Space Systems and Operational Art

A Monograph

by

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2018

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
24-05-2018

2. REPORT TYPE
Master's Thesis

3. DATES COVERED *(From - To)*
JUN 2017 – MAY 2018

4. TITLE AND SUBTITLE
Space Systems and Operational Art

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
MAJ Jerry V. Drew II

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Command and General Staff College
ATTN: ATZL-SWD-GD
Fort Leavenworth, KS 66027-2301

8. PERFORMING ORG REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
School of Advanced Military Studies

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release; Distribution is Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
To optimize the employment of space systems in the multi-domain conflicts of the future, understanding how space systems relate to military operations is more necessary than ever. The theoretical concepts of systems theory and operational art provide the basis for considering how such systems might be employed in both their traditional role as force enablers and in a cross-domain or multi-domain capacities. Indeed, given the current and anticipated demands for Joint capabilities, an application of operational art specific to the space domain is neither adequate nor desirable for the operational artists who must consider the employment of space systems as means. Fortunately, theory, history, and doctrine provide a guide for how such an artist might plan for and synchronize space systems within the framework of multi-domain operational art to achieve strategic ends.

15. SUBJECT TERMS
Space; Systems Theory; Operational Art; Satellite; Cross-domain; Multi-domain; Jomini

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					MAJ Jerry V. Drew II
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. PHONE NUMBER *(include area code)*
(U)	(U)	(U)	(U)	43	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

Monograph Approval Page

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Monograph Title: Space Systems and Operational Art

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The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the US Army Command and General Staff College or any other government agency. (References to this study should include the foregoing statement.)

Abstract

Space Systems and Operational Art, by MAJ Jerry V. Drew II, US Army, 43 pages.

To optimize the employment of space systems in the multi-domain conflicts of the future, understanding how space systems relate to military operations is more necessary than ever. The theoretical concepts of systems theory and operational art provide the basis for considering how such systems might be employed in both their traditional role as force enablers and in a cross-domain or multi-domain capacities. Indeed, given the current and anticipated demands for Joint capabilities, an application of operational art specific to the space domain is neither adequate nor desirable for the operational artists who must consider the employment of space systems as means. Fortunately, theory, history, and doctrine provide a guide for how such an artist might plan for and synchronize space systems within the framework of multi-domain operational art to achieve strategic ends.

Contents

Acknowledgements

In many respects, this paper represents the culmination of the last seven years of my professional development. Since I became a Space Operations officer, I have repeatedly asked and been asked "What does an Army Space Operations officer do?" The better questions may be "What *should* an Army Space Operations officer do, and *how*?" My desire to answer these questions guided me through a study of spacecraft engineering at the Naval Postgraduate School (NPS), the study of military art and science at the Command and General Staff College (CGSC), and the study of operational art at the School of Advanced Military Studies (SAMS). While I cannot possibly thank all the people who have contributed to this journey, several individuals do deserve thanks for their direct support throughout this year at SAMS.

First and foremost, I need to thank my wife Meagan and our children—Jerry, Clara, Marian, and Laurel. They have made this time at Fort Leavenworth tremendously special. Second, I would like to thank my monograph director, Dr. Scott Gorman, for his constructive feedback and encouragement throughout the process. Third, I need to thank my seminar leadership, Colonel J. Scot Davis and Dr. Bruce Stanley whose insights, particularly during the exercises and the Evolutions of Operational Art phase of the course, helped me connect the dots on several key ideas. Finally, I would like to thank three previous professors, Dr. Sean Kalic and Dr. Dean Nowowiejski at CGSC and Dr. J. Clay Moltz at NPS. All provided me the opportunity to build a sound historical foundation and develop my own ideas on military space applications.

Acronyms

ADP	Army Doctrine Publication
ADRP	Army Doctrine Reference Publication
ASAT	Anti-satellite
CGSC	Command and General Staff College
CLOC	Celestial Line of Communication
CZOC	Celestial Zone of Communication
DARPA	Defense Advanced Research Projects Agency
DSC	Defensive Space Control
EMP	Electromagnetic Pulse
ETS-VII	Engineering Test Satellite-Seven
EUR	Europe
EW	Electronic Warfare
FM	Field Manual
GEO	Geosynchronous Orbit
GWOT	Global War on Terror
JP	Joint Publication
JTAGS	Joint Tactical Ground Station
LEO	Low-Earth Orbit
LOC	Line of Communication
LOO	Line of Operation
MEO	Medium-Earth Orbit
MW	Missile Warning
NPS	Naval Postgraduate School
OBJ	Objective
OSC	Offensive Space Control

PAC	Pacific
PNT	Position, Navigation, and Timing
SAINT	Satellite Inspector
SAMS	School of Advanced Military Studies
SATCOM	Satellite Communications
SDI	Strategic Defense Initiative
SIGINT	Signals Intelligence
TAA	Tactical Assembly Area
THEL	Tactical High Energy Laser
ZOC	Zone of Communication
ZOO	Zone of Operation

Illustrations

Chapter One: Introduction

More than ever, space systems are essential to US military operations. Satellites, ground stations, end-user equipment, and the network architectures that connect them enable a distinctly American way of conducting global operations. While the United States has long enjoyed a relative advantage within the space domain, the capabilities of adversaries to deny, degrade, disrupt, or destroy US space assets have significantly expanded in the past two decades. Anti-satellite systems, jammers, cyber action, and nuclear threats place US space systems in jeopardy and require serious consideration. Against a near-peer enemy, the United States will not enjoy uninhibited access to its space systems. To gain and maintain a relative advantage, therefore, military forces must link tactical actions—including those of space systems—and strategic ends through the employment of operational art.

The employment of space systems in the multi-domain battles of the future requires an understanding of how space systems contribute or could contribute to the employment of operational art. How should the operational artist employ space systems within the framework of operational art? It seems reasonable that, either within the space domain or in conjunction with multi-domain forces, the role of space systems within the framework of operational art is to provide an asymmetric advantage to the belligerent who can more successfully synchronize those assets.

There is considerable literature available on both the strategic and tactical aspects of space operations. In addition to government documents like the National Security Space Strategy, major academic works have focused on the strategic and political aspects of the space domain.[1] Much of the professional literature produced by military practitioners, on the other hand, has focused on the tactical exploitation of space systems (e.g., Air University's *Space Primer,* a host

[1] See, for example, from the Air University, Everett Dolman, *Astropolitik: Classical Geopolitics in the Space Age* (London: Frank Cass, 2002); from the Naval War College, Joan Johnson-Freese, *Space as Strategic Asset* (New York: Columbia University Press, 2007); from the Naval Postgraduate School, James C. Moltz, *The Politics of Space Security*, 2nd ed. (Stanford: Stanford University Press, 2011).

of articles in the *Army Space Journal,* and multiple master's degree theses and monographs from both the Naval Postgraduate School and the Command and General Staff College). While these works sometimes hint at the possibility of synchronizing tactical action to achieve strategic ends, a practical exploration of space systems and operational art remains unwritten.

The literature of operational art itself has a long history, stretching at least as far back as the Napoleonic Wars. This monograph particularly employs the theoretical writings of Baron Antoine Henri Jomini, the Swiss general and theoretician who published his *Art of War* in 1838. Like his contemporary, the Prussian general Carl von Clausewitz, Jomini was concerned primarily with land warfare. Nonetheless, his writings are useful to this monograph in two distinct ways. First, several Jominian concepts are applicable to space systems in modern warfare (as covered in chapter five). Second, like Clausewitz, Jomini continues to influence modern military doctrine and theoreticians of operational art. Within the realm of military space literature, Everett Dolman's *Astropolitik* makes reference to the sea power theory of Alfred Thayer Mahan, himself a disciple of Jominian thought.[2] Furthermore, John Klein's *Space Warfare* leverages the writings of Sir Julian Corbett whose *Some Principles of Maritime Strategy* was a reaction to Mahanian thought.[3] When taken as a whole, the existing body of theory provides rich source material from which to discuss military space systems within the larger context of operational art.

An exploration of theoretical concepts, doctrinal terms, and historical examples provides the method through which to evaluate the hypothesis that the employment of space systems through operational art provides an asymmetric advantage. Examining operational art vis-à-vis military space systems requires settling on a series of definitions—the goal of chapter two. First, a theoretical discussion of space systems requires an invocation of systems theory and a conceptual explanation of what constitutes space systems. Second, operational art itself requires a preliminary discussion of tactics and strategy. While informed by US military doctrine and a

[2] Dolman, *Astropolitik*, 33.

[3] John J. Klein, *Space Warfare* (New York: Routledge, 2006), 3.

theoretical debate on the subject, a practical definition of operational art is necessarily synthetic. Since tactics depend on the means available, a discussion of means follows. Chapter three addresses enabling means, and chapter four addresses hostile means.

With the means laid out, a discussion of the ways follows in chapter five. As the definition of operational art in chapter one implies, the ways to employ the means depend upon the desired ends. To achieve the desired ends, an imaginative operational artist may link ends to means in a large number of combinations. Although the employment of space systems in large-scale combat operations has a limited (and often classified) history, examples provide considerable evidence on how belligerents have employed space systems in the past.[4] In many historical cases, the effects of space systems have enabled synchronization by virtue of their primary functions (the use of satellite communications for command and control, for example). Synchronizing tactical actions in time, physical space, and purpose *through the use of* space systems implies operational art but not necessarily operational art within the space domain or synchronization of space systems themselves. In a more complex evolution, then, the operational art of the space domain must include the synchronization of forces not only *through* the use of space systems, but the synchronization of tactical actions *of* and *against* space systems themselves. With a theoretical, doctrinal, and historical foundation established, a plausible operational scenario suggests how an operational artist may conduct such synchronization to achieve the desired strategic ends. In the multi-domain battles of the future, space systems increase options for the operational commander while also imposing dilemmas on the enemy, and this monograph explains how that can happen.

[4] "Large-scale combat operations occur in the form of major operations and campaigns aimed at defeating an enemy's armed forces and military capabilities in support of national objectives." US Department of the Army, Field Manual (FM) 3-0, Operations (Washington, DC: Government Printing Office, 2017), 1-1.

Chapter Two: Defining Space Systems and Operational Art

> When a war is decided upon, it becomes necessary to prepare not an entire plan of operations—which is always impossible—but a system of operations in reference to a prescribed aim; to provide a base, as well as all the material means necessary to guarantee the success of the enterprise.
>
> —Baron Antoine Henri Jomini, *Art of War*

Introduction

From his military experience, Jomini understood warfare as an interaction of complementary functions that comprised a system of operations. In his view, a successful commander understood both how to create a system and how to employ it effectively. While a simple notion, the complex operating environment of today inhibits a commander from understanding the entire system of operations at his disposal. As a subset of the system of operations, space systems require unique consideration. This chapter explores a definition of systems theory and the application of those ideas to space systems. Discussions on the definitions of strategy, tactics, and operational art follow with consideration of current military doctrine and other theoretical writings. Finally, the chapter concludes with a consideration of space systems as means.

Defining Space Systems

First, while multiple definitions of a system exist, this monograph follows Alex Ryan's definition of a system as a "representation of an entity as a complex whole open to feedback from its environment."[5] In the discussion of military space operations, a satellite provides a ready example of a system that consists of multiple subcomponents. One may view each of the satellite's subcomponents—the guidance and control subsystem, for example—as a system in itself. Oppositely, multiple satellites constitute a system of satellites or a constellation.

[5] Alex Ryan, "What is a Systems Approach?" last modified September 10, 2008, 28, accessed November 1, 2017, https://arXiv:0809.1698v1 [nlin.AO].

While a strength of systems theory is that it allows for simplifying assumptions, it also requires the practitioner to be cognizant of those assumptions.[6] In the context of military space systems, specific definitions of the system become particularly important. To continue along with the theme of satellites, a system definition that considers a constellation composed of many satellites may have utility, but such a model lacks fidelity. Constellations depend upon ground stations, radio frequencies, and a multitude of personnel to complete their missions. It is in this broader sense that the idea of space systems becomes particularly useful to the operational artist.

Importantly, the broader definition of space systems precludes the use of domain-specific models for three reasons. First, the satellites themselves reside in outer space, but control stations and downlink sites exist on land, sea, and in the air. Second, the network architectures that make the satellites useful take advantage of the electromagnetic spectrum and depend upon data routing and processing by a variety of hardware and software components—elements of the cyber domain. Finally, systems like jammers, missiles, and even nuclear weapons may operate from, through, or in the other domains. If the effects of such systems occur within the space domain, they may fall under the rubric of space systems. In general, then, discussions of the space domain imply the cross-domain nature of space systems. The operational artist, therefore, must be aware of the interconnected nature of space systems, even if there are practical limits to how holistically one can define such systems.

Defining Strategy, Tactics, and Operational Art

Because the meaning of strategy has changed over time, and because strategy can take on multiple meanings, it is necessary to define strategy as used in this monograph. Joint Publication 1-02, Department of Defense Dictionary of Military and Associated Terms, defines strategy as "a prudent idea or set of ideas for employing the instruments of national power in a synchronized

[6] Ryan, "What is a Systems Approach?" 31.

and integrated fashion to achieve theater, national, and/or multinational objectives."[7] This general definition considers all elements of national power while avoiding the specific, political nature of the objectives. In an alternative definition Dolman suggests that the strategist determines how to apply the available means to achieve the desired political intent.[8] Without invalidating either definition, one may consider military strategy as the activity that concerns itself particularly with application of military means to achieve political ends.[9] This definition of military strategy highlights the importance of employing means. Doctrinally, tactics is "the employment and ordered arrangement of forces [i.e. means] in relation to each other."[10]

As with definitions of strategy, definitions of operational art as a linkage between strategy and tactics shed light on the discrepancies that arise among various uses. In Joint doctrine, for example, operational art is "a cognitive approach by commanders and staffs—supported by their skill, knowledge, experience, creativity, and judgement—to develop strategies, campaigns, and operations to organize and employ military forces by integrating ends, ways, and means."[11] The US Army builds upon the Joint definition but adds an important clarifier: "For Army forces, operational art is the pursuit of strategic objectives, in whole or in part, through the arrangement of tactical actions in time, [physical] space, and purpose."[12] The campaigns and

[7] US Department of Defense, Joint Staff, Joint Publication (JP) 1-02, *Department of Defense Dictionary of Military and Associated Terms* (Washington, DC: Government Printing Office, 2016), 227.

[8] Everett Dolman, *Pure Strategy: Power and Principle in the Space and Information Age* (New York: Routledge, 2005), 14; Hew Strachan, *The Direction of War: Contemporary Strategy in Historical Perspective* (Cambridge: Cambridge University Press, 2013), 12.

[9] In the quest for precise definitions, it is interesting to note that Dolman describes that which is to be obtained as both the "intent of policy" and the "political aims" (Dolman, *Pure Strategy*, 14). Strachan and joint military doctrine refer to the same concept as "ends" (Strachan, 12). If strategy is "in pursuit of continuing advantage," as Dolman claims, then any "ends" are ephemeral.

[10] Here the Joint force and the Army share a common definition. US Joint Staff, JP 1-02, *Department of Defense Dictionary of Military and Associated Terms 2016*, 234; US Department of the Army, Army Doctrine Reference Publication (ADRP) 1-02, *Terms and Military Symbols* (Washington, DC: Government Printing Office, 2011), 1-33.

[11] US Joint Staff, JP 1-02, *Department of Defense Dictionary of Military and Associated Terms 2016*, 174.

[12] US Department of the Army, Army Doctrine Reference Publication (ADRP) 3-0, *Unified Land Operations* (Washington, DC: Government Printing Office, 2012) 1-13.

operations implied by the Joint definition of operational art pursue either strategic or operational objectives, but the Army's version of operational art hinges on the pursuit of strategic objectives alone. Confusingly, though, Army doctrine claims that operational art "applies to all levels of warfare, strategic, operational, and tactical."[13]

If the doctrine of operational art lacks clarity, and if doctrine is an attempt to synthesize theory with historical lessons, a return to theory may aid in the quest for clarity. From theoretical writings, cognitive tension between the strategic and the tactical seems to be the link that provides a starting point for a practical definition of operational art. For the American theorist and practitioner Huba Wass de Czege, operational art does not correspond to the operational level of warfare but is a cognitive process that balances strategic and tactical reasoning. Strategy keeps in mind the ultimate goal, is emergent, and must be reframed periodically while tactics are the everyday actions that develop the situation.[14] The Israeli soldier and writer Shimon Naveh developed a set of criteria to determine whether a military action was "operational" (as opposed to tactical or strategic). The first of these criteria was the existence of cognitive tension between "the general orientation towards the strategic aim and the adherence to the tactical missions."[15] In this sense, Wass de Czege's and Naveh's views align with the notion that the primary goal of operational art is to link the strategic to the tactical, a notion that Army doctrine shares.

A synthetic definition of operational art, then, must include several key elements. First, it is a cognitive process of commanders and staff, the operational artists engaged in the creative

[13] Ibid., 2-1.

[14] Huba Wass de Czege, "Thinking and Acting Like an Early Explorer: Operational Art is not a Level of War," *Small Wars Journal*, accessed August 11, 2017, http://www.smallwarsjournal.com.

[15] Shimon Naveh, *In Pursuit of Military Excellence: the Evolution of Operational Theory* (London: Frank Cass, 1997), 13.

act.[16] Second, the process requires an understanding of strategy as derived from policy. In the case of military operations, the operational artist must specifically understand both the policy and the strategy. Third, the operational artist must have an in-depth understanding of tactics, which requires an understanding of the various means available.[17] Means include personnel, equipment, and supplies and may be employed in various ways. The means (and thus the ways) available to the operational artist will likely depend upon the echelon at which the operational artist is operating. It is important to note, however, that echelon (or level) is not the operative principle in this definition of operational art; the operative principle is the ability to link strategic ends with tactical actions. As the Army and Joint definitions suggest, integrating these means and ways in a synchronized manner across domains produces the greatest effect—a concept analogous to Jomini's notion of massing at the decisive point.[18]

Conclusion: Space Systems as Means

The previous discussion has proposed functional definitions for space systems and operational art. In their multiple forms, space systems are available means that the operational artist may choose to employ in a variety of ways to meet the ends of military strategy. According to the derived concept of operational art, this employment is necessarily an act of creative cognition that involves multiple people, many of whom will lack familiarity with military space operations. A continued discussion of the role of space systems in operational art, then, requires a discussion of the means available.

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[16] One definition of an operational artist is the individual who interfaces with policy for means. While an Eisenhower or a Westmoreland may be an operational artist, such a definition negates the value of a creative staff, which the joint definition of operational art acknowledges. See Stephen G. Lauer, "The Tao of Doctrine: Contesting an Art of Operations," *Joint Forces Quarterly* 82 (3rd Quarter 2016): 118-124, accessed August 12, 2017, http://ndupress.ndu.edu/Media/News/Article/830866/the-tao-of-doctrine-contesting-an-art-of-operations/.

[17] US Army, ADRP 1-02, (2011), 1-22; US Joint Staff, JP 1-02, *Department of Defense Dictionary of Military and Associated Terms 2016*, 234.

[18] J.D. Hittle, ed., *Jomini's Art of War* (Harrisburg: Stackpole, 1965), 70.

Chapter Three: Enabling Means

> From an operational viewpoint, tomorrow's most pressing requirement is to make space systems more available and "user-friendly" to battlefield commanders.
>
> —General John L. Piotrowski, Jr.
> Commander-in-Chief, US Space Command, 1988

Introduction

Space as a warfighting domain is not separable from the other domains because space systems include components that reside in all of the other domains. Furthermore routine functions of spacecraft or other means (such as anti-satellite missiles) in space depend upon operations in one or more of the traditional domains. One may divide the general category of space systems into two different categories of means, enabling means and hostile means. This chapter addresses enabling means, while chapter four addresses hostile means. Enabling means do not cause damaging effects to enemy space systems but include the various uses of friendly space systems in support of multi-domain military operations. Enabling means include environmental monitoring; missile warning; intelligence collection; satellite communications (SATCOM); position, navigation, and timing (PNT); space situational awareness; defensive space control (DSC); launch and on-orbit operations.[19]

Enabling means are those space system capabilities that Joint forces use to enable the conduct of their own operations. As the epigraph attests, the integration of these capabilities has served as a major goal for the Joint force since the 1980s, and much writing, particularly since the beginning of the Global War on Terror (GWOT), has explored how the Joint force may take advantage of the products provided. In the contemporary force, intelligence staffs routinely

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[19] The terms "enabling" and "hostile" are not doctrinal, but I have picked those labels because I believe they convey the nature of the two categories. Joint doctrine defines the space mission areas as space situational awareness, space force enhancement (intelligence, surveillance, and reconnaissance; missile warning, environmental monitoring, satellite communications; and position, navigation, and timing), space support (launch and on-orbit operations), and space control (both defensive and offensive). I have chosen to include DSC with enabling means while including offensive space control (OSC) as a hostile means. US Department of Defense, Joint Staff, Joint Publication (JP) 3-14, *Space Operations* (Washington, DC: Government Printing Office, 2013), II-4 to II-9.

incorporate space-based products into their repertoire, Space Operations officers model the effects of terrain and enemy activity on PNT accuracy, missile warning systems enjoy well-established dissemination architectures, and SATCOM—both military and civilian—enable global communications and serve as a conduit for cyber operations. While such tactical functions are indispensable to modern military operations, operational art demands a more conceptual view of how to apply these capabilities in relation to capabilities in other domains.

A Visualization Tool

To situate enabling space systems within the framework of operational art requires a consideration of how an operational artist may synchronize them in time, physical space, and purpose with operations in other domains. The systems approach is particularly important to this method because, while it is unlikely that the operational artist will manipulate the orbits of the satellites themselves, considerations of ground station emplacement, radio frequency distribution, and potential enemy action all bear on the operational problem. The graphic below (Figure 1) is based on a synchronization and visualization tool developed during the early stages of a recent exercise at the Command and General Staff College's (CGSC's) School of Advanced Military Studies (SAMS). It is primarily a planning tool, intended to aid an operational planning team in its conceptual approach to the operational problem. It is not a tool for precise synchronization but for achieving shared understanding among the staff before beginning detailed synchronization later in the planning process. As such, the graphic provides a way to visualize space enabling operations in time and physical space—in this case, along with a ground assault—but one might easily adapt it to include operations in any or all domains.

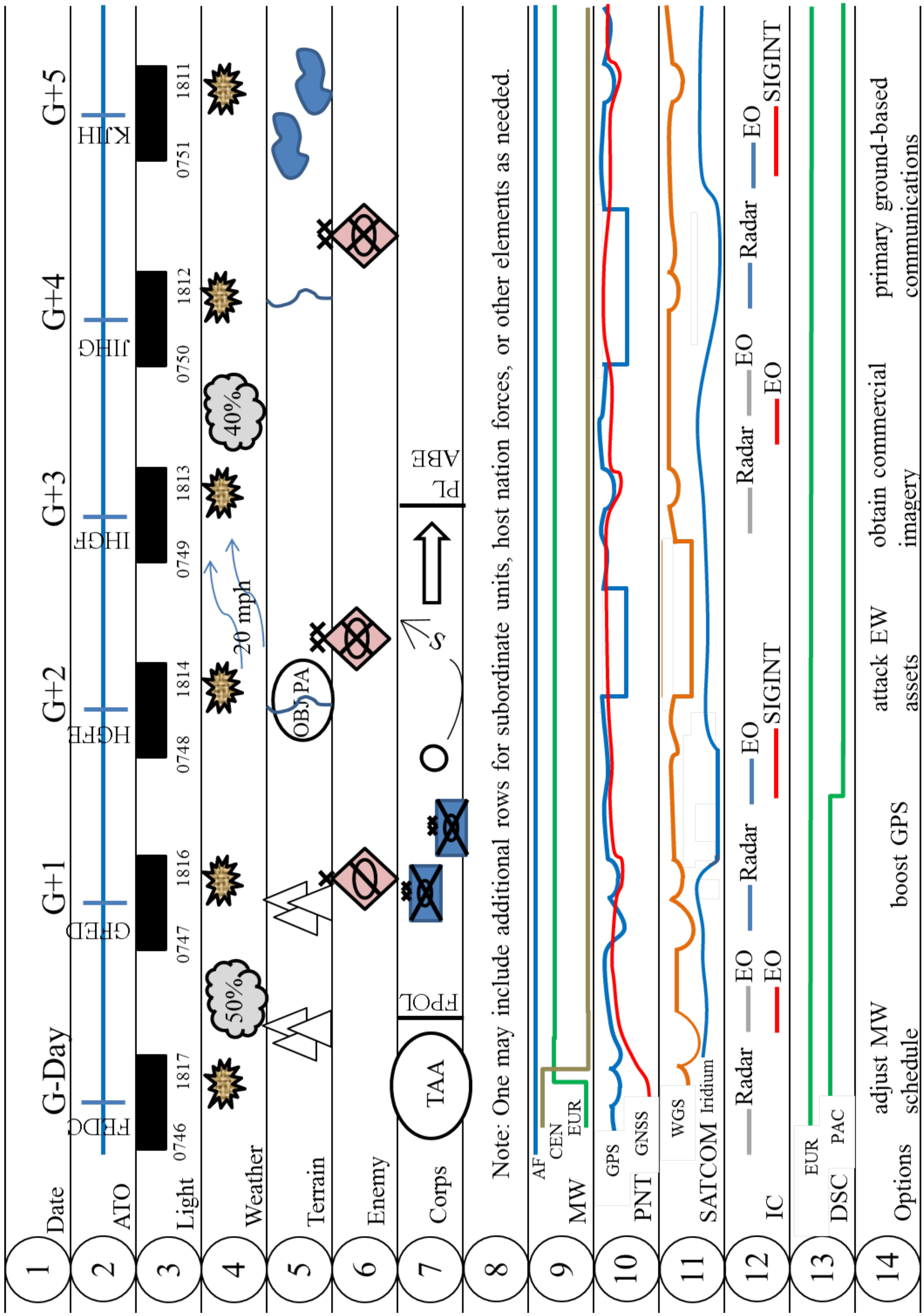

Figure 1: A Visualization Tool. *Source*: Author.

The top half of the chart depicts traditional elements considered during mission analysis, including terrain, weather, and anticipated friendly and enemy dispositions. Row (1) shows the beginning of the ground offensive (G-Day) as the primary time reference. Row (2) shows the air tasking order (ATO) cycle in its relation to G-Day. On G-Day, the combined force is executing ATO "C" while the other lettered ATOs are in various stages of planning and preparation that will lead to their future execution. The letters in Row (3) depict light data with sunrise and sunset times. The black bars represent hours of limited visibility. Row (4) is the first that incorporates a space-specific element. The bottom half of Row (4) depicts terrestrial weather including cloud cover and anticipated wind speeds. The top half shows expected scintillation (electrical charging of particles in the ionosphere) windows that may degrade satellite communications. Row (5) depicts the terrain as it affects the timing of the operation from a friendly perspective. The terrain depicted in the visualization tool corresponds to significant terrain determined from a map analysis. The map, naturally, provides a more precise tool for the detailed planning that comes later in the planning process. At this stage in the planning effort, the ground unit expects to reach mountains on G-Day and again on G+1 before reaching the main river crossing complex (Objective Pennsylvania, or OBJ PA) on G+2. Another river crossing operation follows on G+4 with marshes slowing ground maneuver on G+5.

Row (6) depicts the templated enemy in its temporal and spatial relationships. Intelligence suggests an enemy reconnaissance unit will occupy the disruption zone in the mountain valley during the hours of darkness on G+1. The main force, which is defending at the river crossing complex will be in position no later than G+2 with organic electronic warfare (including satellite and GPS ground jamming equipment) and an operational reserve within reinforcing distance. A second enemy division defends in the marshes beyond the second river crossing.

Row (7) depicts the predicted dispositions of friendly units. On G-Day, the Corps is in the tactical assembly area (TAA) with special operations forces (SOF) and military information support operations (MISO) units beginning their operations. The main body conducts a forward passage of lines (FPOL) with host nation (HN) forces as it leaves the TAA, and two infantry divisions encounter the enemy force in the disruption zone. They anticipate reaching OBJ PA on G+2. As Row (8) suggests, a more complete infographic could contain additional rows for individual maneuver units, HN forces, logistic efforts, and more. In keeping with the focus of space systems and the operational art, the additional rows include a sample of enabling means.

Visualization of Space Enabling Means

The bottom portion of the chart depicts the traditional space force enhancement missions (missile warning, PNT, SATCOM, space-based intelligence collection) and defensive space control. Row (9) depicts three different lines, each representative of the mission status of a unit engaged in satellite-based missile warning. The top line shows the US-based Air Force unit that is routinely on mission, the middle line shows the Army's Joint Tactical Ground Station in US Central Command (JTAGS-CEN), and the bottom line shows the JTAGS unit in Europe (JTAGS-EUR). In this scenario, all three are capable of providing missile warning to the task force. The rise of the "EUR" line followed by the drop of the "CEN" on G-Day indicates that JTAGS-CEN is scheduled to go off mission just after JTAGS-EUR comes onto mission. Given the high probability of enemy missile activity early in the campaign, the operational artist may request JTAGS-CEN defer its scheduled maintenance period and remain on mission. It may also be prudent to request JTAGS-EUR to come back onto mission earlier than anticipated.

Row (10) depicts a conceptual flow of the accuracy of the GPS system (top) and the enemy's global navigation satellite system (GNSS, bottom). In the course of its normal operations, the accuracy of GPS dips and rises as a result of the relative motions of the satellites. Terrain and enemy can also affect accuracy. On the GPS curve, accuracy dips on G and G+1 when friendly forces are within the mountain range, again on G+2 as the enemy main effort employs its EW assets near the river crossing site, and a third time as friendly forces near the river crossing on G+4. While such anticipated dips may affect the ground maneuver, they also carry implications for the employment of precision-guided munitions and unmanned aerial systems. Smaller dips reflect the potential effects of atmospheric scintillation—depicted in Row (3)—during early morning hours.[20] By way of comparison, the enemy's curve drops slightly on G-Day as it travels into the mountains but is predicted to remain steady throughout the remainder of the campaign. With this visualization in hand, the operational artist may begin considering how to mitigate the effects of degraded GPS for friendly forces and how to enhance degradation to the enemy's satellite navigation system.

Conceptually, Row (11) functions like Row (10). In the consideration of SATCOM, one may include any number of constellations depending on those in use by the force. In this depiction, the top line represents the availability of the Wideband Global SATCOM (WGS) system, a commonly used military space system. The bottom line shows the availability of the Iridium system, a civilian space system that the US military frequently uses. As with the GPS accuracy shown in Row (10), the WGS availability in Row (11) may dip slightly with scintillation, terrain, and enemy effects. For Iridium, the dips represent known gaps in coverage. Such forecasted gaps allow for anticipation of communications contingencies.

Row (12) depicts space-based intelligence collection platforms. As in the PNT row, blue denotes friendly while red denotes enemy. Importantly, gray denotes commercial systems that may be available to either belligerent. Such commercial imagery provides an opportunity to augment the intelligence collection of both belligerents. On G-Day, enemy electro-optical imagers are expected to photograph the corps assembly area. Commercial radar and commercial electro-optical systems may also be collecting over friendly forces during this time. Friendly radar imagery provides an option for gathering intelligence as the enemy moves into the mountain valley during the hours of darkness between G-Day and G+1. Also on G+1, enemy spacecraft

[20] "Satellite Communications," National Oceanic and Atmospheric Administration Space Weather Prediction Center, accessed November 1, 2017, http://www.swpc.noaa.gov/impacts/satellite-communications.

will be in a position to collect signals intelligence (SIGINT), a prediction that may drive plans to implement communications discipline measures. Since the orbital patterns of satellites are predictable, this general pattern repeats periodically.

Rows (10) through (12) have highlighted some of the vulnerabilities considered in the employment of space systems. Protecting those requires DSC means for monitoring SATCOM links for interference. As with Row (9) and the missile warning forces, Row (13) depicts units in various geographic positions and their operational tempo.[21] The top line represents a DSC unit stationed in Europe (EUR). It operates at a steady state, and for the sake of the infographic, it is monitoring channels on one or more WGS satellites. Similarly, the DSC unit in the Pacific (PAC) is on mission but scheduled to come off mission on G+2.

Conclusion

As a visualization and planning tool, an infographic like this can provide the valuable service of allowing conceptual synchronization that informs the subsequent employment of space systems. Throughout the execution of the operation, an updated visualization can provide insight into how the space systems are contributing to current tactical action and into how they contribute to furthering the force's progress toward its strategic objectives. Furthermore, as operational planning progresses from the conceptual to the detailed, the plan for the use of space systems—indeed for the systems of all domains—must proceed likewise.

In this respect, the graphic illustrates the multi-domain nature of modern conflict, the need to synchronize assets among the domains, and the expansion of the battlefield geometry that this synchronization entails. When the operational artist can visualize the array of friendly and enemy forces in time and physical space, vulnerabilities and opportunities become apparent. Anticipating responses to both helps generate options and potentially decision points for commanders and staffs—Row (14). In this way, the plan emerges early in the planning process,

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[21] While the units listed in the missile warning section are fielded units, the units listed in Row (13) are entirely notional.

allowing the operational artist to leverage support relationships and request resources sooner rather than later. In a similar manner, one may add additional rows to synchronize the various hostile means discussed in chapter four and the employment of the ways suggested in chapter five.

Chapter Four: Hostile Means

Introduction

In the discussion of space systems, hostile does not imply use by the enemy but rather refers to a space system or a component of a space system that can deny, degrade, destroy, or disrupt another space system. This assessment of hostile means addresses the litany of capabilities that provide viable options for employment by the operational artist. Such means include cyber activity, jamming, ground-based lasers, direct ascent anti-satellite missiles, co-orbital anti-satellite systems, and nuclear detonations. Historical examples provide context for the possible employment of such capabilities.

Cyber

Cyberspace systems, like space systems, do not fit neatly into the traditional construct of domains. Cyber actions occur among a worldwide network of devices that connect either via wire (phone lines, coaxial cable, fiber optics) or wireless means (radio waves).[22] Both wired and wireless means deserve consideration by the operational artists.

From a cyberspace system perspective, satellites and their ground stations serve as nodes of a network—part of the "infrastructure layer" of the cyberspace domain.[23] SATCOM satellites, for example, relay telecommunications data and thus serve not only as important elements of the military communications infrastructure but also as potential conduits for offensive and defensive cyber action. All satellites, whether specifically designed for communications or not, receive signals from ground control stations. The instructions may direct a change of orbit, a sensor or

[22] It is worth noting that the National Aeronautics and Space Administration (NASA) successfully tested laser communications between a spacecraft and a satellite. The Lunar Atmosphere Dust Environment Explorer (LADEE) mission carried the Lunar Laser Communications Demonstration (LLCD) in 2013. Although not yet available for military use, this technology promises higher data rates and more secure transmissions than traditional radio wave communications. See NASA, "Lunar Laser Communications Demonstration, NASA's First Space Laser Communication System Demonstration," accessed September 15, 2017, https://www.nasa.gov/sites/default/files/llcdfactsheet.final_.web_.pdf.

[23] John Sheldon, "Deciphering Cyberpower: Strategic Purpose in Peace and War," *Strategic Studies Quarterly* (Summer 2011): 98.

antenna reorientation, or a change in transmission power output. In a simple space system, one ground station transmits data to and receives data from a single ground station (see Figure 2).

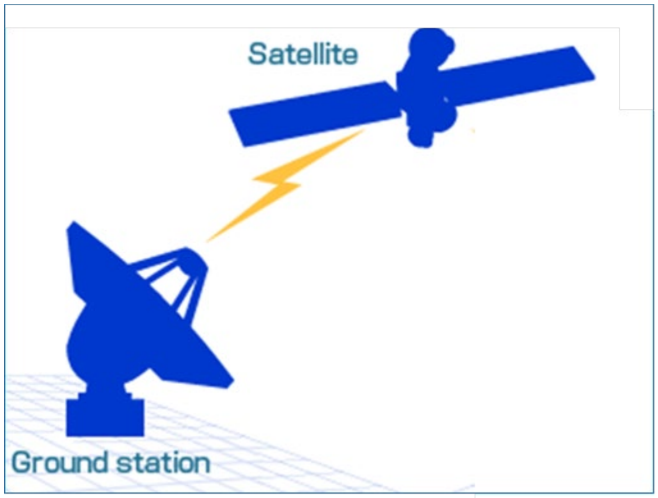

Figure 2: A System of One Satellite, One Ground Station. *Source:* Adapted by Author from Microsoft Clipart, accessed November 4, 2014, http://insertmedia.office.microsoft.com.

In more complex versions, one ground station communicates with multiple satellites, or one satellite communicates with multiple ground station (see Figure 3).

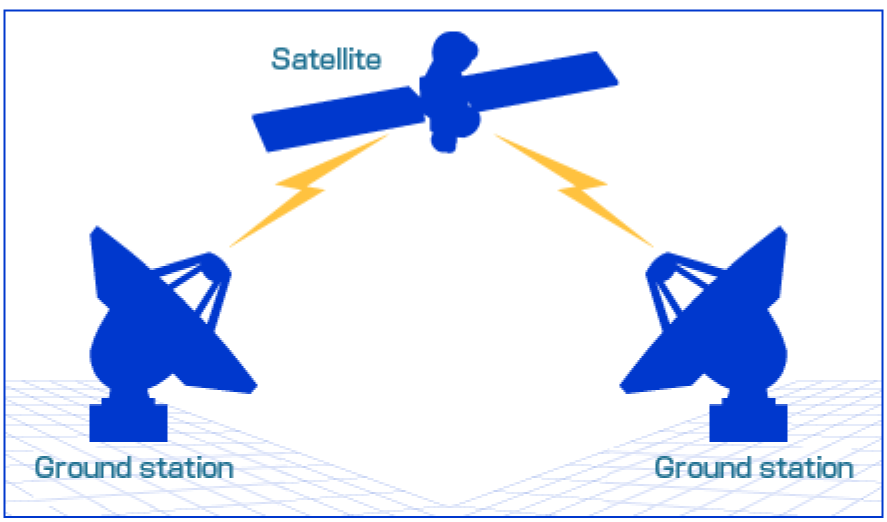

Figure 3: A System of One Satellite, Multiple Ground Stations. *Source:* Adapted by Author from Microsoft Clipart, accessed November 4, 2014, http://insertmedia.office.microsoft.com.

In the most complex version of such systems, multiple satellites communicate with multiple ground stations, the ground stations communicate with each other, and the satellites communicate with other members of their constellation or with other constellations (see Figure

4). Given the varying characteristics of such networks, the operational artist must deliberately define the system and endeavor to understand the particulars of the systems that directly affect operations.

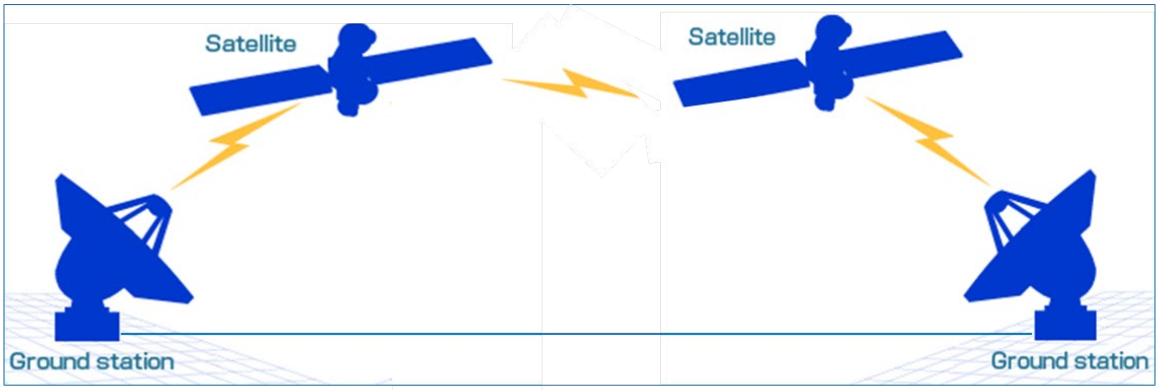

Figure 4: System of Multiple Satellites and Multiple Ground Stations. *Source:* Adapted by Author from Microsoft Clipart, accessed November 4, 2014, http://insertmedia.office.microsoft.com.

Whether performing uplink or downlink functions, ground stations depend on additional communication links (satellite, radio, or wired) to provide their data to the necessary customers.[24] If these networks link to outside networks, they are vulnerable to offensive cyber action that could penetrate a satellite control facility's network. Once penetrated, the attacker may send false instructions to a satellite or corrupt the data stream as it leaves the ground control station. A simpler approach, however, might include a cyber (or physical) attack on the ground control station, a nearby electrical power plant, or another point of vulnerability. Such an attack may not be debilitating in itself, but it would certainly induce friction into routine operations and possibly negate the advantage that a belligerent derives from a given space system. The potential latency of cyber effects suggests that a belligerent could enter a malicious program (or multiple malicious programs) into the system and not activate it until the necessary moment. The STUXNET attack

[24] Ground stations that process data from one constellation may retransmit that data via a different satellite system. In this manner, the space system under consideration may expand to include multiple constellations with the ground station deserving particular notice as a critical link in the overall system's functionality.

on Iranian nuclear enrichment facilities provides an example of such a tactic that the operational artist could synchronize with other operations to achieve a strategic objective.[25]

Jamming

Generally, jamming consists of using radio waves (a form of electromagnetic energy) to overpower the desired radio signal. A belligerent can jam a radio signal from the transmitter or at the receiver. Jammers exist on surface and air platforms, and they may affect satellite capabilities in one theater while physically operating from a separate theater.[26] In this respect, then, the effort to integrate ends, ways, and means extends beyond traditional command authorities based upon geography. This physical dispersion does not necessarily negate the possibility of synchronizing the tactical action of jamming assets with a campaign in another theater, but it does add an additional level of complexity for the operational artist.

Further complicating the matter is the fact that jammers are relatively cheap and easy to employ—especially in comparison to military satellite systems.[27] For a military that depends heavily on satellites, jammers provide an effective means for an adversary to diminish US technological overmatch. While cryptography can provide satellite signals some protection against jamming, the strength of the signal depends upon a limited power supply available on-board the satellite itself. With their readily available power supplies (generator or grid power),

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[25] David E. Sanger, "Obama Order Sped Up Wave of Cyberattacks Against Iran," *The New York Times,* June 1, 2012, accessed September 15, 2017, http://www.nytimes.com/2012/06/01/world/middleeast/obama-ordered-wave-of-cyberattacks-against-iran.html?mcubz=1.

[26] A space-based jammer is not a technical impossibility. Indeed, a communications satellite that transmits a radio signal could be aimed at another transmitting satellite to overpower the second satellite's transmission. See Kurt Schendzielos, "Electronic Combat in Space: Examining the Legality of Fielding a Space-Based Disruptive Electromagnetic Jamming System" (monograph, US Army Command and General Staff College, 1993).

[27] A Russian company called Aviaconversia began selling portable Global Positioning System (GPS) jammers in the late 1990s for several thousand dollars each. Although the effect of such jammers in the Iraq invasion of 2003 was minimal (only about four were employed), similar systems have improved and proliferated in the past two decades. Anthony Cordesman, *The Iraq War: Strategy, Tactics, and Military Lessons* (Washington, DC: Center for Strategic and International Studies, 2003), 201; "Electronic Weapons: The Antidote for GPS Jamming," *Strategy Page*, accessed October 30, 2017, http://www.strategypage.com/htmw/htecm/articles20160921.aspx.

ground-based jammers have the advantage of being able to produce greater signal strengths to provide effective jamming. While space system techniques for locating jammers fall under the heading of defensive space control, one particular type of jamming requires special mention because of its potential to affect operations.[28]

A special type of jamming called spoofing occurs when an enemy receives a signal and then retransmits the same signal after a time delay. Spoofing is particularly detrimental to GPS signals because the rebroadcast signal provides false position and timing information to tactical GPS receivers. A spoofed signal can lead to serious effects in military operations by preventing an accurate depiction of friendly forces on the common operating picture, a particularly dangerous situation when fires or medical evacuation depend on precise locations. Furthermore, the loss of precision timing means an eventual loss in radio encryption. Without the synchronization provided by the timing signal, secure communication can become difficult or even impossible.[29]

Lasers

Like jammers, lasers utilize directed energy. Unlike jammer signals, however, the energy of lasers is more focused. This focused energy is particularly useful for degrading or destroying the optical sensors of imaging satellites, but research has also explored the possibility of lasers for missile defense. In the late 1980s, the Soviet Union fielded two ground-based lasers at its test facilities in Sary Shagan, Kazakhstan to threaten US imagery satellites.[30] At the same time, the United States investigated space-based and ground-based lasers for missile defense under the

[28] Brian Garino, "Space System Threats," in *AU-18: Space Primer* (Maxwell Air Force Base: Air University Press, 2010), 276.

[29] Jerry V. Drew II, "Global Positioning System and the Maneuver Soldier," *ARMOR Mounted Maneuver Journal* (March-June 2014): 75.

[30] John M. Collins, *Military Space Forces, the Next 50 Years* (Washington, DC: Pergamon-Brassey, 1989), 138.

Strategic Defense Initiative (SDI) program.[31] Investigations of similar capabilities continued after the Cold War with programs like the Army's Tactical High Energy Laser (THEL) and the Air Force's Airborne Laser (ABL), but their extreme complexity and varying levels of political support have hindered their operationalization.[32]

Anti-Satellite Missiles

The destruction of a Chinese satellite in January 2007 by one of their own direct-ascent missiles drew the world's attention.[33] The United States followed in 2009 with the destruction of the intelligence satellite US-193 by a modified Standard Missile-3 fired from the *USS Lake Erie*.[34] While surprising to many observers, the employment of ASAT missiles originated in the 1960s. Throughout that decade, the United States deployed two types of nuclear-capable missiles theoretically able to shoot down either a satellite or an intercontinental ballistic missile (ICBM). Projects 505 and 437 employed variants of the Army's Nike Zeus missile and the Air Force's Thor missile, respectively.[35] A more recent ASAT system consisted of an ASAT launched from an F-15, which the US Air Force successfully tested in 1985.[36]

Although ostensibly an attractive option for destroying an enemy's satellites, the orbital debris produced could prohibit future satellite operations. Unlike a destroyed aircraft that immediately plummets to earth, the debris from a satellite continues to circle the earth in a gradually dispersing cloud that has the potential to increase in size as secondary and tertiary collisions occur. The Chinese satellite, for example, created over 3,000 pieces of debris large

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31 James Walker, Lewis Bernstein, Sharon Lang, *Seize the High Ground*: *the Army in Space and Missile Defense* (Washington, DC: Center of Military History, 2003), 107.

32 Bert Chapman, *Space Warfare and Defense, a Historical Encyclopedia and Research Guide* (Santa Barbara: ABC-CLIO, 2008), 141, 147-148.

33 James C. Moltz, *The Politics of Space Security*, 2nd ed. (Stanford: Stanford University Press, 2011), 297.

34 Ibid., 301.

35 Clayton K.S. Chun, *Shooting Down a 'Star:' Program 437, the US Nuclear ASAT System and Present-Day Copycat Killers* (Maxwell Air Force Base: Air University Press, 2000), 9.

36 Moltz, *The Politics of Space Security,* 202.

enough for the US Air Force's Space Surveillance Network to track with an estimated 30,000 more pieces too small to track.[37] The majority of those pieces—approximately 79%—will remain in orbit for a century.[38]

Filling commonly used orbits with debris clouds increases the probability of subsequent collisions among debris and useful satellites. From a military perspective, the destruction of a GPS satellite, for example, could cause a debris cascade throughout the GPS constellation, rendering the large portions of the constellation ineffective. Furthermore, a polluted orbital belt would impede or prevent reconstitution of a constellation at that altitude or beyond it.[39] Thus, capabilities provided by satellites in geosynchronous orbits (including the many missile warning, intelligence collection, environmental monitoring, and SATCOM satellites roughly 22,000 miles from Earth) would diminish over time because the debris fields would prevent satellite replacement.

With such significant second- and third-order effects, it seems unlikely that a belligerent with a vested interest in the space domain would readily employ an ASAT missile in a conflict. However, if the belligerent assesses that its enemy is highly dependent on space systems or that the predicted effects are irrelevant to its overall strategy, it may be inclined to employ an ASAT missile. This same rationale applies to the potential use of co-orbital ASATs and nuclear detonations in space.

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[37] Brian Weeden, "2007 Chinese Anti-Satellite Test Fact Sheet," Secure World Foundation, November 23, 2010, accessed September 18, 2017, https://swfound.org/media/9550/chinese_asat_fact_sheet_updated_2012.pdf.

[38] Ibid.

[39] Multiple organizations including NASA and the Aerospace Corporation have been investigating potential options for debris removal for years. Such options include ground-based lasers and "space tugs" to drag debris to a desired location. At present, such concepts are not viable options for debris removal, but a large-scale debris cascade would surely provide impetus for such technology to mature. See Marlon E. Sorge and Glenn E. Peterson, "How to Clean Space: Disposal and Active Debris Removal," Aerospace Corporation, December 10, 2015, accessed September 19, 2017, http://www.aerospace.org/crosslinkmag/fall-2015/how-to-clean-space-disposal-and-active-debris-removal/.

Co-orbital Anti-Satellite Weapons

Like ASAT missiles, co-orbital ASATs trace their origins to the Cold War and appear in multiple forms. Broadly, co-orbital ASATs include satellites with the means to interfere with or manipulate another satellite. The US SAINT ("Satellite Inspector") program of the early 1960s and a similar Soviet program in the late 1960s both explored putting satellites into orbit specifically to blow up the satellites of the other nation.[40] In 1975, the Soviet Union test-fired fired the Almaz ("Diamond"), a 14.2 millimeter cannon, from a manned space station.[41]

With the use of the Space Shuttle's robotic manipulator beginning in the early 1980s, the Soviet Union began accusing the US of employing dual-use ASAT technology.[42] The ability to seize and manipulate a satellite like the Hubble Space Telescope demonstrated to the Soviet Union a capability to do the same to any low-earth orbiting satellite. The continuous progression of technology has allowed for the employment of more sophisticated robotic manipulators. Launched in 1997, Japan's Engineering Test Satellite 7 (ETS-VII) first demonstrated autonomous rendezvous and docking between two spacecraft with the use of a robotic arm.[43]A decade later, the Defense Advanced Research Projects Agency (DARPA) launched the Orbital Express mission, a conceptually similar mission to ETS-VII but capable of more autonomous behavior.[44]

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[40] Moltz, *The Politics of Space Security,* 100, 156-7.

[41] Anatoly Zak, "Here is the Soviet Union's Secret Space Cannon," *Popular Mechanics*, November 16, 2015, accessed September 19, 2017. http://www.popularmechanics.com/military/weapons/a18187/here-is-the-soviet-unions-secret-space-cannon/.

[42] Moltz, *The Politics of Space Security*, 186.

[43] I. Kawano, M. T. Suzuki, H. Koyama, and M. Kunugi, "Approach Trajectory Design for Autonomous Rendezvous of ETS-VII," *Journal of the Japan Society for Aeronautical and Space Sciences* 49, no. 575 (2001): 432.

[44] A. Ogilvie, J. Allport, M. Hannah, and J. Lymer, "Autonomous Satellite Servicing Using the Orbital Express Demonstration Manipulator System," in *Proc. of the Ninth International Symposium on Artificial Intelligence, Robotics, and Automation in Space (i-SAIRAS'08),* 25–29, 2008.

In the light of these historical precedents, news reports in 2016, of Russian "kamikaze" satellites and Chinese "kidnapper" satellites, should hardly come as a surprise.[45] The fact that such space systems still exist, however, demands that the operational artist consider their employment in contemporary warfare. While the employment of a 14.2 millimeter cannon is unlikely, the possibility of a loitering space mine or an on-orbit electromagnetic pulse (EMP) device are not as far-fetched as they may sound at first.

Nuclear Weapons

In 1962, a series of high-altitude nuclear tests known as Operation Fishbowl unintentionally demonstrated the effects of nuclear explosions against satellites.[46] Although the blast did not destroy any satellites directly, the resulting EMP of January 9, 1962 disabled all seven satellites then on orbit and disrupted the electrical infrastructure on earth.[47] At a time when few satellites were in space, the consequences of the EMP blast were not catastrophic. However, with the large number of satellites in space today, such a burst would have far-reaching military and economic consequences.

As with ASAT missiles, the employment of nuclear weapons to destroy satellites benefits the belligerent that does not rely on satellites for its own military and economic advantages. Against a space-dependent adversary, a nuclear blast in space provides the disadvantaged belligerent the chance to achieve some parity without targeting distant ground stations (perhaps in neutral countries) or actual humans. While the political ramifications against a nuclear detonation

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[45] Jim Sciutto and Jennifer Rizzo, "War in Space: Kamikazes, Kidnapper Satellites and Lasers," Cable News Network, November 29, 2016, accessed September 19, 2017, http://www.cnn.com/2016/11/29/politics/space-war-lasers-satellites-russia-china/.

[46] Moltz, *The Politics of Space Security*, 118.

[47] Michael L. Howard, "Rendezvous in Space: Looking in on Military Space Power," *Army Space Journal* 9, no. 2 (Summer 2010): 21.

in space would certainly be significant, history has not yet provided an example of whether or not a nation will go to war over the destruction of satellites.[48]

Conclusion

The various space systems discussed in this chapter range from the fairly common to the very extreme. While modern warfare depends heavily on the more traditional uses of spacecraft to enable military action in other domains, the inventory of hostile space systems continues to expand, and capabilities of systems already in existence continue to improve. While not all of the means discussed may be appropriate to attain a given strategic end, the operational artist must consider the enemy's perspective and clearly understand how these means enable operational ways.

[48] It is interesting to note that international law prohibits emplacing nuclear weapons in space (in the Outer Space Treaty of 1967) and testing nuclear weapons in space (the Limited Test Ban Treaty of 1963). These laws do not prohibit launching a nuclear missile through space or detonating a nuclear weapon in space in self-defense. The US has ratified both, but not all nuclear powers have. There are not international legal prohibitions against the other means discussed. See the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (commonly known as the "Outer Space Treaty"), as passed by the United Nations General Assembly on December 19, 1966, accessed December 5, 2017, http://www.state.gov/t/isn/5181.htm. See also the Text of the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water (commonly known as the "Limited Test Ban Treaty"), as entered into force on October 10, 1963, accessed December 5, 2017, https://www.state.gov/t/isn/4797.htm.

Chapter Five: Applied Concepts (Ways)

Introduction

The visualization tool of chapter three and a discussion of hostile means in chapter four hinted at the employment possibilities of space systems, but further discussion of the ways in which to employ space systems requires the introduction of several additional concepts from theories of operational art, military doctrine, and historical examples. The operational artist may then apply these concepts to work toward an understanding of how space systems, along with systems centered in other domains, contribute to an overall strategic goal. From the perspective of space systems, the most important among these concepts are lines of communications (LOCs), lines of operation (LOOs), zones of operation (ZOOs), and zones of communication (ZOCs). While these concepts have theoretical, historical, and doctrinal precedent, they take on a new form in the context of the employment of space systems.

Lines of Communication

In *The Art of War,* Jomini simply defines LOCs as “the practicable routes between the different portions of the army occupying different positions throughout the zone of operations.”[49] Jomini’s contemporary, Carl von Clausewitz, provided more detail. In *On War*, Clausewitz wrote that LOCs “lead from an army’s main position back to the main sources of food and replacements.” [50] They allow for the conduct of various functions including resupply, troop movement, delivery of mail, transit of couriers, and the conduct of administrative action. The Joint definition of LOCs follows the vein of the Clausewitzian theory but falls short on two accounts. First, it only acknowledges the troop movement and resupply functions of a LOC. Second, it concedes the domain-specific or multi-domain nature of LOCs insofar as they apply to

[49] Hittle, *Jomini’s Art of War*, 78-79.

[50] Carl von Clausewitz, *On War*, eds. Michael Howard and Peter Paret (Princeton: Princeton University Press, 1976), 345.

the land, maritime, and air domains, but offers no consideration to the space (to say nothing of the cyber) domain.[51]

In an effort to expand these concepts into the space domain, John Klein defines celestial lines of communication "in and through space used for the movement of trade, materiel, supplies, personnel, spacecraft, electromagnetic transmissions, and some military effects."[52] Thus Klein's celestial LOCs (CLOCs) maintain similar functions to those of Clausewitz and include "physical CLOCs" that launch satellites or replenish constellations and the "non-physical LOCs" of radio communications links.[53] While traditional LOCs can perform all of the Clausewitzian functions, non-physical CLOCs are a special type of non-doctrinal LOC in that they perform only the information transmission function. These communications links fulfill the courier functions mentioned by Clausewitz, but unlike the LOCs of nineteenth-century wars, CLOCs are not tethered to supply routes.

The concept of CLOCs and their independence from traditional LOCs carries tremendous significance for the operational artist. First, physical CLOCs are a concern to the military planner if constellation replenishment is a concern. Historically, constellations receive new satellites as older models fail—a very deliberate process that requires significant lead time. In a protracted conflict that witnesses the destruction or degradation of vital space systems, however, a belligerent may endeavor to launch replacement capabilities. Massive satellites require large rockets to lift them into orbit, which in turn necessitates significant infrastructure. In the case of the United States, large rocket launches occur either over the eastern coast of Florida or the western coast of California. In terms of CLOCs, these launch sites represent a base, and the typical rocket flight and orbital path the CLOC to satellite replenishment. As the trend toward

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[51] According to joint doctrine, a LOC is "a route, either land, water, and/or air, that connects an operating military force with a base of operations and along which supplies and military forces move." US Joint Staff, JP 1-02, *Department of Defense Dictionary of Military and Associated Terms 2016*, 141.

[52] Klein, *Space Warfare*, 51.

[53] Ibid., 52-53.

smaller, more capable satellites continues, future constellation replenishment may not be dependent on traditional launch facilities but may employ an *ad hoc* launch site or launch-capable air and sea platforms. If ever realized, such launch options will give the operational artist greater flexibility in opening physical CLOCs.

As for non-physical CLOCs, those too provide flexibility to the operational artist. In a space-domain context, such CLOCs allow for the control of the spacecraft themselves. In support of multi-domain operations, the non-physical CLOCs allow for communication not only with a military force's rear area (in the Clausewitzian sense of LOCs) but also with other units operating in the same zone (in the more Jominian sense of LOCs). In contemporary US military operations, the force largely takes for granted the ability to talk to rearward and adjacent units via SATCOM, but an enemy with hostile space means could threaten such access. As a concept, then, non-physical CLOCs provide a tool for the operational artist to use in the deliberate planning and employment of space systems.

Lines of Operation

In theory and doctrine, the LOC and the LOO are related concepts that center on the friendly military force. Generally, LOCs lead from the massed force rearward and connect terrain already traversed with rearward bases. LOOs, on the other hand, lay out the path that the force intends to follow to reach its objectives. In the words of Jomini, they connect "the decisive points of the theater of operations."[54] As in Jomini, the doctrinal definition of decisive point hinges on the "marked advantage" gained by acting upon such a point, but whereas Jomini concerned himself with physical locations, the Joint definition expands to include not just places but also events, critical factors, or functions.[55]

[54] Hittle, *Jomini's Art of War,* 78.

[55] US Joint Staff, JP 1-02, *Department of Defense Dictionary of Military and Associated Terms 2016*, 60.

In Joint doctrine, a LOO connects actions "on nodes and/or decisive points related in time and [physical] space to an objective."[56] As in more traditional domains, an objective may be terrain oriented (attainment of a specific orbit or orbital slot) or enemy based (in the case of an anti-satellite system). Also as in traditional domains, time and distance calculations figure prominently into mission accomplishment. Depending upon the orbit desired, a satellite may take weeks or months to reach its final destination and once in position, will not typically have robust fuel reserves with which to drastically change its orbit. Any effort to synchronize the tactical actions of such a satellite, then, requires an understanding of these time-distance calculations.

Typical LOOs occur both on earth and in space. One LOO might follow the mission's critical events: launch—attain orbit—transfer orbit—final orbit—begin proximity operations. Another LOO involving space systems may include action by a space system (for example, ground-based jammers) as part of the synchronized effort of the Joint force. Since LOOs are possible in space or in the employment of space systems from the earth, zones of operation (ZOOs) are also possible in both locales. A ZOO is not a defined doctrinal term but a Jominian concept, "a fraction of the whole theater of war which may be traversed by an army in the attainment of its objective."[57] A ZOO consists of multiple LOOs, and like a LOO, ZOOs can exist in any single domain or across multiple domains.

Zones of Communication

Combining the concepts of LOCs and ZOOs leads to the concept of zones of communication (ZOCs). Although not a concept in US doctrine or Napoleonic theory, the idea comes from the German Army of World War Two.[58] Like its cousin the ZOO, multiple LOCs combine to form a ZOC.

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[56] US Joint Staff, JP 1-02, *Department of Defense Dictionary of Military and Associated Terms 2016*, 141.

[57] Hittle, *Jomini's Art of War,* 78.

[58] Geoffrey Megargee, *Inside Hitler's High Command* (Lawrence: University Press of Kansas, 2000), 118.

In the context of space systems, it may be tempting to view the uplink/downlink beams as CLOCs. Indeed, such links form part of the LOC, and in the simplest configuration (e.g. a single satellite that downlinks to only one ground station), "LOC" may be the appropriate designation for that link (see Figure 5). In modern military systems, however, the reality can be much more complicated.

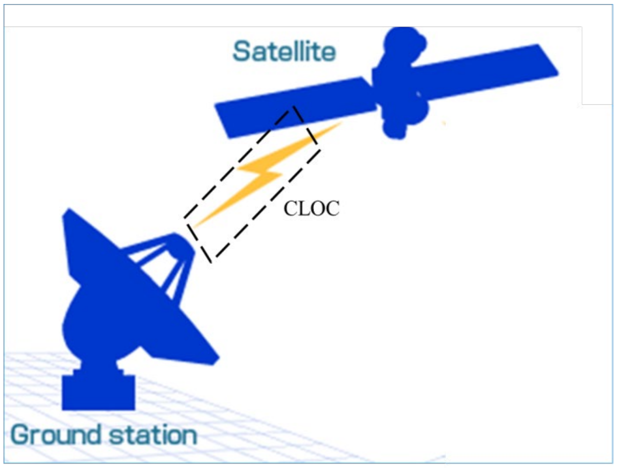

Figure 5: A Non-physical CLOC between a Single Satellite and a Single Ground Station. *Source:* Adapted by Author from Microsoft Clipart, accessed November 4, 2014, http://insertmedia.office.microsoft.com.

A typical beam from a transmitting satellite (e.g. a communications satellite) covers a large area on the ground. One need only to think of how many backyard satellite dishes a single communications satellite may service. Similarly, in military operations, one satellite may service many ground receivers within a single theater or even within multiple theaters. Although the beam is continuous, one may imagine lines linking each receiver to the satellite antenna and consider this group of links a celestial zone of communication (CZOC). Figure 6 shows a CZOC consisting of one satellite communicating with multiple receivers.

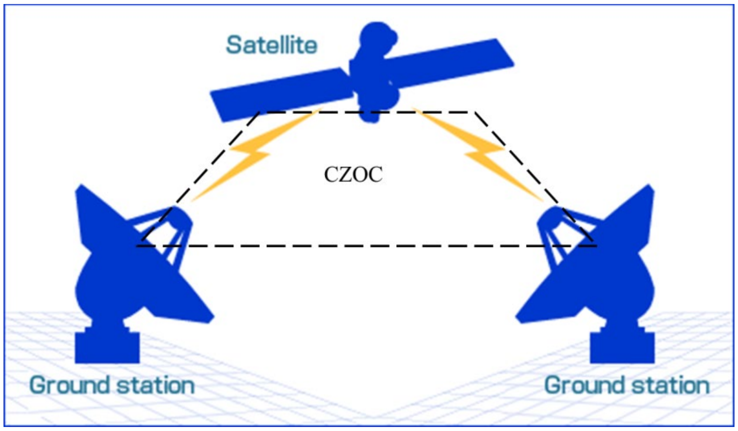

Figure 6: A CZOC of One Satellite and Multiple Receivers. *Source:* Adapted by Author from Microsoft Clipart, accessed November 4, 2014, http://insertmedia.office.microsoft.com.

While one satellite may transmit to multiple receivers with a single transmitter, it is also possible for a satellite to have multiple transponders, each capable of servicing multiple receivers. In this situation, each transponder and the multiple links to its multiple receivers may be considered CZOCs.

The visualization of CZOCs changes slightly depending upon the orbital altitude of the satellite in question. For satellites in geosynchronous earth orbit, the satellite remains in view of the same locations on earth. Its orbital speed matches the rotational speed of the earth giving an observer on the ground the perception that the satellite is stationary over that point. As altitudes become lower, the speed of the satellite relative to the ground increases. For low-earth satellites (LEO, a few hundred miles from earth), the access period is much shorter, perhaps only several minutes.

As a system, the GPS constellation resides in medium-earth orbit (MEO, approximately 12,000 miles from earth) and is designed to provide multiple links to handheld and vehicle-mounted receivers. For an accurate solution, each receiver requires access to four satellites, although due to redundancy in the system, more than four are typically in view. When considering space systems such as these, each satellite allows for an access window as it passes overhead. Again, the system design is such that the passage of a satellite below the horizon typically does not degrade the receiver's solution because another satellite will have risen to offer its own link.

As a space system, GPS offers a unique situation in the consideration of CZOCs. Because the system's mission is to provide global coverage, the CZOCs are relative to each receiver. Unlike the typical parabolic receivers depicted in the first two cases, GPS receivers accept simultaneous input from multiple satellites. Figure 7 shows the changing CZOCs as GPS satellites move relative to the ground observer.

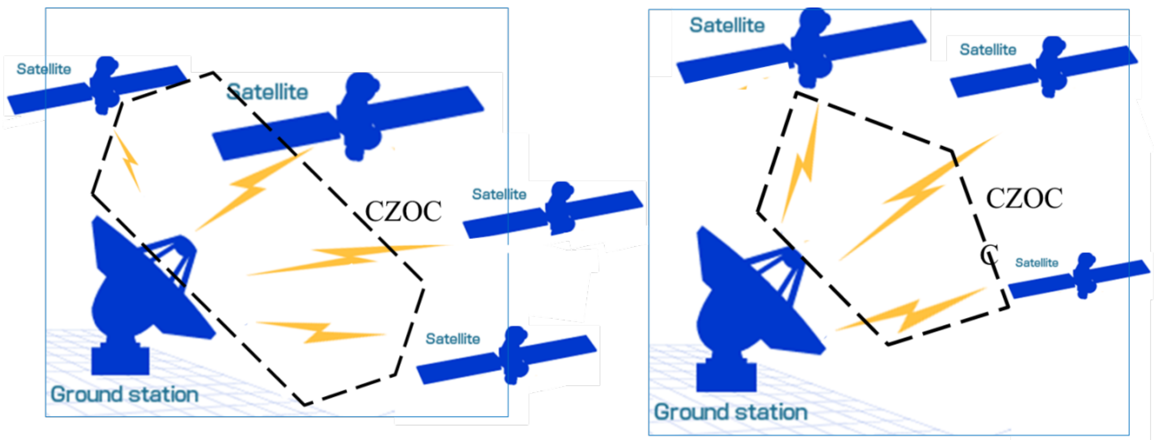

Figure 7: As Satellites Move, the CZOC Changes. *Source:* Adapted by Author from Microsoft Clipart, accessed November 4, 2014, http://insertmedia.office.microsoft.com.

As with missile warning, weather, intelligence, and communications satellites, GPS satellites offer tactical capabilities that have historically operated with little enemy interference. As long as they are working normally and the space domain remains uncontested, the operational artist may be tempted to devote less consideration to such space systems. However, when a system becomes degraded, the synchronization of operations with windows of system capabilities becomes a significant concern.

Security of Celestial Lines and Zones

The vulnerability of space systems to degradation by any of the hostile means previously considered demands a consideration of the fundamental principle of security. In terms of physical CLOCs, friendly bases and heavily trafficked launch trajectories or orbits should be defended from interference. Such means of defense may include defensive cyber operations or the enforcement of no-fly or maritime exclusion zones. In a broad sense, the doctrinal task of defensive space control (DSC) involves such defensive measures. In terms of non-physical CLOCs, DSC takes on a different form.

In relation to non-physical CLOCs, DSC involves monitoring communication links for interference and geolocating the source of the interference.[59] In Jominian ground LOCs, soldiers did not necessarily have to occupy the LOC to secure it. In the context of non-physical CLOCs, DSC assets may be within a CZOC, but given the expansive size of such CZOCs—hemispherical in some cases—the monitoring asset may not be necessarily within the same theater as the user whose link is being protected. Thus, positioning of such assets takes on a fundamental importance for the operational artist. A second important question concerns which links to monitor. As shown previously, one satellite can be responsible for many links, but not all links may be equally important at all times. Assets are limited in number and range thus forcing prioritization of which assets must be protected. By way of analogy, missile defense units face similar choices, which is why they develop critical and defended asset lists. For DSC operations, priority for monitoring may change by phase, by transfer of the main effort, in response to an aggressive act, or under some other criteria. Protection may focus on a CLOC or a CZOC.

Efforts to employ offensive space control (OSC) systems require similar considerations. Rather than protecting CLOCs, jammers and lasers attack CLOCs. Like DSC monitoring, OSC action need only be within line-of-sight of the target and thus not necessarily within the same theater. The operational artist must synchronize the deployment and employment of these assets to provide maximum effect in the decisive theater.

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[59] One may assume that defensive or offensive cyber operations could be occurring over such communications links. DCO concerned with thwarting malicious software aimed at negatively impacting a satellite or ground station may broadly fall under the umbrella of DSC. Furthermore, one may also include encryption and radio discipline as simple methods that contribute to DSC.

Options and Dilemmas

Jomini states as the first point of his fundamental principle that the aim of war is to mass combat power at the decisive point.[60] One may imagine Napoleon arriving at the preordained time of battle with three corps converging on the enemy army. Jomini had certainly observed such operations, but what does such a concept mean in a multi-domain operating environment that includes space systems?

One way to think of this principle is through the complementary concepts of options and dilemmas. With three corps at his disposal, Napoleon had options. For example, he could attack with two while keeping the third in reserve. Alternatively, he could have used two for a turning movement while employing the third as a guard force. He could have used two as an enveloping force while sending the third against a weaker enemy detachment. An enemy commander with five corps could have parried every dilemma presented by Napoleon with forces to spare. In other words, he would have retained options in the face of multiple dilemmas. Retaining options in the face of dilemmas is the essence of flexibility.[61] All other things being equal, an enemy with only two corps, however, would have fewer options. If employed with simultaneity, Napoleon's three corps could present more dilemmas than the enemy could absorb. When one force presents an enemy force with multiple, synchronized dilemmas along the depth of his force, the enemy's entire ability to wage war effectively becomes overwhelmed; the friendly force has achieved operational shock.[62]

How does a Joint force create dilemmas? One way is to open multiple zones of operations that the enemy must address. These ZOOs may correspond to domains. In the case of the Persian Gulf War, for example, US Central Command opened land and air ZOOs from Saudi

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[60] Hittle, *Jomini's Art of War*, 67.

[61] In Army doctrine, the tenets of Unified Land Operations are flexibility, depth, synchronization, and simultaneity. Neither joint nor army doctrine formally defines these terms. US Army FM 3-0 (2017), 5-5.

[62] Naveh, *In Pursuit of Military Excellence*, 18.

Arabia and a maritime ZOO in the Persian Gulf.[63] Arguably, the air assault of the 101st Airborne Division on the Allied northern flank represented a cross-domain ZOO.[64] The ability of US forces to open multiple ZOOs imposed upon the Iraqi armed forces a state of operational shock. Too many dilemmas were coming too fast, and the advantage of space-based intelligence, communications, and protection functions directly contributed to the ability of US forces to maintain operational tempo.

As far as the space domain is concerned, little unclassified information is available on how the United States did or did not open space zones during the Persian Gulf War.[65] It is important to consider, however, that multiple LOOs had placed all of the space systems into operation over a period of decades preceding the conflict, and it is possible that the US Air Force adjusted satellites during the conflict to maximize their usefulness. While LOOs and ZOOs may not have been the operative concept for the use of space systems during the Persian Gulf War, space systems did provide CLOCs for weather, intelligence, and missile warning and CZOCs for communications and a not-fully-operational GPS constellation.[66] In Desert Storm, then, the means in use were enabling space systems rather than hostile space systems.

Imagine now a similar scenario in which a near-peer belligerent is able to counter US forces in the land, sea, and air domains and perhaps overmatch US forces in the cyberspace domain. In such a scenario, how does the operational artist employ space systems? As in the Persian Gulf War, the operational artist must consider possible ZOOs and make provisions for opening and maintaining CZOCs through the deliberate placement of assets. The operational artist may address the employment of any space system means—both enabling and hostile--

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[63] Robert M. Scales, *Certain Victory: The US Army in the Gulf War* (Fort Leavenworth: US Army Command and General Staff College, 1994), 84, 390-391, fig. 5-3.

[64] Ibid., 221.

[65] Except for three pages of overview on the general conclusions of the study, the portion of the *Gulf War Air Power Survey* regarding space operations remains classified. Eliot A. Cohen et al., *Gulf War Air Power Survey*, vol. 4 (Washington, DC: Government Printing Office, 1993), v-vii.

[66] Walker, *Seize the High Ground,* 151-157.

within the specific strategic context. Employing new satellites, however, presents a difficult problem.

While it may be possible to accelerate or reprioritize launch and on-orbit testing timelines, military satellites require long lead times for operational employment. For this reason, the planning and employment of such constellations falls more within the realm of strategy, but their destruction poses immediate problems for both the operational artist and the tactician.[67] While the tactician must adjust tactics to the capability of the remaining resources, the operational artist must understand the strategy and work to readjust the means to enable the most effective strategy. With the limitations of satellite replenishment in mind, one may still find it necessary to counter the enemy's satellite replenishment capability by cross-domain attacks on launch facilities or by cyber action against the enemy's industrial base.

Unlike the operational employment of enabling means, the operational employment of hostile means requires a different calculus. First, co-orbital ASATs, inspector satellites, or manipulator satellites are niche capabilities. Based on the desired target, the distance they are required to travel, and their design specifications, there is a trade between how far they can travel and how fast they can get there. As with the infantryman, a satellite may travel a long distance slowly without expending all its fuel, or it may travel a short distance very rapidly with a greater expenditure. Satellite refueling, however, is not currently practicable, and any LOO that involves such capabilities must bear the limitations in mind. With such capabilities, however, a belligerent may combine multiple LOOs to form a CZOO, thus presenting the enemy with an additional dilemma set. A less complicated way of establishing a CZOO is from earth.

Given the fundamental importance of information transmission to the Joint force, the employment of DSC assets should be an early consideration for the operational artist. Like aircraft and missiles, DSC assets may be placed outside or inside the theater of war to protect the

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[67] Everett Dolman, *Astropolitik: Classical Geopolitics in the Space Age* (London: Frank Cass, 2002), 61. Much of Dolman's discussion in *Astropolitik* engages this aspect of "astrostrategy."

most necessary celestial lines or zones. The effort to deploy, emplace, and operate these assets constitutes a contributing LOO, the ultimate goal of which is to establish a CLOC. The employment of multiple assets into multiple theaters represents additional LOOs and additional CLOCs that may coalesce into celestial zones.

A third type of space LOO consists of the employment of satellite jammers. As with DSC assets, these may establish their CLOCs in the theater of war or from an external theater. The combination of multiple offensive CLOCs constitutes an offensive CZOC, and depending on the orbital motion of the target satellites, the operational artist must determine the appropriate sequencing of the tactical OSC action to contribute to the overall strategic effect.

From the point at which the Joint, Combined, and/or Interagency elements have completed configuration of celestial zones of operation and communization, tactical employment may involve a multitude of ways. As Naveh and Wass de Czege stress, the cognitive process that is linking the tactical actions to the strategic ends is ongoing.[68] While it is possible that the forces of a single domain may be able to achieve those ends, it is unlikely—and perhaps even foolish—for any modern nation to operate in that way. The Jominian idea of massing forces at the decisive point applies conceptually, if not in the literal sense.

Conclusion

Theory and doctrine both posit that it behooves a belligerent to present as many dilemmas as possible to an enemy across all domains (simultaneity) while maintaining as many options as possible for one's own force (flexibility). The operational artist may approach these goals through the establishment of ZOOs in as many domains as possible and through the maximal use of CZOCs. The operational artist must strive to synchronize the activity across domains so that the actions in all domains contribute to the overall achievement of the strategic goals.

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[68] Huba Wass de Czege, "Thinking and Acting Like an Early Explorer: Operational Art is not a Level of War;" Naveh, *In Pursuit of Military Excellence,* 13.

Chapter Six: Conclusion

There's no such thing as space war. There's just war.

—General John E. Hyten
Commander, US Strategic Command, 2017

While evidence suggests the validity of this monograph's initial hypothesis—that the synchronized employment of space systems somehow provides a belligerent with an asymmetric advantage—the exploration of means and ways also suggests the shortcomings of the claim. The operative concept is not *that* space systems somehow provide an asymmetric advantage but determining *how* to employ space systems toward an achievable strategic end. Thus, asymmetry is not an end in itself, but a means to the strategic end.

To begin addressing the question of *how*, theoretical and doctrinal concepts allowed for a consideration of the means within the framework of operational art. Historical examples provided context and clarity, and in the case of ZOCs, provided a useful concept neither in traditional theory nor in US doctrine. That the ideas of Jomini came to the fore indicate his importance to operational thought though the theories of Alfred Thayer Mahan, Julian Corbett, and Giulio Douhet appear in the cited works by Klein and Dolman, who offer their own useful frameworks. Systems theory provided the bridge that allowed a consideration of space systems as holistic units rather with the domain-specific bins within the US military's institutional thought. Indeed, this monograph suggests that from a systems perspective, contemporary warfare domains are inseparable.

If that is the case, operational art itself must be domain agnostic. While ideas like LOOs and LOCs apply within single domains, applying them to a single domain without considering the synchronization of all domains misses the point. The visualization tool of chapter three highlights interdependence among the various domains and provides a way to visualize and plan for the synchronization of assets in multiple domains. Although not included in the discussion of the visualization tool, one might easily add the employment of celestial zones and lines into such a visualization. Surely, the expanded consideration of systems adds additional complexity to the operation, but to understand how the various domains and their myriad of means can work together to achieve strategic ends is the hallmark of operational art.

As a practical matter, this is very difficult. It implies that an operational artist must work in multiple media and have at least a general knowledge of means in all domains. Fortunately, as chapter five suggests, the ways of operational art (for example, establishing ZOOs) apply to all domains and allow for synchronization, simultaneity, flexibility, and depth. For this reason, concepts—whether they come from history, theory, or doctrine—are the most important tools for an operational artist.

As US Joint doctrine asserts, the complex process of operational art is necessarily dependent upon the knowledge of commanders and staffs of the means available, their understanding of tactics and doctrine, and their ability to imagine creative applications. Within this construct, multi-domain operational art also implies that coordination among the various services is achievable and understanding of the mission shared. Space systems are essential to such applications, and by virtue of their tendency to operate across domains, they perhaps force holistic consideration of operational art in a way that the traditional domains do not.

With their cross-domain nature in mind, the utility of space systems and the organizations that employ them have moved beyond simply enabling tactics. Without a doubt, such functions remain important, but space systems have the potential to do more than simply provide an asymmetric advantage to the forces of the other domains vis-à-vis their space-disadvantaged enemies. Contemporary operational artists must consider the space domain as one domain of many in the employment of operational art with the tactical actions of space systems synchronized in time, multi-domain space, and purpose accordingly.

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