

A Broader Look at Dynamic Space Operations: Creating Multi-Dimensional Dilemmas for Adversaries



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A BROADER LOOK AT DYNAMIC SPACE OPERATIONS: IMPOSING MULTI-DIMENSIONAL DILEMMAS ON ADVERSARIES

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Foreword

Space operations are deeply intertwined with all military operations. However, the legacy space architecture was not built for the dynamic threat environment we face today. Adversaries like China, intend to exploit this fact. The creation of the U.S. Space Command and Space Force in 2019 were clear recognition that things must change. Since their establishment, both organizations have been focused on addressing the growing threats, preserving the U.S. ability to gain and maintain space superiority, and continuing the delivery of effects upon which military operations depend.

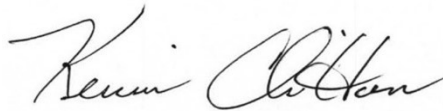
Space Force efforts like shifting to a more proliferated architecture will increase mission resilience. The consistent call from U.S. Space Command for dynamic space operations and the need to maneuver satellites without regret for the fuel used will add another dimension to the challenges we could impose on adversaries. However, there's a wider set of options that the United States can pursue to increase the adaptability of our space architecture. These changes could impact all elements of the U.S. military space enterprise. Changes to on-orbit capabilities and activities, ground operations, the link segments, and even launch operations can increase mission effectiveness and survivability of U.S. space operations.

In this research study, Charles Galbreath examines the wider applications of dynamic space operations and makes recommendations on how the United States can transform its space enterprise to create a set of challenges that deter adversaries from pursuing hostile courses of action. Based on decades of technology development and maturation, the United States is poised to make a transformational change to its space architecture to one enabled by on-orbit logistics. This will accelerate the adoption of time-proven principles of warfare that will maintain the initiative for U.S. forces and create compounding problems for potential adversaries—ultimately contributing to the deterrent posture of the United States.

This complex undertaking is why the Mitchell Institute created its Spacepower Advantage Center of Excellence (MI-SPACE)—to inform the American public, Congress, and the Department of War about the emerging challenges and opportunities that space presents.



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Abstract

The evolution of the U.S. military space architecture is at an inflection point. China is aggressively pursuing dynamic space approaches to increase and sustain its space architecture capabilities and place U.S. assets at a position of disadvantage. Should the United States fail to adapt and adopt dynamic space operations, its vulnerabilities in the domain will endure and risk losing U.S. space superiority—a unique advantage that is foundational to all U.S. joint operations.

Dynamic Space Operations

For this paper, dynamic space operations (DSO) refers to the employment of methods that leverage increased versatility, adaptability, and maneuverability, in physical space and across the spectrum of the space architecture and its component systems. Intertwined with this concept is on-orbit logistics, which refers to both the infrastructure and activities, including refueling, servicing, repair, augmentation, and assembly, necessary to enable warfighting applications.

Legacy U.S. space system designs were premised on a peaceful, non-hostile space domain and operated static missions in energy-constant orbits. Space is now a warfighting domain, with new and growing threats to space systems, plus increasing operational demands on U.S. space capabilities. New capabilities that increase the resilience and effectiveness of the U.S. military space architecture are needed. Space operations must similarly transform to one defined by dynamic space operations (DSO)—employing these new capabilities with the ability to frequently and rapidly change parameters to achieve mission effects.

The phrase “dynamic space operations” is typically associated with the need to reposition satellites without regret for the fuel used. However, enabling the free maneuver of satellites is only one facet of the innovation needed to improve space architecture resilience and complicate adversary planning and countermeasures. True dynamic space operations will require changes and practices associated with all segments of the U.S. space architecture. This encompasses orbital, terrestrial, link, and launch segments, as well as establishing a logistics infrastructure and new concepts of operations (CONOPS) as a foundation for future DSO. This broader application of DSO will increase the overall flexibility of the U.S. space architecture, thereby accelerating a greater application of long-standing principles of warfare such as maneuver and surprise, which will in turn increase resilience and mission effectiveness. Furthermore, it will facilitate the employment of new missions and novel approaches to help U.S. forces maintain the initiative and create compounding problems for potential adversaries—ultimately strengthening the deterrent posture of the United States.

Hesitancy to fully implement dynamic space operations at scale risks ceding valuable time and initiative to adversaries. The Space Force must move decisively to embrace all opportunities of this new operational paradigm. The Space Force is already moving ahead on many fronts, but now is the time to accelerate dynamic space operations.

Introduction

“There is a lot implied when we start to unpack what we need to conduct dynamic space operations, whether it is on-orbit refueling, on-orbit maintenance, responsive launch, or other ways to achieve sustained maneuver and in-domain logistics on orbit... Exploring ways to increase mobility and proliferation will become key facets of the way we envision fighting in 2040.”

—General Stephen Whiting, Commander U.S. Space Command⁵³

China’s stated goal of supplanting the United States as the world’s preeminent space power cannot go unchecked. The U.S. economy and warfighting capabilities fundamentally rely on technologies, services, and effects from orbit. Moreover, whoever controls space will establish new norms and standards for decades to come in this boundless domain. The U.S. recognition that space is now a warfighting domain is not, in itself, enough. It comes with the inherent need to embrace and apply principles of warfare. Just as all military services have long sought to be versatile, adaptable, and maneuverable, so too must the Space Force. It must adopt dynamic space operations (DSO) and on-orbit logistics. While these terms are typically associated with the desire to maneuver without regret, a broader application of the concepts of DSO can fundamentally change all segments of the U.S. space architecture. By increasing the flexibility of the orbital, terrestrial, link, and launch segments, the Space Force and U.S. Space Command can apply warfare principles like maneuver and surprise in ways that could be the deciding factors in a future conflict.

China is actively fielding weapon systems and space capabilities at an alarming rate. They are also demonstrating the ability to sustain prolonged space operations through on-orbit refueling and other techniques. Static U.S. systems will be particularly vulnerable to an adversary like China, which can out-maneuver them by employing such operational strategies and tactics. China is implementing these changes in the operational space environment today, which means the United States must accelerate its efforts to employ DSO. Fortunately, the United States has spent decades developing technologies and demonstrating the potential for such systems. The U.S. Space Force needs to implement them at scale and fully integrate dynamic space operations into future force designs, such as the 15-year plan expected by the Space Force by the end of 2025.¹

National security leaders understand this and have begun transforming the U.S. space architecture, but achieving a full transition will be a monumental undertaking, but not insurmountable. The good news is that the United States Space Force has significantly shifted its architecture, in just five years, from one consisting of “big, fat, juicy targets” to one with proliferated assets in Low Earth Orbit (LEO).² But this is just a single dimension of added resilience and mission effectiveness, not an adoption of dynamic space operations across all segments of the enterprise. A broad application of DSO is necessary to further create multiple compounding dimensions of dilemmas, which make it more difficult for an adversary to counter U.S. space operations or target U.S. systems, whether in space, on the ground, or in the electromagnetic spectrum. Success in this effort is critical to the safety and security of the nation and its allies.

Going back to the 1960s, NASA began a series of missions to progressively advance U.S. space capabilities in its race to the Moon and continued activities in orbit. These missions included demonstrating rendezvous and docking with the Gemini program and satellite rescue and repair missions with the Space Shuttle—like Solar Max and the Hubble Space Telescope—and ultimately led to the construction of the International Space Station.³ NASA even demonstrated the ability to refuel a satellite on-orbit with STS 41G in 1984.⁴ While these activities paved the way for modern dynamic space operations, they were all crewed missions. The keys to unlocking uncrewed DSO date back to the 1990s through programs such as TAOS, XSS-11, Orbital Express, and, most recently, the Mission Extension Vehicle. While these programs were not strictly DSO efforts, the rapid and frequent maneuver, versatility, or adaptability skills they developed helped the United States create a technological foundation and operational concepts, which must now be actualized. The modularity, autonomy, technology maturation, and operational demonstrations of several decades of innovation point the way to more dynamic and flexible approaches to future space operations.

The U.S. Space Force and U.S. SPACECOM, as warfighting entities, must be able to employ enduring principles of warfare. The increased flexibility that DSO offers across all segments of the space architecture can help deliver this advantage. The resulting disruption of an adversary's operational planning and execution will help the United States reclaim the initiative in space. All of this directly supports the goal of deterring conflict in both space and on Earth. A holistic look at DSO will be transformative and require decisive and sustained action across many government organizations.

- U.S. Space Command must continue to provide the demand signal through capability need statements that drive every military service, particularly the U.S. Space Force, to develop an architecture that is better suited for the realities of space warfighting.
- The Space Force must develop an operational warfighting architecture and CONOPS that integrate the methods of DSO. These efforts require the development and fielding of an architecture based on a new foundation of in-space logistics. This will include procuring at scale and sustaining several existing efforts, such as phased array radars for command and control; employing modular and serviceable spacecraft; creating a network of optical communications to deliver assured, path-agnostic communications across the space enterprise; and developing more flexible launch operations.
- Congress must provide consistent funding growth to support the Space Force's transformation efforts.
- The Space Force should continue to invest in basic and applied research to develop alternative forms of propulsion and methods to increase the flexibility of space operations.
- The Space Force should establish a program office focused on the establishment of an in-space logistics infrastructure to accelerate the development of capabilities; doctrine; tactics, techniques, and procedures (TTPs); and plans for sustained space combat operations.

By taking these steps, the United States can field a space architecture that is more dynamic, resilient, and capable of responding to any crisis or threat situation—and equally capable of presenting a set of complex challenges too formidable for an adversary to defeat.

Tail & Tooth—Integrated Space Combat Logistics

“Amateurs talk strategy, professionals talk logistics”

—Gen Omar Bradley

The imperative for integrating DSO is clear, and the basic technological building blocks exist. However, Space Force must establish the required logistics infrastructure before it can execute sustained dynamic space operations. Like all traditional warfighting domains, the ability to replenish expendables, such as ammunition, fuel, and food, can be the deciding factor in the effectiveness, duration, and reach of operations. This is true for space operations, both terrestrially and on-orbit. Having the necessary logistics “tail” will be essential to assuring space superiority in a prolonged competition or conflict. Across the U.S. space architecture, the most apparent aspect of future change is on-orbit logistics and refueling satellites to enable sustained space maneuver (SSM)—the ability to change aspects of a satellite’s orbit without restrictions on the mission life of the vehicle. Such an ability can extend the life of a satellite and transform the way it operates by enabling frequent orbital changes. Importantly, on-orbit logistics and dynamic space operations go far beyond just fuel: they also include a wide set of functions known as in-space servicing, assembly, and manufacturing (ISAM). The ability to dynamically alter the mission and capabilities of spacecraft through ISAM can add “teeth” to otherwise benign platforms, dramatically and dynamically increasing the warfighting capability of the enterprise.

By examining the entire space architecture and seeking opportunities to broadly apply tenets of dynamic space operations to increase versatility, adaptability, and survivability, the United States can radically enhance the effectiveness and resiliency of its military space enterprise. Taking these actions will catalyze the U.S. ability to make the orbital, terrestrial, link, and launch segments more responsive in times of crises and better able to prevail in conflict. The U.S. Space Command and military services presenting forces should think of space operations holistically, consisting of the desired effect and supporting elements such as awareness, logistics, and command and control. This approach recognizes that a satellite, or even a constellation of satellites, does not operate in isolation. It is, in fact, operating with a family of systems across all segments of the architecture. DSO opportunities exist across much of this ecosystem.

The broad application of DSO can transform space operations in a time of crisis or conflict. Notionally, the approach could include the deployment of additional capabilities from multiple launch sites and from multiple launch vehicles to assure continued access to space and deliver new capabilities and mission augmentation systems to orbit. Commanding the command and control (C2) and payload operations of these new systems through a resilient combination of ground and mobile operations centers that leverage path-agnostic links will inhibit an adversary’s ability to interfere. Once in orbit, these newly deployed capabilities can rendezvous with prepositioned forces and supporting infrastructure elements that are closer to the point of execution. Satellite modularity and on-orbit servicing capabilities enable the Space

Force and U.S. Space Command to dynamically equip satellites for the specific mission at hand. These changes to operational parameters over time can confound an adversary's understanding of the role, capabilities, and limitations of the DSO satellites. This obfuscation of mission and operational parameters will create increased uncertainty for adversary decision-makers, and the "fog of war" will force them to spend resources and time to orient their picture of U.S. actions—potentially delaying or even preventing adversary offensive operations or hostile acts. These satellites could then maneuver as a package with supply and refueling capacity added to them so that they can conduct multiple operations in the needed region of space. This force package could also include the deployment of decoys to further overwhelm an adversary's space object surveillance and identification (SOSI) and countermeasure planning.

This application of DSO allows U.S. Space Command to position forces in mass to conduct mission operations and allow for some level of attrition caused by adversary action. The ability to resupply and refuel means that these systems can frequently change trajectories and orbits, again to preemptively throw off adversary tracking and targeting. It can even enable the formation of a virtual array or network of satellites to create a synthetic aperture that would be far more capable than any single aperture that could be launched on a booster. Such large synthetic apertures would have significant performance advantages, such as sensitivity over smaller traditional antennas. The increased ability to maneuver would likewise allow the execution of defensive and offensive actions from multiple directions. By simultaneously engaging a target from multiple vectors, the United States can exploit aspects, such as sun lighting angles, that place adversaries in a more vulnerable position. Undoubtedly, as technologies and operations mature, the U.S. Space Force and U.S. SPACECOM planners and operators will develop new TTPs that exploit the multiple opportunities of DSO and in-space logistics that integrate camouflage, concealment, and deception (CCD); maneuver; and surprise.

The combination of multiple approaches in a dynamic, logistically enabled architecture can create a Gordian Knot for potential adversaries and will have a significant impact on the deterrence calculations between the United States and China. America's opponents will pursue any weaknesses or vulnerabilities in the allied space architecture to attempt to seize some level of initiative against coalition forces. China's desire for an overwhelming attack and rapid victory could be denied through increased awareness monitoring and the dynamic delivery of military force to the area of operations. The movement and maneuver of U.S. space systems as a show of force and the augmentation of existing capabilities will minimize vulnerabilities and enhance deterrence by signaling to China that the United States is prepared for both a rapid response and logistically sustainable combat operations. The inherent mission flexibility of this approach introduces the potential for deception and surprise to further complicate China's calculus, which may compel its leadership to pause or not execute hostile actions. This could have a significant impact on their decision of when, how, and if they attack. The ultimate goal of the United States is to have China decide that today is not the day to test the United States militarily, which is possible through fielding a dynamic space architecture.

Predictable Space Operations Could Result in the United States Losing the Next War

The criticality of today's U.S. space operations cannot be overstated. Current systems fielded by the Space Force and employed by U.S. Space Command have fundamentally changed the way the United States operates its military and conducts operations in all domains. The asymmetric advantages the United States enjoys from operating successfully in space have not gone unnoticed. Potential adversaries understand the strategic and operational benefits and utility that the United States derives from space operations. China, in particular, views America's space dependency as the Achilles' heel of the U.S. military.⁵ China and Russia are now pursuing a dual-path strategy to contest that advantage. First, adversaries are developing their own capabilities to rival the United States and create a kill web that enables the expansion of their anti-access/area-denial strategy. Second, they are also developing terrestrial and space-based weapon systems designed to deny the United States its ability to launch, operate, and deliver vital space effects.

The reality and recognition that space is now a contested, warfighting domain is a fundamental driver in the establishment of both the United States Space Force and United States Space Command. Organizations like Space Systems Command (SSC), the Space Development Agency (SDA), and the Space Rapid Capabilities Office (SpRCO) understand they must adapt to the reality of space as a warfighting domain. They are fielding systems and delivering capabilities at breakneck speed to remedy the long-standing vulnerabilities of the old way of doing business. However, more can be done. The Space Force has not yet made the decision to change to a logistics-enabled architecture or pursued the ability to conduct in-space servicing, assembly, and manufacturing. The upcoming release of a fifteen-year objective architecture is the perfect opportunity to lay out a bold new direction.⁶

The traditional method of placing a dedicated, mission-unique satellite into a specific orbit that is tied to a single, fixed ground station presents a set of vulnerabilities that are easy for an adversary to exploit. This has led many leaders, including commanders and deputy commanders at U.S. Space Command, to call for a change—to develop dynamic space operations. While much of the discussion about DSO deals with the desire to maneuver a satellite without regard for its limited supply of fuel, the Space Force is concurrently pursuing other aspects to fully maximize the benefits of the concept.⁷ Changes to the U.S. space architecture must not merely include the satellites in space but the entire systems approach. Concepts of operations, training, launch, link, ground, and orbital segments must all work in unison with robust and dynamic attributes. Successfully adopting this approach will increase operational resilience and create the opportunity to deliver effects that are dynamic, complex, and more difficult for an adversary to counter.

To fully realize DSO approaches, the Space Force must develop, organize, train, equip, and present logistics forces to U.S. Space Command. Today, the U.S. Space Force presents forces to U.S. Space Command without any supporting on-orbit logistics—they simply do not exist. As a result, space capabilities are limited by both their current payload and finite fuel. These constraints define and limit the operational employment of the orbital segment. Future on-orbit logistics can include measures to replace expendables such as fuel or potentially munitions, add new capabilities, or replace and repair damaged components. Failure to fully adopt dynamic space operations across all segments with on-orbit logistics support will risk leaving the total architecture vulnerable at its weakest points.

The Traditional U.S. Architecture & CONOPS are Based on an Outdated Assumption

The space architecture the United States operates today is rooted in the past and tied to an assumption that space is a sanctuary, not a warfighting domain. After the Cold War, the United States faced very few adversaries with significant space capabilities and even fewer with the means to threaten U.S. space systems. As a result, U.S. space policies, capabilities, and operations were all oriented around space as an uncontested domain. The Space Force is making dramatic shifts, but a transformation of this magnitude takes time. While certain systems, such as nuclear command and control and communication systems (NC3), have inherent defensive and resilience capabilities, the vast majority of legacy space systems were developed without defensive or significant maneuver capabilities. Most legacy satellite protections focus on natural environmental threats, such as solar and cosmic radiation and temperature extremes—not directly on potential hostile threats. As CSO Gen Saltzman often explains, this force, lacking the kind of offensive and defensive combat capabilities a warfighting force would have, is akin to the difference between a merchant marine and a combat-ready navy.

The imperative for change has only grown since 2007, when China launched a direct-ascent anti-satellite (ASAT) weapon. Since then, Chinese threats to space systems, including ground-based direct-ascent ASATs, ground-based electronic warfare, ground-based lasers, as well as cyber and space-based threats, pose an increasingly significant challenge to U.S. and allied space systems.

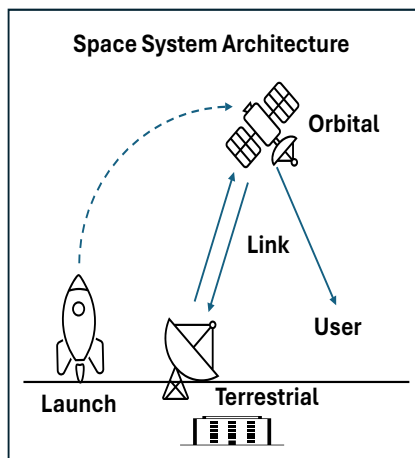


Figure 1: Space system architecture. Negatively impacting any portion could prevent delivery of vital information or effects to the end user.

Source: Mitchell Institute.

The NC3 architecture is an example of a system with inherent, built-in resilience and defensive capabilities. These capabilities included anti-jam systems as well as mobile ground stations to increase the resilience of the terrestrial segment for the C2 of those assets.⁸ Additionally, satellites, particularly those operating in geosynchronous and geostationary orbits, utilized radiation hardening technologies to decrease not only the impact of cosmic radiation, but also the potential for nuclear radiation from an attack by the Soviet Union.

While some satellite systems today continue to possess some of these capabilities, other approaches, such as mobile ground systems, have atrophied. It's important to remember that when examining the space systems of the United States, it's not just the satellites that are of concern. As described in Space Force Doctrine Document 1, a space systems architecture includes orbital, terrestrial, and link segments.⁹ Additionally, launch systems and the impact that launch operations have on the overall space architecture cannot be ignored.¹⁰ Adversary disruption to any element can prevent the delivery of mission-critical information, services, and effects. DSO seeks to add agility and resilience to each aspect of the architecture. Examining the orbital, terrestrial, link, and launch segments through a DSO lens can

enhance the understanding of how each contributes to the overall resilience and capabilities of the space architecture, increase the effects the U.S. space systems can generate, and maximize the multi-dimensional challenges facing an adversary seeking to deny U.S. access to space.

The Orbital Segment. Each satellite is typically built for a specific mission and launched into a specific orbit for the duration of that mission life. This is an optimized use of the unique aspects of orbital mechanics that enables satellites in specific orbits to perform their missions. Little is traditionally done to change the orbit of a satellite once it is launched.

With no appreciable force other than gravity acting on a satellite to alter its path, satellites are in an unpropelled coast-phase for most of their lives.¹¹ Known as a Keplerian orbit, satellites follow a highly predictable elliptical path largely defined by the inclination into which they were launched and their velocity, which dictates their altitude. There may be some maneuvers required to maintain their attitude or position within their orbit, but significant orbital changes are rare. This anchors most U.S. space systems to a specific orbit that can be thought of as a static position. Even though U.S. satellites move at an incredible rate of speed, they are highly predictable and therefore easily targetable by would-be adversaries. In an environment where endurance, speed, and maneuverability are essential for mission effectiveness and survivability, China will be able to exploit the predictable nature of U.S. space operations.¹²

Systems such as the Geosynchronous Space Situational Awareness Program (GSSAP) do have maneuver capabilities inherently built into their mission design. Their purpose is to maneuver around the geosynchronous belt to monitor activities and maintain awareness of the health and status of U.S. and other friendly assets. U.S. Space Command can also task GSSAP to investigate the potentially harmful activities of adversary capabilities. Although it has no offensive capabilities, GSSAP is currently the premier orbital warfare system in the Space Force. However, the fuel on board these GSSAP satellites is a fixed quantity that is carefully rationed to preserve the life of the vehicles. In many ways, this limits the utility and employment of GSSAP vehicles.¹³ Furthermore, the design of GSSAP—as with all current operational satellites—does not include sufficient thrust to rapidly avoid threats or move to a position of advantage. The potential inclusion of in-space logistics, like refueling, is not only about increasing the lifespan of a GSSAP vehicle, but also its ability to conduct more operations to significantly increase mission utility. But without a steady and reliable growth in resources to support DSO, systems like GSSAP will continue to operate more like blimps than F-35s.

The Terrestrial Segment. Most of the space architecture today is heavily reliant on a few fixed ground stations within the terrestrial segment for the command and control and downlink of mission data from satellites. Primarily located at Buckley and Schriever Space Force Bases in Colorado, these Space Operations Centers (SOCs) are where guardian operators perform their missions. They are also potential targets for would-be adversaries. These robust and defended sites are secured deeply in the continental United States and safeguarded by multiple force protection measures. However, they are not immune to attack. In a potential protracted conflict with China, the Space Force must plan for the contingency of cyber, special operations, or direct physical attack against these sites and other locations in the United States. Additionally, the nodes of the terrestrial segment are connected through ground-based fiber optic connections, which must also be secured.

The Link Segment. The link segment includes the uplink of commands from the ground station to the satellites, as well as the downlink of telemetry (health and status data of the satellites) and mission data from the satellite to the ground station. The mission data may come down the same path as the telemetry, or it could come down a secondary path. In either case, the frequencies guardians use to control and interact with satellites are fairly static and contained within well-established communications bands. Additionally, the Satellite Control Network (SCN), the primary means to transmit and receive data from satellites, is a global network of 19 antennas at seven locations, with some dating back to the late 1950s.¹⁴ Like the terrestrial segment, these fixed sites will be likely targets in a potential conflict with China.

The Launch Segment. Today, most U.S. launch capabilities are based on what is called a launch-on-schedule manifest. This schedule is planned months and even years in advance to deploy satellites into space from two primary launch locations on boosters that can take many months, or even years, to develop and field. Recent examples of more rapid launch cadences, especially with the advent of reusable boosters, have increased the tempo of launch services. However, very little flexibility exists to replace payloads to meet urgent operational needs or to respond to immediate threats. Additionally, the extensive terrestrial-based network of components and commodities enabling launch operations is a likely target in the event of conflict.

The net result of predictable launches, fixed ground stations, established frequency links, and satellites with little maneuver capability is a very static and inflexible way of conducting space operations. The Space Force recognizes that it needs an architecture and operations better suited for the realities of warfighting and is pursuing multiple lines of effort that aid this transformation.

China Can Exploit Traditional U.S. Approaches and is Preparing for Conflict in Space

Every element of the space architecture has vulnerabilities that the United States must minimize to prevent adversary exploitation. The predictable paths of intelligence, surveillance, and reconnaissance satellites make it easy for adversary forces to know when they will be overhead. At the appropriate times, adversaries can utilize protective or defensive measures such as camouflage, concealment, deception, or they can simply halt their operations to thwart U.S. intelligence collection efforts. All other satellites have similarly predictable paths, making it relatively easy for adversaries to find, fix, track, target, and engage them. GSSAP represents perhaps the leading edge of satellite maneuverability within the United States' order of battle, but even GSSAP is easily tracked by potential adversaries due to a constrained maneuver profile driven by limited fuel.¹⁵

As China rapidly expands its space systems, it is pursuing methods to increase the maneuverability and flexibility of its own satellites. It has launched a series of satellites within the Shijian (SJ) family of spacecraft with maneuver, servicing, and counterspace capabilities. China has demonstrated the repositioning of a dead satellite to an alternate orbit using SJ-21, which is known to have a robotic arm.¹⁶ It is also rapidly investing in technology to refuel and service existing satellites. Reports suggest that China's SJ-25 may have already conducted refueling of the SJ-21.¹⁷ After refueling, SJ-21 appears to have conducted the largest delta-V maneuver ever seen in GEO.¹⁸ China has also demonstrated the ability to control five satellites simultaneously

maneuvering and engaging in operations among one another—what the U.S. Space Force and media describe as “space dog fighting.”¹⁹ China is subject to the same laws of orbital motion as the United States, so this may be more akin to five dirigibles demonstrating warfighting tactics than a true aerial dogfight among 5th-generation fighters, but it still demonstrates key technology required to conduct orbital warfare and establish a positional advantage. The fact that China is openly demonstrating multiple-satellite engagements illustrates its commitment to the objective of being the dominant spacefaring nation and may also be a signal intended to deter the United States. Finally, following the United States’ X-37B, or space plane, China has developed its own highly maneuverable, reusable space vehicle capable of hosting multiple and varying mission payloads.²⁰ In-domain sustainment to prolong operations and maneuver of that vehicle may come next.

All of these are strong indications of China’s intent to develop the most robust space architecture possible to confront the United States and gain an advantage in space. China is determined to supplant the United States as the world’s leading space power. This will not only degrade overall effectiveness of U.S. and coalition military operations in future conflicts, but it will also be a significant blow to the United States’ current lead in the geopolitical order.

Increasing Space Flexibility is Critical to Prevailing in a Future Conflict

Recognizing that space is indeed a warfighting domain means that new approaches to space operations are required to overcome the mounting threats. The Space Force must now fully embrace the principles of warfare that each of the other services has executed and matured over centuries of conflict in their operational domains. A dynamic space architecture, built on a foundation of in-space logistics, will have increased flexibility and facilitate a greater application of principles of warfare. The concepts of surprise and maneuver, in particular, will become key to preserving space superiority in future conflicts.

It’s time to apply proven warfighting principles to space operations

By fully adopting technologies and practices associated with a broad examination of DSO, the Space Force can implement long-standing principles of warfare. The acknowledgement that space is a warfighting domain brings with it the necessity to apply these enduring and proven pillars of military operations. As demonstrated in other domains throughout time, the successful application of these principles can be decisive in space warfare. However, there are two areas that appear to have great potential through the flexibility facilitated by the adoption of DSO for the future of space warfare: surprise and maneuver.

These principles of warfare all have an element of both defensive and offensive capacity. For example, militaries use CCD to hide the location and strength of friendly forces as a protective measure. Reciprocally, operating with stealth, such as with a B-2 or other stealth aircraft, conceals a system’s location from enemy radar and enables an offensive action to be successful through an element of surprise. Equally, forces can maneuver to avoid an incoming attack or apply maneuver to gain a positional advantage to facilitate victory. Surprise and maneuver are also fundamentally interrelated in that the ability to maneuver at unexpected rates or distances enables a force to achieve surprise.

“Mobility is the capability to move from one location and incorporates the principle of movement and maneuver. Frequent movement of spacecraft, signals, terrestrial nodes, and other systems occurring within the enemy’s decision cycle can be of critical importance to joint operations. Mobility reduces vulnerability and increases survivability of friendly assets by complicating enemy surveillance, reconnaissance, and targeting.”

—*Space Warfighting: A Framework for Planners*⁵⁴

Surprise

One of the most fundamental principles of warfare is the need to achieve surprise in the minds of adversaries. By keeping a potential adversary off balance or misinformed of U.S. intentions and capabilities, military operations stand a better chance of achieving their objectives. Just as the theory of competitive endurance seeks to avoid operational surprise, the Space Force and U.S. Space Command must now seek to create surprise for their opponents.²¹

Military deception, such as the use of CCD to confound an enemy’s understanding of a force’s intentions and capabilities, is a proven practice for achieving surprise. Through CCD and other methods to achieve surprise, one side can put an adversary at a weaker position, forcing them to cede the initiative and thus enabling friendly forces to more decisively deliver offensive and defensive effects.

Maneuver

In numerous historic examples, deception combined with movement and maneuver created the necessary surprise for mission success. The ability to reposition forces in unexpected or unobserved ways, across significant distances, or rapidly evade an attack to preserve vital resources can achieve desired effects and create surprise. Essential to executing the necessary movement and maneuver is the logistics support to enable and sustain operations.

Since antiquity, one side has sought to exploit the ability to maneuver and achieve surprise over the other. This has been done for both offensive and defensive purposes. Examples include the Trojan horse used to surreptitiously position Greek soldiers within the walls of Troy, who were then able to open the gates, allowing the Greek army to devastate Troy. In World War II (WWII), surprise and maneuver included the use of inflatable tanks to make the Nazis think that the Allied force structure was larger than it was or massing in a different location. Modern examples include the build-up to Operation Desert Storm, where open speculation believed that a Marine amphibious assault would be required to liberate Kuwait. What actually unfolded was a month-long strategic air campaign that bombarded key Iraqi targets and fielded forces, followed by a rapid ground assault through the desert and a famous left hook. More recently, the 2025 B-2 strike on Iran’s nuclear facilities used deception in different ways. First, it deployed B-2s westward through the Pacific as a decoy force. And, of course, secondly, it used the inherent stealth characteristics of the B-2 bomber to penetrate Iranian air defenses and achieve operational surprise and success.

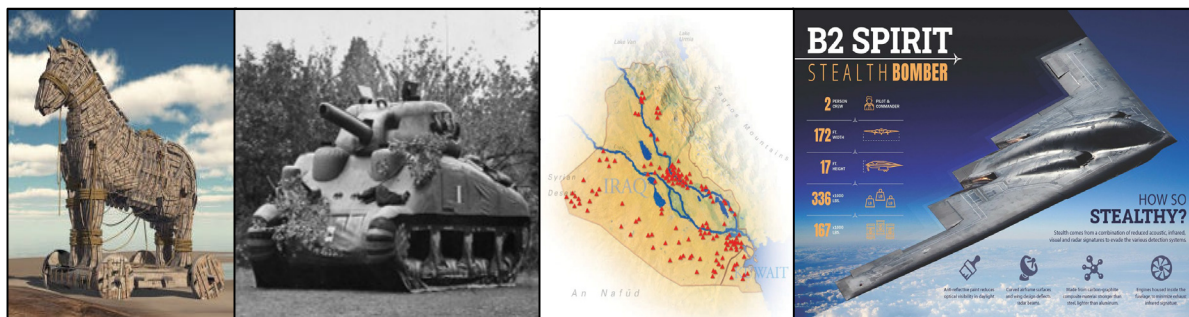


Figure 2: Examples of military deception and surprise from antiquity to the present.

Photo credits from left to right: AI generated image; [U.S. Army photo](#); [Aerospace Education Foundation](#); [U.S. Air Force](#).

The ability to create a false impression in the minds of an adversary through combinations of appearance, movement, and maneuver is often a key to military success. Applying these same principles offers opportunities for the Space Force to simultaneously increase the flexibility and resilience of its architecture to create multiple and compounding challenges for potential adversaries. Finally, just as logistics enables maneuver for military operations in the air, land, and maritime domains, it offers the potential to transform military space operations to be more dynamic, flexible, and capable of creating surprise. Transitioning from the legacy architecture to a new warfighting architecture will not be easy. Fortunately, the Space Force is not starting from scratch. Years of technology demonstration and prior operational experience can enable the Space Force to rapidly accelerate the transformation of its architecture and operations, but only if adequately resourced.

The Groundwork is Laid for the Next Revolution in Space Operations

The Space Force is already pursuing several capabilities that increase the dynamic nature of the satellite, ground, link, and launch segments of its operational architecture. Additionally, the Space Force is exploring various options to further increase operational flexibility through a series of technology demonstrations. The combination of these efforts has the potential to transform the once static space architecture into one capable of dynamic space operations. However, the Space Force has not yet made a final decision on critical aspects of that future architecture, such as on-orbit servicing and refueling or the alternative of fielding low-cost satellites in greater numbers. As such, the largest area for potential change resides in the orbital segment. While the ideas of DSO and increasing the overall flexibility of the U.S. space architecture have recently gained prevalence, the objective of increasing resilience and flexibility in the architecture dates back decades and has established the foundation to now accelerate architectural change. Multiple space servicing and maneuver technology demonstrations over the past 30-plus years have advanced the state-of-the-art and an understanding of the art-of-the-possible for increasing the overall flexibility of the U.S. space architecture.

Before discussing how these efforts can holistically and synergistically create new mission possibilities, it is useful to understand the evolution, current status, and future plans in each area individually. The Space Force and other defense organizations are demonstrating key technologies that can make future operations more dynamic—some focused on the orbital segment, while others concern the other segments of the space architecture.



Figure 3: John Grunfeld and Richard M. Linnehan, STS-109, servicing the Near-Infrared Camera and Multi-Object Spectrometer (NICMOS) on the Hubble Space Telescope.

Source: [NASA photo](#).

Orbital Segment

The most frequently discussed area and the one with the most opportunity for transformative change, through increased maneuver, servicing, and assembly, is the orbital segment. Once launched, the overwhelming majority of satellites do not change their mission, capabilities, or position within an orbit. The inability to physically access and move satellites in space locks them into static orbits and set mission performance. However, there are notable exceptions that show the potential for change that will fundamentally transform space operations.

Many may recall the servicing missions performed by NASA astronauts to the Hubble Space Telescope to correct defects in the design and enhance operations of that system.²² What enabled these missions to succeed was the fact that engineers designed the Hubble Space Telescope to be serviced in the first place. By swapping out key components, they knew that upgrades to extend the effectiveness and service life of the Hubble Space Telescope would be possible. Further, the ability of NASA to launch astronauts and deliver key components via the space shuttle and its robotic arm was an essential element in making the upgrades and repairs possible.

Autonomy, Rendezvous, & Refueling

Technology demonstration efforts across the Department of Defense have consistently explored increased operational flexibility and effectiveness of satellites through autonomy, rendezvous and proximity operations (RPO), docking/birthing, and refueling. These progressively complex endeavors have paved the way for current operational systems and are poised to drive a transformation to DSO. Beyond simply refueling a satellite, it is possible to replace any consumables, such as weapons magazines and defensive systems, and replace or augment spacecraft sub-systems.

In 1994, the Technology for Autonomous Operational Survivability (TAOS) program conducted a set of space experiments using a common bus and hosted various payloads to demonstrate the utility of autonomous operations to increase the overall effectiveness of a system.²³ The Air Force launched XSS-11 in 2005 to further demonstrate autonomous rendezvous and proximity operations (RPO).²⁴ These two programs laid the foundation for what eventually became programs such as GSSAP. Advancing still further, DARPA launched two satellites in 2007 as part of the Orbital Express program to examine satellite refueling and reconfiguration.²⁵ In addition to the prerequisite autonomous RPO and docking, the program successfully demonstrated two key technologies: refueling and component replacement. First, Orbital Express successfully used an open, non-proprietary standard to transfer fuel from the Autonomous Space Transport Robotic Operations (ASTRO) satellite to the Next Generation Satellite (NEXTSat). Second, using a robotic arm, ASTRO installed two Orbital Replacement Units (ORUs) into NEXTSat. The first ORU was a battery, and the second was a computer. These actions successfully demonstrated autonomous satellite servicing and the potential benefits of modular spacecraft.²⁶

Not all the advancements in on-orbit servicing have been military-led. Northrop Grumman's Mission Extension Vehicles (MEVs), launched in 2019 and 2020, have docked with commercial communication satellites and used their fuel and thrusters to extend the operational life of the original spacecraft.²⁷ Given current satellite design, MEV may not offer the rapid change in position needed for future combat, but similar approaches can add defensive countermeasures to otherwise defenseless satellites.

These past demonstrations and experiments paved the way for what can be operationalized today and in the future. The concepts associated with In-space Servicing, Assembly and Manufacturing, as well as Space Mobility and Logistics (SML) create bountiful opportunities for the United States to enhance the resilience and effectiveness of its on-orbit architecture. One effort toward realizing this objective is the Consortium for Space Mobility and ISAM Capabilities (COSMIC), a nationwide coalition working to invigorate United States leadership in ISAM capabilities.²⁸ Its goal is to advance on-orbit servicing and manufacturing, as well as explore other ways to increase the resilience and flexibility of the overall U.S. space architecture.

Rendezvous Proximity Operations

Rendezvous Proximity Operations (RPO) is compound term. combining the activities. **Rendezvous** is the set of activities to get two spacecraft near each other, by plane and orbit matching and closing range to close proximity. **Proximity Operations** encompassed activities one or both spacecraft perform while close to one another. **Zero proximity operations** result in the two spacecrafts coming in contact. **Docking** requires one vehicle to perform precise maneuvers to contact, or mate, to a specific point on the other spacecraft. **Berthing** is when one spacecraft captures another using a robotic arm to position the second vehicle for subsequent servicing, repair, or mating.

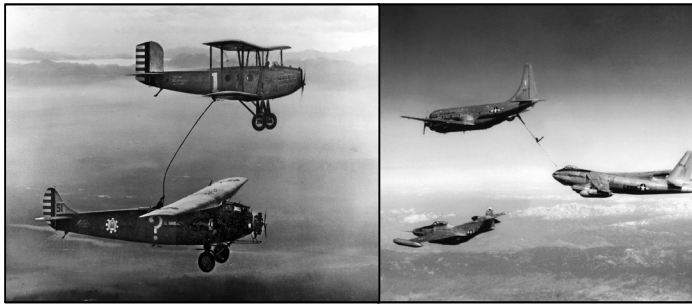


Figure 4: Origins of Air-to-Air Refueling. In 1929, Maj Carl Spaatz flew the Question Mark for over 150 hours and conducted 42 refueling operations, demonstrating the potential utility of air-to-air refueling. However, operational tanker operations did not begin until 1952. A similar gap in space-to-space refueling advancements is now occurring.

Source: [U.S. Air Force photo](#); [U.S. Air Force photo](#); "Background Paper on the History of Air Refuelling."

Standardized connections, modularity, and servicing interfaces on satellites and other orbital systems will be key to supporting the logistics that a dynamic space architecture will demand. Tetra-5, which is a technology demonstration satellite scheduled to launch in 2026, will demonstrate docking and refueling capabilities using the Rapid Attachable Fluid Transfer Interface (RAFTI) connection.²⁹ Such a standardized connection could become mandatory on designated future spacecraft, enabling them to be refueled if the mission requires it. Additionally, DARPA's Robotic Servicing of Geosynchronous Satellites (RSGS) aims to demonstrate flexibility to adapt to a variety of on-orbit missions and conditions through modularity and servicing.³⁰ Finally, the Elixir program will launch in 2027 to demonstrate fuel transfer with the Geosynchronous Auxiliary Support Tanker (GAS-T) system.³¹ These three technology demonstrations could have potential residual operational capabilities if the United States is willing to head down the path of space logistics.

The recent announcement that the Space Force is seeking commercial options for the GSSAP follow-on system with refueling ports, RG-XX, opens the potential to build in refueling and servicing as integral elements of the future architecture.³²

Alternate Propulsion

Alternate propulsion types, such as nuclear thermal and electric propulsion, are mature technologies that can provide other means to increase maneuverability and extend the operational utility of satellites with limited fuel. With increased propellant, these capabilities offer a range of specific impulse and delta-V. However, they both still require the ejection of a mass to create thrust, which must eventually be replenished just as existing chemically propelled spacecraft do. DARPA also recently cancelled its Demonstration Rocket for Agile Cislunar Operations (DRACO) project, citing decreasing launch costs as weakening the imperative for nuclear thermal propulsion.³³ Other forms of more novel propulsion, such as leveraging the pressure of the solar wind, could theoretically continue to maneuver without the expulsion of a propellant mass. However, those systems would operate much more like sailboats and would lack the rapid maneuverability required for dynamic space operations. Other emerging propulsion systems, such as a plasma engine offering variable specific impulse, have great potential but are not yet fielded.³⁴ For this effort, it is safe to assume chemical propulsion will remain the primary means of achieving in-space maneuverability; however, a more detailed analysis of alternative in-space propulsion warrants its own separate examination.

Spacecraft Propulsion

Three terms help inform the discussion of spacecraft maneuver.

Delta-V: The measure of the change in velocity a spacecraft can achieve and a measure of performance. Delta-V is a key parameter for dynamic spacecraft maneuverability.

Specific Impulse: The measure of thrust per unit of fuel over time and a measure of efficiency. Electric propulsion systems have high specific impulse, but low delta-v and thrust, making them less suited for DSO.

Thrust to Weight Ratio: A ratio representation of the ability of an engine to overcome the inertia of a vehicle to maneuver. Even in the micro-gravity of space, vehicles have mass. Spacecraft mass and velocity result in inertia that must be overcome to change the spacecraft orbit or position within an orbit. DSO maneuvers will likely require high thrust to weight ratio. This makes electric propulsion unlikely to meet the demands of DSO.

Modularity

Beyond propulsion and maneuver, the use of modularity is another means for increasing the operational flexibility of satellites, which are typically unchanged from the time of launch throughout their operational life. The X-37B and the use of payload adaptor rings to host modular payloads are examples of current ways to increase the versatility of spacecraft. The modularity of these approaches increases mission versatility and, therefore, operational ambiguity and surprise—which can create confusion in the minds of adversaries.

The X-37B has considerable maneuver capability and can host multiple payloads within its bay. Each payload can be swapped out after return to the Earth.³⁵ The inherent flexibility of a system like the X-37B, which is only a test vehicle, could be operationalized to significantly expand the set of dilemmas that the United States could present to potential adversaries. This is akin to a combat aircraft carrying a broad range of munitions, modular sensors, and fuel loadouts. Each mission payload is configured for specific desired effects. A similar paradigm can be used for DSO satellites in future operations.

The U.S. Space Force *does* currently host payloads on secondary adaptor rings, connecting satellites to boosters as another modular method to increase mission flexibility. SSC's Rapid On-Orbit Space Technology Evaluation Ring (ROOSTER) program allows payloads to remain attached to the ring or be deployed as free-flying satellites. By hosting multiple, diverse payloads on a single ROOSTER, this modular approach creates operational flexibility because each payload can perform different or complementary missions. The ROOSTER program and its predecessor—the Long Duration Propulsive EELV Secondary Payload Adaptor (LDPE)—are already seeing widespread employment to advance technologies.³⁶ The Space Force has launched or plans to launch at least three LDPEs and at least five ROOSTER missions.³⁷ ROOSTER-5 will be an integral part of the Tetra-5 mission, demonstrating on-orbit refueling.³⁸

The flexibility of the X-37B and ROOSTER programs also enables the Space Force to obfuscate the true mission and capabilities of individual spacecraft. Operational planners can use this feature to induce an element of surprise in the minds of potential adversaries. The increased uncertainty will complicate adversary planning of offensive and defensive space operations and may create enough hesitation in their decision-making process to ultimately deter hostile action.

Spacecraft Subsystems

In addition to the mission payload, typical spacecraft have the following subsystems:

Propulsion: Provides thrust to adjust orbit and attitude and manage angular momentum

Attitude Determination & Control System: Provides determination and control of spacecraft pointing and orbit position

Communications: Communicates with ground and other spacecraft

Command and Data Handling: Processes and distributes commands and processes, stores, and formats data

Thermal: Maintains equipment within allowed temperature ranges

Power: Generates, stores, regulates, and distributes electric power

Structures and Mechanisms: Provides support structure, booster adaptor, and moving parts

James R. Wertz, and Wiley J. Larson, *Space Mission Analysis and Design*, 3rd Edition (Microcosm Press, 1999).

Taken to an extreme, modularity could facilitate the ability to swap or upgrade components of each of a spacecraft's subsystems rather than replacing entire satellites. Like an aircraft or automobile, a satellite is not a single unit but consists of multiple subsystems, each performing specific functions. Either through damage or technology obsolescence, the need may arise to replace a subsystem. Current satellite design integrates all subsystems within the satellite bus, or body, making replacement impractical. Designing spacecraft using modularity concepts to provide the ability to replace subsystems or add mission capability, like the Hubble Space Telescope, would enable upgrades, mission extension, and mission change without incurring the cost of replacing the entire satellite. This could also facilitate a more rapid delivery of a minimum viable product (MVP) satellite with the intent of upgrading it iteratively over time.

In-Space Assembly

Modularity, demonstrated by ROOSTER, and the ability to replace subsystems, demonstrated with Hubble, point the way to a new military paradigm for assembling full spacecraft in orbit, similar to the International Space Station, just on a smaller scale. While it would be hyperbole to "build the aircraft while you are flying," the potential exists to one day assemble a spacecraft while it is in orbit and make modifications to it.

In-space assembly would enable satellite and spacecraft design to focus entirely on mission objectives with fewer tradeoffs for launch vehicle size, shape, and load restrictions or capacity. As a result, spacecraft could conceivably be larger, with increased capabilities and capacity to address a range of potential challenges and create an extensive array of effects against adversary systems. An orbiting logistics center where spacecraft could deploy at unpredictable times with unknown capabilities is also feasible, and it could force potential adversaries to invest valuable resources to track and identify all spacecraft as if each posed a significant threat. Deployments from such a location could also include decoys, like the inflatable tanks in WWII, that would further challenge adversary understanding and planning. This level of flexibility could confound adversary SOSI networks and create confusion in the minds of adversaries.

Software Reprogrammability

Software-defined radios could allow guardians to reprogram a satellite to fundamentally change the mission that it is conducting even after it's been launched. For example, a communications satellite could be reprogrammed to deliver positioning, navigation, and timing signals or potentially transmit at higher power levels to generate disruptive jamming effects. While major mission changes via software reprogrammability may be years away, refinements and enhancements within a single mission are much nearer term. As Mr. Cordell DeLaPena, Program Executive Officer for Military Communications and Positioning, Navigation, and Timing, Space Systems Command, explained, "As we look at different frequencies and bands, a software-defined terminal with the ability to adapt back and forth—that's really where the future needs to go."³⁹ An example of this reprogrammability is the Navigation Technology Satellite 3 (NTS-3) from the Air Force Research Laboratory (AFRL), which will use a reprogrammable signal generator as a key element of its system. This will facilitate dynamic methods to defeat interference and spoofing.⁴⁰

Terrestrial Segment

The Space Force is making significant progress in transforming the terrestrial segment from the traditional bespoke ground station and operations centers for each satellite family to more dynamic, web-enabled operations. The fundamental role of the terrestrial segment is to command and control the vehicles in the orbital segment. Some systems operators also employ the terrestrial segment to transmit and receive information from the mission payloads aboard the satellite. The traditional method of C2 is for each operational space system to have its own dedicated ground system within a dedicated space operations center. These terrestrial SOC are typically concentrated at Schriever Space Force Base and Buckley Space Force Base in Colorado. Regardless of the location for the SOC, connectivity to the satellite is currently provided via the space control network (SCN), a global array of parabolic radio antennas that send and receive commands and signals between the SOC and the orbital segment as the satellite moves around the planet. These periodic, brief contacts are just enough to downlink telemetry to ensure that the satellite is continuing to perform its mission and operate safely and, for some satellites, to upload commands, execute payload operations, and receive the data coming from those payloads. In a peaceful environment, intermittent contacts and long gaps between contacts are tolerable. In a more dynamic warfighting domain, it could mean defeat. The Space Force is therefore pursuing alternate methods to increase its connectivity between the terrestrial segment and the orbital segment.

Web-based

One such approach to ensure more resilient operations is web-based command and control. Rather than having a dedicated ground system for each type of mission or satellite, a web-based format can speed the delivery of capabilities and provide a more standard interface for operators. Another key element of NTS-3 was its planned use of the Enterprise Ground System (EGS), which intended to move away from bespoke ground systems for each program to a single ground system for all programs, avoiding costly duplication of effort. EGS has since been subsumed by the combined SSC and SpRCO Rapid Resilient Command and Control (R2C2) program, a more narrowly focused effort specific to missions requiring DSO.⁴¹ Using a web-based cloud infrastructure, R2C2 will enable guardians to operate multiple satellites from any location with the appropriate security measures.⁴² Because command and control of the orbital segment can be executed from anywhere that the R2C2 web-based application

can be accessed, operations no longer need to be exclusively conducted from within a dedicated SOC. This allows the terrestrial segment to conduct maneuver operations—controlling satellites from nearly any location and even passing control between different geographic stations—which complicates adversary targeting and increases mission resilience. This is extremely beneficial in the event Space Force bases come under attack during a conflict.

Phased Array Antennas

The Space Force is seeking to augment the satellite control network with phased array antennas that can contact multiple satellites simultaneously. This will also increase connectivity with vital assets and minimize the periods between contacts driven by the limitations of existing parabolic antenna. Moving away from the legacy SCN, R2C2 will employ phased array antennas under SpRCO's Satellite Communications Augmentation Resource (SCAR). SCAR antennas are transportable and capable of communicating with satellites as they maneuver on-orbit.⁴³ This increased capacity permits the near-continuous command and control of satellites, a capability that will be vital to the United States prevailing in future space conflicts.

Mobile Ground Stations

Another approach that will increase the flexibility and maneuverability of the terrestrial segment is the use of mobile ground terminals. Mobile ground stations are an integral part of providing resilience to NC3 and launch detection systems. Today, thanks to globally available communications and the web-based applications previously discussed, a wider set of satellite operations can become more mobile. When combined with a web-based tool, like R2C2, operators, regardless of location, can send commands to a satellite at the appropriate classification level and then move and reconnect. If that terrestrial segment connectivity can be maintained, the Space Force would have the potential to C2 satellites while on the move. The global wideband communications capability made possible by proliferated Low Earth Orbit (pLEO) constellations means the potential exists to conduct ground operations from virtually anywhere on Earth. The resilience from such flexibility, disaggregation, and mobility could be a strong deterrent against attacks on the limited number of fixed ground stations. The outstanding collaboration between the SpRCO and SSC suggests these systems and capabilities will move beyond demonstration and could become an integral element of the future U.S. military space architecture. These examples illustrate the basic tenet that DSO is not exclusive to the space segment.

Link Segment

Since all military space operations involve the transmission of data between the satellite and terrestrial segments, the link segment cannot be ignored. The link segment enables guardians to operate satellites and their payloads, execute C2 functions, direct payload employment, and download mission data. Assuring this connection despite adversary jamming and intrusion threats through frequency hopping, multi-path linkage, and laser communications is an increasingly vital element of a flexible and dynamic space architecture.

Frequency Hopping

One of the oldest methods of preserving connectivity through jamming is frequency hopping. Rather than using a static frequency for all communication, frequency hopping randomly moves between various frequencies. This approach can prevent an adversary from maintaining a lock on the link signal and intruding or jamming it.

Frequency hopping dates back to WWII, and many systems, such as the tactical airborne radio Have Quick, use frequency hopping to secure communications. Frequency hopping also provides secure, jam-resistant communications for national command and control and NC3 systems such as Milstar and Advanced Extremely High Frequency (AEHF) satellites. However, this approach is not standard practice on all satellites.⁴⁴ As identified in “Space Warfighting: A Framework for Planners,” frequency hopping is a method of movement and maneuver within the electromagnetic spectrum, and Space Force planners and system developers should ensure the continued and broader application of this proven approach.⁴⁵

Path-Agnostic Connectivity

Another way to increase the assuredness of the link segment is to not rely on a single, predefined, direct path between the terrestrial and orbital segments, as is currently done with the SCN. Relying on the traditional dedicated link segment that can be identified, targeted, and interfered with by a potential adversary creates a vulnerability. However, having multiple paths to transmit commands and receive the data would allow U.S. Space Command to circumvent any given jamming or interference threat. By utilizing a variety of relay nodes and crosslinks, the Space Force can create a path-agnostic mesh web for communications that increases the resilience and flexibility of the link segment. The development of the transport layer of the Proliferated Warfighter Space Architecture (PWSA) creates the potential for any authorized ground user to access any satellite that is connected to the transport layer. The assuredness of a path-agnostic link, or mesh web, will further increase the connectivity to the orbital segment to decrease the vulnerable periods of non-contact.

Laser Crosslinks

A key technology to facilitate this path-agnostic connectivity will be the continued development and employment of optical communications in space. Inherently more secure than radio frequency communications, optical signals have a much smaller footprint and a much narrower beam, and therefore they have a lower probability of detection and a lower probability of intercept. The bandwidth capacity minimizes the time required to transmit information during satellite contacts, further decreasing the potential for disruption. The security and assuredness of optical communications, or laser cross-links, make them a natural aspect of a path-agnostic approach and future secure communications, particularly for in-space cross-links, but also for connection between the space layer, terrestrial segment, and end users. The recent success of SDA and General Atomic using optical communications between a satellite and aircraft demonstrates the viability and benefits of laser crosslinks.⁴⁶

Launch Segment

Finally, there's the launch segment. While not traditionally included as a segment of the space system architecture, the impact of launch locations, boosters, schedules, and cost on the resulting space operations cannot be ignored.⁴⁷ Assuming any future space conflict may be an enduring conflict between peers, the ability to reconstitute lost capabilities or augment mission effects where and when needed means that launch will be a critical element of future warfare. The entire U.S. military space enterprise currently operates out of two primary launch sites on the Eastern and Western coasts of the United States: Cape Canaveral, Florida, and Vandenberg, California. Having so few locations for assured access to space creates inherent vulnerabilities from natural disasters or attacks that could have an outsized impact on U.S. launch operations.

Furthermore, the current paradigm of manifesting launch missions on a rigid schedule, sometimes planned years in advance, does not lend itself to DSO. Matching satellite delivery, booster availability, and launch site cadence is currently a complex challenge in risk mitigation. As launch cadences increase and costs for launch decrease, the potential exists to transform the way the Space Force conducts launch operations and plans the mission manifest. DSO launch could include elements such as dynamic manifest planning, launch site diversification, and launch vehicle diversification. Cumulatively, this enables the exchange of one payload for another aboard a booster on demand, which could create a more dynamic launch manifest that will respond better to urgent warfighter needs.

Dynamic Manifest Planning

Assuming there is in-space attrition resulting from a prolonged conflict, the ability to replenish lost assets may prove to be a pivotal logistical factor. Continuing changes that reduce the overall costs of launch, as well as increasing the cadence of launches, create new opportunities for the flexibility of the U.S. space architecture. The potential for a super-heavy launcher such as Starship or Vulcan creates further opportunities for flexibility in what could be manifested and placed into orbit—and potentially into multiple orbits—from a single launch. Launch manifest planning does not need to be a multi-year process. With more frequent opportunities, the potential for various payloads to hop on a ride into orbit in a more dynamic and flexible way becomes possible. As an airline travel customer, you would not want to have to plan your flight from Point A to Point B two years in advance. You want to have multiple options to get there so that you can determine what meets your needs best. The same can be true for launch operations: if satellites are designed to operate within a greater range of dynamic loads, it allows for greater flexibility in launch vehicle selection to better meet mission requirements. Each launch vehicle has unique acceleration and vibration profiles; if satellites are designed to withstand a wider range of launch profiles, these differences will no longer be limiting factors in manifest planning. This can be realized by using more standardized space vehicles with common buses or modular designs. Satellites or components can then be easily replaced with one another on boosters to generate greater manifest flexibility.

Launch Site Resilience

Given that there are two primary launch locations in the United States, ensuring resilience for these facilities is key. While other sites, such as Wallops and Kodiak, offer limited launch capability, they are not equipped to handle medium and large launch systems. The Space Force is proactively working to ensure continued operations are secure at existing launch sites. Air and missile defense will likely need to be a key part of future protection efforts. Increased location diversification and proliferation will also inherently increase the resilience of the overall architecture by eliminating single points of failure resulting from damage, degradation, or destruction at any one site, whether that be from natural events or cyber or physical attacks.⁴⁸ Launch site proliferation, to include launch sites of allies, will also increase the capacity of the launch enterprise to deploy spacecraft to desired orbits when and where needed to meet operational demands.

Launch Vehicle Diversification

Diversification in launch vehicles is critical to ensure guaranteed access to space because it minimizes the impact of any failure or anomaly that could derail multiple missions. It also provides greater flexibility of launch locations and providers, and, potentially, allied or international boosters and locations could be exploited. Recently, there have been incredible increases in the tempo and capacity as well as a massive cost reduction of launch operations, but most of this has occurred within a single family of launch vehicles. All the same, the utilization of small

launch vehicles has enjoyed solid, steady growth in recent years. The potential for super-heavy lift is on the horizon and could enable manifesting multiple satellite missions simultaneously. The combination of these approaches can create a much more dynamic launch architecture than is currently realized.

Now is the time for a bold decision

Current Space Force leaders know that bold and decisive leadership is required to fully transform the Space Force architecture and U.S. Space Command operations to integrate maneuver and surprise to achieve superiority. As those leaders press hard for these reforms, it is imperative that Pentagon and Congressional leadership provide the necessary funding to transform concepts into reality. While the numerous technology initiatives and programs are impressive, it's important to remember that most are just demonstrations, and they have not been adopted as operational capabilities. They are limited in the scope and capacity with which they can conduct operations. The progress of the Space Force must continue, accelerate, and spread across all segments of space operations. The Space Force requires sufficient and steady funding to procure these capabilities at a scale and pace to meet the growing threats posed by China and Russia.

A Holistic Look at Opportunities to Create More Dynamic Space Operations

While fielding DSO technologies is critical, real change will only be manifested through new approaches to space operations: tools are only effective if used appropriately. The Space Force must pursue new CONOPS to adjust to a dynamic and logistically enabled architecture. To that end, the Space Force must organize, train, and equip a complete architecture that includes logistics capabilities to maximize the utility and effectiveness for mission execution and minimize the vulnerabilities of the U.S. space architecture and operations. Just as the move to pLEO simultaneously increases resilience against attack and effectiveness in detecting and tracking new missile threats, growing the architecture's flexibility will support mission assurance and mission effectiveness. Such a dramatic transformation in operations may facilitate the execution of new mission types and drive new organizational constructs. However, before exploring the potential implications of this transformation, several important planning factors must be considered.

Planning Factors

When examining how best to increase the flexibility and dynamism of military space operations, it's important to recognize that not all missions and not all orbits will be ideal for a full implementation of this approach. Measures to improve resilience and mission effectiveness, such as the transition to pLEO constellations, add enough of an element of change from the traditional approach that it may be sufficient for those missions and for that orbital regime to not concern itself with some factors of DSO. Operational impacts on the supply chain and other secondary effects could also be significant and must be thoughtfully handled before selecting and implementing a specific path forward.

Missions

While every mission could employ some aspects of DSO, not all missions should fully implement all aspects across all elements. Leaders should examine how some elements of DSO, such as refueling or maneuver, impact mission execution. They must account for the method of refueling or more frequent maneuvers and how those actions could affect mission performance for that satellite. In those cases, they will need to ensure that steps are taken to mitigate any complications arising from DSO and provide continuous mission coverage.

Conversely, some missions are better suited than others to implement all aspects of DSO, such as missions that would benefit from frequent maneuvers. Just as only some U.S. Air Force aircraft are capable of air-to-air refueling, only certain missions and spacecraft in the U.S. Space Force order of battle will require in-space refueling. Form must follow function. Missions such as intelligence, surveillance, reconnaissance (ISR); inspection; and, of course, defensive and offensive counterspace operations are much more suited to the adoption of dynamic measures. For these missions, the ability to reposition to gain an advantage of observation or to monitor in an area of emerging action generated by adversary operations may be essential. Furthermore, response options for emergency situations that would require rescue, recovery, or repair would also need to have maneuvering capability. New missions may also benefit from leveraging increased maneuver. Concentrating the number of satellites in a particular area either as a demonstration of force or to increase capacity at a specific time and place of U.S. choosing is one potential example.

Given that the clearest missions requiring DSO are unique to national security, such as ISR, counterspace operations, or shows of force, it is doubtful that a commercial infrastructure will emerge to satisfy military DSO requirements. Some commercial technologies and approaches may hold value, but, akin to applications like air-to-air refueling in the air domain, space-to-space refueling to enable mission execution will likely remain a practice unique to military operations. This reality should shape future Space Force architecture planning and acquisition strategies.

Another consideration is the need to develop tactics, techniques, and procedures that ensure continued execution of existing missions while conducting increasingly frequent maneuvers and logistics activities. A satellite that maneuvers to execute sustainment activities could “come out of mission,” meaning that it may no longer be pointing at the Earth or an intended target to collect or transmit information. Satellites that constantly maneuver to complicate adversary SOSI may not be able to continue executing their intended mission unless additional C2 capabilities are fielded to help realize the change in CONOPS. The method of satellite servicing could also impact mission operations. If a satellite must maneuver to a servicing location, it will likely be out of mission. Fielding fallback systems to bridge the mission capability while an asset is being serviced will be necessary. The Space Force and U.S. SPACECOM will need to develop TTPs to address this challenge. Changes to satellite configurations or missions described earlier will likewise drive alternative mission requirements while the primary satellite is being serviced. If, however, the servicer or refueler maneuvers, it can simply dock to the rear of a satellite, as demonstrated by MEV, and allow mission operations to continue concurrently.

Orbital Regime

Certain orbital regimes will be better suited for full DSO than others. For example, LEO is not conducive to frequent or large satellite maneuvers. Satellites rapidly changing position or following unpredictable trajectories would come at a huge cost to fuel usage because of the high velocities in LEO. Such maneuvers would also likely create more problems than they would solve because of the number of satellites in LEO and the increased risk of collision. This does not preclude the adoption of other DSO techniques in LEO, such as deception, frequency hopping, or life extension for exquisite systems. Additionally, the shift to pLEO operations has its own inherent set of resilience and mission effectiveness factors.

Beyond LEO, however, the potential for dynamic operations becomes increasingly viable and indeed necessary to ensure future mission success. As threats continue to grow, applying DSO in orbits beyond LEO preserves the United States' continued use of the space domain, especially in the valuable geosynchronous belt. The benefits of unique orbital regimes, such as geosynchronous orbits, to maintain constant presence over portions of the Earth and to achieve global coverage with a small number of satellites, are too great to abandon.

DSO also enables the potential for spacecraft to maneuver between orbital regimes and cislunar space. This will have the two-fold benefit of enabling more effective mission execution while complicating adversary tracking and targeting efforts. Without being confined to a specific orbital regime and location, satellites can maneuver to an orbit and attitude ideal for mission execution or to evade threat systems.

Resupply or Disposal

A key question facing leadership today is whether DSO is best achieved through on-orbit refueling and servicing or the utilization of shorter-lived disposable satellites. Certainly, as launch costs go down and launch rates go up, the ability to manufacture satellites at scale suggests that disposal might be a viable approach for GEO and beyond, as it is for LEO. However, unlike LEO, where a satellite disposal plan is to re-enter the Earth's atmosphere, GEO satellite disposal consists of maneuvering to a graveyard orbit. Moving hundreds or thousands of satellites into a graveyard orbit beyond GEO would inevitably create a larger field of dead satellites and debris. Leaders should consider how they would address this and plan to mitigate, or at least operationally avoid, this potentially hazardous consequence. A more responsible approach may be through servicing and resupply to avoid the creation of long-lived debris.

The decision to pursue resupply or disposal should also weigh the resulting requirements on the launch infrastructure during conflict. In a time of crisis or conflict, DSO satellites will be under increased pressure to maneuver. This creates a more frequent need to replace or refuel them. Assuming launch capabilities have not been damaged, destroyed, or disabled, launching a whole new satellite, getting it into the proper orbit, completing check-out, and entering operations will take time that may cede initiative to an adversary. Alternatively, refueling an existing operational satellite with propellant already on orbit would be much quicker. This operation requires protection and defense of the orbital refueling infrastructure, just as the U.S. Air Force must protect tanker aircraft today. Despite this additional requirement, by choosing the resupply approach, the U.S. Space Force can significantly lower the overall vulnerability of the enterprise and increase mission effectiveness by decreasing what must be replaced—fuel versus entire satellites—and establishing those replacement elements closer to the point of execution.

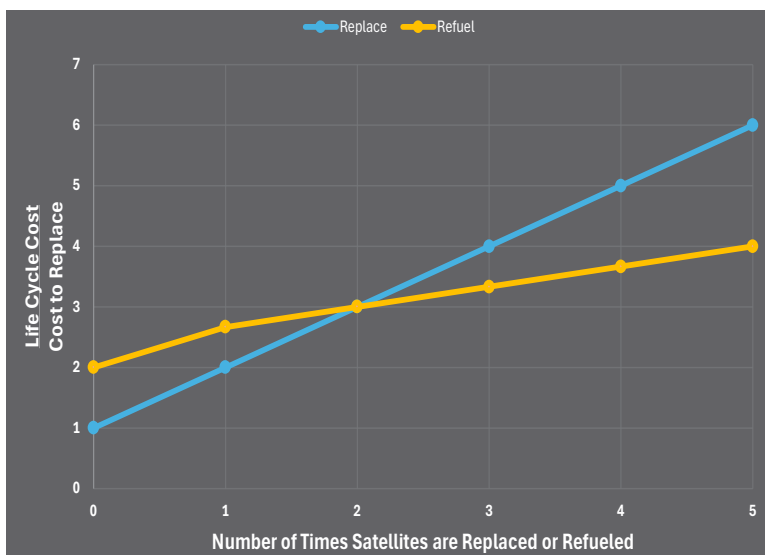


Figure 5: Normalized Comparison of Frequent Orbital Maneuver Architecture Options. Several factors impact cumulative life cycle cost for options to frequently maneuver satellites: number, cost, and mass of satellites; fuel required per maneuver; cost to resupply fuel; launch costs; and refueling infrastructure costs. However, the cumulative costs of fully replacing satellites increase more rapidly than replacing only the fuel and quickly exceeds the initial investment costs of creating a refueling infrastructure. In this example, the cost of refuellable satellites and their required infrastructure is twice the initial cost of traditional satellites, yet the life cycle cost of the satellite replacement option surpasses the refuellable option by the second mission cycle.

Source: analysis conducted by the Mitchell Institute.

Supply Chains & Costs

Another facet of the decision to use resupply or disposable satellites is the impact on supply chains and the resulting operations and sustainment costs. Disposable satellites are a viable option only if resources are available and costs are low enough to produce replacements at the scale and rate needed for operations. However, limited resources and production costs may make this approach unviable in the long term. Alternatively, establishing a space logistics infrastructure will incur an initial investment but may be more cost-effective over time. Just as launch vehicle reuse has helped realize cost savings, the initial investment in establishing a space logistics infrastructure may prove more cost-effective in the long run.

Replacing components, rather than entire satellites, could reduce costs per effect generated and lessen the burden on critical supply chain materials. The traditional approach to fielding a space capability incurs roughly 70 percent of the life cycle cost before launch. This is in stark contrast to aircraft, which incur over 70 percent of their life cycle cost *after* fielding—due to operations and sustainment.⁴⁹ Deploying modular satellites as minimum viable products that can have components replaced and upgraded and use expendable commodities that can be resupplied, such as fuel, could drastically change the cost paradigm for space and shift a greater portion of life cycle costs into operations and sustainment. Before decision-makers choose a way forward, they should carefully examine the implications for the supply chain to ensure that they do not select a path doomed to failure due to unsustainable demands on personnel, raw materials, or production capabilities.

Supply and Demand: Chicken and Egg

Space Force leaders must drive both demand and supply-side policies for developing and fielding on-orbit sustainment capabilities. As a recent Government Accounting Office report identified, the advancement of In-space Servicing, Assembly, and Manufacturing capabilities has stalled because of a standoff between developers and end users.⁵⁰ Fundamentally, a chicken-and-egg situation exists where end users are reluctant to build architectures around servicing until capabilities are more widely available, while ISAM developers are waiting for the user community to signal a demand before investing to create that logistics architecture.

Bold, decisive leadership is required to break out of the current stand-off. Any significant transformation of the architecture from one paradigm to another incurs an inherent cost in terms of investment and time. Currently, the Space Force is waiting to see if technologies will pan out and if CONOPS can be made viable for on-orbit refueling or other sustainment systems. However, most agree that the long-term prospects of operations in space will require some level of space logistics. Additionally, given China's stated objectives and demonstrated employment of dynamic operations, it could wield the unique advantages of DSO against U.S. and friendly forces. Ensuring that the United States and the U.S. Space Force gain and maintain an advantage in on-orbit logistics calls for leadership to choose a path and rapidly implement the needed transformations—doing so is critical to future space superiority.

Organizational Alignments

As it moves forward implementing DSO, the Space Force will need to consider how it might need to adapt to a logistics-based space architecture and CONOPS. These changes may include organizational structures in addition to the enterprise architecture elements. The U.S. Space Force may examine naval underway replenishment or the implementation of air-to-air refueling in the air domain as a pointer toward the architectural elements that the Space Force may need to put in place to accelerate such a foundational change to operations on orbit. The Space Force should also look at how its organizational structures and operations may evolve to enable DSO. For example, Mission Deltas may need to evolve to account for on-orbit logistics, or perhaps new Logistics Deltas may be necessary to consolidate mission expertise and resources.

Role of Crewed Missions

It is important to remember that the most flexible system ever launched into space by the United States is the human being. Just as human astronauts were essential to the repair of and upgrades to the Hubble Space Telescope and the rescue of several other satellites, guardians in space may be essential for future Space Force missions. Today, the Space Force does not have guardians operating in the space domain for military missions. However, as humanity's



Figure 6: The near-term possibility of giving guardians experience in the space domain exists through efforts like the Commercial LEO Destination Effort.

Source: Photo courtesy of Vast.

interests in space go further from the Earth, astronaut guardians may be necessary to execute and secure missions that cannot be accomplished through remote operations. The adaptability and flexibility of human decision-making, as well as their ability to conduct a variety of mission operations, could present fundamental challenges to an adversary's decision calculations. There is, of course, another facet of humans in space, which is the potential to raise the threshold of acceptability for hostile actions that may be lethal to humans. Harming an uncrewed satellite is one thing; harming a space station with military crew on it is a completely different risk calculus for an adversary to consider.⁵¹

Objective Architectures & CONOPS

The Space Force can cultivate truly dynamic space operations by employing alternative methods of satellite delivery, operations, and sustainment to create a multi-dimensional set of dilemmas for potential adversaries. The Space Force is already exploring many of these dimensions, but it must now take proactive steps to fully implement these concepts operationally. However, progress moves at the rate it is resourced. Overly constrained budgets have created a barrier to full adoption of DSO. The Space Force must be resourced to field space systems with the ability to evolve beyond the current state of static launch, orbits, frequencies, and missions that are easily understood and exploited by a potential adversary. Failing to evolve risks America's spacepower advantage.

The broad application of dynamic space operations in the U.S. Space Force and U.S. Space Command should consider the following principles that increase the flexibility of the U.S. military space architecture and present challenges to adversaries from multiple aspects of their own space operations. The time to evolve is now.

1. Fielding proliferated constellations significantly expands missions beyond a single or very few satellites to track and target. This approach to increasing architectural resilience is already in progress with the Space Force's PWSA.
2. Enabling frequent maneuvers adds unpredictable trajectories, making it harder for adversaries to track and target satellites and their users.
3. Broadly employing frequency hopping, laser communications, and path-agnostic communications employs the principle of maneuver and resilience to the electromagnetic spectrum and will increase the resilience of the link segment.
4. Proliferating ground-mobile, phased-array antennas and web-based satellite command and control will increase the resilience and maneuver of the terrestrial segment.
5. Developing satellite modularity and software reprogrammability will add mission flexibility, introduce further uncertainty in adversary planning, and help create operational surprise.
6. Employing a logistics-based space architecture enables resupply, refueling, augmentation, and the use of CCD techniques such as decoys.
7. Adopting dynamic launch manifesting and launch diversification will increase resilience and responsiveness to emerging operational demands.

Injecting these dimensions into U.S. space operations will support increased resiliency in the U.S. space architecture and provide increased mission capabilities, ultimately enabling new missions and presenting a compounding set of challenges to potential adversaries. The questions will undoubtedly arise, "How many dilemmas is enough?" and, "Is the incremental value of adding another dilemma worth the additional cost?" However, it is important to remember that the entire space architecture is required to deliver needed effects, and a failure or vulnerability in any one area could undermine the total architecture and threaten mission success. The loss of space superiority in a future conflict will make all other military operations more difficult and less effective, place U.S. sons and daughters in greater harm, and risk failure to achieve military and national objectives. Those costs are incalculable.

Recommendations & Conclusion

“[DSO] allows for more simultaneous dilemmas imposed on an adversary and an improved ability to strategically message through spacecraft posturing.”

*—Lt Gen (ret) John Shaw, Marcus Shaw, and Daniel Bourque
“Dynamic Space Operations: The New Sustained Space Maneuver Imperative”⁵⁵*

The old ways of conducting space operations and the legacy U.S. space architecture are not suited for the realities of space warfare. Predictable orbits and static operations are too easy for a potential adversary to exploit. The United States Space Force has already made significant progress toward a more resilient architecture, but it will take time to emplace the hardware and refine CONOPS at the scale needed to secure desired effects. Time is currently not on the United States’ side—China is moving forward at a breathtaking pace. If the United States wishes to maintain space superiority, it must act boldly and decisively now to take the steps necessary for a logistics-based future architecture. Maintaining a “wait and see” approach only cedes time to China—time that the United States and its allies will never get back.

Achieving true DSO across all elements of the space architecture will require concerted effort from multiple parties within the United States, Space Force, U.S. Space Command, and Congress. The following recommendations are intended to accelerate the development of dynamic capabilities and accelerate the work already underway.

Recommendations

Many of these recommendations support the increased resilience of the entire space architecture, which is the top priority in achieving space superiority. Improvements to increase the flexibility and resilience of the orbital, terrestrial, link, and launch segments are essential to prevent exploitation of a weakness in a singular facet that could undermine the whole architecture. Additionally, several of these improvements are essential to integrating maneuver and surprise to create compounding dilemmas for adversaries and deny them access to and confidence in their space systems.

Orbital Segment

The orbital segment of the space architecture receives the most attention in discussions about dynamic space operations for good reason—it is the area with the greatest potential for improvement. Aspects of DSO for the orbital segment include maneuver without regret via a refueling infrastructure, modular spacecraft, mission flexibility, use of decoys and deception, and the ability to deliver decisive mass or effects when and where needed. Senior leaders in the Space Force should:

- Design and field an on-orbit logistics infrastructure. This will require defining and distributing a standard set of interfaces and refining doctrine, CONOPS, and TTPs.
- Procure a GSSAP replacement that incorporates refueling, at a minimum, and, ideally, with the capacity to replace or add mission capability.
- Put into operation more systems like X-37B and ROOSTER that can leverage modularity to increase operational flexibility, obfuscate mission capabilities, and employ CCD operations to exploit the enduring principles of maneuver and surprise.
- Field capabilities leveraging in-space assembly to increase mission effectiveness beyond the constraints of existing launch vehicles, as mission requirements demand.
- Implement software reprogrammability to alter the mission capabilities of satellites.

Terrestrial Segment

The Space Force is already pursuing several approaches to increase the effectiveness, resilience, and flexibility of its terrestrial segment, largely led by activities of the Space Rapid Capabilities Office and Space Systems Command. Programs such as SCAR and R2C2 are essential to gaining and maintaining space superiority. Service leaders should:

- Continue to advance and scale the application of web-based C2.
- Expand the use of phased array antennas to create multiple opportunities to establish ground links with satellites.
- Invest in capabilities to exploit mobile C2 of satellites.

Link Segment

To prevent interception, intrusion, and jamming, the Space Force must continue its efforts to field the means to secure the vital link segment. Time-proven methods, like frequency hopping, combined with rapidly maturing methods, like laser communications, can create a secure, resilient, and highly capable link web that connects the orbital and terrestrial segments and end-users. Space Force leaders should:

- Expand the employment of frequency hopping as a method to increase the security and assuredness of the link segment.
- Invest in a network of laser communication satellites to create a path-agnostic web that provides multiple avenues to C2 satellites and means for end-users in all domains to access their mission data.

Launch Segment

The criticality of the launch segment to the capabilities of the U.S. space architecture cannot be ignored. Increasing the flexibility and resilience of the launch enterprise is an ongoing priority for the Space Force. A few key recommendations are important to establish the infrastructure necessary to enable DSO. Space Force leaders should:

- Employ standardized satellite buses and form factors that can more easily be replaced aboard launch vehicles to increase responsiveness to emerging operational demands.
- Continue to increase launch site and launch vehicle diversification.

Overarching and Enabling

The capabilities and recommendations above can only occur with sustained support from military leadership and elected officials. To preserve space superiority over a rapidly growing Chinese space program will take unified efforts among the U.S. Space Command, the Space Force, and Congress.

- U.S. Space Command must continue to identify the need for flexible operational capabilities to increase resilience and complicate adversary planning. Comments from leaders, including U.S. Space Command commander Gen Stephen Whiting, repeatedly demonstrate this.⁵²
- The Space Force must take the stated operational needs of U.S. Space Command as the defining signal for the future space architecture. U.S. Space Command and U.S. Space Force must closely coordinate their efforts as operational needs flow to requirements, architectures, technologies, systems, and fielded operational capabilities.
- Congress must provide reliable funding growth to accelerate procurement and fielding of flexible operational capabilities at scale.
- The Space Force should continue to invest in basic and applied research to develop alternative forms of propulsion and methods to increase the flexibility of space operations.
- The Space Force should establish a program office focused on the establishment of an in-space logistics infrastructure to accelerate the development of capabilities, doctrine, TTPs, and plans for sustained space combat operations.

The Space Force must appreciate and embrace the fact that these approaches to improve the dynamic nature of space operations increase both the resilience and effectiveness of mission execution. Dynamic space operations can impose significant costs on an adversary's system development and operations by creating a compounding set of problems for adversaries to calculate. The flexibility of a DSO architecture allows U.S. forces to withstand attack and simultaneously complicate an adversary's understanding of U.S. systems, capabilities, assigned missions, and intent. These cumulatively help deter an adversary attack in the first place. All of this hinges on the Space Force decisively embracing the concepts of flexibility and logistics in its force designs to achieve DSO.

Conclusion

Space is a warfighting domain, and China is striving to supplant the United States as the world's preeminent space power by developing advanced weapon systems to deny the United States and its allies the benefits of space. Moreover, the race for space logistics is here. China is pursuing counterspace weapon systems and is actively engaging in methods to extend the operational life of its space capabilities and, therefore, the effects it can achieve.

With decades of technology demonstration as a foundation, the United States is poised for a broad implementation of DSO. However, the United States must make the decisive choice to head down this path and fundamentally change the entire architecture. By broadly applying the concepts of DSO to *all* elements of the space architecture, the United States can simultaneously increase the resilience and effectiveness of its space operations. This will enable U.S. Space Command to operate its space architecture in new ways that will fundamentally change the deterrent calculus. DSO is more than rapidly or repeatedly repositioning satellites. *All* elements of the U.S. space architecture can benefit from increased flexibility and more dynamic

operations. Furthermore, space logistics that include maintenance, depot, and modernization upgrades on orbit provide far more mission capability and life extension than just satellite refueling. Taken as a whole, DSO creates the foundation for future operations that can accelerate the integration of time-proven principles of warfare, such as maneuver and surprise.

This transformation will not be quick or easy. It will require sustained support from Congress and commitment from the Space Force to see it through to its full potential. At the end, the United States will possess a more robust and capable space architecture that will facilitate the incorporation of maneuver and surprise to ultimately preserve space superiority for the United States. 🌟



Figure 7: X-37B conducting aerobraking maneuvers in a highly elliptical orbit.

Source: [U.S. Space Force photo](#).

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