DYNAMIC SPACE OPERATIONS

THE NEW SUSTAINED SPACE MANEUVER IMPERATIVE

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As in the battlespace on Earth, the force capable of sustaining maneuver in space will have the advantage. This maneuver, however, will require a scale previously unknown to a domain thus far dominated by Keplerian and Newtonian thought. The paradigm of positional space operations must be replaced by a paradigm of dynamic space operations, where spaceborne combat forces are no longer static and predictable.

Military history is replete with examples of combat forces employing maneuver warfare to move quickly, sidestep defenses, achieve surprise, reorient quickly in the battlespace, and hold centers of gravity at risk to achieve victory.[1] As in domains of human endeavor on Earth, the advantage in space will go to the force capable of sustaining maneuver on a scale previously unknown to a domain dominated thus far by Keplerian and Newtonian thinking.

The current paradigm of positional space operations (PSO) must naturally give way to dynamic space operations (DSO), where spaceborne combat forces are no longer static and predictable. Moreover, a dynamic and dominant force in space will only be as effective as its ability to sustain space maneuver—particularly in the face of an adversary. Only then can that force maintain initiative, achieve surprise, and outmaneuver an adversary in the space domain to achieve victory.

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1. John E. Shaw (remarks, Space Foundation Space Symposium, Colorado Springs, CO, April 16, 2023); and John E. Shaw and Kevin Chilton, "7.6 Schriever Spacepower Series: Lt Gen John E. Shaw," July 6, 2023, in *Aerospace Nation*, produced by Mitchell Institute for Aerospace Studies, podcast and YouTube presentation, 1:02, MP3 audio and video, https://mitchellaerospacepower.org/. All authors have been instrumental in the development of these emerging doctrinal and operational ideas.

The Timeless Value of Maneuver

In past warfare, the military advantage has often gone not to the larger or more powerful force but rather to the one capable of placing its forces at a position of advantage over the adversary at the right time—US Joint doctrine calls this action maneuver.[2] But space operations to date have not focused on sustained maneuver as a key capability. Rather, they have historically been characterized by Keplerian thinking. Using Kepler's laws of motion, satellites have been launched into desirable orbits to achieve the objectives of their predominantly Earth-focused missions.

While these satellites move at great velocities relative to Earth, from an orbital mechanics perspective, they are actually energy-constant and static—relatively unchanging and highly predictable. In these positional space operations, the mission of a satellite drives the selection of its "parking spot" on orbit, and the satellite's design, launch vehicle, and supporting infrastructure are tailored to the needs of attaining and maintaining this energy-constant position in an environment relatively free from human-made threats. Satellites designed for these PSOs generally carry only enough propulsion to maintain their position and perhaps conduct a handful of low-energy strategic repositionings over the expected lifetime of the satellite.

Positional space operations dominated the beginning of the Space Age, an era where space exploration and exploitation were extensions of strategic competition between the United States and the Soviet Union. In these early decades, sustained maneuver capability was technologically prohibitive. Combat in the space domain was considered a likely prelude to nuclear war as satellites were strategic assets, quickly escalating and making sustained space maneuver (SSM), or replenishment of consumables used in combat, an unlikely need.[3]

After the fall of the Soviet Union, space operations were characterized by the rapid proliferation of Earth-facing space capabilities—commercial, civil, and military—made possible by technological advancements and relative freedom from threats. These factors combined to push space-derived information and services down to individual users and tactical operations on Earth, and the lack of threats emphasized the Keplerian advantages of placing satellites in the right energy-constant orbits to achieve the best effect on Earth.

But humanity is now in a new Space Age, where access to space-enabled capability in daily life is ubiquitous, militaries are increasingly dependent on space to extend their reach and lethality, and commerce and reach are expanding beyond the geosynchronous belt with increasingly space-facing missions. Like any other domain of human endeavor, threats have emerged to challenge freedom of action in the space domain. These changes precipitated the creation of the new US Space Command and US Space

2. Chairman of the Joint Chiefs of Staff (CJCS), *Joint Operations*, Joint Publication (JP) 3-0 (Washington, DC: CJCS, 2022).

3. Robin Dickey, *The Rise and Fall of Space Sanctuary in U.S. Policy, 5-6* (El Segundo, CA: Aerospace Corporation, September 1, 2020), https://csps.aerospace.org/.

Force in 2019 and require the United States and like-minded partners to think differently about space operations.[4]

Traditional Earth-facing military missions now require space-facing, in-domain military missions to expand reach, keep watch, deter adversaries, project effects, and protect national and international interests. Keplerian "positional" thinking that treats powered movement across orbits as a rare and costly event is no longer adequate. The force capable of sustaining maneuver will gain and maintain the advantage over time; indeed, competitors such as China are already demonstrating many of the technologies required to sustain maneuver and act dynamically in space.[5]

Maneuver is a timeless principle of war and involves identifying adversary centers of gravity and vulnerabilities, sidestepping adversary strengths, complicating the enemy's calculus, fogging the enemy's battlespace picture, constantly changing friendly positions and vulnerabilities to mitigate weaknesses, and arriving at decisive points to gain the advantage and achieve objectives before reaching culmination, the "point in time and/or space when the operation can no longer maintain momentum."[6]

Sustained maneuver allows a force to maintain initiative, achieve surprise, and outmaneuver an adversary in the field not just instantaneously but also over the course of a campaign while forestalling the costly mistake of reaching culmination before offensive or defensive objectives are achieved and ceding advantage to the adversary. Maneuver is more than just movement; it is "movement for effect" and has often been achieved and maintained through revolutions in logistics.

Napoleon famously used large-scale maneuver in his conquest of Europe, dividing his forces into independent corps capable of moving rapidly and sustaining much of their own needs before decisively converging on an objective.[7] Admiral Chester Nimitz hailed the US Navy's ability to conduct underway replenishment as its "secret weapon" in World War II, which enabled a high operations tempo and increased fleet sortie rates.[8] Aerial refueling was explored in the interwar years between World War I and World War II and perfected in the 1950s to extend the operational range, loiter time, and therefore overall capability of combat aircraft.[9]

These revolutions in combat logistics greatly improved combat capability by enabling the most dynamic portions of a force to operate flexibly to maintain initiative, achieve surprise, outmaneuver adversaries in the field, and forestall culmination. Of

4. US Department of Defense (DoD), "Department of Defense Establishes U.S. Space Command," press release, DoD, August 29, 2019, https://www.defense.gov/.

5. XueAi Li, Dapeng Yang, and Hong Liu, "China's Space Robotics for On-Orbit Servicing: the State of the Art," *National Science Review* 10 (2023): 1, https://academic.oup.com/.

6. CJCS, *Joint Planning*, JP 5-0 (Washington, DC: CJCS, 2020).

7. Jon Chavous, "Saddles and Sabers: Napoleon Bonaparte's Contributions to Modern Warfare," *Armor* (March–June 2014).

8. John A. Lukacs IV, "A Century of Replenishment at Sea," *Naval History Magazine* 32, no. 3 (2018), https://www.usni.org/.

9. Erin Lasley, "Refueling through the Century," USAF Air Mobility Command, March 26, 2018, https://www.amc.af.mil/.

note, each of these advances in combat capability could be looked at through a certain lens as cost-saving measures, but to do so would miss the point. The increased combat effectiveness of the military force was—and should remain— the driver for advancements in military logistics and maneuver.

Like the castle walls, trenches, Maginot Lines, fixed logistics points, static air defenses, and hardened aircraft shelters of past conflicts, positional space operations are no longer adequate to maintain the advantage in space. The continued adherence to PSO approaches for military space capabilities will also become increasingly risky and dangerous, analogous to warships in port, or combat aircraft on the ground. Instead, dynamic space operations will be the key to success, and sustained space maneuver will enable effective and sustained DSO. Like other advancements, cost savings may be a benefit of sustained space maneuver, but enhanced combat capability is the primary driver. Combat readiness and deterrence are also greatly enhanced through robust test and training, which are not possible without the ability to replenish capability through SSM capability.

Imagine a new main battle tank is delivered from the factory with its fuel tank and magazine permanently sealed, and its projected replacement will not arrive for eight years. Every time the tank moves a meter or fires a round, its capability is incrementally yet permanently diminished with no immediate replacement. Regardless of the size of the fuel tank or magazine, commanders would be driven to continually constrain movement and fires to avoid untenable future risk. Such a system that turns every action for short-term advantage over the adversary into long-term risk of future capability loss would be unacceptable to any military commander, yet this is exactly how today's space-domain systems are built and delivered to combatant commanders, even those designed for dynamic space operations.

The Geosynchronous Space Situational Awareness Program (GSSAP) is one such contemporary system designed for dynamic, space-facing operations.[10] GSSAP missions require the spacecraft to maneuver around the geosynchronous belt to maintain awareness on objects and activities in this congested and valuable Earth-facing orbit. While GSSAP is designed to maneuver routinely, like the imaginary unrefuellable main battle tank, it arrives on-orbit with fuel tanks sealed at the factory and programmed replacement spacecraft many years in the future.

GSSAP's limited capacity to sustain maneuver dramatically hinders an operational commander's ability and willingness to routinely maintain a position of advantage over competitors in space. The system's ability to conduct dynamic space operations is constrained by the risk of future mission failure if the limited consumable of fuel is not mission planned and heavily managed across the projected lifetime of the spacecraft. Immediate maneuver constrained by significant future risk is a poor and myopic way to compete in the emerging age of DSOs.

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10. "Geosynchronous Space Situational Awareness Program," US Space Force, October 2020, https://www.spaceforce.mil/.

As it is in other domains, the advantage in space will go to the force able to fully utilize maneuver to maintain initiative, achieve surprise, outmaneuver an adversary in the field, and forestall culmination. The better a force is able to create and sustain maneuver over time and distance, the more capable that force will be in achieving both offensive and defensive objectives without ceding advantage to the adversary. In the terrestrial domains, otherwise stationary objects achieve movement for maneuver through engines and motors which consume fuel to provide the energy to turn them from Newton's objects at rest to objects in motion.

Likewise, otherwise static objects in orbit require routine and sometimes aggressive and continuous propulsion to provide the energy to avoid remaining stationary and predictable in a Keplerian sense. A good portion of operational satellites are already capable of maneuver in space for short durations, but they have very limited capability to sustain such maneuvers, potentially reaching culmination well before operational and strategic objectives can be met and increasing the opportunity for an adversary to seize the advantage. Sustained space maneuver is the ability to keep a space capability operating dynamically over time to continually gain and maintain advantage. The force able to achieve SSM will have a clear advantage in the space domain.

Acquisition versus Operations Cost Curves: Space Imbalance?

Resource use for weapon systems over time across domains is particularly revealing in the value—or, rather, lack thereof—the space enterprise has historically put on sustainment and maneuver. At a high level, US weapon system lifecycle costs can be broken into two major categories: 1) systems acquisition (research and development plus procurement), and 2) operating and support (sustainment, maintenance, consumables, and disposal), which includes replenishment of consumables important to maneuver such as fuel.

A historical comparison of the ratios between these two categories at the turn of the twenty-first century when positional space operations were the norm shows the great disparity between space and other domains (fig. 1). For space weapon systems, systems acquisition accounted for approximately 84 percent of lifecycle cost, while only 16 percent was dedicated to operating and support. Conversely, weapon system lifecycle costs for ships and aircraft were approximately 30 to 50 percent for systems acquisition and 50 to 70 percent for operating and support.[11]

The Keplerian nature of orbits allows PSO spacecraft to perform most of their Earth-facing missions with little operating and support costs in a benign environment, but as DSO platforms and missions increase the need for sustained space maneuver, the ratio of acquisition to operations cost should naturally shift to be more in line with weapon systems in other domains where maneuver is routine.

11. Gary Jones et al., "Investigation into the Ratio of Operating and Support Costs to Life-Cycle Costs for DoD Weapon Systems," *Defense Acquisition Research Journal* 21, no. 1 (2014), https://www.dau.edu/.

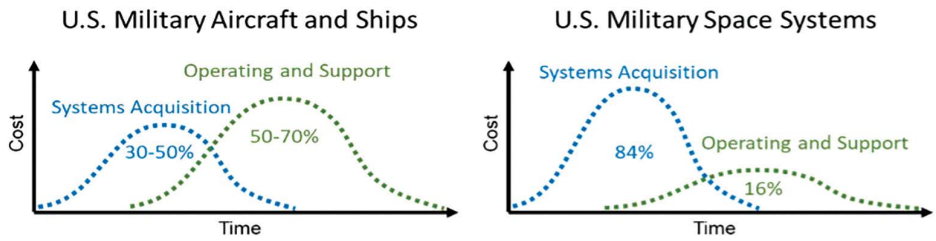

Figure 1. Lifecycle costs between acquisition and operating and support, circa 2000—when military space was focused on positional space operations[12]

Solution Vectors

Sustained space maneuver is a capability rather than a system, so there are many potential ways to achieve it. Perhaps the most obvious—and, in the near-term, most viable—approach is on-orbit servicing to replace consumables such as fuel as they are depleted. This approach might be similar to a terrestrial depot or port. Even better, on-orbit servicing could employ space maneuver itself to be more analogous to aerial refueling or underway replenishment at sea—akin to supply ships and oilers rather than ports—moving to the place of need in the space domain to keep the serviced spacecraft closer to their missions and objectives.

Another in-domain solution might come from a separate system of expendable or replenishable jetpacks. These devices would be able to connect to mission satellites and provide separate maneuver or even augmenting capabilities such as power generation that could be replaced as needed to sustain maneuver. This approach has the potential to add SSM capability to older-generation satellites that were deployed to the space domain without organic sustainable maneuver capability. These on-orbit servicing approaches also open possibilities for more agile launch operations by using smaller and more flexible launch methods to place incomplete or lighter and smaller spacecraft in the space domain to be fueled or paired with jetpacks on orbit.

More advanced propulsion technologies can also contribute to SSM, particularly ones that provide more efficient use of fuel and greater thrust-to-weight ratios. Gains in efficiency could enable significantly greater maneuver for a given propellant mass. Efficiency alone, however, is not a silver bullet for dynamic space operations. The key to sustaining DSO is the ability to remove the long-term capability risk from short-term maneuver decisions, so even spacecraft with hyperefficient propulsion systems would likely still need replenishment, just less often.

On-orbit servicing capabilities and more efficient propulsion address the challenges of DSO by removing the constraint of limited consumables over time. An alternative approach to SSM is to remove the constraint of lifetime required from a single

12. Jones et al., table 1, table 7.

spacecraft. Instead of replacing consumables on an individual spacecraft, the spacecraft itself would be the consumable, and an on-call replacement spacecraft would be deployed as a replacement when consumables are depleted rather than on a fixed replacement timeline.

This commoditization approach has the additional challenge of storing replacements or building them on demand, improving rapid launch capability, and disposing of depleted spacecraft, but it also opens new possibilities for surge operations to rapidly expand capability by increasing the maximum sortie rate for particularly advantageous periods of time.

A force capable of robust sustained space maneuver will likely employ a combination of all these capabilities and more. Regardless of the means, a force enabled by sustained space maneuver will enjoy numerous advantages with significant military utility:

- *Increased capability and flexibility* – provide a better range of operations, greater reach, more frequent operations, improved timelines for force movement and execution, improved posturing, and increased ambiguity for an adversary to overcome. It allows for more simultaneous dilemmas imposed on an adversary and an improved ability to strategically message through spacecraft posturing.
- *A more resilient force* – is able to respond to unplanned changes in adversary force size or effectiveness, is less susceptible to incorrect assumptions on duration of operations or adversary approach, and is more responsive to changing assumptions of probability of success.
- *Increased technical opportunities* – create more maneuverable spacecraft that are inherently more difficult to track and target, opening new avenues for protection and defense. They provide the ability to outfit spacecraft to best meet short-term mission needs and upgrade capabilities over spacecraft lifetime.
- *Greater decentralization of execution* – creates reversible decisions that can be pushed to lower levels with less risk and opportunities for more expansive and resilient use of artificial intelligence (AI) and autonomy. It decreases response times and increases the ability to improvise and pursue fleeting opportunities.
- *Improved readiness* – enables routine and robust live training with on-orbit forces without sacrificing long-term mission success. It establishes better avenues to reversibly explore new operating concepts, provides more robust testing opportunities for new systems and tactics, improves deterrence through demonstrated strength, and ensures capabilities can be quickly reconstituted to deter opportunistic third parties.

The aggregate solution set to SSM needs and challenges will likely lead to a sophisticated and versatile logistics infrastructure in the space domain, one that can benefit not only DSO platforms but traditional PSO capabilities as well. These solutions also offer many potential benefits to the civil and commercial sectors.

Space Domain Awareness Implications

Dynamic space operations will also change the nature of foundational space capabilities such as space domain awareness. Positional space operations of the past have led to the assumption that an accurate picture of the space domain can be maintained by keeping track of each object's Keplerian orbit parking spot. If these parking spots are constantly changing due to DSO, maintaining a catalog of previously observed orbital parameters for satellites is no longer adequate to address the emerging dynamic nature of space.

As in other domains, maneuvering objects must be tracked nearly continuously and in real time for the information to be of operational value. Maintaining real-time tracks of large numbers of objects over long periods of time may no longer be feasible or even desirable. Rather than maintain tracks of individual objects, space will need a more dynamic traffic management framework and a battle management framework like other domains where objects relevant to operations are quickly observed, identified, designated as threats or factors, and tracked as needed until they are no longer factors.

Impacts on Multidomain Operations

The risks of continued PSO and lack of sustainable DSO capabilities are not limited to the space domain or battlespace itself. In the era of Joint warfare and multidomain operations, maneuver in one domain can have dramatic impacts on other domains. Conversely, a lack of maneuver in one domain can create a liability for the Joint Force.

Multidomain operations rely on combinations of effects or asymmetric effects across domains with each domain maneuvering as needed to gain and maintain advantage. Any domain whose maneuver is significantly restricted will be unable to contribute its full potential to the Joint fight and will likely require significant effort in other domains to overcome its lack of effective maneuver. Even if maneuver within a conflict is possible, any domain whose short-term maneuver creates significant long-term gaps could be exploited by other strategic competitors postconflict. Sustained space maneuver is imperative to avoiding these significant risks in space and to make space forces an effective partner within the Joint Force.

Conclusion

Maneuver has historically given decisive advantages to one force over another in every domain of human endeavor and conflict, and space will be no different. Current space forces are not designed to sustain maneuver. These forces severely limit both short-term and long-term combat capability by making every maneuver decision a choice between immediate gain and long-term loss.

Military forces in space need the essential capability to continually gain and maintain decisive advantage over an adversary in both competition and conflict. This decisive advantage will allow military forces in space to maintain the initiative, achieve surprise, outmaneuver an adversary, and forestall culmination without sacrificing long-term capability. Regardless of how it is obtained, the ability to conduct dynamic space

operations through sustained space maneuver will give space commanders and forces the essential advantage necessary to fulfill their role within the Joint Force and compete and prevail in future conflicts. ***Æ***