Space Operations

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.

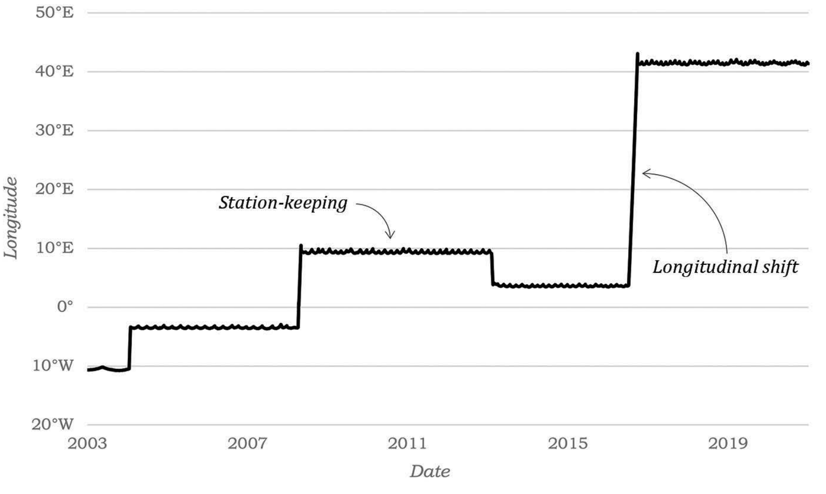

Figure 1: Longitudinal-shift maneuvers shown in a longitudinal position history

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]

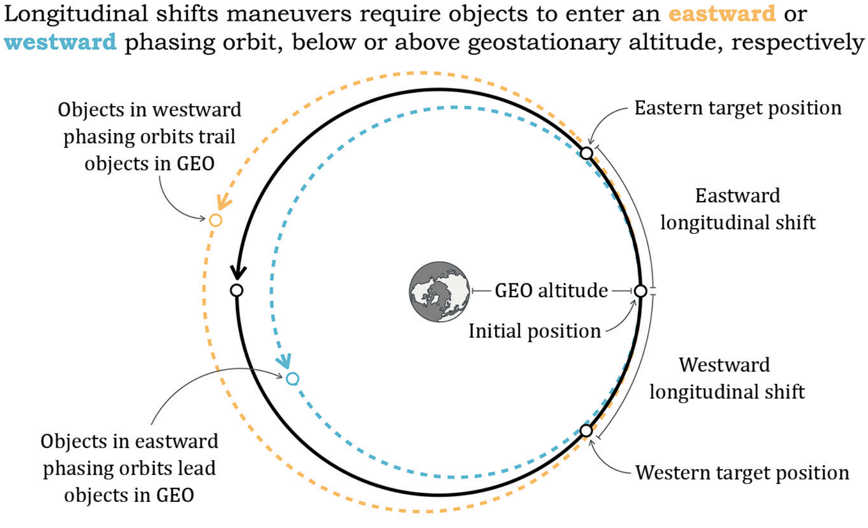

Figure 2: Nominal eastward and westward longitudinal shift maneuver orbits in GEO

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.

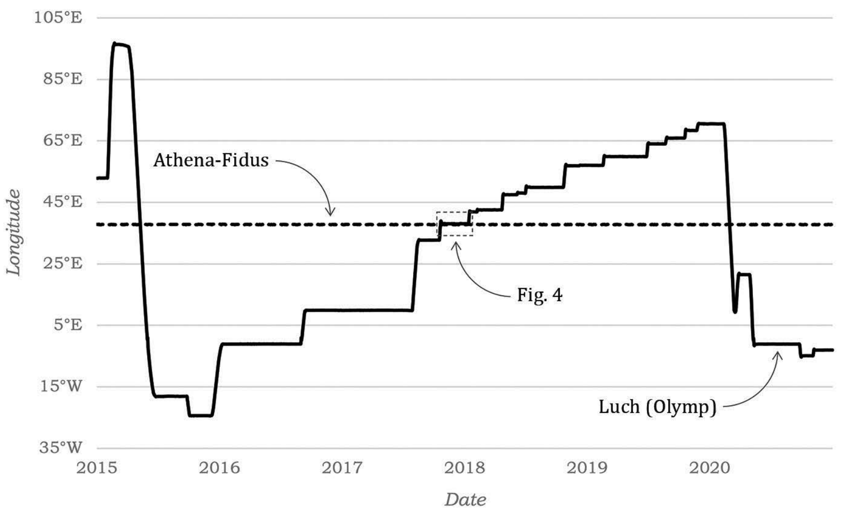

Figure 3: Close approaches revealed by comparison of two satellites' longitudinal position histories

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.

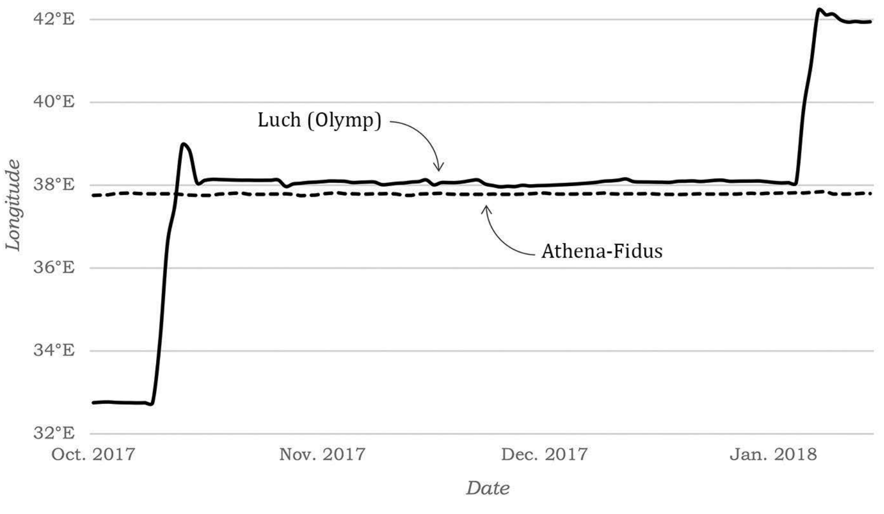

Figure 4: Luch station-keeping near Athena-Fidus in late 2017 and early 2018

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**