly technologies. These technology areas underpin the establishment of a celestial line of communication connecting the Moon to the Earth and facilitating the inclusion of the Moon into our economic sphere. In all three areas, an in-space logistics commission should coordinate among all stakeholders in the sustainment system-of-systems. Stakeholders will span the space resources value chain, from resource prospecting and extraction companies, through companies providing storage, processing, and distribution, to the governments, companies, and organizations that are the end in-space consumers of propellants, goods, and services.

First, strategic modularity—a systems engineering management approach that seeks a middle ground between top-down dictates of the interfaces (strangling necessary innovation) and a completely hands off approach leaving individual program managers free to select their own interfaces—needs to be achieved across a new space coalition. An in-space logistics commission could coordinate stakeholders to adopt common practices, technologies, and procedures to ensure the interoperable sustainment of their civil and military space capabilities. The commission could also map and functionally partition the components of the logistics system, specify the interfaces, and then freeze those interfaces to establish technical stability for the overall system-of-systems.[52]

If left without system-of-system level guidance, program managers may adopt the first interface that successfully meets their system's needs, achieving "technical modularity."[53] The absence of a collective interface requirement will lead to multiple standards, which increases the engineering requirements for the sustainment system-of-systems. The sustainment system-of-systems would then be required to support each standard, increasing mass and reducing efficiency. Ultimately not adopting a single standard or well-thought-out set of standards increases the cost for every system. Stra-

52. Ron Sanchez, "Modularity in the Mediation of Market and Technology Change," *International Journal of Technology Management* 42, no. 4 (2008) 338–39.

53. Ron Sanchez and Joseph Mahoney, "Modularity and Economic Organization: Concepts, Theory, Observations, and Predictions," in *Handbook of Economic Organization*, ed. Anna Grandori (Northampton, MA: Edward Elgar, 2013) 387.

tegic modularity should be designed into any future space logistics system rather than engaging back-office, technical modularity, which has traditionally been used by the satellite industry.

An in-space logistics commission should also focus on the development of space resources utilization technologies. Technologies surrounding prospecting, extraction, processing, and distribution need to be matured in the context of civil space exploration programs. Until lunar- and near-Earth-object-sourced propellant can be transported through an in-space sustainment architecture, Earth-sourced propellants can be used to test existing and upcoming alternatives for storing and distributing propellant in space.

Finally, the commission should promote investment in orbital servicing assembly and manufacturing technologies such as space tugs (offering space mobility in the form of LEO-GEO orbital lifts), Earth-launched refueling missions, and Robotic Servicing of Geosynchronous Satellites. These missions form experimentation building blocks, mature concepts of operations, and refine the technology for international standards adoption.[54]

Conclusion

Establishing an in-space propellant sustainment architecture is both legal and necessary. Space resource law is rapidly maturing toward adopting a common framework for managing the use and extraction of celestial object resources and the property rights, responsibilities, and limitations of the countries and companies manufacturing products from them. Maneuver in space is inextricably tied to the use of propellant; reliable resupply will enhance national spacepower by reducing the cost of all other space activities.

This architecture will enable cheaper space exploration missions and lay the foundation for a material-based (an addition to the existing data-based) space economy. A new space coalition's space forces need to be prepared to leverage these new logistics capabilities, as it will extend their operational reach in cislunar space and enable maneuver without regret in the space domain.

An international coalition under the Artemis Accords should establish a civilian-led in-space logistics commission to map out the functional component of space logistics centers and networks, identify the common interfaces and procedures, and freeze those interfaces to create technical stability. An in-space logistics capability requires deliberate but decentralized coordination among its partner constituents, and strategic modularity is a prerequisite. Technical modularity, which emerges through individual program manager coordination, will not suffice, as it will increase complexity and hinder full interoperability. **Æ**

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54. Elizabeth Howell, "Space Tug Company Names DARPA Military Veteran as New President," Forbes, September 15, 2020, https://www.forbes.com/; and Jeff Foust, "Orbit Fab and Benchmark Space Systems to Partner on In-Space Refueling Technologies," Space News, February 23, 2021, https://spacenews.com/.

LAWN DART NETWORK UTILIZATION ON THE MOON

Liberty Shockley

The Lawn Dart program, a proliferated mesh network of security commodities staged across the lunar surface, will promote a stable and sustainable space operating environment. Lawn Darts will deploy as probes from lunar orbit around the surface of the Moon to provide an Internet of Things and a power network for other operational assets such as rovers, people, and Moon bases. This capability and its execution raises questions about international law and geopolitical concerns related to territorial claims on the lunar surface and the planned organization of space activities by conflicting parties, but the program is compliant with the current framework of law and policy. The Lawn Dart program is essential for providing security for lunar assets, protecting mission data against adversaries, and laying the groundwork for NASA and European Space Agency exploration mission success.

Space is busy, however, there is still insufficient infrastructure to support or protect assets in space, and no agreed upon coordination of space activities. Companies and governments worldwide have proposed important technologies to explore the edges of the universe, and these technologies depend on resources such as power, fuel, autonomous communication and operations, communication relay, and a place in orbit or on a celestial surface.

In an increasingly contested space environment, security is becoming critical. The United States, its Allies, and partners do not have adequately mature technology or concepts of operations to ensure safety and security against adversaries. We need commodities that provide security for mission data, communication, navigation, and power for other operations such as rovers or personnel on bases.

Lawn Darts, currently being developed by the Air Force Research Laboratory Center for Rapid Innovation, will provide a proliferated mesh network of security commodities around valuable parts of the lunar surface. Probes, or "Lawn Darts," would be deployed from orbit and lodge permanently in the ground. These probes would be composed of different sensors to perform a variety of security functions. Lawn Darts will essentially create a network that provides internet-like services and "charging stations" on the Moon.[1]

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1. Donald J. Trump, *Presidential Memorandum on Reinvigorating America's Human Space Exploration Program* (Washington, DC: The White House, December 11, 2017), https://trumpwhitehouse.archives.gov/.

Yet, deploying a physical communications network such as the one provided by the Lawn Dart program raises questions about international cooperation with regard to surveillance, resource utilization, and territorial claims on the Moon's surface pursuant to international law and US national policy. While space exploration has always had a joint and peaceful focus, securing and supporting the space domain could cause conflicts of state interests as space operations progress.

The United States seeks to lead the effort to establish cooperative norms of behavior that thwart adversarial interests, recognizing the strategic importance of the Moon to developing a cislunar econosphere. The current international framework, which primarily encourages the peaceful use of outer space, is not robust enough to guide space traffic management and will not be suited to resolve territorial claims and conflicts on the Moon. Decisionmakers must navigate what is in the realm of technical possibility and norms of behavior, and what provides the strategic advantage to accomplish their missions.

The Lawn Dart program will promote a stable and secure space operating environment on the Moon in a way that is internationally cooperative and harmonious with the current and future development of space law and policy.

Background

The Lawn Dart program is intended to protect communication, sensing, navigation, power generation and distribution on the lunar surface for connected assets. It will use unattended ground sensor nodes to conduct situational awareness information using cameras, transmit vital communications to and from any rover or sensor connected to the network in an Internet-of-Things manner, provide asset and adversary tracking, and provide power infrastructure for assets on the Moon.

The deployment method and unattended ground sensor design of Lawn Darts ensure accessibility to remote locations on the Moon. For this, individual Lawn Darts will be designed as penetrator-type spacecraft. They will deploy from another spacecraft in low lunar orbit, survive impact to the surface, power on, and connect to other nodes autonomously. The collection of nodes will provide a grid for use on the lunar surface and a communication relay back to Earth. This system will provide the required infrastructure to support future US, Ally and partner lunar missions. The concept of operation and technologies involved are illustrated in Fig. 1.

US national law directs the execution of space programs to ensure compliance with international law and minimize the spread of critical technologies to nations that could threaten US national security.[2] Myriad US laws, standards, and regulations dictate space missions and technologies and focus particularly on operational objectives, launch, space-debris creation, territorial claims on celestial bodies, and weapons. Therefore, the Lawn Dart program must be designed in a way that minimizes debris

2. National and Commercial Space Programs, 51 U.S.C. (2010), § 20102, Congressional Declaration of Policy and Purpose, https://uscode.house.gov/.

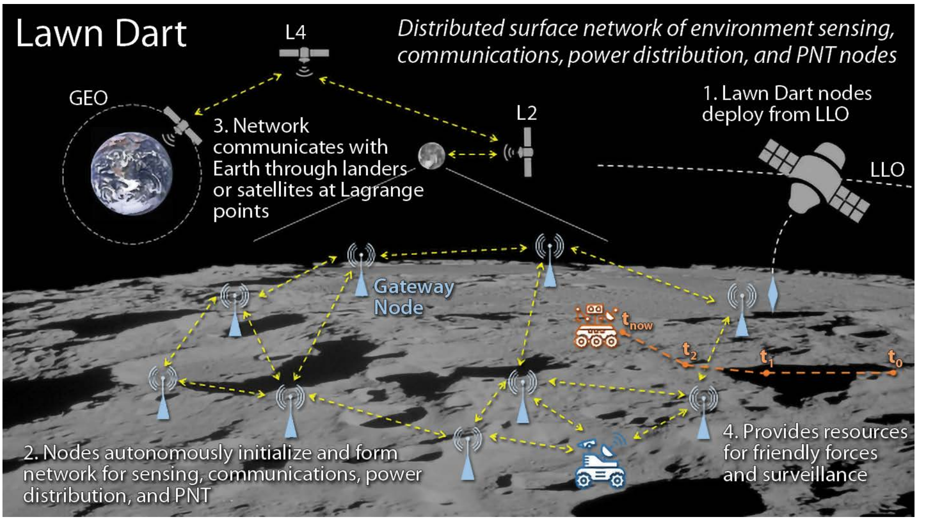

Figure 1: Lawn Darts network utilization on the lunar surface[3]

creation, does not appear to be a weapon or claim territory, and fits into both US national security and NASA interests.

Unattended ground sensor nodes and networks provide security infrastructure in the terrestrial operational domains, but this experiment extends them to the space domain. These sensors are typically used in military multidomain operations, soliciting concerns about the militarization of space. Similar hard-landing/penetrator concepts such as the Deep Space 2 mission have flown before but not for the purpose of communications infrastructure, and not with Chinese or other adversary assets in close proximity.[4]

NASA's plan for Sustained Lunar Exploration and Development and National Space Directive #1—"Lead an innovative and sustainable program of exploration . . . the United States will lead the return of humans to the Moon for long-term exploration and utilization"—generally describes how this technology will support plans for US exploration of the Moon and international participation in activities on the Moon.[5]

3. Graphic created by Charles Finely, Air Force Research Laboratory Center for Rapid Innovation, NASA Ames.

4. Suzanne Smrekar et al., "Deep Space 2: The Mars Microprobe Mission," *Journal of Geophysical Research* 104, no. E11 (November 1999), https://agupubs.onlinelibrary.wiley.com/; and National Aeronautics and Space Administration (NASA), "NASA Space Science Data Coordinated Archive," "Deep Space 2," vers. 5.1.15, October 28, 2022, https://nssdc.gsfc.nasa.gov/.

5. Smrekar et al., "Deep Space 2"; and NASA, "Deep Space 2."

Interpreting Space Law and Policy

International Law and Policy

Space Law originates principally from bilateral agreements between the United States and the former Soviet Union during the space race of the twentieth century, but soft law is currently used to supplement outdated treaties from this period.[6] Accordingly, there is a lack of legally binding international law concerning the space domain. Currently, only five treaties adopted by the UN General Assembly exist: the Outer Space Treaty (1967) the Rescue and Return Agreement (1967), the Liability Convention (1972), the Registration Convention (1976), and the Moon Agreement (1984).[7]

The Outer Space Treaty provides a legal framework for states to create unique national space laws that guide the treaty's implementation. Predominantly, the Outer Space Treaty requires space to be used for peaceful purposes and declares there can be no state sovereignty in the space domain.[8] National space law then trickles down into policy for and regulations of public and commercial space programs.

Other than these legally binding treaties, the UN has adopted formal principles through the UN Committee on the Peaceful Uses of Outer Space (UN COPUOS) and guided by the UN Office of Outer Space Affairs, although they do not influence the utilization of Lawn Darts. These include: the Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space (1963), Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting (1982), Principles Relating to Remote Sensing of the Earth from Outer Space (1986), Principles Relevant to the Use of Nuclear Power Sources in Outer Space (1992), and the Declaration on International Cooperation the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account of the Needs of Developing Countries (1996).

The UN has also adopted documents and guidelines that are not considered legally binding. These paired with the budding establishment of norms of behavior in space collectively are also considered soft law, which guides most space activities. For Lawn Darts and the majority of other spacecraft built, the Space Debris Mitigation Guidelines of the COPUOS, the Inter-Agency Space Debris Coordination Committee

6. Liberty Shockley et al., "Policy and Geopolitical Implications of Launch-On-Demand Capabilities," *Journal of Defense Research & Engineering*, 3, no. 1 (2020); and Frans von der Dunk and Fabio Tronchetti, eds., *Handbook of Space Law* (Northampton, MA: Edward Elgar, 2017).

7. Shockley, "On-Demand Capabilities."

8. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (Outer Space Treaty), U.S., U.K., U.S.S.R., January 27, 1967, 18 U.S.T. 2410, arts. 2, 3, https://www.unoosa.org/; and UN, "Space Law Treaties and Principles," UN Office of Outer Space Affairs (website), n.d., accessed December 15, 2022, https://www.unoosa.org/.

(IADC) Space Debris Mitigation Guidelines, and the International Standards Organization (ISO) are the most applicable references.[9]

For legally binding guidance, Lawn Darts must adhere to the Outer Space Treaty, the Liability Convention, and the Registration Convention, though compliance is already baked into the guiding regulations described in US national space law.[10] Critically, no state that self-launches human spaceflight has ratified the Moon Agreement, meaning US national and commercial space programs are not subject to its terms.[11] Yet this agreement still worth considering since it is widely mentioned, especially as nations are planning more Moon missions and proposing more bilateral agreements on lunar activities.

Most existing space policy and regulations pertain to the creation of space debris due to its ability to clog up orbits and physically threaten space assets and space use. The definition of space debris, however, does not include any objects not in Earth orbit, so there are no international standards for the disposal of mission hardware on the Moon or other celestial bodies.[12]

The IADC Space Debris Mitigation Guidelines state debris creation "shall be minimized," but there are no further stipulations for the creation of debris on the Moon.[13] In conclusion, while there is not thorough guidance on disposal in the cislunar sphere, the Lawn Dart program intends to use the experimental nodes in the operational infrastructure once the technology is proven, along with interoperability in the LunaNet architecture, adhering to the call for responsible and sustainable actions in the space domain.

US Law and Policy

As noted above, Title 51 of US Code describes the laws applicable to national and commercial space programs in the United States. There are many administrative offices under the Executive Branch that further guide how space programs are to be conducted including NASA, the Federal Communications Commission, the Department of Defense, and the Federal Aviation Administration. The International Traffic

9. UN Office of Outer Space Affairs, *International Space Law: United Nations Instruments* (Vienna: United Nations, May 2017).

10. Convention on International Liability for Damage Caused by Space Objects, RES 2777 (XXVI), November 29, 1971, https://www.unoosa.org/; and Convention on Registration of Objects Launched into Outer Space, RES 3235 (XXIX), November 12, 1974, https://www.unoosa.org/; and 51 U.S.C.

11. UN General Assembly, Resolution 34/68, Agreement Governing Activities of States on the Moon and Other Celestial Bodies (Moon Agreement), A/RES/34/68 (1979), https://www.unoosa.org/.

12. International Standards Organization (ISO), *Space Systems and Operations including Space Data and Information Transfer Systems, and Ground Support Equipment for Launch Site Operations*, ISO 49.140 (Geneva: ISO, n.d., accessed December 20, 2022), https://www.iso.org/; and ISO, *Space Systems – Lunar Simulants*, ISO 10788:2014 (Geneva: ISO, current as of 2019), https://www.iso.org/.

13. Inter-Agency Space Debris Coordination Committee (IADC), *IADC Space Debris Mitigation Guidelines*, IADC-02-01 rev. 2 (IADC, March 2020), https://orbitaldebris.jsc.nasa.gov/.

in Arms Regulations (ITAR) also levies many requirements on the development and collaboration of space programs and their technologies.

Title 51 does not specifically regulate activities on the Moon that Lawn Darts could be subject to; it simply directs the Department of Defense, Federal Aviation Administration, and NASA to implement programs through policy directives and instructions.[14] The National Space Council's policy directive calls specifically for a program with Lawn Dart's capabilities: "To execute this vision [A New Era for Deep Space Exploration and Development] requires a secure international environment that is conducive to US commercial growth."[15] NASA's Strategic Goal 2 issues a similar call: "Extend human presence deeper into space and to the Moon for sustainable long term exploration and utilization."[16] These directives reinforce that the United States should and will be a dominant leader in lunar exploration; consequently, the Department of Defense's role is to protect and defend those missions.[17]

The Lawn Dart program falls under the US Space Force. According to the memorandum of understanding between the Space Force and NASA, "USSF organizes, trains, and equips to provide the resources necessary to protect and defend vital U.S. interests in and beyond Earth-orbit, new collaborations will be key to operating safely and securely on these distant frontiers."[18]

While Lawn Dart will function as the surface layer to help deliver vital security commodities and secure the space domain, the Space Force is currently working with NASA to address how Lawn Darts support NASA's LunaNet architecture, which plans to provide similar network and detection information.[19] This collaboration not only meets the intention of US national policy directives and memorandum of understanding, but it also mitigates concerns for space-debris creation because Lawn Darts will fully integrate with the LunaNet architecture.

Geopolitical Implications

A point of ambiguity in Lawn Dart's mission stems from the geopolitical implications of the presence of military sensors on the surface of the Moon. A Lawn Dart is a semipermanent US object on the lunar surface capable of surveillance and providing security supplied by the US military, a function typically associated with conflict prevention in the terrestrial domain. Immobile sensors and coverage also cause

14. 51 U.S.C.

15. The White House National Space Council, *A New Era for Deep Space Exploration and Development* (Washington, DC: The White House, July 23, 2020), page #, https://csps.aerospace.org/.

16. NASA, *NASA Strategic Plan 2022* (Washington, DC: NASA, 2022), 20, https://www.nasa.gov/.

17. NASA, *NASA's Plan for Sustained Lunar Exploration and Development* (Washington, DC: NASA, 2020), https://www.nasa.gov/.

18. NASA and US Space Force (USSF), "Memorandum of Understanding between the National Aeronautics and Space Administration and the United States Space Force," (Washington, DC: NASA and USSF, September 2020), 2, https://www.nasa.gov/.

19. Katherine Schauer and Danny Baird, "LunaNet: Empowering Artemis with Communications and Navigation Interoperability," NASA (website), October 6, 2021, https://www.nasa.gov/.

perceptions of territorial claims on the surface of the Moon that are prohibited by international law. But this concern is mitigated with specific guidance from the first-ever *National Cislunar Science & Technology Strategy*, published in November 2022.

The strategy outlines how the US government will focus its funding on civil, commercial, and defense on certain technologies to enable long-term growth in cislunar space.[20] It also frequently acknowledges that "a comprehensive framework for the SSA [space situational awareness] R&D needs for Cislunar space remains undeveloped" and that "SSA is essential to safe and successful . . . operations."[21] Finally, it outlines the methods the United States will use for international cooperation, including data sharing, and how a safe and predictable cislunar space is paramount for this cooperation.

To the Moon

As the only countries that self-launch human spaceflight and have soft-landed on the Moon, the United States, China, and Russia are the primary actors in space. The well-documented space race resulted in the successful landing of humans on the Moon over 50 years ago, but a new competition has begun—a quest for space superiority. "[Politicians] understand that China wants to lead the race to the moon and establish industrial - and likely military - supremacy in cislunar space with the support of Russia and other allies."[22]

China is often seen as the most active participant (and threat) in the lunar domain, though it still supports joint international ventures in accordance with international space law. In January 2019, the China National Space Administration successfully landed the first robotic, far-side lunar mission, Chang'e-4.[23] The mission's purpose was to orbit, land, and return lunar samples to Earth. In 2020, Chang'e-5 successfully launched, landed, and returned more lunar samples while also testing additional communication and landing technology. Chang'e-6, with even further objectives, is planned for 2024.[24] China has been the only state to successfully land on the far side of the moon, unseen by any terrestrial or lunar near-side observation equipment.

The China National Space Administration has its own plans for lunar scientific research stations with the goal of long-term stay of astronauts. Turkey, Ethiopia, and Pakistan are participating in China's lunar efforts, but other dominant spacefaring nations are not.[25] Incidentally, multilateral treaties and the White House-published

20. Cislunar Technology Strategy Interagency Working Group (CTSIWG), *National Cislunar Science & Technology Strategy* (Washington, DC: National Science and Technology Council, November 2022), https://www.whitehouse.gov/.

21. CTSIWG, *Strategy*, page 11.

22. Guilio Prisco, "Op-ed | SpaceX Fans Should Stand behind NASA and Support Artemis," Spacenews, November 15, 2022, https://spacenews.com/.

23. Lin Xu et al., "China's Lunar and Deep Space Exploration Program for The Next Decade (2020-2030)," *Chinese Journal of Space Science* 40, no. 5 (2020), https://www.cjss.ac.cn/.

24. Chunlai Li et al., "China's Present and Future Lunar Exploration Program," *Science* 365, no. 6450 (2019): 238–39, https://doi.org/.

25. Li et al., "Lunar Exploration Program."

Cislunar Strategy call for international cooperation, yet NASA is barred from bilateral activities with China through the Wolf Amendment.[26]

China is notably absent from the well-known Artemis Accords despite having a significant presence on the moon. This is due in part to the Wolf Amendment and because China remains highly criticized for its lack of transparency, disregard for human rights, and contempt of internationally accepted norms of behavior.[27]

While it seems "the world's space agencies are coming into surprising, if delicate, alignment about returning to the Moon and building a settlement there," questions remain as to which party will be first, and how all lunar actors will coexist.[28]

Expanded lunar exploration plans from the United States, China, and the European Space Agency include autonomous robotic support, which will require a communication network between them, and power, especially on the far side. If completed and employed by the Defense Department, Lawn Darts would likely introduce a game-changing capability that would advance US security in lunar exploration. In addition to the strategic importance of the cislunar orbit, the lunar surface has strategically advantageous elements including the South Pole, far side, subsurface, and resource concentrations.

With the prevalence of Chinese missions, particularly on the far side of the Moon, and the planned human presence on bases developed by multiple countries, a Lawn Dart capability is both necessary and urgent. The potential for a non-Allied lunar-capable nation conducting unknown science experiments in a location currently undetectable or hidden from current US-based lunar infrastructure poses a significant security risk.

If an opposing force deployed an outpost or undisclosed venture in an area currently outside the orbital coverage of existing reconnaissance satellites, the US and its Allies and partners would have to rely on the adversary being completely forthcoming about its activities. But the deployment of a Lawn Dart in the vicinity and in communication with its mesh network could relay vital information back to the United States. Moreover, anti-access, area-denial tactics inspire US lunar security strategy without compromising the UN's call to not militarize the space domain.

Ultimately, if the United States does not contest China's lunar dominance, it could lose an opportunity to make use of many lunar natural resources, including physical mission space and economic benefits of lunar materials, and see future trade and commerce opportunities compromised.

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26. Elliot Ji, Michael B. Cerny, and Raphael J. Piliero, "What does China think about NASA's Artemis Accords?," *Diplomat*, September 17, 2020, https://thediplomat.com/.

27. Makena Young, "Bad Idea: The Wolf Amendment (Limiting Collaboration with China in Space)," Defense360, December 4, 2019, https://defense360.csis.org/.

28. Eliza Strickland and Glenn Zorpette, "The Coming Moon Rush: Technology, Billionaires, and Geopolitics Will All Help Get Us Back to the Moon, but They Won't Be Enough to Let Us Live There Indefinitely," *IEEE Spectrum* 56, no. 7 (July 2019), https://doi.org/.

Concerns

The International Telecommunications Union (ITU) radio regulations contain a regulatory argument against employment of Lawn Darts, particularly on the far side of the Moon. "ITU-R RA.479 describes a shielded zone of the Moon" protected from certain lunar activities.[29] This regulatory zone protects science objectives of missions on the far side of the Moon that include measurements and observations free of radio frequency interference from the Earth. A networked communication infrastructure such as the Lawn Dart program could obstruct these missions. This ITU regulation thus impedes the space situational awareness and power capabilities Lawn Dart could provide via transmitter abilities and access to the far side of the Moon. As noted earlier, there is an insufficient framework guiding activities in cislunar space.

The Moon Agreement has not been signed by the United States, China, or Russia, likely due to its restriction regarding ownership of any part of the lunar surface or subsurface in addition to the general Outer Space Treaty restriction of claims to sovereignty. Lawn Darts would not lay claim to territory on the Moon just by their presence, as they could provide power and support functions to any nearby mission if desired. The network created would also not act as a fence; they would not restrict any movement on the surface.[30]

Often cited in discussions of future colonization of the Moon and Mars, the successfully implemented multilateral Antarctic Treaty restricts claims to sovereignty and requires use of the land and its resources to be peaceful and for scientific purposes.[31] But it is only signed by 54 states (compared to the Outer Space Treaty (112), the Artemis Accords (20), and the Moon Agreement (4)), and 7 states already had territorial (sovereign) claims on the continent that they were allowed to keep.

Another source of inspiration in terms of potential treaty language, the UN Convention of the Law of the Sea (UNCLOS) was ratified in 1982 and has since been updated due to the new practice (and economic benefits) of offshore drilling.[32]

In the same way that UNCLOS was developed in part due to economic opportunities in offshore international waters, space law must develop to allow for trade and commerce in its domain and regulate it.[33] Lawn Dart can provide critical support to such a regulatory schema. It is likely that as technologies from states accelerate the

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29. Jack O. Burns et al., "A Lunar L2-Far Side Exploration and Science Mission Concept with the Orion Multi-Purpose Crew Vehicle and a Teleoperated Lander/Rover, *Advances in Space Research* 52, no. 2 (July 2013), https://doi.org/.

30. Moon Agreement.

31. Strickland and Zorpette, "Moon Rush,"; and the Antarctic Treaty, Argentina, Australia, Belgium, Chile, the French Republic, Japan, New Zealand, Norway, the Union of South Africa, U.S.S.R., U.K., U.S., December 1, 1959, https://documents.ats.aq/.

32. Convention on the Law of the Sea, December 10, 1982, 1833 U.N.T.S. 397, https://www.refworld.org/; and P. Hoagland, J. Jacoby and M. E. Schumacher, "Law of the Sea," in *Encyclopedia of Ocean Sciences*, 2nd ed., ed. John H. Steele (Cambridge, MA: Academic Press, 2008), 432–43.

33. Willem van Genugten, Daniela Heerdt, and Nico Schrijver, *Discover International Law with Special Attention for The Hague, City of Peace and Justice* (Oisterwijk, Netherlands: Wolf Legal Publishers, 2017).

ability for dominance in the beyond-Earth orbit, the international space community will have to decide if the fate of the Moon and other celestial bodies will follow the path laid by the Antarctic Treaty, UNCLOS, or a system of entirely new international law and custom design.

Conclusion

The Lawn Dart capability provides a forward-deployed, networked, and expandable solution for communication and power on the Moon. This technology furnishes infrastructure to future lunar missions, complimenting international and US plans for lunar exploration. Permanent, hardened lunar-surface unattended ground sensor nodes will integrate with future nodes like NASA's LunaNet, through a series of experimental, then operational launches. This architecture minimizes the creation of polluting space debris while still rapidly providing much-needed security for US missions.

Finally, the Lawn Dart program completes science objectives by mapping the lunar terrain and sensing the lunar environment in support of international lunar exploration goals. This complies with space law and the spirit of the community regarding the peaceful utilization of space for exploration. Despite some geopolitical concerns, Lawn Darts support scientific exploration of space and are critical for US participation in the space domain. If the United States does not provide security solutions for the further exploration of space and its celestial bodies, then other key actors in space certainly will, which may lead to the absence of US participation in these activities.

Furthermore, as lunar exploration is a joint international venture, the Lawn Darts program will strengthen US participation in this venture by complementing key technologies developed by NASA, the China National Space Administration, and the European Space Agency, such as Artemis, Chang'e missions, and the Moon Village, respectively.[34]

The current practices in emerging, challenged domains of operations like the cislunar sphere and on the lunar surface is to "bring everything you need." By providing a power, communication, and security infrastructure that feeds into larger planned network architectures like LunaNet, Lawn Darts reduce the cost and resources of missions and discourages the one-time-use mindset that can create more space debris. It supports key scientific missions, adheres to US national space directives mandating peaceful uses of outer space, and counters threat posed by US adversaries. Lawn Darts and the security they provide will enable the cooperative proliferation of lunar exploration missions and allow human presence to expand further, safer, and longer in the emerging lunar domain. **Æ**

34. Jan Woerner, "Moon Village: A Vision for Global Cooperation and Space 4.0," European Space Agency (website), n.d., accessed September 23, 2022, https://www.esa.int/

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