CLAUSEWITZ IN SPACE

FRICTION IN SPACE STRATEGY AND OPERATIONS

Randall E. Carlson

Ron Gurantz

One of Clausewitz's most well-known contributions is the notion of friction, which refers to obstacles to the application of military power other than enemy action. While friction has been recognized as an enduring feature of warfare, the concept has not been explicitly applied to military space strategy or operations. The military must account for four potential sources of space friction when making decisions about strategy and operations: the space environment, spacecraft-maneuvering limitations, space intelligence, and the reliance on complex technological solutions. The military can alleviate friction with the right policies, but it must realize that many of its efforts will involve frictional tradeoffs that trade one form of friction for another.

Prussian military strategist Carl von Clausewitz once wrote, "Everything in war is very simple, but the simplest thing is difficult. The difficulties accumulate and end by producing a kind of friction."[1] In his classic *On War*, Clausewitz uses the term friction to refer to the various difficulties in war that are not caused by enemy action. Just as friction slows an object's momentum for Sir Isaac Newton, friction slows the momentum of military power for Clausewitz. Despite technological advances promising to reduce it, friction remains a reality in modern warfare and one of Clausewitz's most enduring contributions to the theory of war.

The US military should consider friction while developing spacepower strategy, tactics, and culture. The US Space Force and US Space Command (USSPACECOM) were established to manage and lead military space forces and develop strategies and operational concepts for their use. As they do this work, they must recognize that the application of military space power will be subject to the same difficulties and uncertainties that military power faces in other domains. Not all problems can be anticipated, but identifying potential sources of difficulty is the first step toward managing them.

Dr. Randall E. Carlson, Colonel, USSF, is the Space Systems Command chief of Missile Warning Capability Integration.

Dr. Ron Gurantz is a Research Professor of National Security Affairs at the Strategic Studies Institute, US Army War College.

1. Carl von Clausewitz, *On War*, trans. Peter Paret and Michael Howard (Princeton, NJ: Princeton University Press, 1984), 119. (Special thanks to Vanya Bellinger, Carl Bottolfson, Antulio Echevarria, Brian Fry, Benjamin Ogden, and two anonymous reviewers for their comments. All errors are the sole responsibility of the authors.)

This article identifies and analyzes four sources of friction that will create challenges in the use of military spacepower: (1) the space environment, (2) spacecraft-maneuvering limitations, (3) space intelligence, and (4) reliance on complex technological solutions. This article also identifies potential and ongoing efforts to mitigate these sources of friction. While military space forces can address these challenges through technology and training, attempts to reduce friction often just trade one form of friction for another. These are best described as frictional tradeoffs.

Military Space Operations and Clausewitzian Friction

In 2019, the United States established the US Space Force and reestablished USSPACECOM to manage and lead US military operations in space. Like the other military services, the mission of US Space Force is to organize, train, and equip military space forces. Space Command's mission is to employ these forces and others across the military and government to conduct operations "in, from, and to space," deliver "space combat power" to the rest of the US military, and "defend vital US interests" in space.[2] Along with these organizational changes, there has been a shift in attitude. Top DoD officials began describing space as a war-fighting domain even before the establishment of the Space Force.[3]

These changes were driven partly by new security challenges in space. US military operations rely on satellites for communication; positioning, navigation, and timing; intelligence, surveillance, and reconnaissance; and missile warning. Potential adversaries, whose operations also depend on satellites, have developed ways to damage or destroy US and ally military, civil, and commercial satellites; disrupt signals; and otherwise interfere with operations.[4] Consequently, the United States is now preparing for a future war that could extend into space, including developing defensive and offensive measures and anticipating the possibility of fighting without the benefit of space-based assets.

Wartime Space Operations

Military space operations have been described as any operation that delivers effects "to, from, or through space."[5] At its most fundamental level, this means launching, operating, and maneuvering satellites so they can provide services to forces on the

2. "United States Space Command (USSPACECOM) Organizational Fact Sheet," United States Space Command (website), June 18, 2020, https://www.spacecom.mil/.

3. Marcia Smith, "Top Air Force Official: Space Is Now a Warfighting Domain," SpacePolicyOnline, May 18, 2017, https://spacepolicyonline.com/; and James N. Mattis, *Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military's Competitive Edge* (Washington, DC: Office of the Secretary of Defense, February 2018), 6, https://dod.defense.gov/.

4. Brian Weeden and Victoria Samson, eds., *Global Counterspace Capabilities: An Open Source Assessment* (Washington, DC: Secure World Foundation, April 2021), 3-28–3-35, xix, https://swfound.org/.

5. Todd Harrison, Kaitlyn Johnson, and Makena Young, *Defense Against the Dark Arts in Space* (Washington, DC: Center for Strategic and International Studies, February 25, 2021), 3, https://www.csis.org/.

ground. It can also mean space control operations like jamming satellite signals, cyberattacks, or an array of physical attacks using lasers, missiles, and satellites armed with weapons like chemical sprays and grappling arms.[6] These attacks can come from the ground, sea, or air, or from space itself. Defensive actions can also include maneuvering and reconstitution.

In the developing field of space operations, the United States and others have explored space-based missile defenses and space-to-ground bombardment concepts. Though development along these lines seems unlikely anytime soon, China recently tested what some have called a fractional orbital bombardment system.[7] Operations in the near term will likely remain unmanned, but future operations may involve manned stations or the protection of human space travel. Operations will also likely be confined to Earth orbits, but states or private entities may soon develop a presence with military components on other celestial bodies.

Clausewitzian Friction

As the United States develops strategies and operational concepts for the military use of space, it will benefit from applying classical war-fighting concepts to understand its challenges. One of these concepts is Clausewitz's notion of friction. Some refer to space as a "frictionless environment."[8] The almost total absence of gasses in the vacuum of deep space means objects there experience almost no drag. While this of course refers to Newtonian friction, Space Force members cannot ignore Clausewitzian friction.

The insights of an eighteenth-century theorist may not seem relevant for futuristic warfare, but his concept of friction has survived to the present day because it has been an enduring feature of warfare. Clausewitz dedicated a whole chapter in *On War* to describing and analyzing friction. He depicted friction as anything other than enemy action that causes unexpected difficulties. Before a war starts, "everything looks simple; the knowledge required does not look remarkable, the strategic options are so obvious."[9]

Once war commences, however, frictional elements appear and can impede operations and strategy execution. Militaries endure "the thousand little breakages, delays, and misunderstandings that impede and bedevil all activities."[10] The complexity of military organizations and operations ensures that unexpected dilemmas and challenges

6. National Air and Space Intelligence Center (NASIC) Public Affairs, *Competing in Space* (Wright-Patterson AFB, OH: NASIC Public Affairs Office, December 2018), https://www.nasic.af.mil/.

7. David E. Sanger and William J. Broad, "China's Weapon Tests Close to a 'Sputnik Moment,' U.S. General Says," *New York Times*, November 3, 2021, https://www.nytimes.com/.

8. Marc Rayman, "Dr. Marc Rayman's Mission Log: Voyage of Deep Space 1," Jet Propulsion Laboratory, National Aeronautics and Space Administration (NASA) (website), August 8, 2000, https://www.jpl.nasa.gov/.

9. Clausewitz, *On War*, 119.

10. Philip S. Meilinger, "Busting the Icon: Restoring Balance to the Influence of Clausewitz," *Strategic Studies Quarterly* 1, no. 1 (Fall 2007): 117, https://www.airuniversity.af.edu/.

will surface that interrupt the smooth execution of plans.[11] As "the difficulties accumulate," actual operations deviate further and further from plans and lose effectiveness. Enough friction can disrupt an entire war plan.

Clausewitz warned friction is unavoidable. Particularly in the era of mass armies, those armies' leaders cannot perfect the conduct of war through planning and training. Instead, they must expect and tolerate friction. A general needs to understand friction in order that she or he "not expect a standard of achievement in his operations that this very friction makes impossible."[12] Clausewitz believed much of the ability to overcome friction would come from instinct and experience rather than study, as friction is the one thing that "distinguish[es] real war from war on paper."[13] He also warned no one could ever predict all friction forms.

Still, Clausewitz tried to provide some insight into the causes of friction to help leaders prepare for it, which recent scholarship usefully divides into two categories.[14] The first category involves physical difficulties such as equipment breakdown, accidents, physical exhaustion, and poor weather, which can interfere with moving and fighting. The second category includes mental difficulties such as stress, fatigue, miscommunication, and incomplete intelligence, which can cause confusion and lead to poor decisions.

Clearly, Clausewitz believed friction to be unavoidable for mass armies. The US Space Force, however, is a small, technologically sophisticated, and highly professional force. Still, the force has and will continue to experience friction. Many view the Persian Gulf War as the gold standard for the professional, technologically advanced, and efficient delivery of military power. But even that war saw friction including equipment malfunctions, lapses in intelligence, coordination problems, and poor weather.[15] Indeed, some argue the amount of friction in the Gulf War was relatively similar to the friction troops faced in World War II.[16]

Even in space, where all actions are precisely calculated, things may not always go according to plan. Space activities outside of war have shown themselves to be imperfect, unpredictable, and dangerous. Well-known examples of catastrophe in manned US spaceflight exist, such as the *Challenger* and *Columbia* space shuttle disasters. The Russian space program has had its share of tragedies too, such as the deaths of the first cosmonauts to dock with the space station Salyut and a deadly rocket explosion in the

11. Alan Beyerchen, "Clausewitz, Nonlinearity, and the Unpredictability of War," *International Security* 17, no. 3 (Winter 1992–93): 77, https://www.jstor.org/.

12. Clausewitz, *On War*, 120.

13. Clausewitz, *On War*, 119–20, 122.

14. Eugenia C. Kiesling, "On War: Without the Fog," *Military Review* 81, no. 5 (September–October 2001), 86–87.

15. Barry D. Watts, "Clausewitzian Friction and Future War," McNair Paper 68 (Washington, DC: Institute for National Strategic Studies, October 2004), 24, https://apps.dtic.mil/.

16. Watts, "Future War."

early Mars program.[17] The Apollo 13 mission, which aborted its lunar landing after an onboard explosion but ended in the safe return of the astronauts, demonstrated the value of improvising following disaster in space.

There are also many less-well-known failures in unmanned space flight, including failures to launch or orbit, malfunctions, collisions, and breakups.[18] In early 1963, radiation from an American high-altitude nuclear test disabled the first private satellite, the communications satellite Telstar.[19] In 2009, an American and a defunct Russian communication satellite collided, generating thousands of pieces of debris that will continue to orbit the Earth for decades.[20] Most recently, SpaceX lost 40 small satellites from its Starlink constellation due to a magnetic storm.[21]

In war, the unpredictability and danger involved in space operations can only be amplified, and the consequences may be more severe. This article attempts to identify some reasons military space operations may encounter friction in war. Accordingly, friction should be an important consideration in planning for and executing military space operations.

Following Clausewitz, *friction* is anything besides enemy action itself that unexpectedly impedes the planned application of military power. This article does not attempt to list all types of friction that can arise in space—an impossible task. Instead, it highlights four important sources: (1) the space environment, (2) spacecraft-maneuvering limitations, (3) space intelligence, and (4) the reliance on complex technological solutions. The article then explores the implications of friction in space for the US military.

Sources of Friction in Space

Space Environment

The first set of frictional challenges the US military faces is due to the space environment itself. Clausewitz wrote about terrestrial weather slowing down progress and preventing the friendly side from seeing the enemy in time.[22] Weather is often the first example cited when discussing the concept of friction and is recognized as a major

17. Walter A. McDougall, *The Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1985), 243–44, 430.

18. MacDougall, *Heavens and the Earth*, 183, 190; Joe Hanson, "The Forgotten Cold War Plan That Put a Ring of Copper around the Earth," *Wired*, August 13, 2013, https://www.wired.com/; and Anz-Meador, "Top Ten Satellite Breakups Reevaluated," *Orbital Debris Quarterly News* 20, no. 1–2, (April 2016), https://orbitaldebris.jsc.nasa.gov/.

19. McDougall, *Heavens and the Earth*, 358

20. Brian Weeden, "2009 Iridium-Cosmos Collision Fact Sheet," (Washington, DC: Secure World Foundation, November 10, 2010), https://swfound.org/.

21. Robin George Andrews, "Solar Storm Destroys 40 New SpaceX Satellites in Orbit," *New York Times*, February 9, 2022, https://www.nytimes.com/.

22. Clausewitz, *On War*, 120.

physical obstacle to operations. Terrestrial weather itself can impact space operations by delaying spacecraft launches or interfering with terrestrial observations of space. Similarly, space weather can slow down the progress of the intended use of military power.

Department of Defense Joint Publication 3-59 defines space weather as "the conditions and phenomena in space and specifically in the near-Earth environment that may affect space assets or space operations."[23] Space weather, which often consists of the bombardment of high-energy charged particles from the Sun and outside the solar system, can inhibit military action by degrading a spacecraft's efficiency and lifetime. In its Space Capstone Publication, the US Space Force describes space as "dynamic" and "hostile" due to "a constant barrage of radiation and charged particles capable of severely damaging a spacecraft's physical and electrical components."[24]

Additionally, according to the National Oceanic and Atmospheric Administration (NOAA) Space Weather Prediction Center, solar flares can reduce or block high-energy radio waves employed for radio communications that the military and others use.[25] Historically intense solar flares capable of disrupting satellite operations occurred in October 2003 during Operation Iraqi Freedom.[26]

Finally, the worst space weather events, coronal mass ejections (CMEs), can take out power grids, as was the case for six million Canadians in Quebec in 1989.[27] While unlikely, a record-setting CME, on the scale of the 1859 Carrington Event, a massive geomagnetic storm that caused telegraph systems worldwide to fail, "would be powerful enough to knock out electrical and communications systems across Earth for days, months, or even years—nixing power grids, satellites, global positioning system (GPS), the internet, telephones, transportation systems, banking, you name it."[28]

Like terrestrial weather, space weather can be difficult to predict. Still, its intensity is correlated with the 11-year activity cycle of the Sun. The Quebec event happened during the solar maximum, the period of greatest solar activity during this cycle. Therefore, future space war operations may be constrained by space weather, much like early British World War II bombing campaigns were by terrestrial weather.[29] At a

23. Chairman of the Joint Chiefs of Staff (CJCS), Joint Publication 3-59: *Meteorological and Oceanographic Operations* (Washington, DC: CJCS, January 10, 2018), GL-5, https://www.jcs.mil/.

24. John W. Raymond, *Spacepower: Doctrine for Space Forces*, Space Capstone Publication (Washington, DC: US Space Force, June 2020), iii, iv, 9, https://www.spaceforce.mil/.

25. "Space Weather Impacts," National Oceanic and Atmospheric Administration Space Weather Prediction Center (website), n.d., accessed May 9, 2021, https://www.swpc.noaa.gov/.

26. Robert B. Collom, "Remembering the Historic Storms of 2003," NASA History, NASA (website), last updated August 6, 2017, https://www.nasa.gov/; and Rebecca Grant, "Storms of War," *Air Force Magazine*, July 1, 2004, https://www.airforcemag.com/.

27. Sten Odenwald, "The Day the Sun Brought Darkness," NASA (website), last updated August 7, 2017, https://www.nasa.gov/.

28. Andrew May and Daisy Dobrijevic, The Carrington Event: History's Greatest Solar Storm," Space-com, May 20, 2022, https://www.space.com/; and Peter Dockrill, "Scientists Are Preparing for a Solar Storm so Powerful They're Calling It the Big One," *Science Alert*, April 8, 2016, https://www.sciencealert.com/.

29. Richard Overy, *Why the Allies Won* (New York: W. W. Norton, 1995), 108.

minimum, "having the proper understanding of space weather is critical when planning and conducting military operations. It also helps contribute to good space domain awareness, which is crucial when air and ground operators experience interference and degradation to radio signals, satellite communications, GPS signals, or radar operations."[30]

Maneuvering Limitations

Spacecraft-maneuvering limitations can cause friction as well. Except for the occasional astronaut it temporarily lends to NASA, the US military does not have people in space. Eventually it likely will, and Clausewitz's human physical exhaustion will apply to people working in free-fall or reduced-gravity environments inside vulnerable space suits. Until then, the problem of physical exhaustion in space applies not to people but to Space Force spacecraft due to their limited fuel. Spacecraft may be unable to conduct necessary tasks if they have already depleted their fuel due to unexpected maneuvers.

The Space Capstone Publication calls the space environment "contested, congested, and competitive."[31] Space is "congested" due to the proliferation of active satellites and debris along the most desirable orbits, creating the potential for unexpected collisions. A handful of collisions and near-collisions in the space age have already occurred; independent of necessary maneuvering to avoid enemy action itself, most spacecraft, with increasing frequency, must move to avoid collisions with space debris. This adds to the "physical exertion" the spacecraft experience as they deplete their cherished propellant.

Currently, except for the International Space Station, which NASA regularly resupplies, very limited refueling options for spacecraft exist.[32] Therefore, most spacecraft have limited maneuverability. Small maneuvers, such as firing onboard thrusters parallel or antiparallel to the direction of motion to slow down or speed up to avoid space debris, cost little propellant. In contrast, larger maneuvers, such as changing orbital planes, expend large amounts of fuel. Ultimately, the lifetime of many military spacecraft, unless space weather kills them first, is constrained by fuel.

Maneuvering limitations can be a source of physical friction because spacecraft may not have the maneuverability desired when operators call upon them. Perhaps more importantly, they can be a cause of mental friction. Maneuvering limitations pose difficult operational problems: when faced with the decision to maneuver, commanders must consider the effects on immediate events and on the longevity of the spacecraft and the importance of future missions. The complexity of these decisions can induce paralysis. Imperfect knowledge of a situation can lead to wrong decisions

30. US Air Force, Air Force Doctrine Publication 3-59: *Weather Operations* (Maxwell AFB, AL: LeMay Center for Doctrine Development and Education, October 28, 2020), 6.

31. Raymond, *Spacepower*, 10.

32. Sandra Erwin, "Northrop Grumman to Launch New Satellite-Servicing Robot Aimed at Commercial and Government Market," *SpaceNews*, September 23, 2021, https://spacenews.com/.

and introduce a paralysis that will "undermine one's resolve to act at all."[33] The same can be said for decisions that may permanently affect a spacecraft's future.

Space Intelligence

Third, space intelligence can cause friction. Clausewitz called intelligence a major source of friction burdened with "contradictory," "false," and "uncertain" information.[34] The seriousness of this makes "things appear entirely different from what one had expected" and "can bring military action to a standstill."[35] Scholars debate whether intelligence can be decisive for victory or defeat, but no one sees it as unimportant.[36] Intelligence failures can result in surprise attacks, inadequate or unnecessary defense preparations, and poor adaptation to enemy strategy and tactics.[37] Inaccurate intelligence can lead to war if states wrongly perceive an imminent threat or a window of opportunity, and it can prolong war by giving belligerents overly optimistic assessments of their prospects.[38]

Space intelligence is one piece of space domain awareness (SDA), a function that involves a surveillance network of satellites and ground-based radars, telescopes, and other sensors, and related systems and procedures, for monitoring and analyzing objects in space for potential threats.[39] It is a sophisticated system that "must be deliberately planned and maintained to ensure the right information is delivered to the right decisionmaker at the right time."[40]

But the current system is subject to uncertainty in the measurements of a satellite's position and velocity and does not provide complete coverage of the space environment. For instance, the system has historically had little coverage from the Southern Hemisphere—it could not continually track objects in certain parts of their orbits, though that has improved in recent years.[41]

A major driver of friction concerning the SDA mission is the uncertainty of locations of friendly and adversarial satellites and other resident space objects. Typically, the higher in altitude an object orbits, the more uncertain the Space Force SDA network is regarding that object's precise location, especially if that object modifies its orbit with maneuvers. The Space Force tracks objects with tags or unique identification

33. Watts, "Friction and Future War," 18.

34. Clausewitz, *On War*, 117.

35. Clausewitz, *On War*, 84, 117–18.

36. Robert Angevine, "*Intelligence in War: Knowledge of the Enemy from Napoleon to Al-Qaeda*, by John Keegan and *Uncovering Ways of War: U.S. Intelligence and Foreign Military Innovation, 1918–1941*, by Thomas G. Mahnken," (review) *Technology and Culture* 45, no. 4 (October 2004), https://muse.jhu.edu/.

37. Richard Betts, "Analysis, War, and Decision: Why Intelligence Failures Are Inevitable," *World Politics* 31, no. 1 (October 1978): 65–68, https://www.jstor.org/.

38. Fred Ikle, *Every War Must End*, 2nd ed. (New York: Columbia University Press, 2005), 17–37.

39. Raymond, *Spacepower*, 38; and Brian Weeden, "Space Situational Awareness Factsheet," Secure World Foundation (website), May 2017, 1, https://swfound.org/.

40. Raymond, *Spacepower,* 39–40.

41. Weeden, "Situational Awareness," 8.

codes. Unfortunately, cross-tagging, or mixing up the correct satellite tags, is an issue and source of friction.[42]

The US military should continue prioritizing SDA, but it should never expect it to be perfect. The area to be monitored is vast, and spacecraft can be designed in ways that make them more difficult to track.[43] More importantly, the fidelity of intelligence is a challenge. Even when satellites can be located and tracked, their capabilities and purposes may remain hidden. In 2017 for example, the Air Force and US Intelligence Community observed a new Russian satellite and thought they had an adequate understanding of its purpose and design. To their surprise, two other subsatellites deployed from the original.[44] Although none of these satellites were hostile, Russia proved some new technology and was able to spoof initial US attempts at analysis.

Even with fidelity, SDA will face challenges in interpreting information and divining intent. Space faces a particular challenge due to dual-use technologies. For instance, US Space Command revealed last year that China has a satellite with a robotic arm. More recently, China used a satellite to "tug" one of its other satellites into another orbit.[45] While an operator could use these capabilities for repairs or debris removal, they could also use them as weapons against enemy satellites. Communications, positioning, navigation, and timing, and intelligence, surveillance, and reconnaissance satellites can all be used for both civilian and military purposes, often at the same time, which complicates the assessment of each satellite's military utility and an adversary's strategy.

Ironically, attempting to improve understanding of the space environment can introduce friction into intelligence. The United States and its allies collect large amounts of data through their sensor networks. This introduces the problem of data processing, also called "computational friction," which is the challenge of transforming large amounts of data into usable information.[46] The problem of too much information may have replaced the problem of too little.[47]

Beyond the computational problems, an unavoidable role exists for humans in the process that can introduce friction, referred to as "information friction," caused by the

42. Phan Dao, *Automated Algorithm to Detect Changes in Geostationary Satellite's Configuration and Cross-Tagging* (Kihei, HI: Advanced Maui Optical and Space Surveillance Technologies Conference, 2015), https://apps.dtic.mil/; and Daniel L. Oltogge and Sal Alfano, *Determination of Orbit Cross-Tag Events and Maneuvers with Orbit Detective*, publication 11-413 (Noordwijk, Netherlands: International Association for the Advancement of Space Safety, 2011), https://www.agi.com/.

43. Harrison, Johnson, and Young, *Dark Arts in Space*, 17.

44. Harrison, Johnson, and Young, 22.

45. Brian G. Chow and Brandon W. Kelly, "Peace in the Era of Weaponized Space," *SpaceNews*, July 2021, https://spacenews.com/; and Theresa Hitchens, "China SJ-21 'Tugs' Dead Satellite out of GEO Belt: Trackers," Breaking Defense, January 26, 2022, https://breakingdefense.com/.

46. Paul N. Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming* (Cambridge, MA: Massachusetts Institute of Technology (MIT) Press, 2010), 84.

47. Nikolas Gardner, "Clausewitzian Friction and Autonomous Weapons Systems," *Comparative Strategy* 40, no. 1 (2021): 86–87.

"endless minor obstacles" to using information collected by advanced systems.[48] Bureaucratic processes and human biases can affect how data is collected, stored, and accessed.[49] Operators must still sift through noise, interpret information, and fill inevitable gaps.

Even artificial intelligence can introduce friction due to limits in its powers of recognition and judgment, making it susceptible to deception and introducing an element of unpredictability into its actions.[50] Operators can mitigate some of these frictional components by combining their own intuition and training with artificial intelligence. Still, this all means that the Space Force and the Joint Force should use caution when making strategic decisions based on SDA. While it can be improved, SDA will never be perfect.

Complex Technological Solutions

Finally, the Space Force faces potential frictional challenges due to an emphasis on complex technology as a solution to strategic problems. Although Clausewitz did not explicitly address this category as a source of friction, he alluded to it by mentioning that improvements in firearms had not changed the central idea of war.[51]

Of course, advanced technology will be part of everything that the Space Force does, being the first service primarily focused on the remote operation of unmanned vehicles. Even solutions that place less emphasis on technological development will require some innovation to implement. But the United States has a long history of adapting by developing the most innovative and advanced systems.[52] While advanced technology has served the nation well, it can also increase complexity and expense, lead to overconfidence in technological superiority if strategists misunderstand inherent limitations, and lead strategists to ignore other options.

The Space Force and the Joint Force must grapple with some strategic decisions about how much they want to emphasize advanced technology as the solution to military problems. While the answer to these questions will depend on technical feasibility, resource availability, and adversary capability, choosing the more technological route will also carry the danger of adding to friction.

Without question, new technologies employed correctly can help war efforts. But new technologies can also cause friction by complicating operations. During World War II, the Germans lost momentum as a result of having a "bewildering array of

48. Jon R. Lindsay, "Information Friction: Information Technology and Military Performance" (PhD dissertation, MIT, 2011), 86–87, https://dspace.mit.edu/.

49. Jon R. Lindsay, "Target Practice: Counterterrorism and the Amplification of Data Friction," *Science, Technology, and Human Values* 42, no. 6 (2017), https://journals.sagepub.com/.

50. Gardner, "Autonomous Weapons," 86–87.

51. Clausewitz, *On War*, 76.

52. Thomas G. Mahnken, *Technology and the American Way of War Since 1945* (New York: Columbia University Press, 2010).

different vehicles and engines" that complicated logistical and maintenance efforts.[53] By contrast, the Soviet Union and the United States overwhelmed Germany by mass producing a limited number of less sophisticated designs.

Complex technological solutions can increase friction in many ways. They can result in a greater susceptibility to equipment breakdown and difficulties in reconstituting. They can increase expense, the need for expertise, the demand for support and logistics, and the complexity of operations.[54] They also take time and experience to incorporate into operations, as the proper utilization of new systems is not always obvious on day one and can make integration with Allies and partners more difficult. [55] In all cases, technical solutions can make the United States overly reliant on the shiny option rather than the rugged option and can increase the difficulty of responding when friction inevitably arises.

Another source of friction associated with complex technological solutions is information classification and potential over-classification. Since the 1950s, the US military has classified most of its space technology. While the intent is obvious, classification can hinder space operations, as ground-station operators may not have identical access to program information. In a conflict situation, an operator may not have access to critical information, and this could inhibit decision-making. Current Space Force and Space Command leadership admit that over-classification with space capabilities is a problem for communication with Allies and partners and even for deterring potential adversaries, since the leaders cannot easily discuss holding capabilities at risk.[56]

A preference for advanced technological solutions can also lead strategists to disregard other options. Scholars have distinguished between three different approaches to passively defending space assets: architectural, technical, and operational.[57] Architectural and operational approaches often rely on developing simple and redundant satellite systems rather than trying to develop systems more technically advanced than those of the adversary. Of course, these also require technological innovations and may demand a more technologically advanced network, but the individual systems on orbit may have simpler technology. Solutions may also involve adjusting the entire Joint Force to be less reliant on satellites, whether by finding other systems to replace satellite services or learning to live without those services.[58]

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53. Overy, *Why the Allies Won*, 217, 225.

54. Jacob W. Kipp and Lester W. Grau, "The Fog and Friction of Technology," *Military Review* 81, no. 5 (September–October 2001): 3.

55. Kipp and Grau, "Fog and Friction," 5; and William J. Perry, "Technology and National Security: Risks and Responsibilities" (presentation, Conference on Risk and Responsibility in Contemporary Engineering and Science: French and U.S. Perspectives, France-Stanford Center for Interdisciplinary Studies, Stanford University, April 7–8, 2003).

56. Brian W. Everstine, "Space Force, SPACECOM Working on New Communication Strategy to Fight Overclassification," *Air Force Magazine*, May 3, 2021, https://www.airforcemag.com/.

57. Harrison, Johnson, and Young, *Dark Arts in Space*, 11–18.

58. Paul Scharre, "The US Military Should Not Be Doubling Down on Space," Defense One, August 1, 2018, https://www.defenseone.com/.

In short, friction will influence space operations, whether in providing services to the Joint Force or conducting counterspace or space control operations. Space friction will be one component of the larger friction that invariably affects any military operation and will induce physical and cognitive limitations that influence how military decisions are made.

Addressing Friction in Space

Most officers recognize uncertainty characterizes warfare, as reflected in popular military sayings like "fog and friction" and "no plan survives first contact." Still, all military members must also recognize that military space operations are subject to the same kinds of issues as operations in other domains, including friction, and military campaigns could suffer accordingly.

For the Joint Force, friction in space can have many of the same impacts as enemy action in space. The availability and quality of space services such as communications, positioning, navigation, and timing, and intelligence, surveillance, and reconnaissance might be impacted. Operations to protect our space assets or deny the enemy access to space might fail. The timing of space operations, and therefore the timing of other operations that rely on space, can be affected. All these frictional sources can hinder military campaigns, disadvantaging the United States in attritional warfare and endangering the objective of space control.

Quantifying the total frictional elements' impact on space operations is difficult, but some elements seem more likely to affect operations than others. Space weather and maneuvering limitations have impacted spacecraft operations but, to our knowledge, have not yet crippled military space operations. But intelligence shortcomings in space are frequent, and disastrous results from an overemphasis on complex technological solutions may occur any day, as expensive and sophisticated satellites serve as "large, big, fat, juicy targets."[59]

Fortunately, US Space Force seems to be moving toward distributed or proliferated constellations or at least acknowledging that a trade-off exists between expensive, complex satellites more resistant to space weather and cheaper, simpler satellites less susceptible to antisatellite attacks. The service has recognized all these problems and has dedicated major engineering efforts to mitigate them. Still, they are problems for the application of military force in space.

What can the Joint Force do to prepare for friction in space operations? To some extent, simply being aware of the problem is part of the solution. Clausewitz warned commanders about friction, so they would be flexible and prepared to respond. In the same way, planners and commanders must anticipate friction in space operations and the terrestrial operations that depend on them.

59. Sandra Erwin, "STRATCOM Chief Hyten: 'I Will Not Support Buying Big Satellites That Make Juicy Targets,'" *SpaceNews*, November 19, 2017, https://spacenews.com/.

Beyond awareness, many of the Defense Department's preparations for protecting access to space, or operating after losing space capabilities to enemy action, also apply to overcoming friction. Space Force officers know space weather, maneuverability limitations, and shortcomings in space intelligence. Their planners and Air Force Research Laboratory's Space Laboratories are actively working to address these problems.[60] Still, Clausewitz tells us friction in military operations will always exist, a fact which leads to the notion of frictional tradeoffs.

Frictional Tradeoffs

Some argue friction in warfare has not been meaningfully reduced in centuries despite technological advances that greatly improve battlefield awareness and command and control.[61] Often, attempts to reduce friction result in trading one type of friction for another. Accordingly, the Department of Defense and US Space Force should not lose sight of frictional elements they might create as they work to eliminate others. Whatever the specific circumstances, decisions about the future of military space forces will inevitably involve frictional tradeoffs. These tradeoffs center around technology, operations, and culture.

Technology

Many of the problems discussed will require technological solutions. Advanced technology will be part of everything the Space Force does. For example, electric propulsion may be a solution to maneuvering limitations. It is more efficient but slower than chemical propulsion and can be a great substitute if the mission allows a later arrival to the destination. It has been used on some spacecraft and will be used for the Cislunar Highway Patrol Satellite that must maneuver often.

Another solution is a space tug. Like their naval counterparts, these little but powerful spacecraft can connect to other spacecraft and provide needed services like propulsion. Additionally, with the proper equipment on board, such as a 3D printer, space tugs could also perform spacecraft repair operations.[62] The United States recently released a national strategy for developing in-space servicing, assembly, and manufacturing capabilities.[63]

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60. US Air Force Research Laboratory (AFRL), "Air Force Research Laboratory," US Air Force (website), last updated October 2021, https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104463/air-force research-laboratory/.

61. Watts, "Friction and Future War," 81.

62. Aaron Rogers et al., "SHERPA: A Flexible, Modular Spacecraft for Orbit Transfer and On-Orbit Operations" (presentation, 17th Annual American Institute of Aeronautics and Astronautics, Utah State University Conference on Small Satellites, Logan, UT, August 2003), https://digitalcommons.usu.edu/.

63. In-Space Servicing, Assembly, and Manufacturing Interagency Working Group of the National Science and Technology Council, *In-Space Servicing, Assembly, and Manufacturing National Strategy* (Washington, DC: The White House, April 4, 2022), https://www.whitehouse.gov/.

Moreover, technical and design solutions can be used to adapt to friction. For example, the Space Force can develop reconfigurable satellites that can modify missions in orbit and plug-and-play satellites that can simplify design processes and manufacturing.[64] The service can shift from utilizing single, large spacecraft for specific mission objectives to a constellation of smaller, redundant ones capable of flexing objectives.

When friction like space weather degrades one system, the various missions can continue. Space intelligence problems can be relieved with an improved architecture incorporating new capabilities for identifying and characterizing space objects and integrating allied and commercial information. The Department of Defense is also seeking technological solutions to conducting war without space. For example, the Defense Department is exploring a meshed communication network called the Joint Aerial Layer Network (JALN) that is less reliant on satellite communications. Instead, the nodes of that network could come from airborne or ground-based platforms.[65]

Still, technological solutions introduce their sources of friction. The Space Force and Joint Force must implement solutions that consider the dangers of adding complexity to operations, logistics, and interoperability. In particular, adding more information does not necessarily improve understanding, even with artificial intelligence and machine learning methods for processing the information. Machines cannot remove the human decision-maker from the loop and may introduce other sources of friction.[66]

Operations

The Department of Defense's preparations to operate when enemy action degrades space capabilities could also help overcome friction. During certain wargames, with limited success, participants have attempted to overcome and prevail despite losing GPS. The US Marine Corps consistently conducts parts of its large-scale training exercises with degraded GPS and communications.[67] Similarly, in 2016, the US Naval Academy brought back celestial navigation to its curriculum after a hiatus that lasted almost 20 years.[68] Space aggressor squadrons support the Air Force in training for

64. UK Space Agency, "World's First Fully Flexible Satellite Lifts Off," July 31, 2021, https://www.gov.uk/; and James C. Lyke, "U.S. Air Force's Plug-and-Play Satellites," IEEE Spectrum, July 20, 2012, https://spectrum.ieee.org/.

65. Stew Magnuson, "U.S. Forces Prepare for a 'Day without Space,'" *National Defense Magazine*, February 1, 2014, https://www.nationaldefensemagazine.org/.

66. Gardner, "Autonomous Weapons."

67. Magnuson, "Day without Space."

68. Lily Hay Newman, "Naval Academy Brings Back Celestial Navigation Training in Case of a Cyberattack on GPS," *Slate*, October 9, 2015, https://slate.com/.

denied environments, and the US Army Space and Missile Defense Command does the same for the Army.[69]

Space friction or enemy action may also result in certain military units or members being cut off from others with little or no way to communicate. The idea of mission command exists DoD wide. Under mission command orders, leadership is more decentralized. Strategic leaders provide the commander's intent to operational and even tactical leaders, who are then trusted to carry out that intent, especially when they can no longer communicate with the leaders above them.

Mission command can also introduce friction. Under mission command, commanders may be forced to act without enough information about the battlefield. Decisions are made piecemeal, and units cannot coordinate adjustments to larger plans.[70] This is especially problematic if commanders need synchronization for space-surface operations. A lack of coordination or understanding can be a recipe for chaos. The same issues affect space-space operations, where any action will likely have enormous informational demands and terrestrial impacts. Moreover, space operations carry political sensitivities that make commanders wary of devolving authority and can result in unwanted strategic effects if they do. Again, commanders must take care when making these frictional tradeoffs.

Culture

The Space Force should do its best to plan and train toward contingencies as it develops its spacepower strategy, but it should also accept that this planning and training will inevitably fall short. Although it can gain some experience through wargaming, much of the experience Clausewitz calls for cannot be earned until the actual war starts, as every war is unique and brings different challenges. Therefore, the Space Force must develop a culture of risk-taking and adaptability to the numerous forms of friction that will arise.

Indeed, the Space Capstone Publication states Space Force values include "prizing risk-taking as opportunities to rapidly learn and adapt," but penning words today is much easier than executing war tomorrow.[71] The force's acquisition approach to developing new satellites specifically needs smarter risk-taking and adaptable methods. Military planners and leaders must avoid falling into a trap of thinking that operations will go exactly as planned.

69. Arielle Vasquez, "527th SAS: Preparing Warfighters Now, into the Future," 50th Space Wing Public Affairs, February 2, 2018, https://www.schriever.spaceforce.mil/; and US Army Space and Missile Defense Command, "Disrupted Space Operational Environment," US Army (website), August 7, 2018, https://www.army.mil/.

70. Lawrence Skelly, "Getting the Conditions Right: Seeking Competitive Advantage in Military Operations through a Leadership Approach" (presentation at the Midwest Political Science Association Conference, Chicago, IL, April 2019).

71. Raymond, *Spacepower*, vii.

Of course, inculcating a certain strategic culture can be difficult, and there are contradictory impulses in the type of culture needed. Some have characterized space operators with the mentality of engineers and checklist-focused service providers.[72] With the growth of threats to space systems, military leaders have called for the creation of a war-fighter mentality within the Space Force that recognizes the military consequences of actions in space and reacts to interruptions to services as if they are potentially from enemy action. But it is not clear which culture can better handle the friction problems. While Guardians should absolutely understand their roles in supporting war-fighting operations, maneuvering through friction may still require some elements of an attitude of trying to "keep the lights on."

Conclusion

Unlike strategies in other war-fighting domains except cyberspace, spacepower strategy is in its infancy. While the Space Force continues to develop its strategy, technologies, and culture, it must not forget to consider certain friction elements. Friction will make operations and campaigns unpredictable, requiring an adaptable force if future space war occurs. Ultimately, the Space Force should look for ways to minimize its friction while recognizing it will have to deal with the unexpected. **Æ**

72. Kenneth Grosselin, "A Culture of Military Spacepower," *Air & Space Power Journal* 34, no. 1 (Spring 2020), https://www.airuniversity.af.edu/; and William D. Sanders, "Space Force Culture: A Dialogue of Competiting Traditions," *Air & Space Operations Review* 1, no. 2 (Summer 2022), https://www.airuniversity.af.edu/.